RECLAMATION
Managing Water in the West

FINAL DEADWOOD RESERVOIR OPERATIONS FLEXIBILITY EVALUATION

BOISE PROJECT, IDAHO



U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Snake River Area Office
Boise, Idaho

March 2016 (revised)

U.S. DEPARTMENT OF THE INTERIOR

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Cover photo – Deadwood Dam and Reservoir

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EXECUTIVE SUMMARY

Deadwood Reservoir and Dam are located in west-central Idaho's Sawtooth Mountains. The Deadwood River flows into the South Fork Payette River. At its normal full-pool elevation of 1,625.8 meters (m) the reservoir contains about 190 million cubic meters (m^3) and has a maximum depth of about 35 m. The dam and reservoir are managed by the U.S. Bureau of Reclamation (Reclamation) to provide irrigation water supply and flood control in the Payette River basin. Irrigation releases generally occur between June and mid-September. More recently, water stored in the reservoir is also used to augment streamflows to improve migration conditions for endangered or threatened salmon and steelhead. Current water operations manage the reservoir to maximize water storage (fill) during winter and spring months, and release irrigation water during the summer months. During wetter conditions, when run-off exceeds storage capacity, water is released at the dam either through the outlet works or spillway during the winter and/or spring months.

Bull Trout (*Salvelinus confluentus*) in the Columbia River basin were listed as threatened in 1998 (63 FR 31647), and critical habitat was listed in 2010 (75 FR 63898). Bull Trout are present in the Deadwood Reservoir and River, and tributaries throughout the Deadwood River basin. The U.S. Fish and Wildlife Service (USFWS) completed a Biological Opinion in 2005 (USFWS 2005) requiring Reclamation to investigate the flexibility in operation of Deadwood Reservoir to reduce impacts to Bull Trout in the Deadwood River and Reservoir. The operation of Deadwood Dam is primarily aimed toward storage and delivery of water during irrigation season and flood control measures that work within the system of dams in the Boise and Payette River basins. The delivery of water for irrigation depends on several variables such as weather and available storage; however the typical irrigation season starts around June and ends in September. Terms and Conditions in this Biological Opinion require Reclamation to examine operational flexibility to improve reservoir and river conditions (water temperatures and streamflows), identify ramping rates that would reduce impacts to Bull Trout downstream from the dam, and identify actions to reduce entrainment of Bull Trout over the dam. This study was performed to address these Terms and Conditions.

Operational scenarios examining water availability and timing in dry, wet, and average climatic conditions were modeled for the Deadwood Reservoir and River below Deadwood Dam to identify effects to aquatic habitat and species. Within the range of operations described in the 2005 Biological Opinion, Reclamation has flexibility to operate Deadwood Dam in three major operational actions: (1) the amount of post-irrigation streamflow released from Deadwood Dam, (2) the rates that streamflows are ramped up in the spring

and subsequently ramped down in the fall after irrigation water releases, and (3) use of the spillway to discharge water seasonally, when reservoir water surface elevation is sufficient. From 1993 to 2013, the wintertime streamflow was set at 50 cubic feet per second (cfs) minimum streamflow which is close to the natural estimated inflow to Deadwood Reservoir during drier climatic conditions. This study tested the current post-irrigation minimum streamflow of 50 cfs against reduced streamflows of 2.3 and 0 cfs, and compared a fast (2-day change in flow) ramping rate to a slower (7 to 10-day change in flow) ramping rate.

The project included intensive data collection that were used to develop, calibrate and validate hydrologic, water temperature, water chemistry and primary production models developed for the study area from 2006 to 2010. Short-term test flows were implemented in 2009 and 2010 so that data collection of physical habitat and other stream channel variables could occur. Bull Trout were monitored with various tagging technologies from 2006 to 2011 with most of the data generated between 2006 and 2009. Additional monitoring data were collected in water years 2014 and 2015 for interim water operations with a 2.3 cfs post-irrigation streamflow provided from the dam.

Overall, the various analyses found trade-offs between optimal reservoir habitat conditions and optimal river conditions downstream for Bull Trout and other species. Essentially, the higher post-irrigation season reservoir elevation creates better rearing and migration conditions for Bull Trout for the entire year, but can alter some conditions in the river, such as summer temperatures that remain colder than natural water temperatures in the later part of the summer and marginal connectivity for 3.0 kilometers (km) of the river downstream from the dam. The rate of up ramping at the beginning of the irrigation season flows did not result in measurable differences in the water temperatures downstream from the dam. However, analyses of down-ramping rates at the end of the irrigation season streamflows found that the fast ramping rate resulted in water temperatures closer to natural in the river downstream from the dam. Additionally, in the case of a lowered winter flow (i.e., 2.3 or 0 cfs) scenario, the water saved with fast ramping (as opposed to slow ramping) would remain in reservoir storage to provide additional temperature and reservoir content benefits particularly to the varial zone to improve Bull Trout spawning migrations. Fast down ramping appeared to result in higher rates of stranded fish in the river downstream from the dam; however, no Bull Trout were collected during stranding surveys.

Reservoir analyses show that higher than expected nutrient load stimulates primary production in the upper strata of the reservoir which was observed during the fall (late October to December) after thermal release (turn-over) of the reservoir and recirculation. When this abundant algal community dies, it settles to the reservoir bottom where the decay creates additional biological oxygen demand in the hypolimnion during the winter months and resulting anoxia prior to spring turn-over of the reservoir. Recurrent anoxic conditions in the hypolimnion of the reservoir led to increased concentrations of phosphorus, iron, and manganese downstream from the dam due to the placement of the outlets works and the

hydrogenerator inflow near the reservoir bottom. Water operations had little influence on net primary production in the reservoir, but hydrologic conditions had a strong influence with wet years 134 to 156 percent (%) more productive than dry years. The greatest difference was between wet and dry years with 50 cfs releases due to the lower reservoir volume in the spring of dry years when production rates are greatest. Production was about 15% higher when implementing the low (0 and 2 cfs) post-irrigation streamflows in comparison to the 50 cfs post-irrigation streamflow.

The dam and operations affected the river habitat, periphyton, and macroinvertebrate community structure for 3.7 km downstream from the dam. The increased nutrients and organic matter from the reservoir likely alter the composition of the macroinvertebrate community downstream where, for example, there were a higher proportion of gatherers – insects that collect and process organic matter. Additionally in this 3.7 km reach, insect drift was lower. Farther downstream on the Deadwood River, there were no measureable effects of the dam or operations on macroinvertebrate, drift, density, biomass, or production in comparison to unregulated sites. When considering the predicted effect of water operations, the 2.3 cfs post-irrigation streamflow supported the most biomass of Bull Trout and macroinvertebrate species during dry and wet climatic conditions. Average climatic conditions had little difference among the potential biomass supported by the different water operations scenarios. Ramping rate also had no effect on biomass of prey. Downstream from the dam, the 50 cfs post-irrigation streamflow had the highest annual production of macroinvertebrates. However, invertebrate production was not a concern for any of the water operational scenarios considered due to the rapid replacement of biomass after lower streamflows.

Bull Trout rearing in the reservoir exhibited significantly different behaviors under different years and associated reservoir conditions. In 2007, when the reservoir level declined and water temperatures approached 20^{o}C, Bull Trout left the reservoir and reared in the tributaries upstream. Yet, average growth was not affected by this shift in habitat. In 2011, when the reservoir level was higher, Bull Trout remained in the reservoir for the entire summer and into the fall. Acoustic and radio telemetry tag data indicated that Bull Trout utilized the shallower areas of the reservoir (< 2 m depth) and were often located near tributaries. Although Bull Trout appear to adjust to reservoir levels and shift habitat use, these analyses indicate that higher summertime reservoir levels benefit Bull Trout and associated prey upstream from the dam. Bull Trout were only captured in the stilling basin downstream from the dam. Local resident populations are present in nearby tributaries and in the South Fork Payette River; therefore, the habitat should be considered accessible for Bull Trout migration and rearing. The Bull Trout captured in the stilling basin were genetically assigned to source populations sampled upstream from the dam.

The potential production of Bull Trout predicted in the reservoir ranged from 7,000 to 11,000 kilograms per year (kg/yr) among the water operations scenarios. Reservoir

operations had little effect on the potential biomass of Bull Trout and other fishes for average and wet climatic conditions, but in dry climatic conditions the potential for Bull Trout production was about 15% higher under the low post-irrigation streamflow release scenarios as compared to the 50 cfs streamflow release. Bull Trout growth in the reservoir is high, nearly double the measured growth in the tributaries downstream from the dam. These analyses indicate that the production of Bull Trout in the reservoir is not limited by food. In other words, the food base can support more Bull Trout than are present in the reservoir/stream populations upstream from the dam; therefore, other factors likely limit population size, such as spawning habitat quality or quantity, temperatures or dissolved oxygen.

In summary, reservoir operations directly affect the river habitats downstream; however, macroinvertebrate production does not seem to be affected particularly more than 3.7 km downstream from the dam. Other reasons for depressed populations could be due to climatic conditions and trends, spawning habitat quantity and quality and/or loss of anadromous fish and associated production – factors not examined in this study. Lastly, distribution studies indicate that the Deadwood Dam may be on the edge of suitable habitat within the Payette River basin.

Acronyms and Abbreviations

µg/L	microgram per liter
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
ac-ft	acre-feet
BiOp	Biological Opinion
CAEDYM	Computational Aquatic Ecosystem Dynamics Model
CFL	Couránt-Friederich-Levy
cfs	cubic feet per second
CRYPT	Cryptophytes
CS	change in reservoir storage
DEM	digital elevation model
DEQ	Department of Environmental Quality
DIN	dissolved inorganic nitrogen
DINOF	Dinoflagellates
DO	dissolved oxygen
DOC	dissolved organic carbon
DOP	dissolved orthophosphate
DYANO	Cyanobacteria
EAARL	Experimental Advanced Airborne Research LiDAR
ELCOM	Estuary, Lake, and Coastal Ocean Model
FDIAT	Diatoms
GI	gaged inflow
GO	gaged outflow
ha	hectare
IDFG	Idaho Department of Fish and Game
kg	kilogram
kg/yr	kilogram per year

km	kilometer
km^2	square kilometer
LDS	Lake Diagnostic System
LWD	large woody debris
m	meter
m^2	square meters
m^3	cubic meters
m^3/s or $m^3\ s^{-1}$	cubic meter per second
mg/L	milligrams per liter
mph	miles per hour
MSL	mean sea level
NH_4	ammonium
NMFS	National Marine Fisheries Service
NO_3	nitrate
NRCS	National Resources Conservation Service
PO_4	orthophosphate
POC	particulate organic carbon
POP	particulate organic phosphorus
R	residual
Reclamation	U.S. Bureau of Reclamation
RO	unit runoff
SOP	Standard Operating Procedures
TKN	Total Kjeldahl nitrogen
TP	total phosphorus
UI	ungaged inflow
USFWS or Service	U.S. Fish and Wildlife Service
WSE	water surface elevation

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Chapter 1 INTRODUCTION

1.1 Background

Deadwood Reservoir, located in west-central Idaho's Sawtooth Mountains, was created in 1931 by impoundment of the Deadwood River by Deadwood Dam. The 12.6 square kilometer (km^2) reservoir is located 38 kilometers (km) upstream of the Deadwood River's confluence with the South Fork of the Payette River (Figure 1-1). The Deadwood River watershed is approximately 614 km^2. The watershed upstream from the reservoir is about 287 km^2 of mountainous terrain; the maximum elevation in the drainage basin is about 2,650 meters (m) (above mean sea level) at Price Peak. At its normal full-pool elevation of 1,625.8 m, the reservoir contains about 190 million cubic meters (m^3) and has a maximum depth of about 35 m. The U.S. Bureau of Reclamation (Reclamation) has historically operated the reservoir for irrigation water supply, a small hydropower generator for operation of the facility, flood control, and hydroelectric power production at Black Canyon Dam. More recently, the reservoir has also been used to augment streamflows for out-migrating salmon downstream in the Snake and Columbia River basins (NMFS 2008).

Annual operations of the reservoir store water outside irrigation season (mid-September to mid-June). Spring operations are determined by the amount of storage available and predicted run-off. In drier years, this water may be stored for irrigation delivery during summer, or may be released downstream for flood control. The majority of the water is discharged in the summer months (mid-June to mid-September) for irrigation demand as part of the Boise Project. Therefore, summer flows in the Lower Deadwood River are mostly determined by irrigation demand. During the fall and winter seasons (September to March) various options are available for reservoir/river operations that will still allow sufficient storage of irrigation water for contracted agricultural uses. Between 1993 and 2013, the post-irrigation water releases into the Deadwood River downstream from the dam were set at a minimum of 50 cubic feet per second (cfs). Prior to 1993, post-irrigation water releases into the Deadwood River downstream from the dam were set at 0 cfs.

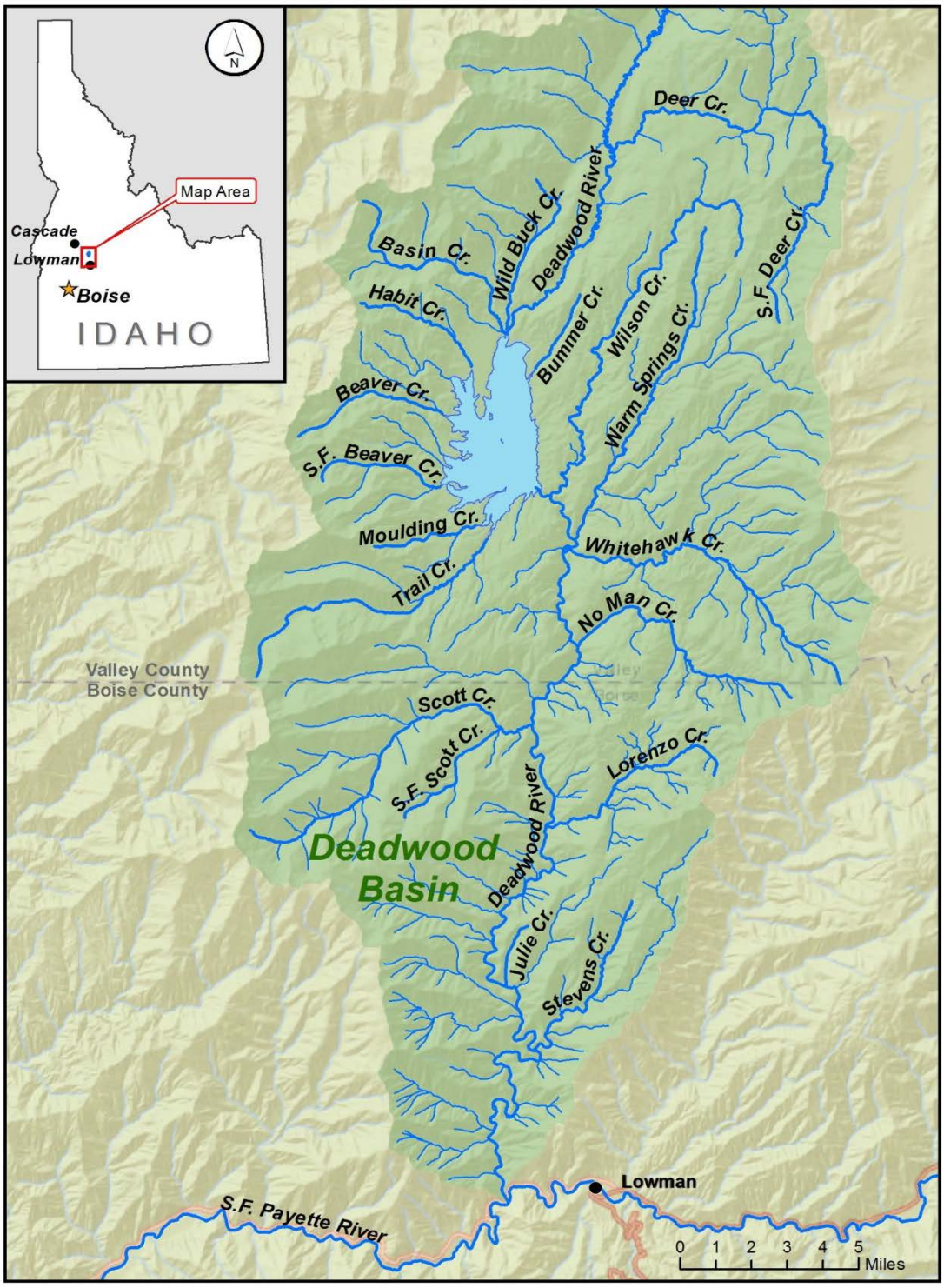


Figure 1-1. Portion of the Deadwood watershed referenced in this report including the Deadwood River and Reservoir, Idaho. Deadwood River basin is highlighted in green.

Bull Trout (*Salvelinus confluentus*) in the Columbia River Basin were listed as threatened in 1998 (63 FR 31647), and critical habitat was listed in 2010 (75 FR 63898). Bull Trout are present in the Deadwood Reservoir and River, and tributaries throughout the Deadwood Basin. The U.S. Fish and Wildlife Service (USFWS) completed a Biological Opinion (BiOp) in 2005 for Bull Trout (USFWS 2005) requiring Reclamation to investigate the flexibility in operation of Deadwood Reservoir to reduce impacts to Bull Trout in the Deadwood River and Reservoir. In 2014, USFWS completed a companion BiOp for Bull Trout critical habitat (USFWS 2014); this document supports the requirements of the 2005 BiOp, however, no additional requirements were added.

Bull Trout in Deadwood Reservoir migrate upstream to tributary spawning and rearing habitat. Bull Trout spawn in the late summer/fall months. Eggs develop in gravels over-winter until hatching during the following spring. In general, migratory Bull Trout will rear in their natal area for up to 4 years prior to migrating to larger habitats (Downs et al. 2006). However, resident (or non-migratory) Bull Trout will remain in the smaller tributary streams for their entire life cycle. At the completion of the 2005 BiOp, it was not known if Bull Trout reside in the mainstem Deadwood River between the dam and the confluence with the South Fork Payette River. Based on available information, the USFWS concluded that Bull Trout likely occur at very low densities in the mainstem Deadwood River below Deadwood Dam. Reservoir operations strongly influence river conditions downstream, so fluvial fish that might utilize the Deadwood River below the reservoir for migration or rearing are included in this report.

Although the 50 cfs minimum post-irrigation streamflow implemented since 1993 could not be clearly traced to any scientific information, 50 cfs is the estimated average inflow into Deadwood Reservoir during dry climatic conditions and can be considered similar to a natural low flow for the stream. Additionally, a study conducted by the USFWS recommended 125 cfs as a maintenance instream flow to support fish, wildlife, and recreation (Pruitt and Nadeau 1978). The 125 cfs is based on the measured lowest streamflow that would provide maximum wetted area of streambed to maximize the production of prey. Streamflow numbers were derived from data collected in 1975 using instream flow methodologies that estimate weighted usable area for spawning and passage for several species of native and non-native trout, including Bull Trout. Streamflows examined ranged from 25 to 250 cfs released from Deadwood Dam. Recommended streamflows were: 50 cfs for Bull Trout passage, 125 cfs for Rainbow Trout (*Oncorhynchus mykiss*) spawning during May and June, and 85 cfs for Rainbow Trout incubation during July and August at the study site which was located about 2.5 miles upstream from the mouth of the Deadwood River. A 50 cfs outflow from the dam coincided with a measurement of 107 cfs at the study site, and 25 cfs from the dam coincided with a measurement of 75 cfs at the study site (Pruitt and Nadeau 1978).

1.2 BiOp Terms and Conditions

The 2005 BiOp identifies potential limiting factors for Bull Trout in the Deadwood system (USFWS 2005). In the Deadwood River downstream of the dam, these include:

1. Low winter flows may limit invertebrate production, restrict Bull Trout movement, and reduce fish habitat.
2. Low winter flow, extreme cold weather, and lack of surface ice may cause conditions that plug Bull Trout gills.
3. Spillway discharges in 35 percent (%) of years may increase metabolic rates and cause early or late spawning migrations.
4. Low water temperature may affect metabolism, growth, and reproduction of Bull Trout and other organisms including their prey base.
5. Absence of down ramping may cause fish stranding.

In the Deadwood Reservoir, potential limiting factors from the USFWS 2005 BiOp include:

1. Low level (<50,000 acre-feet (ac-ft) in 7% of years) may create unsuitable water quality.
2. Spill (in approximately 35% of years) may entrain fish.

The Terms and Conditions listed in the USFWS 2005 BiOp identify mechanisms by which reservoir operations may harm Bull Trout and provide direction for investigating how operations may provide benefits to Bull Trout. These Terms and Conditions specify ramping rates (3c), entrainment of fish in spill (3e), altered streamflow (3a, 3d), and low stream temperature (3b) as likely mechanisms for Bull Trout take (Table 1-1). In response, Reclamation requested that the research team for this study describe how reservoir operations influence Bull Trout in the Deadwood system. With increased ecological knowledge of the system, Reclamation managers will evaluate whether the reservoir may be operated in a manner that reduces impacts to Bull Trout.

Table 1-1. Terms and Conditions for Bull Trout that reside in waters associated with Deadwood Dam (USFWS 2005).

3a	Determine whether there is flexibility within the action as proposed to operate Deadwood Dam to reduce the effects to Bull Trout when winter streamflows in the Deadwood River below Deadwood Dam are less than inflows to Deadwood Reservoir upstream. Cooperate with the Service to identify and implement any actions that can be taken to facilitate winter flows that more closely approximate reservoir inflows to reduce effects to Bull Trout. This Term and Condition shall be implemented no later than March 31, 2014.
3b	Determine whether there is flexibility within the action as proposed to operate Deadwood Dam to reduce harm and harassment of Bull Trout associated with extreme low temperatures in the river below the dam. Cooperate with the Service to identify and implement any actions that can be taken to increase water temperatures from their present range of 3 to 7 C to a range that better supports an adequate and diverse prey base for Bull Trout. Efforts associated with this Term and Condition shall be completed by March 31, 2014.
3c	Determine and implement ramping rates for both increases and decreases of flows that reduce harassment and harm of Bull Trout in the Deadwood River below Deadwood Dam. Cooperate with the Service to develop a strategy for ramping rates associated with the action as proposed. This Term and Condition shall be implemented no later than March 31, 2014.
3d	Determine whether there is flexibility within the action as proposed to manage flow from Deadwood Dam, particularly during the spring, to minimize take through harassment associated with disruption of Bull Trout biological processes, particularly migratory cues. Cooperate with the Service to identify and implement any actions that can be taken to associate with this Term and Condition. Efforts associated with this Term and Condition shall be completed by March 31, 2014.
3e	Minimize the frequency, duration, and extent of discharge of water over the spillway at Deadwood Dam to avoid and reduce the effects of entraining Bull Trout. Coordinate with the Service if the risk of entrainment changes through actions done to address elements 3.a. through 3.d.

1.3 Purpose of Study

The purpose of this study is to explore the effects of reservoir and water operations on the physical, chemical, and biological processes in Deadwood Reservoir and the Deadwood River downstream from Deadwood Dam. This study directly addresses the Terms and Conditions listed in the 2005 BiOp for Deadwood Dam (USFWS 2005). To fully explore these effects, a holistic watershed assessment, coupled with adaptive management, was used to develop the data and management tools included in this study. Specifically, the objectives of the study are to:

1. Identify the water quality, water temperature, and physical habitat conditions in Deadwood Reservoir;
2. Describe the production potential and prey base for Bull Trout in the reservoir.

3. Identify the water temperature and water quality effects of the dam and water operations in the lower Deadwood River downstream from the dam.
4. Compare primary and invertebrate production in the river downstream from the dam to unregulated sites.
5. Identify Bull Trout movements, growth, and effects of entrainment in the reservoir above the dam and the river downstream from the dam.

1.4 Study Approach

A coupled hydrodynamic-ecological model was developed for Deadwood Reservoir. This three-dimensional (3D) model was used to simulate changes in the operation of Deadwood Reservoir in order to assess the impacts of several operational scenarios. This model was coupled with one and two-dimensional hydrologic models to assess the effects of streamflows in the Deadwood River downstream from the dam. These modeling efforts were coupled with the collection and evaluation of substantial physical, chemical, and biological data from Deadwood Reservoir and its tributaries used for model calibration and validation. Additionally, Bull Trout were tracked and monitored throughout the study to provide a better understanding of presence and potential impacts.

In order to investigate operational flexibility and subsequent ecosystem effects, a series of operational scenarios were evaluated covering a range of expected climatic conditions and expected operations and ramping rates. These scenarios encompass an array of operational options available to Reclamation in order to meet the Terms and Conditions of the BiOp. Scenarios and effects were modeled within both the Deadwood Reservoir and River below Deadwood Dam.

Reclamation has operational flexibility at Deadwood Dam during two time periods: (1) rates of post-irrigation streamflows, and (2) the rates that streamflows are ramped up in the spring, and subsequently ramped down in the fall after irrigation flows. Although not tested in this study, spring operations also potentially provide operational flexibility in the type of discharge (colder deep water releases from the outlet works, warmer surface water through spillway use, or mixing the two), which could allow for downstream temperature modulation. Several potential post-irrigation streamflows were investigated with faster and slower ramping rates across a range of climatic conditions (wet, dry, average). From 1993 to 2013, the winter streamflow was set at 50 cfs, which is close to the natural inflow to Deadwood Reservoir during drier climatic conditions. Minimum winter streamflows greater than 50 cfs were not considered, as it would impact reservoir storage and content for irrigation delivery. Additional drawdown on the reservoir, resulting from increased winter discharge, would also create adverse effects to Bull Trout upstream from the dam. Upon examination of operational flexibility, lower post-irrigation streamflows were thoroughly investigated to

predict ecosystem effects for a 14-month period. Although Reclamation has some flexibility in the timing, shape, and release points (i.e., outlet works gate versus spill) of pre-irrigation water releases, this flexibility was not tested in this study.

Post-irrigation streamflow releases are limited by mechanical constraints at Deadwood Dam. Therefore, within the existing constraints, post-irrigation streamflow options include 0, 2.3, and 50 cfs. The 2.3 cfs winter discharge is accomplished by shutting off the outlet works jet flow gates and running only a small hydropower generator. Unfortunately, it is impossible for the release rate to be set between 50 and 2.3 cfs, as lowering discharge below 50 cfs through the dam outlet works has been shown to cause potentially damaging cavitation at the outlet works. Lastly, 0 cfs is also considered as a possible alternative as it allows for maximum reservoir fill and operational flexibility. The small hydropower generator has a small variation in flow (2.2 to 2.5 cfs) dependent on the amount of head at the intake and measurement error, but this outflow generally measures 2.3 cfs. The modeling scenarios use 2.0 cfs as the estimate for streamflow when the generator is operating; however, the chapters analyzing monitoring data use 2.3 cfs as the outflow condition during the time of data collection.

Changes in the hydrograph alter the stream habitats and at times provide behavioral cues to fishes in the river. Therefore, this study examines the effects of ramping rates during increases and decreases in the streamflows to minimize impacts to the physical habitat and fish stranding. Historically, ramping rates have been implemented quickly in response to irrigation needs. For this study, “fast” and “slow” ramping rates were investigated to the spring increase in outflow from the dam (up ramp) and the reduction of outflow from the dam in the fall (down ramp). For the spring rise in dam releases, slow up-ramping was defined as increasing flows over 7 days from the post-irrigation streamflow to a prescribed level (as defined by reservoir, hydrologic, and climatic conditions in a given year) over the course of 1 week, which approximately mimics natural changes in streamflow during precipitation and run-off events in the Deadwood River above Deadwood Reservoir and surrounding tributaries. Fast up ramping is represented by the fastest possible rise in flows, as defined by the Deadwood Standing Operating Procedures (SOP) (Appendix A). The fast down-ramping rate in the fall is set at 2 days, which generally represents how the dam has historically been operated. For the fall, slow down ramping is defined as ramping flows down from summer irrigation flows to post-irrigation streamflows over the course of approximately 10 days.

Additionally, to understand how the Deadwood Reservoir and River behave under different climatic conditions, the post-irrigation streamflows and varying ramping rates are applied to scenarios that represent average (near 50% exceedance), dry (<10% exceedance), and wet (>90% exceedance) climatic conditions. Three years were selected to represent wet (1997), dry (2001), and average (2003) water year conditions. These conditions allow a detailed evaluation of the extreme climatic conditions (< 5% and >95% exceedance) and the average

(50% exceedance) condition to understand effects throughout the range of expected climatic conditions in the basin (Table 1-3). For each of these climatic conditions, two additional simulations were run in order to compare scenarios investigating the hypothetical post-irrigation streamflows (2 and 0 cfs) and ramping rates (fast and slow) to the historically observed conditions (historical) and what conditions might look like if the dam did not exist (unregulated) (Table 1-2). For 2001 and 2003, historical flow and temperature records exist; however, for 1997 only historical flow records exist. Therefore, results were used from a reservoir model to produce the 1997 historical temperature record. For 1997, 2001, and 2003 a natural expected flow (without dam impacts) scenario was explored by utilizing the inputs to the reservoir model as inputs to the river model, thereby eliminating the effect of the reservoir. In total, eight scenarios for each of the three climatic years were considered which aim to answer the questions posed by the Terms and Conditions as defined by the USFWS (2005).

Table 1-2. Operation scenarios evaluated for Deadwood Dam and Reservoir.[1]

Scenario Number	Background Conditions from 2005 BiOp	T&C – 3a, 3b, 3e Winter Reservoir Release	River Modeling Timeframe	T&C – 3d, 3c Spring Ramp Up	T&C – 3c Fall Ramp Down
	Dry (represented by the year 2001)				
1	Historical	Historical	11/1/00-12/31/01	Historical Actual	Historical Actual
2	0 ac-ft carry over	50 cfs	11/1/00-12/31/01	Fast	Fast
3	0 ac-ft carry over	50 cfs	5/27/01-9/12/01	Slow	Slow
4	17,280 ac-ft carry over	2 cfs	11/1/00-12/31/01	Fast	Fast
5	17,280 ac-ft carry over	2 cfs	5/27/01-9/12/01	Slow	Slow
6	18,000 ac-ft carry over	0 cfs	11/1/00-12/31/01	Fast	Fast
7	18,000 ac-ft carry over	0 cfs	5/27/01-9/12/01	Slow	Slow
8	Unregulated Flows	Unregulated Flows	11/1/00-12/31/01	Natural Hydrograph	Natural Hydrograph
	Average (represented by the year 2003)				
9	Historical	Historical	11/1/02-12/31/03	Historical Actual	Historical Actual
10	0 ac-ft carry over	50 cfs	11/1/02-12/31/03	Fast	Fast
11	0 ac-ft carry over	50 cfs	5/27/02-9/12/03	Slow	Slow

[1] Caution should be used when interpreting output from these models, which were run with the actual starting points for each modeled year, and allowed to self-calculate water carryovers. Additional water storage amounts presumed by the model are not necessarily represented in the actual data, as these additional acre-feet calculated do not uniformly translate into actual storage, but rather may become additional spill or flood control releases (additional reservoir water volumes cause flood control releases to begin earlier in the season, according to calculated flood control rule curves followed by dam operations). Model outputs should be compared with actual data for validation before being relied upon for broader extrapolation.

Scenario Number	Background Conditions from 2005 BiOp	T&C – 3a, 3b, 3e Winter Reservoir Release	River Modeling Timeframe	T&C – 3d, 3c Spring Ramp Up	T&C – 3c Fall Ramp Down
12	17,280 ac-ft carry over	2 cfs	11/1/02-12/31/03	Fast	Fast
13	17,280 ac-ft carry over	2 cfs	5/27/02-9/12/03	Slow	Slow
14	18,000 ac-ft carry over	0 cfs	11/1/02-12/31/03	Fast	Fast
15	18,000 ac-ft carry over	0 cfs	5/27/02-9/12/03	Slow	Slow
16	Unregulated Flows	Unregulated Flows	11/1/02-12/31/03	Natural Hydrograph	Natural Hydrograph
	Wet (represented by the year 1997)				
17	Historical	Historical	11/1/96-12/31/97	Historical Actual	Historical Actual
18	0 ac-ft carry over	50 cfs	11/1/96-12/31/97	Fast	Fast
19	0 ac-ft carry over	50 cfs	7/18/97-9/30/97	Slow	Slow
20	17,280 ac-ft carry over	2 cfs	11/1/96-12/31/97	Fast	Fast
21	17,280 ac-ft carry over	2 cfs	7/18/97-9/30/97	Slow	Slow
22	18,000 ac-ft carry over	0 cfs	11/1/96-12/31/97	Fast	Fast
23	18,000 ac-ft carry over	0 cfs	7/17/97-0/30/97	Slow	Slow
24	Unregulated Flows	Unregulated Flows	11/1/96-12/31/97	Natural Hydrograph	Natural Hydrograph

1.5 Conditions during the Study Years

This comprehensive study was conducted in phases over several years. Some of these years included modeling and data collection for model validation while the later part of the study included monitoring of the interim water operation of 2.3 cfs post-irrigation streamflow with fast ramping rates. The study years ranged from 2006 to 2014. Each water year and rank of exceedance is shown in Table 1-3. Water year rankings and percent exceedance of Deadwood Reservoir inflows for the period of record and for recent conditions (1971 to present) are listed in Appendix B.

The project included intensive data collection that was used to develop, calibrate and validate the hydrologic, water temperature, water chemistry and primary production models from 2006 to 2010. Test flows were implemented in 2009 and 2010 which included data collection of physical habitat and other stream channel variables. Bull Trout were monitored with various tagging technologies from 2006 to 2014 with most of the data generated between 2006 and 2009. Data analysis and drafting of the chapters occurred from 2010 to 2013. Additional monitoring data were collected during water years 2014 and 2015 for interim water operations.

Table 1-3. Percent (%) exceedance for water years included in model scenarios or during data collection in this study. The complete period of record for Deadwood Dam includes 1931 to 2014, whereas the recent record includes 1971 to 2014.

Water Year	% Exceedance based on period of record	% Exceedance based on Recent Record	Classification
Model Scenarios			
1997	2.3	4.4	Wet
2001	97.7	95.6	Dry
2003	47.1	48.9	Average
Data Collection and Monitoring			
2006	11.76	15.56	Wet
2007	78.82	73.33	Dry
2008	40.00	42.22	Average
2009	55.29	55.56	Average
2010	56.47	57.78	Average
2011	21.18	28.89	Wet/Average
2012	28.24	33.33	Wet/Average
2013	71.76	66.67	Average/dry
2014	50.59	53.33	Average

1.6 Document Organization

The models and data collection are designed to directly address the various Terms and Conditions of the 2005 BiOp regarding Reclamation's operations at Deadwood Reservoir and potential effects on Bull Trout – with most of the effort in understanding the flexibility and potential effects of water operations in the reservoir and river. This report and analyses are compiled to understand the effects from upstream (in reservoir) to the river downstream from the dam. The study area includes tributaries that inflow into Deadwood Reservoir to the mouth of the Deadwood River – and also includes several comparison sites such as Clear Creek, a tributary to the South Fork Payette River adjacent to the Deadwood Basin, and the South Fork Payette near the Deadwood River confluence.

This report and accompanying analyses are compiled to include the following:

- Chapter 1 provides preliminary information and background, purpose of study, and operational scenarios evaluated for Deadwood Reservoir.
- Chapter 2 is an evaluation of current reservoir conditions and provides information on the data and management tools developed to address the terms and conditions for Bull Trout listed in the 2005 BiOp. The ELCOM-CAEDYM model is described in this chapter used to simulate changes in the operation of Deadwood Reservoir in order to assess operational impacts to the reservoir, water quality/chemistry and primary production. These results were used as inputs to the models described in the next chapter which predict river conditions downstream from the dam. This chapter also

includes a trophic analysis based on isotope data measured in organisms from the reservoir and Bull Trout stomach samples.

- Chapter 3 is an evaluation of current physical conditions in the Deadwood River in response to reservoir operations. This chapter includes a hydrologic analysis of the river, description of operations, models used to assess the effects of dam and reservoir operations on water temperature, chemistry and hyporheic exchange, nutrient and chlorophyll transport, an assessment of the macro-invertebrate community and production in the Deadwood River downstream from the dam.
- Chapter 4 includes analyses on movement and growth of Bull Trout in the reservoir and stilling basin downstream from the dam. Additionally, this chapter describes the physical habitat for Bull Trout at various water operations scenarios in the Deadwood River downstream from the dam.
- Chapter 5 describes the conditions and impacts of the 2.3 cfs post-irrigation streamflow from Deadwood Dam in relation to physical habitat, water temperatures, ice cover, and water chemistry.
- Chapter 6 is a synthesis of the integrated effects of reservoir operations on Bull Trout and aquatic habitat in the Deadwood Reservoir and River. This chapter discusses how the proposed 2.3 cfs post-irrigation streamflow compares to the previously implemented 50 cfs post-irrigation streamflow and also summarizes the results and findings from all of the previous chapters in relation to the Terms and Conditions in the BiOp.
- Chapter 7 discusses the findings supported by the study which is the most comprehensive scientific investigation of the effects of water operations and streamflows in Deadwood River and Reservoir on the aquatic ecosystem and threatened Bull Trout.

1.7 Literature Cited

Parenthetical Reference	Bibliographic Citation
63 FR 31647	Federal Register. 1998. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Klamath River and Columbia River Distinct Population Segments of Bull Trout. June 10, 1998. Vol. 63, No. 111, Pp. 31647-31674.
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Downs et al. 2006	Downs, C.C., D. Horan, E. Morgan-Harris, and R. Jakubowski. 2006. "Spawning Demographics and Juvenile Dispersal of an Adfluvial Bull Trout Population in Trestle Creek, Idaho." *North American Journal of Fisheries Management* 26:190-200.
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Pruitt and Nadeau 1978	Pruitt, T. A. and R. A. Nadeau. 1978. Recommended stream resource maintenance flows on seven southern Idaho streams. Instream Flow Information Paper 8, Cooperative Instream Flow Service Group. U. S. Fish and Wildlife Service, Boise Field Office, Boise, Idaho.
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USFWS 2014	U.S. Fish and Wildlife Service. 2014. *Biological Opinion for the Bureau of Reclamation Operations and Maintenance for Projects in the Snake River Basin Above Brownlee Reservoir Effects to Bull Trout in the Powder River, Oregon and Critical Habitat in Idaho and Oregon*. Idaho Fish and Wildlife Office, Boise, Idaho.

Chapter 2 EVALUATION OF RESERVOIR CONDITIONS

2.1 Physical and Ecological Conditions of Deadwood Reservoir

2.1.1 Introduction

This section describes the configuration, validation, and application of the coupled three-dimensional (3D) hydrodynamic-ecological model ELCOM-CAEDYM for Deadwood Reservoir. The model was developed with the objective of investigating how reservoir operations affect habitat conditions and energy sources for Bull Trout, as listed in the BiOp (USFWS 2005). Specifically, this section illustrates the physical and ecological characteristics of Deadwood Reservoir in response to historical dam operations and to different operational scenarios based on the numerical modeling results. This section also describes the field data collection program that was required for the development of ELCOM-CAEDYM and the main characteristics of Deadwood Reservoir based on field data.

2.1.2 Methods

Field Collection Program

Automated sensors relevant to reservoir processes are listed below. The Lake Diagnostic System (LDS) was installed as part of the project by Precision Measurement Engineering.

Water level (sampling interval in parentheses):

- Deadwood River (15 minute)
- Trail Creek (30 minute summer, 1 hour winter)
- Deadwood Reservoir forebay elevation (15 minute)

Flow:

- Deadwood River below the Dam (15 minute)

Individual flow measurements:

- Deadwood River (several measurements obtained during multiple field seasons)

- Trail Creek (several measurements obtained during multiple field seasons)
- Other tributaries entering Deadwood Reservoir to develop reservoir system water balance (once per year)

Water Temperature:

- Deadwood River (15 minute)
- Trail Creek (60 minute)
- Wild Buck Creek (60 minute)
- Basin Creek (60 minute)
- Beaver Creek (60 minute)
- South Fork Beaver Creek (60 minute)
- Deadwood Reservoir LDS (1 minute)

Dissolved oxygen (DO):

- Deadwood Reservoir LDS (1 minute)

Meteorological parameters (air temperature, relative humidity, wind speed, wind direction, shortwave radiation, and net radiation):

- Deadwood Reservoir LDS (1 minute)

The LDS meteorological sensors are moved onshore during the winter months to protect the frame structure from damage that would result from the winter ice cover on the lake. The LDS was first deployed July 15, 2007 and moved to shore September 24, 2007. It was re-deployed on the lake August 14, 2008, after minor repair work on the temperature chain, and moved back onshore to its winter location on October 14, 2008. For 2009, summer deployment occurred on July 9 and moved back to shore on October 14 for the winter.

Manual sampling program

Reservoir sampling stations, duration, and frequency

Figure 2-1 illustrates the locations of the reservoir sampling sites for Deadwood Reservoir as well as locations for collection of tributary data. The frequency and duration for sampling of the reservoir and tributary stations are listed in Table 2-1 for 2007 through 2009.

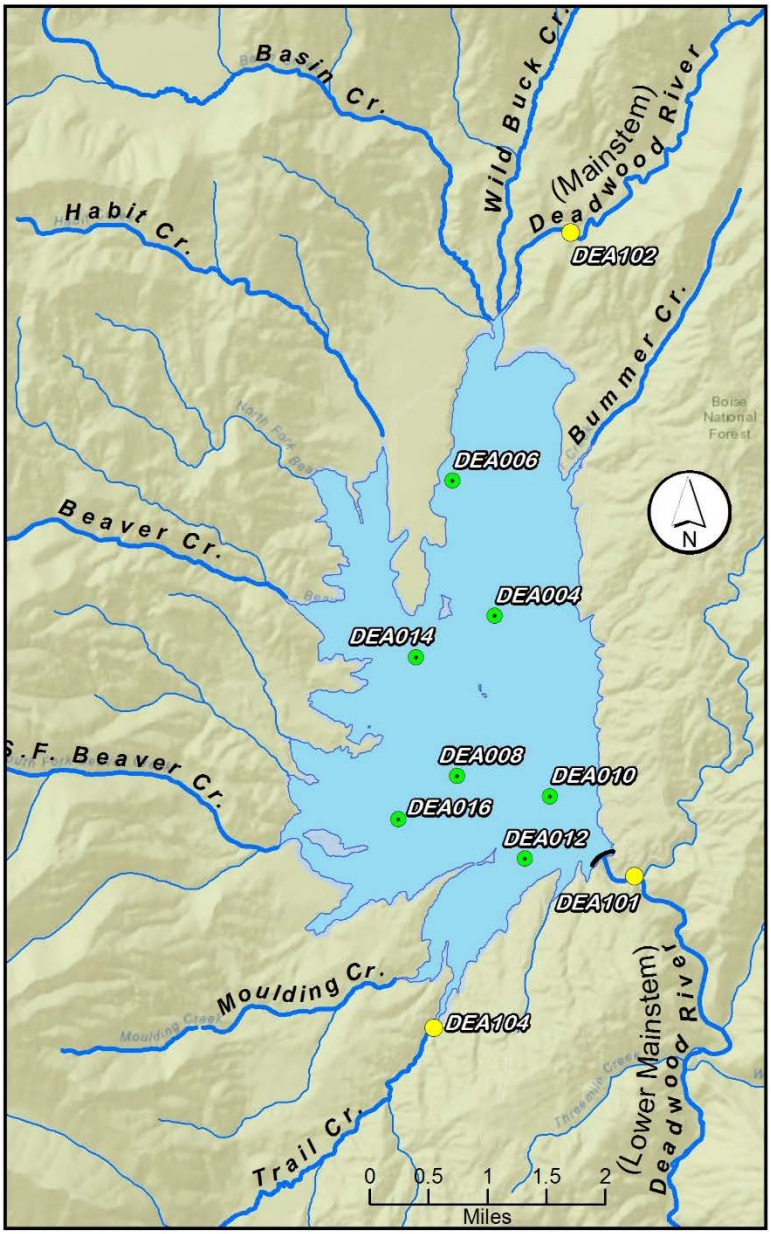


Figure 2-1. Water chemistry and reservoir profile locations (water chemistry also sampled at reservoir profile locations for surface, mid, and bottom water column conditions). Note: green sampling markers denote reservoir locations, while yellow denote tributary locations.

Table 2-1. Reservoir and tributary regular sampling frequency.

Sampling Site	2007 Sampling Duration	2007 Sampling Frequency	2008 Sampling Duration	2008 Sampling Frequency	2009 Sampling Duration	2009 Sampling Frequency
DEA004	5/23-10/9	weekly	6/16-10/6	biweekly	6/29-9/28	monthly
DEA006	5/23-10/9	weekly	6/16-10/6	biweekly	6/29-9/28	monthly
DEA008	4/30-10/9	weekly	---	---	---	---
DEA010	4/30-10/9	weekly	6/5-10/6	biweekly	6/29-9/28	monthly
DEA012	5/29-9/10	biweekly	---	---	---	---
DEA014	5/29-9/10	biweekly	6/30-10/6	biweekly	6/29-9/28	monthly
DEA016	5/29-9/10	biweekly	6/16-10/6	biweekly	6/29-9/28	monthly
DEA101	4/26-10/9	weekly	6/5-10/6	biweekly	6/29-9/28	monthly
DEA102	4/26-10/9	weekly	6/5-10/6	biweekly	6/29-9/28	monthly
DEA104	5/10-10/9	weekly	6/5-10/6	biweekly	6/29-9/28	monthly

During 2007, weekly reservoir and tributary sampling commenced the first week in May and concluded the last week in October for four of the seven reservoir stations. The other three were sampled on a biweekly basis and over a shorter duration. Reservoir water chemistry samples and a profile were collected through the ice at DEA010 in February of 2008. During 2008, biweekly reservoir (five stations) and tributary sampling commenced the first week in June and concluded the first week in October. Reservoir and tributary samples were collected about monthly during 2009, with sampling beginning in late June and ending in late September.

Sampled variables

Table 2-2 presents the field measured water quality parameters for the reservoir profiles and tributaries as well as the laboratory processed constituents for the 2007 through 2009 field seasons.

Evaluation of the 2007 limnological data indicated a need for some modifications to the sampling program. Analyses of silica concentrations and low-level detection analyses for nitrogen and phosphorus were initiated in 2008 and continued in 2009. The trichromatic spectrophotometric method used in 2007 for chlorophyll *a* analyses was changed in 2008 and 2009 to an acid-corrected spectrophotometric one that yields values for both chlorophyll *a* and pheophytin-a. Chlorophyll sampling during 2008 and 2009 was modified to collect samples at the 1-meter (m) depth as well as at the depth of the fluorescence maxima at most of the reservoir stations.

Table 2-2. Measured and analyzed water quality parameters.

Water-column profiles and field data	Lab-analyzed water-quality variables
Water temperature	Nitrite+nitrate, dissolved
DO concentration	Ammonia, dissolved
pH	Orthophosphate, dissolved
Conductivity	Total phosphorus
Turbidity	Total Kjeldahl nitrogen
Fluorescence (reservoir only)	Organic carbon, dissolved
Barometric pressure	Organic carbon, total
Secchi depth (reservoir only)	Turbidity
	Chlorophyll *a*
	Pheophytin-a
	Silica, dissolved

Numerical modeling

The numerical simulations in this study were carried out using the ELCOM, described in detail in Hodges et al. (2000), coupled with the CAEDYM, detailed in Gal et al. (2009). ELCOM is a standalone 3D hydrodynamic model, while CAEDYM is an ecological model that uses ELCOM as its hydrodynamic driver. The coupled models provided a powerful tool in understanding the spatial and temporal interactions between physical, chemical and biological variables in Deadwood Reservoir.

ELCOM Setup – The hydrodynamic simulation included atmospheric exchange, inflow dynamics, turbulent mixing dynamics, Coriolis forcing, and ice formation dynamics. Surface heat transfers included atmospheric boundary layer stability correction. A description of the ice module can be found in Oveisy et al. (2012).

CAEDYM Setup – CAEDYM was configured to simulate four phytoplankton groups: cyanobacteria (CYANO), dinoflagellates (DINOF), diatoms (FDIAT), and cryptophytes (CRYPT). These represent the four main phytoplankton groups observed in Deadwood Reservoir during the sampling period, i.e., *Anabaena spiroides, Ceratium hirundinella*, *Fragilaria* spp., and *Cryptomonas* spp. *A. spiroides* is a filamentous type of cyanobacteria typically found in eutrophic lakes, characterized by its ability to fix atmospheric nitrogen via a heterocyst (Padisak et al. 2009). *C. hirundinella* is a large, slow growing dinoflagellate that is able to actively migrate vertically in the water column due to the presence of flagella. It commonly appears in late summer in eutrophic, stratified lakes (Alexander and Imberger 2009). *Fragilaria* spp. are diatoms typically present in eutrophic systems and normally occur during spring (Padisak et al. 2009). *Cryptomonas* spp. are cryptophytes that are common in freshwater habitats and are known to form blooms at greater depths or during winter beneath the ice.

Algal biomass was modeled as chlorophyll *a*, with a constant carbon to chlorophyll *a* ratio. Nutrient limitation considered dynamic nitrogen intracellular stores for dinoflagellates and cryptophytes, and constant nitrogen stores for cyanobacteria and diatoms. Phosphorus intracellular stores were considered constant for all groups. Light limitation did not include photoinhibition. Although grazing was not modeled explicitly, it was parameterized indirectly with the phytoplankton loss term. Active vertical migration was included for dinoflagellates and cryptophytes, estimated on the basis of the balance between irradiance and internal nitrogen stores. Cyanobacteria were set to be positively buoyant with a constant upwards velocity and diatoms were assigned a constant settling velocity based on their average size and specific gravity.

In addition, the following state variables were included in the configuration of CAEDYM: DO, nitrate (NO_3), ammonium (NH_4), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), orthophosphate (PO_4), dissolved organic phosphorus (DOP), particulate organic phosphorus (POP), dissolved organic carbon (DOC), particulate organic carbon (POC). A simple static sediment model was chosen, based on empirical relationships between the sediment and water.

Model configuration

The time periods for the 3D hydrodynamic and ecological simulations were chosen in order to match critical water years identified by the BiOp, i.e., a wet year (1997), a dry year (2001), and an average year (2003). As field data was collected between 2007 and 2009, this was the period chosen to validate the simulation results. The simulations for 1997, 2001, and 2003 were run for a period of 14 months, starting on November 1, 1996, 2000, and 2002, respectively, while the 2008 simulation was performed for an 18-month period, starting on October 3, 2007.

Bathymetry – Bathymetric reservoir data was available from a survey completed in 2002 by Reclamation. From these data, the domain of Deadwood Reservoir was discretized with a uniform 100 by 100 m horizontal grid and a uniform vertical grid with 1 m resolution (Figure 2-2). The time step was set to 120 s in order to satisfy the Couránt-Friederich-Levy (CFL) stability condition and the ratio of computational time to real time was around 900.

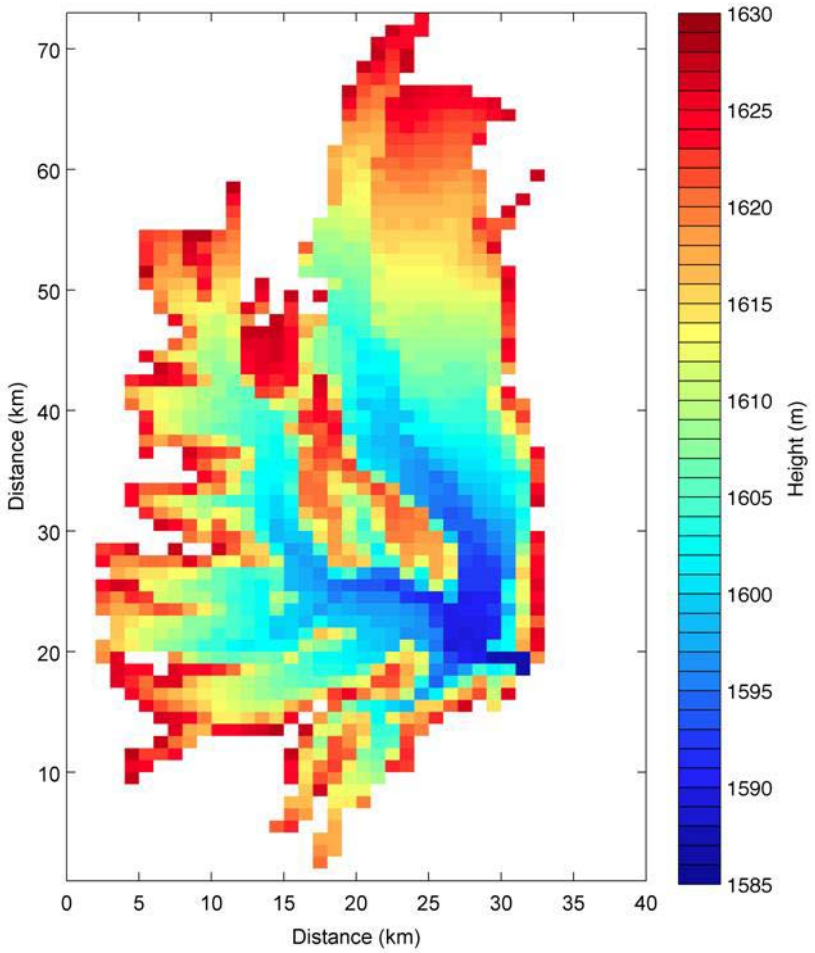


Figure 2-2. Bathymetry of Deadwood Reservoir, with a 100 m horizontal grid.

Water balance – The simulations considered inflows from the six major tributaries to Deadwood Reservoir (Deadwood River and Trail, Wild Buck, Basin, Beaver, and South Fork Beaver creeks), as well as outflows at the dam and spillway (when applicable). As discharge measurements were only available for Deadwood River and Trail Creek, the two primary tributaries of Deadwood Reservoir, a water balance was developed in order to determine flows from ungaged creeks. A storage curve was generated from the bathymetry data and used in conjunction with daily measured inflow and outflow values, water level fluctuations measured at the dam wall, and estimated evaporation rates to determine a residual inflow for each day. The residual flow was then split into five separate flows, according to measured rates during the period 2007-2009. This method attributed 39.13% of the residual inflow to Basin Creek, 24.05% to Wild Buck Creek, 18.41% to South Fork Beaver Creek, 11.97% to Beaver Creek and 6.44% to Trail Creek. The residual flow attributed to Trail Creek was added to measured data. Water temperature and water quality at the inflows were derived from the field monitoring program.

Due to uncertainties in the water balance related to poorly known evaporation rates, groundwater flow and contribution from rainfall, the inflows were further adjusted based on the model results so as to match measured and simulated water levels at the dam wall.

Meteorological forcing – The model was forced with a combination of calculated and measured data at the LDS and meteorological stations present around the area of the reservoir. Air temperature and relative humidity were taken from the LDS; wind speed and direction were derived from combined data at the LDS and Bearskin Creek station; incoming short-wave radiation was derived and scaled from Bogus Basin ski area; cloud cover was calculated based on measured air temperature, relative humidity and short-wave radiation, and daily averaged values were used.

Initial conditions – All variables (i.e., water temperature, DO, and water quality variables) were initialized with data from the field data collection program developed for this study. Except for the initial water level, all simulations presented in this study used the same set of initial conditions.

Model calibration

Before the model was applied to the analysis of the alternative operational scenarios for Deadwood Reservoir, model calibration, and validation were required. The model calibration process consisted of the following steps:

1. Running the model and producing model output files.
2. Analyzing the model output files.
3. Assessing the model accuracy by comparing model outputs with collected field data.
4. Adjusting model input parameters, coefficients, and boundary conditions based on these comparisons (i.e., calibration).
5. Repeat steps 1–4 until validation was complete.

Scenarios

An important use of the reservoir model developed for the Deadwood Reservoir is as a predictive tool to aid management decisions. Specifically, different options for water level manipulation can be assessed using a 'what-if' scenario approach, and the results combined with expert knowledge of the system and various constraints to determine an optimal management strategy.

The selected water years for scenario simulations (1997, 2001, and 2003) represented a range of inflow run-off and outflow management conditions (Table 2-3), from extremely dry (2001) to extremely wet (1997) years, giving a range of possible modes of reservoir operation.

A total of 21 scenario simulations were performed considering alternative options for water release at the dam during the winter period (Table 2-3). The simulations can be divided into four sets of scenarios for each water year mentioned above: one scenario based on historical actual rates through the dam and three forecast scenario with constant discharge rates of 50, 2, and 0 cfs during winter. Each set further consisted of two sub-sets defined by the choice of either slow or fast spring ramp up and fall ramp down rates (Figure 2-3; Table 2-3 for details).

Table 2-3. Scenario simulation characteristics.*

Scenario name	Additional carryover (acre-feet)	Initial height (ft [m])	Initial volume (acre-feet [m^3])	Winter Reservoir Release	Time frame	Spring ramp up[1]	Fall ramp down[1]
Validation year (2008)							
-	0	52965 (1613.22)	52,864.67 (65,207,614)	Historical	10/03/2007 - 03/06/2009	Historical	Historical
Dry year (2001)							
Dry-Historical	0	5308.89 (1618.17)	85,505.67 (105,469,690)	Historical	11/01/2000 - 12/31/2001	Historical	Historical
Dry-50-Fast				50 cfs		Fast	Fast
Dry-50-Slow						Slow	Slow
Dry-2-Fast	17,280			2 cfs		Fast	Fast
Dry-2-Slow						Slow	Slow
Dry-0-Fast	18,000			0 cfs		Fast	Fast
Dry-0-Slow						Slow	Slow
Average year (2003)							
Avg-Historical	0	5291.21 (1617.8)	50,435.30 (62,211,024)	Historical	11/01/2002 - 12/31/2003	Historical	Historical
Avg-50-Fast				50 cfs		Fast	Fast
Avg-50-Slow						Slow	Slow
Avg-2-Fast	17,280			2 cfs		Fast	Fast
Avg-2-Slow						Slow	Slow
Avg-0-Fast	18,000			0 cfs		Fast	Fast
Avg-0-Slow						Slow	Slow
Wet year (1997)							
Wet-Historical	0	5321.43 (1621.99)	117,187.68 (144,548,870)	Historical	11/01/1996 - 12/31/1997	Historical	Historical
Wet-50-Fast				50 cfs		Fast	Fast
Wet-50-Slow						Slow	Slow
Wet-2-Fast	17,280			2 cfs		Fast	Fast
Wet-2-Slow						Slow	Slow
Wet-0-Fast	18,000			0 cfs		Fast	Fast
Wet-0-Slow						Slow	Slow

1 Ramp up and down rates:
Slow ramp up: one week, approximating the duration of the natural rise
Fast ramp up: fastest possible as defined by the standard operating procedures
Slow ramp down: ~ 10 days, modelled after 2011 ramp down, which is the longest possible
Fast ramp down: 2 days, similar to past operations

* Note that simulated model input values may not reflect actual operational values, and may not account for variation due to flood control operations. Values in this table should be interpreted only as approximately representative of the interconnected effects of water year type, carryover, and initial water volume under various ramping and winter release scenarios, rather than as specific predictive values.

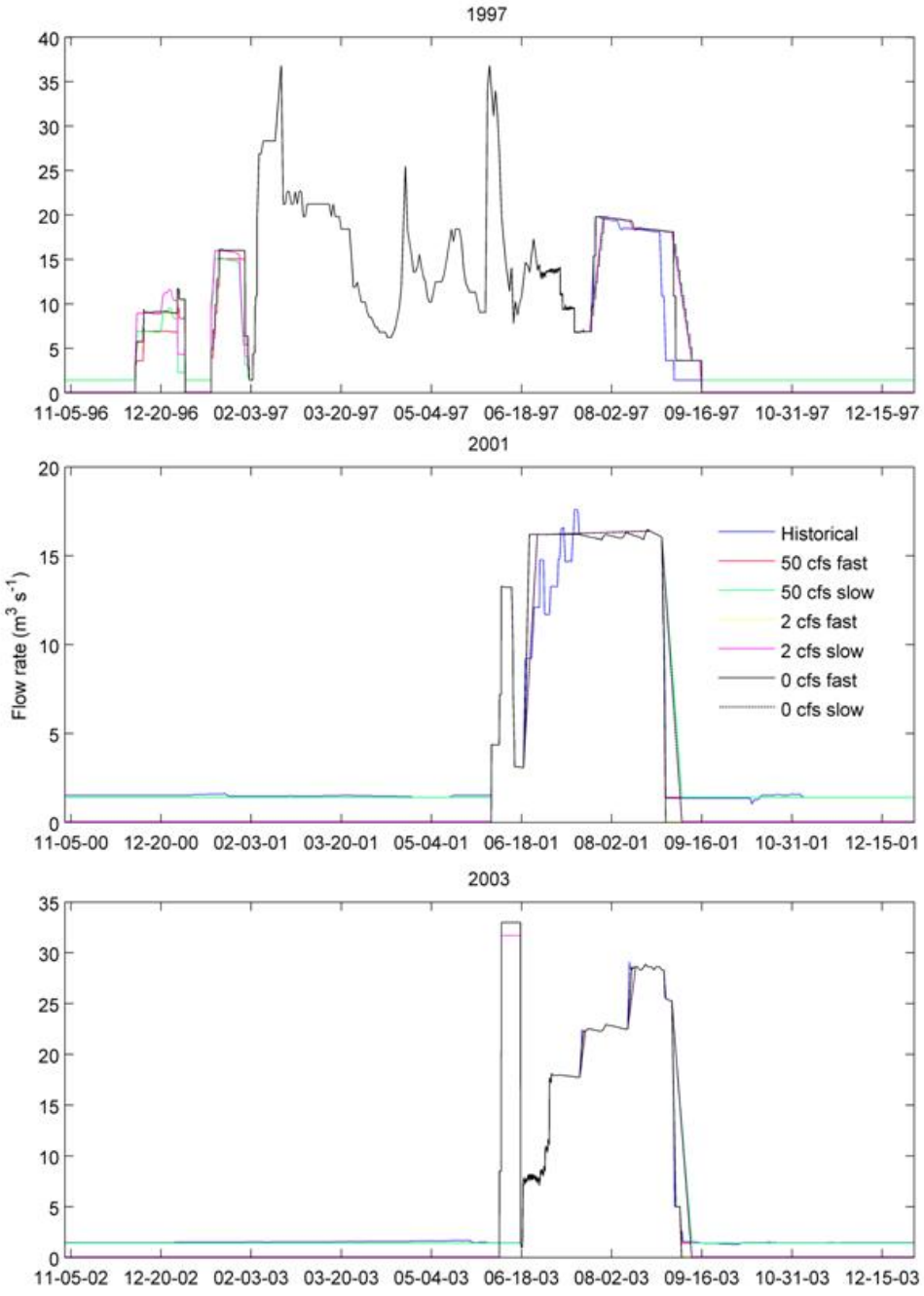


Figure 2-3. Outflow rates considered for each operational scenario (1997 – wet; 2001 – dry; 2003 – average).

Water Balance and Temperature Data – Validation Year (2008)

Based on data from October 2007 to March 2009, it is possible to observe that the major contributor to Deadwood Reservoir is the Deadwood River, which reached ca. 60 cubic meters

per second (m^{3}/s) during the snowmelt period (May-June), compared to less than 10 m^{3}/s from the other tributaries (Figure 2-4). After the snowmelt period, the flows entering the reservoir gradually receded, with occasional storm events that sent short peaks of additional flow to the reservoir. The inflow temperatures from Deadwood River showed strong seasonality, with values of approximately 5 to 6°C during the spring melt flows, increasing to ca. 20°C over the summer period and gradually decreasing to almost 0°C during winter (Figure 2-4). Trail Creek, entering the Deadwood Reservoir, also displayed similar hydrologic and temperature characteristics during the course of the year (Figure 2-4). The regulated outflow rates through the dam wall and spillway are presented in Figure 2-5.

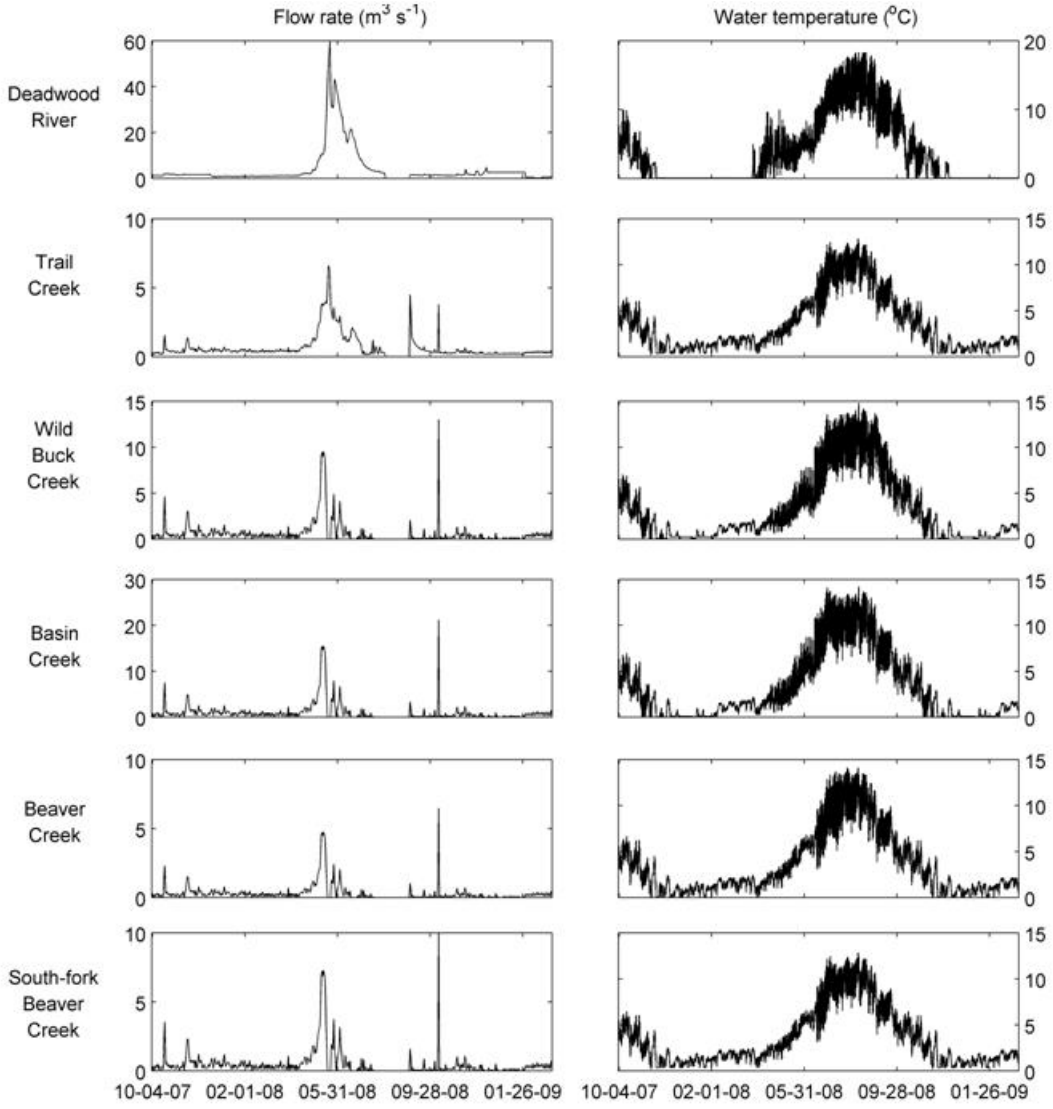


Figure 2-4. Flow rates and water temperatures at the main tributaries to Deadwood Reservoir for the validation year 2008.

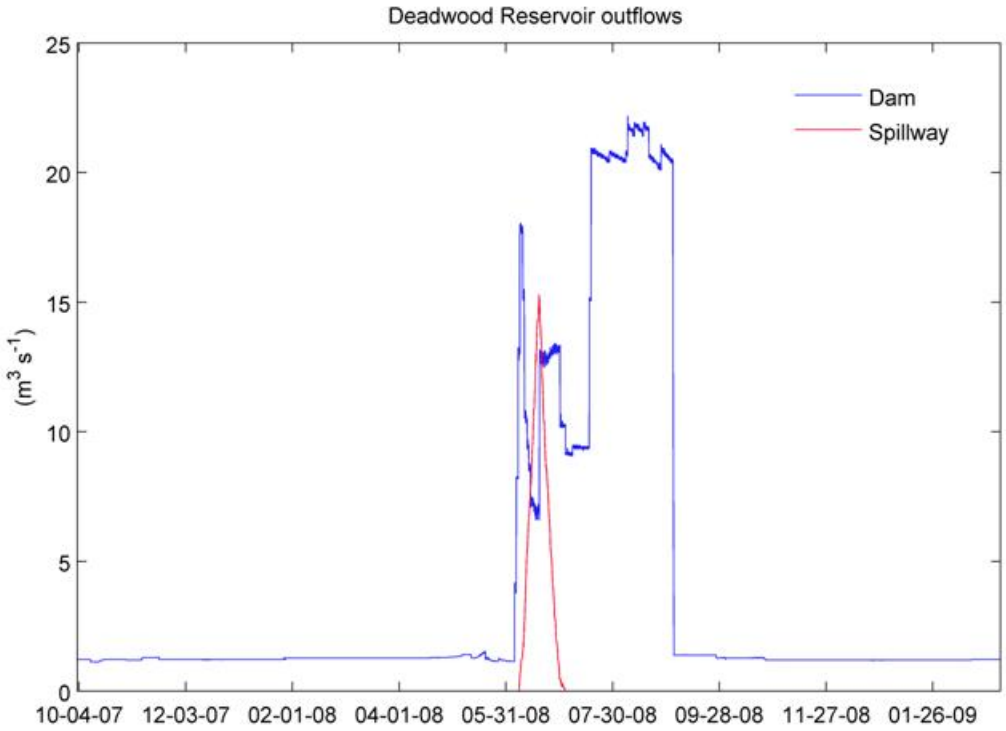


Figure 2-5. Outflow rates at the dam and spillway for the validation year 2008.

Meteorological Variables

Air temperature showed a large annual range from -20°C to approximately 30°C, with a diurnal range regularly exceeding 15°C (Figure 2-6). Relative humidity also showed large annual variability with lower overall humidity during the summer months (Figure 2-6). There was also a strong diurnal variability in the relative humidity during summer, with humidity ranging between 20% during the day to 90% during the night. Solar radiation showed a strong diurnal and seasonal signal, as expected, with lower values during winter (Figure 2-6). Wind speed data showed a consistent daily pattern with higher wind speeds normally in the afternoon and windy conditions were more prevalent during spring and autumn (Figure 2-7). Sustained strong winds were rare with only one noteworthy storm on October 1, 2008 when wind speeds of 45 miles per hour (mph) were recorded (Figure 2-7).

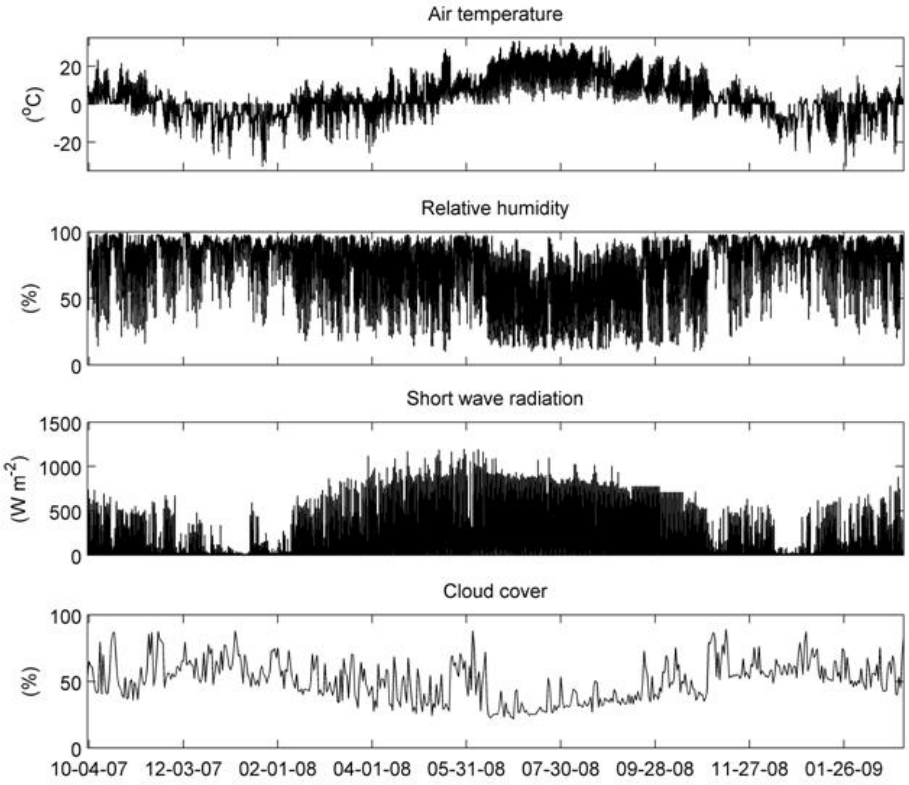


Figure 2-6. Deadwood Reservoir meteorological forcing.

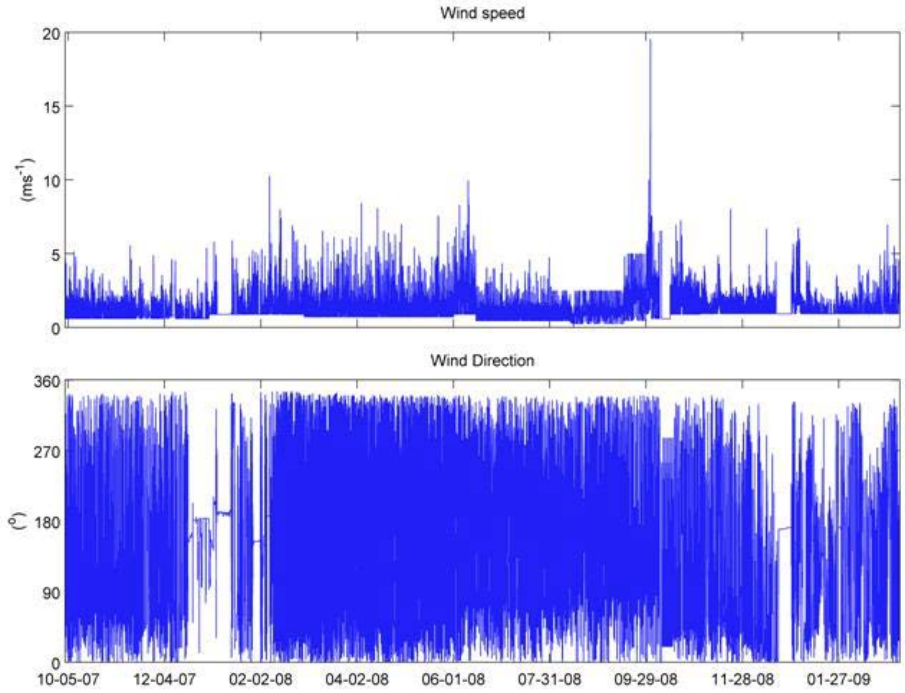


Figure 2-7. Deadwood Reservoir wind speed and direction.

Reservoir Water Temperature Response

The reservoir water temperature response is dominated by surface heating and the location of the deep reservoir outlet. The centerline of the two reservoir outlets is located 39.3 m below the normal water surface elevation. During the summer, when water is released from storage to satisfy irrigation and recreational needs, reservoir drafts exceeding 10 m below the normal water surface elevation (or forebay elevations less than roughly 5,302 feet or 1,616 m) draw the thermocline towards the bottom of the reservoir as the outlets draw the cooler water first (Figure 2-8 and Figure 2-9). This impact can be clearly seen in the time series temperature from the dam (Figure 2-10).

The thermal structure of the reservoir was well reproduced by ELCOM-CAEDYM after extensive calibration (Figure 2-8 and Figure 2-9). The model was able to represent the stratification dynamics during spring and summer and the typical behavior of the thermocline, as described above. The mixed period through fall was also captured reasonably well with a slight delay, but the ice cover period was not well represented, with lower ice penetration and an earlier breakdown (Figure 2-8). The simulated water temperature at the dam wall also showed good agreement with field data (Figure 2-10).

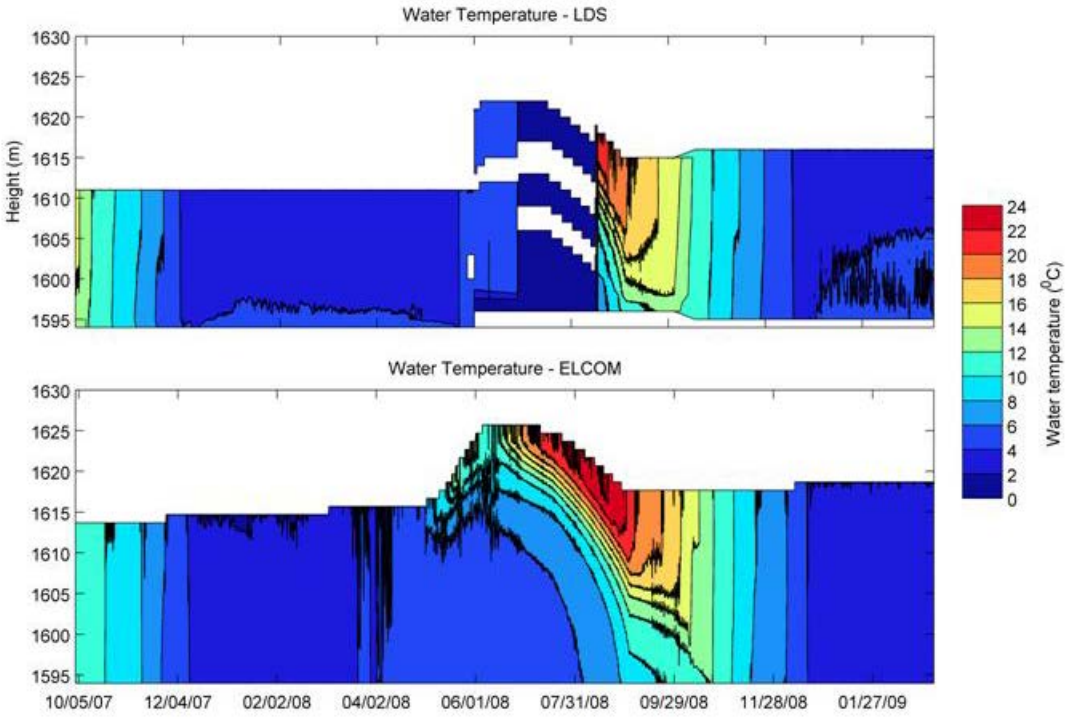


Figure 2-8. Water temperature at the LDS (top panel) and simulated by the model (bottom panel).

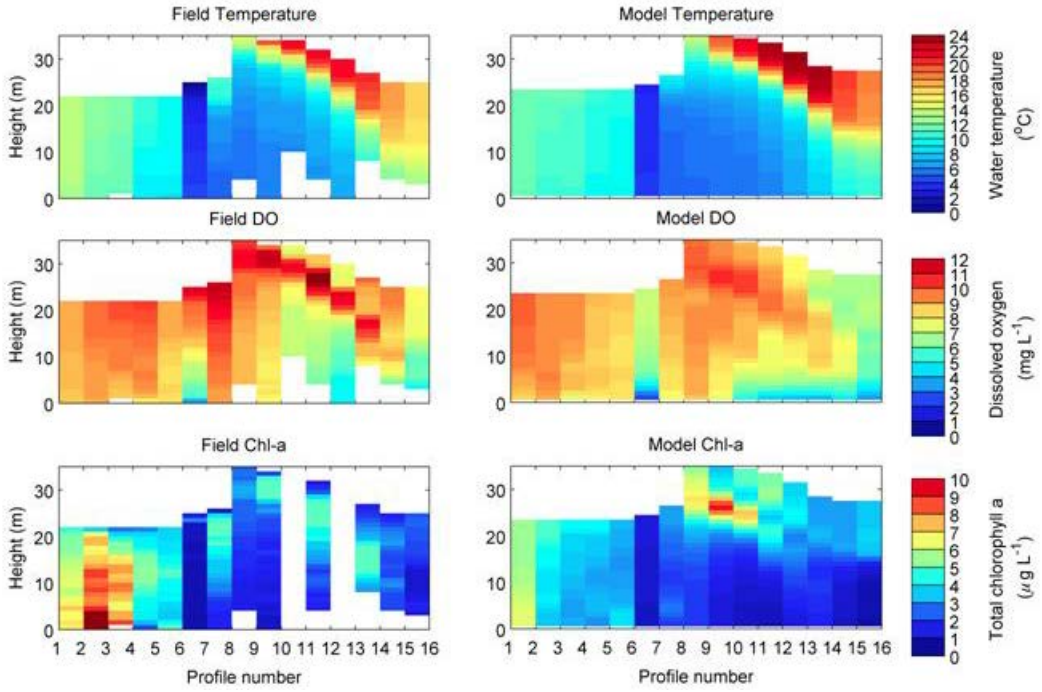


Figure 2-9. Comparison of measured (left column) and simulated (right column) temperature, DO, and chlorophyll *a* measured with the profiler at station DEA010.

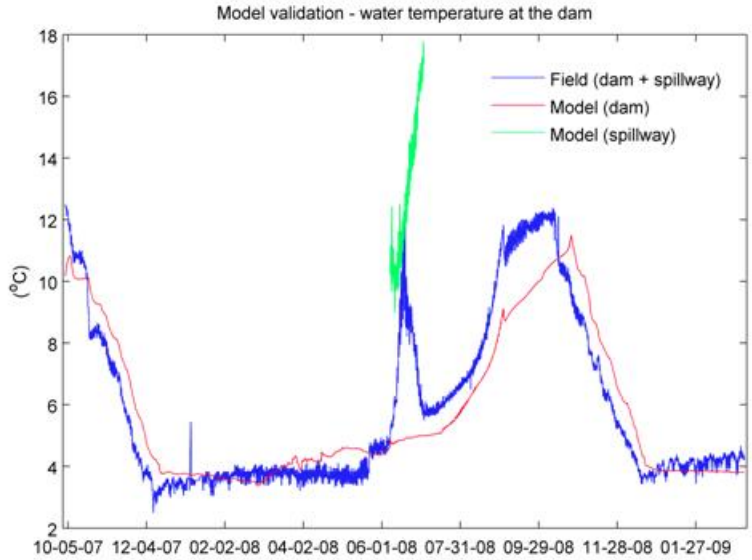


Figure 2-10. Comparison of measured and simulated water temperature at the dam.

Dissolved Oxygen Response

The reservoir oxygen response, as measured by both drop-sondes (Figure 2-9) and the LDS (Figure 2-11), show a super-saturated region at 7 to 10 m depth, with oxygen reaching 130% of saturated values, associated with a deep measured chlorophyll fluorescence maxima. This feature was remarkably persistent for a period of months, and was drawn down to the reservoir base as the outflow operated at a high rate (Figure 2-11).

Further information can be gathered from line plots of the DO saturation (Figure 2-12 and Figure 2-13). During July/August, these showed a cyclical diurnal oxygen signal for the upper two sensors associated with the daily cycle of primary production and respiration. At the start of the record (Figure 2-13), the third and fourth sensors showed supersaturation (relative to surface levels), and as time progressed and the surface layer deepened the third sensor moved into the surface layers, became sub-saturated and started to follow the daily cyclical pattern. The fifth sensor then began to show supersaturation (relative to surface level) as the deep chlorophyll maxima moved to a deeper location. By the end of the first week in August 2007, the fourth sensor was also in the surface layer and started tracking the diurnal cycle. The strong variability in the signal when the sensors are supersaturated indicates an intricate balance between oxygen production and the physical diffusion and/or mixing of that oxygen surplus.

ELCOM-CAEDYM did a reasonable job simulating the DO dynamics (Figure 2-9 and Figure 2-11), including the timing of hypolimnetic anoxia and reaeration. Nearly all comparisons of surface and bottom concentrations were within about 1 milligrams per liter (mg/L). Surface values were 5 mg/L low on August 25 and September 8, 2008 and the bottom value for August 25, 2008 was low by 8 mg/L. Concentrations were also slightly under-predicted during the mixed periods in fall 2007 and 2008. The reservoir oxygen response, as measured by the drop-sondes and the LDS (Figure 2-9 and Figure 2-11), showed a super-saturated region at 7 to 10 m depth that was remarkably persistent for a period of months, as described above. This super-saturated oxygen region was reproduced by the model, although not as pronouncedly as in the field data.

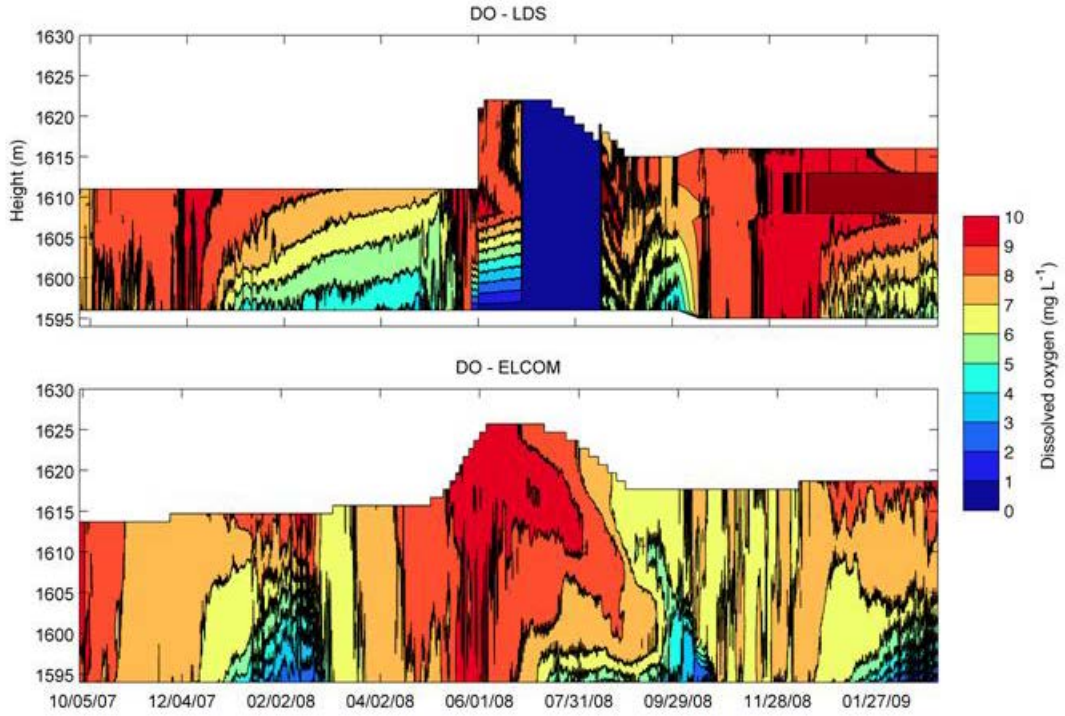


Figure 2-11. DO at the LDS (top panel) and simulated by the model (bottom panel).

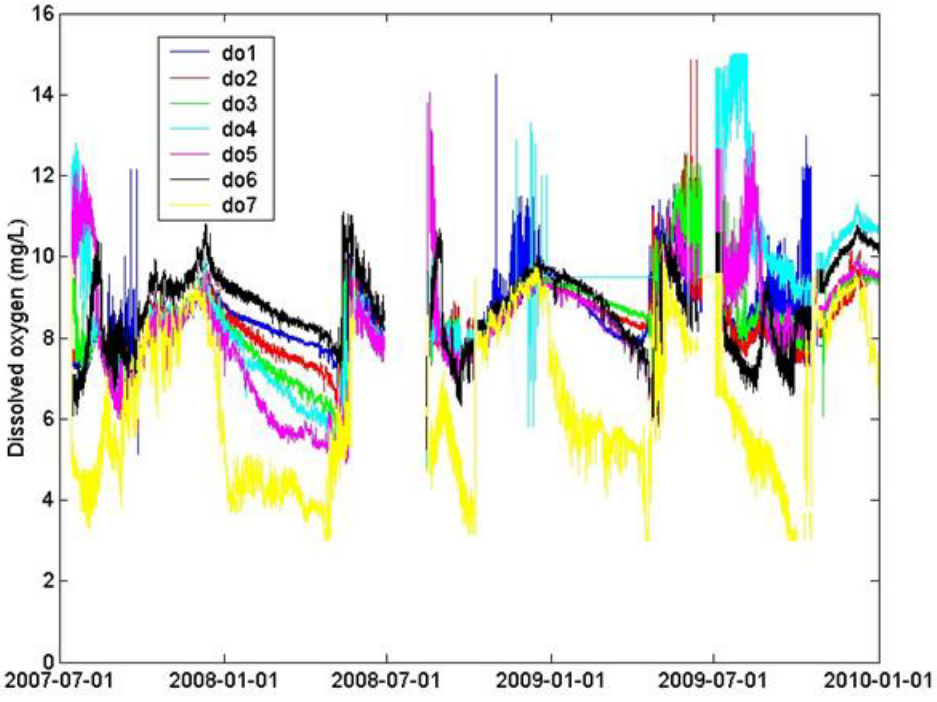


Figure 2-12. Line plots of DO saturation for each of the seven DO sensors.

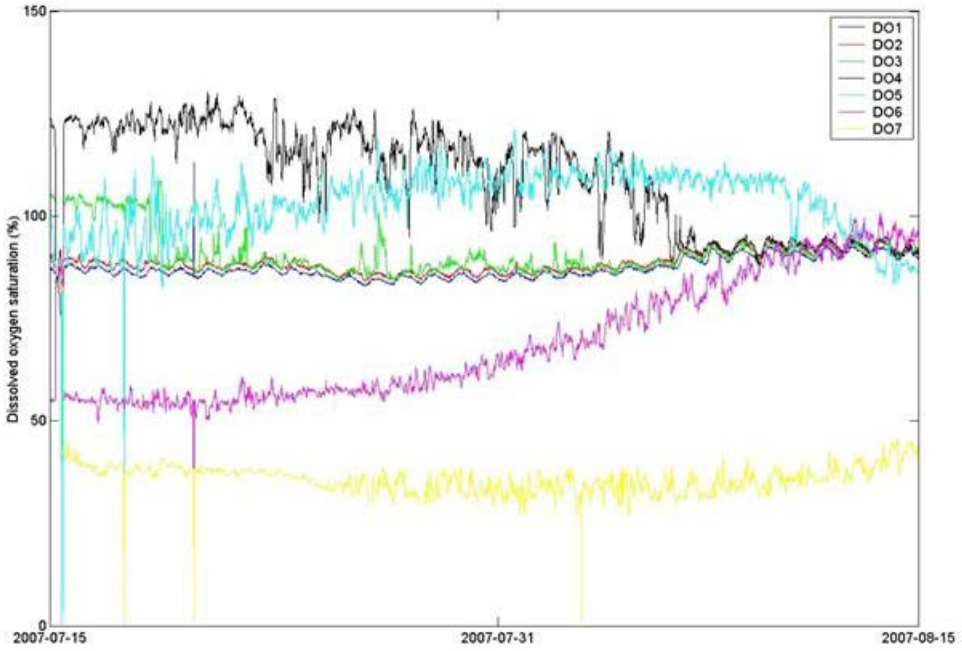


Figure 2-13. As for the previous figure, but for a shorter period.

Water Quality Response

Chlorophyll a

The 2007 protocol for collection of chlorophyll *a* samples only at the 1-m depth did not quantify the chlorophyll *a* layer near the thermocline that had been indicated by the combination of elevated fluorescence, supersaturation of DO, and high pH. The 2008 sampling program collected chlorophyll *a* samples at both the 1-m depth and at the depth of maximum fluorescence (Figure 2-9). The analytical results were very instructive in that, on average, the chlorophyll *a* concentrations at the 1-m depth were only about 28% of those measured at the fluorescence maxima. The ranges in chlorophyll *a* concentrations at the two depths were as follows: 1.5 to 3.5 µg/L at 1-m depth and 3.4 to 15.9 µg/L at the fluorescence maxima (Figure 2-14).

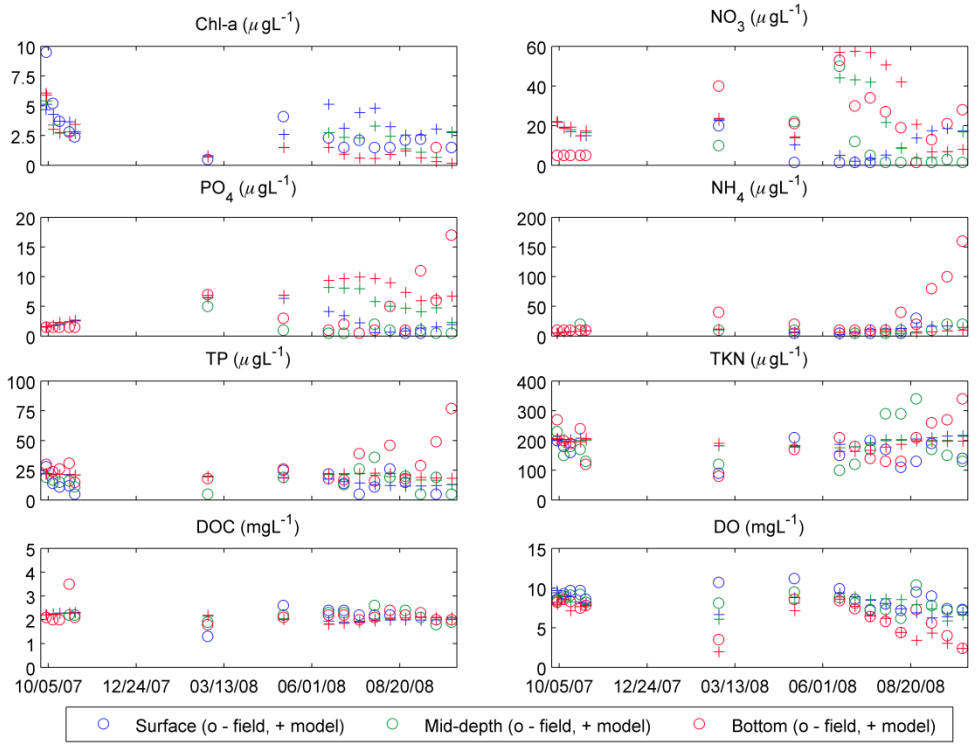


Figure 2-14. Comparison of measured (o) and simulated (+) variables at the surface, mid-depth, and bottom of the water column at station DEA010.

Nutrients

The preponderance of below-detection limit concentrations for the important bioavailable nutrients (dissolved ammonia, nitrite plus nitrate, and orthophosphate) measured by the 2007 sampling program meant that variations in phytoplankton production, as evidenced by variations in chlorophyll *a* concentrations, could not be correlated with nutrients. Additionally, the role of nutrient limitation could not be evaluated because nitrogen to phosphorus ratios could not be computed (those are computed as the sum of dissolved nitrite plus nitrate and ammonia divided by dissolved orthophosphate). These limitations led to a revision in nutrient sample analyses for 2008 in order to achieve lower detection limits on nitrogen and phosphorus analyses. For the 2008 sampling program, analytical detection limits, in µg/L, were as follows: dissolved nitrite plus nitrate, 3.0 (10.0 in 2007); ammonia remained at 10.0; orthophosphate, 1.0 (3.0 in 2007). The analytical results for 2008 were still dominated by below-detection limit concentrations. Most dissolved nitrite plus nitrate and orthophosphate concentrations measured in 2008 were less than a third of detection-limit concentrations measured in 2007. As in 2007, the role of nutrient limitation could not be computed.

Total phosphorus (TP) concentrations for surface, mid-depth, and bottom samples at DEA010 ranged from less than 10 to 76 µg/L (Figure 2-14); the other stations were similar. Surface

samples were often below detection but peaked at 25 µg/L in early August (Figure 2-14). The highest concentration, 76 µg/L, was measured near the bottom in early October prior to complete water-column circulation (Figure 2-14).

Surface and mid-depth concentrations of dissolved orthophosphate (PO_4) at DEA010 were below detection throughout sampling (Figure 2-14). Bottom concentrations reached 18 µg/L in early October as a result of hypolimnetic decomposition.

Total Kjeldahl nitrogen (TKN) concentrations at DEA010 ranged from below detection (3 samples) to 340 µg/L on two occasions, mid-depth in mid-September and bottom in early October (Figure 2-14). Dissolved ammonia (NH_4) concentrations at DEA010 ranged from below detection to as high as 160 µg/L at the bottom in early October. Dissolved nitrite plus nitrate concentrations at DEA010 ranged from below detection to 52 µg/L. The highest concentrations were measured in mid-depth and bottom sample in mid-June during snowmelt inflow.

The model results for total chlorophyll *a* showed reasonable agreement with field data (Figure 2-9; Figure 2-14). ELCOM-CAEDYM evolved a deep chlorophyll maxima starting in July 2008 and persisting through to August. The location of these maxima related well to the measured values (~7-10 m of depth), but the simulated concentrations (~7-9 µg/L) were higher than measured ones (~5-6 µg/L). Figure 2-15 shows the ELCOM-CAEDYM chlorophyll *a* output at full resolution and Figure 2-16 illustrates the phytoplankton community succession simulated by the model, which agreed well with field measurements (Figure 2-17), showing a prevalence of diatoms during spring and an increase in the concentrations of cyanobacteria over the summer months.

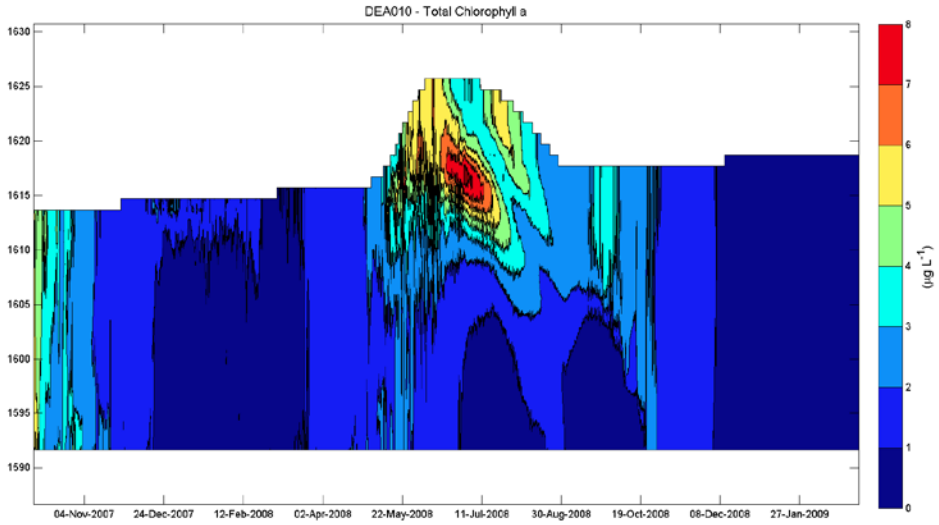


Figure 2-15. Total chlorophyll *a* simulated by ELCOM-CAEDYM at station DEA010.

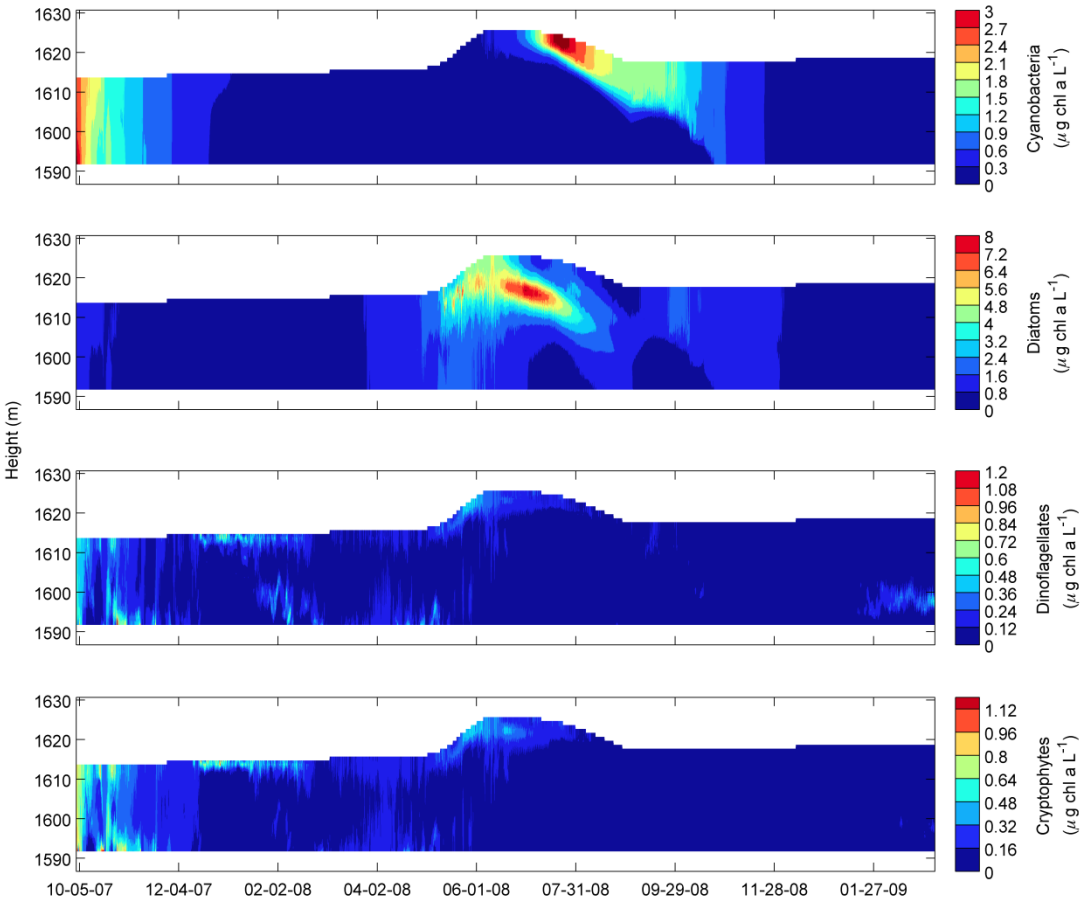


Figure 2-16. Phytoplankton community succession simulated by ELCOM-CAEDYM at station DEA010.

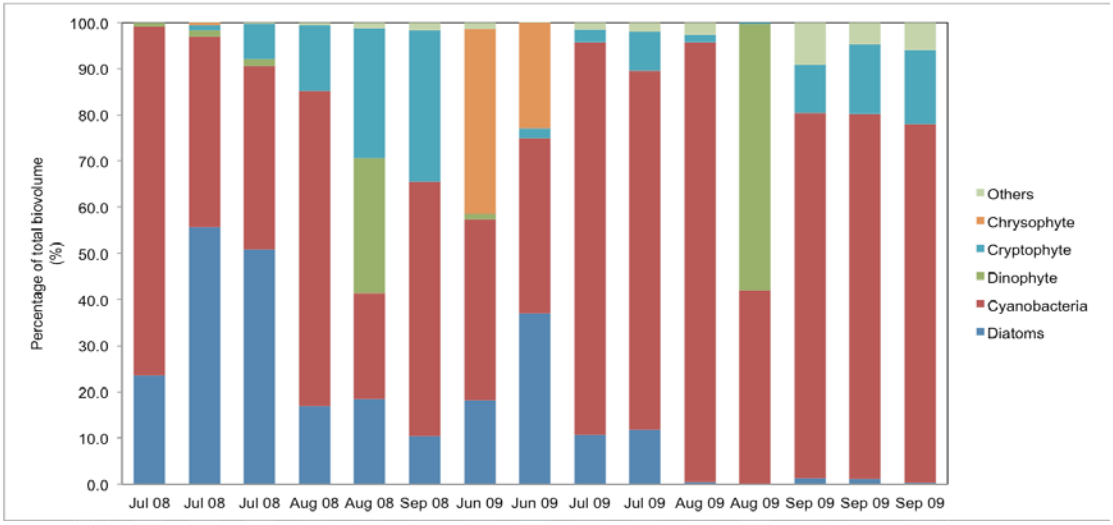


Figure 2-17. Phytoplankton biovolume data at station DEA010.

Results for nutrients were also generally good, with the range of nitrogen, carbon, and phosphorus species well captured (Figure 2-14). The majority of comparisons for NH_4 were satisfactory. The model values tended towards under-prediction (max. factor of about 10) of field values, especially in the bottom comparisons for September and October 2008. The results for nitrate tended to both under and over-prediction of mid-depth and bottom samples, with a maximum factor of ~2-5 µg L^{-1}. About one-half of the comparisons for PO_4 were nearly equal, while the rest had a tendency towards over-prediction of mid-depth and bottom values by factors up to about 10 µg L^{-1}. Figure 2-18 through Figure 2-23 show the model outputs at full resolution for NO_3, NH_4, TKN, PO_4, TP, and DOC.

In summary, the model predicted the very important variables of water temperature and DO remarkably well. The less-accurate prediction of nutrients and chlorophyll was within acceptable levels for these non-conservative, biologically mediated variables.

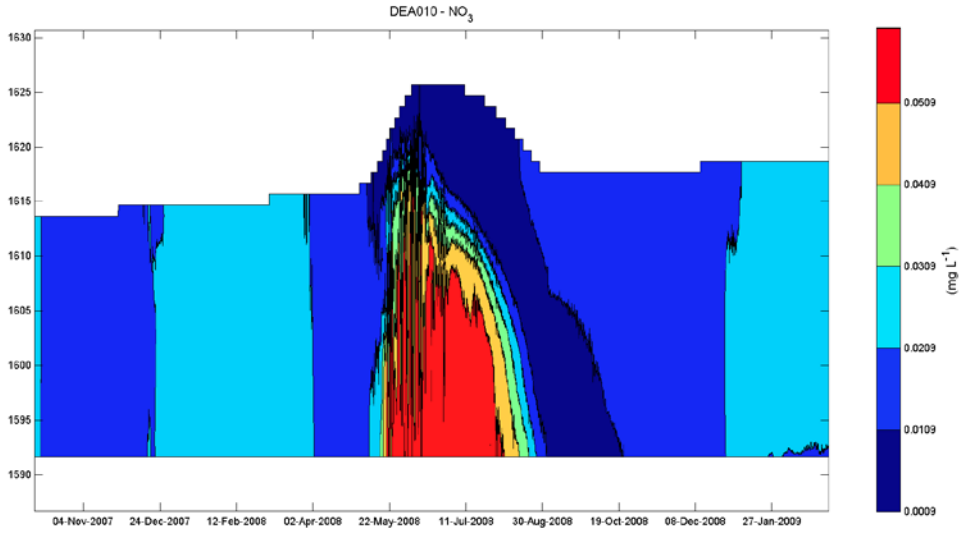


Figure 2-18. NO_3 simulated by ELCOM-CAEDYM at station DEA010.

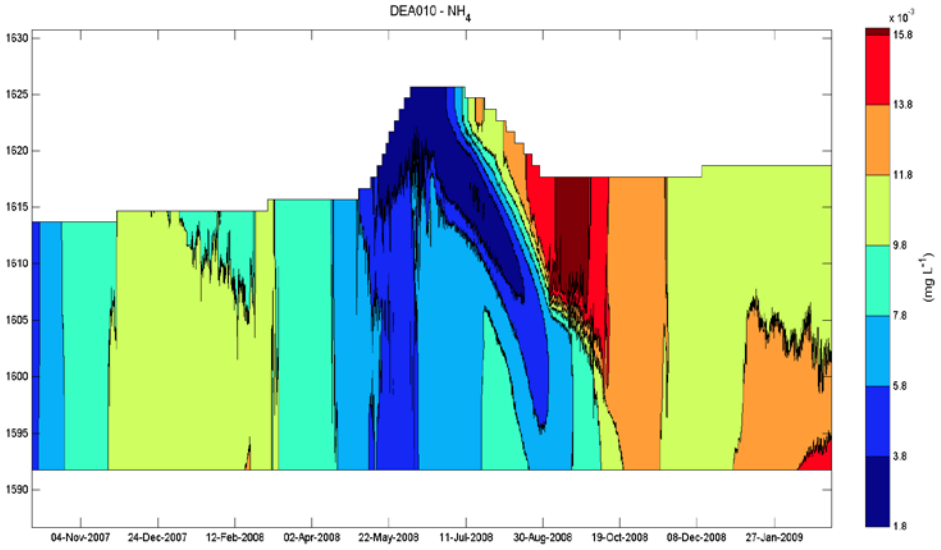


Figure 2-19. NH_4 simulated by ELCOM-CAEDYM at station DEA010.

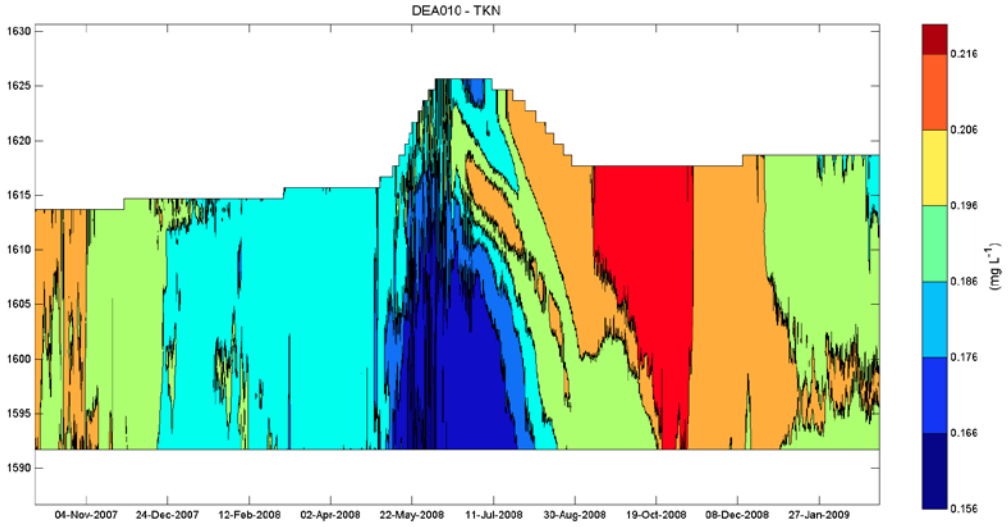


Figure 2-20. TKN simulated by ELCOM-CAEDYM at station DEA010.

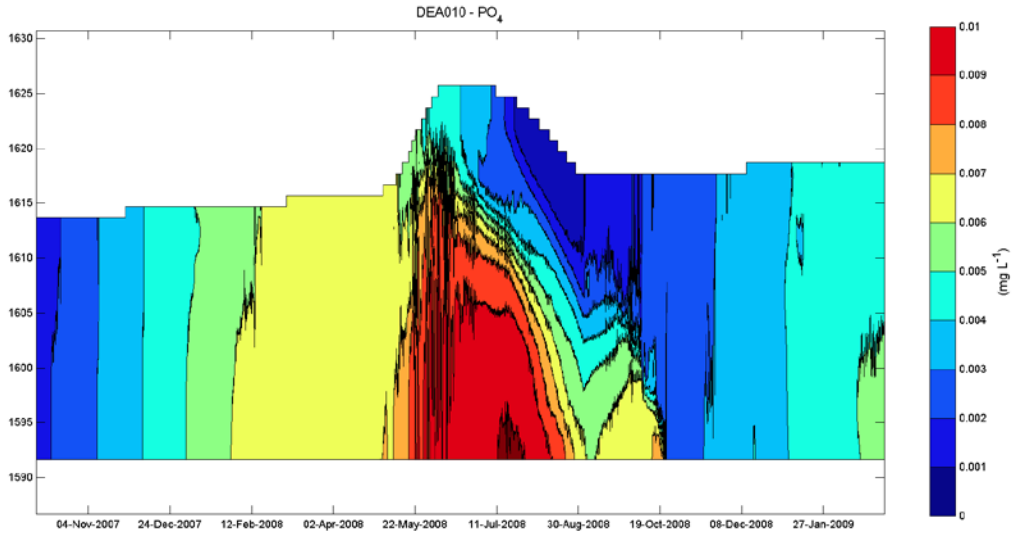


Figure 2-21. PO_4 simulated by ELCOM-CAEDYM at station DEA010.

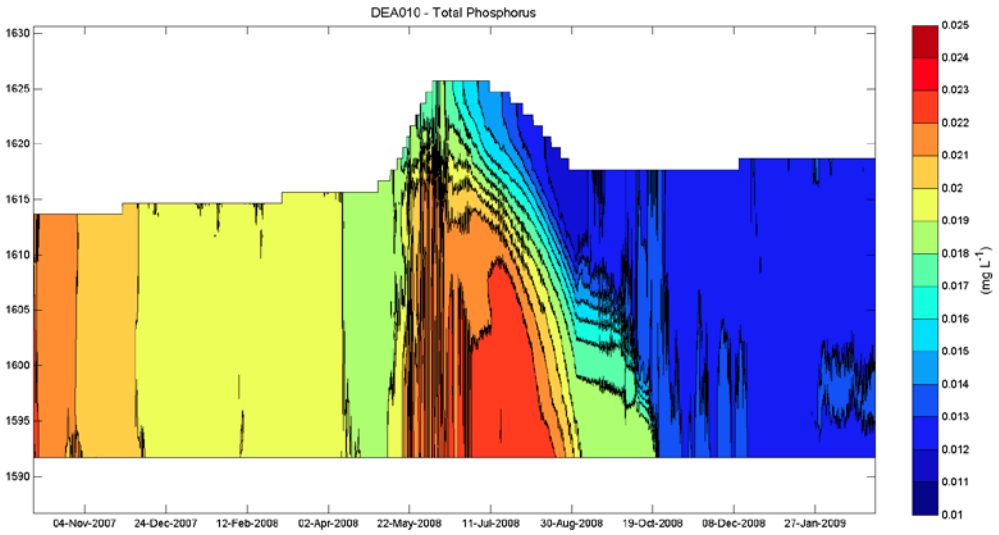


Figure 2-22. TP simulated by ELCOM-CAEDYM at station DEA010.

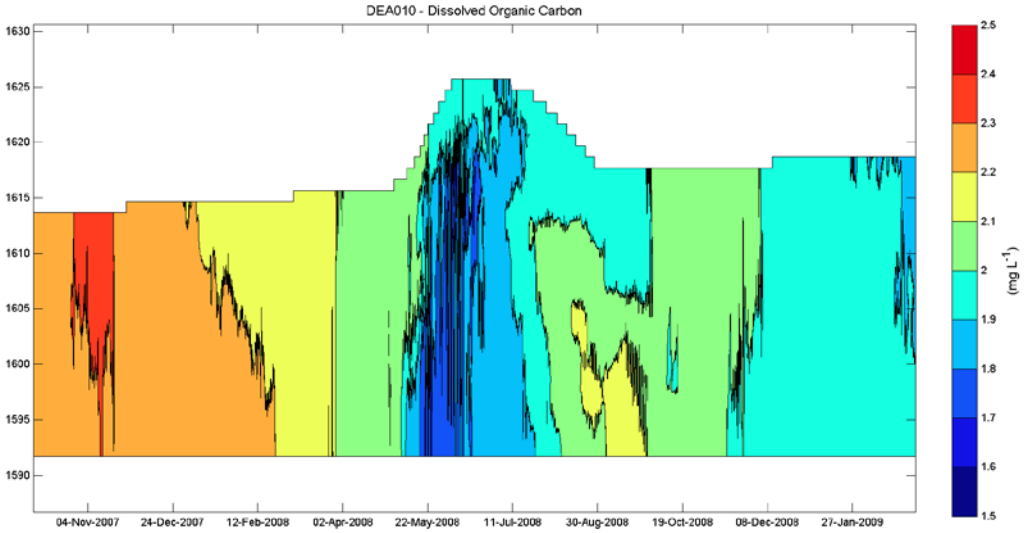


Figure 2-23. DOC simulated by ELCOM-CAEDYM at station DEA010.

Model Performance

One objective of the phytoplankton and zooplankton enumeration conducted for this study was to assist in the CAEDYM simulations of chlorophyll *a*. Previous simulations of the Deadwood Reservoir, configured prior to the receipt of the phytoplankton enumeration data, had only two groups configured, based on expert knowledge – one representative of a diatom group, and one representative of a eutrophic chlorophyte group. The model performance improved considerably after the analysis of the phytoplankton data, which changed the setup to four

groups, as described in a previous section – a eutrophic cyanobacteria group (*A. spiroides*), a diatom group, a dinoflagellate group, and a cryptophyte group. Inclusion of zooplankton, on the other hand, was problematic, and led to serious issues in the nutrient dynamics simulated by the model and a decrease in performance in the oxygen dynamics. More information on feeding habits and excretion characteristics of the different zooplankton groups would be necessary to improve model performance.

To quantitatively assess model performance due to the changes implemented above, four metrics were used:

1. **Correlation Coefficient** (r2). A simple correlation between all measurements for a particular variable, and the simulated values at the same depths and times. Varies between 0 and 1. Note r2 is generally accepted to be a poor indicator of model performance, as its magnitude is not consistently related to the degree to which model-predicted observations approach the magnitudes of their observed counterparts (Willmott 1982).
2. **Model Skill Index** (Willmott 1982). This metric takes a value between 0 and 1, where 1 indicates perfect agreement between measured and simulation and 0 indicates no agreement.
3. **Mean Average Error** (MAE). The mean absolute difference between measured and simulated values. Have the same units as the variable being analyzed, and a lower value indicates a more accurate result.
4. **Root Mean Square Error** (RMSE). The square root of the mean of the squared difference between measured and simulated values. Have the same units as the variable being analyzed, and a lower value indicates a more accurate result.

In this context, we used measurements from the profiler for water temperature, DO and chlorophyll *a* at station DEA010. The values for temperature, DO and chlorophyll *a* were extracted from the model at the same depths and times to make a direct quantitative comparison.

Model skill results are presented in Table 2-4. Generally, water temperature was better represented by the model than DO, which in turn was better represented than chlorophyll *a*. This is typically the case with all similar models, as the complexity increases when moving from physical (temperature) to chemical (DO) and biological (chlorophyll *a*) variables. Inclusion of the new CAEDYM configuration ("New No Zoo") compared to the original ("Original") configuration saw significant improvements in all chlorophyll *a* and DO metrics. Inclusion of zooplankton ("New Zoo") did not have a big effect on temperature and chlorophyll *a* performance, but saw a considerable decrease in all DO metrics.

Table 2-4. Model skill assessment for Deadwood Reservoir ELCOM-CAEDYM model over the period of 2007-2009.

		Temperature	DO	Chlorophyll *a*
Original	r^2	0.93	0.2	0.02
	Skill index	0.96	0.65	0.43
	MAE	1.5	1.2	1.8
	RMSE	1.9	1.5	2.3
New No Zoo	r^2	0.93	0.41	0.24
	Skill index	0.98	0.78	0.72
	MAE	1	1	1.4
	RMSE	1.3	1.3	2
New Zoo	r^2	0.93	0.29	0.22
	Skill index	0.98	0.55	0.65
	MAE	1	1.3	1.5
	RMSE	1.3	1.7	2.2

2.1.3 Model Forecast Scenarios

Years selected for the model forecast scenarios encompass a large range of conditions experienced in the reservoir (Table 2-3): 2001 represents a dry year, with 38% of normal inflow conditions (Figure 2-24); 2003 was a year of average inflows with a wet spring (Figure 2-25); 1997 represents the wettest year in recent history, with 173% of normal inflows (Figure 2-26). Figure 2-27 through Figure 2-29 show the outflow rates imposed to the different scenarios for each of the BiOp years.

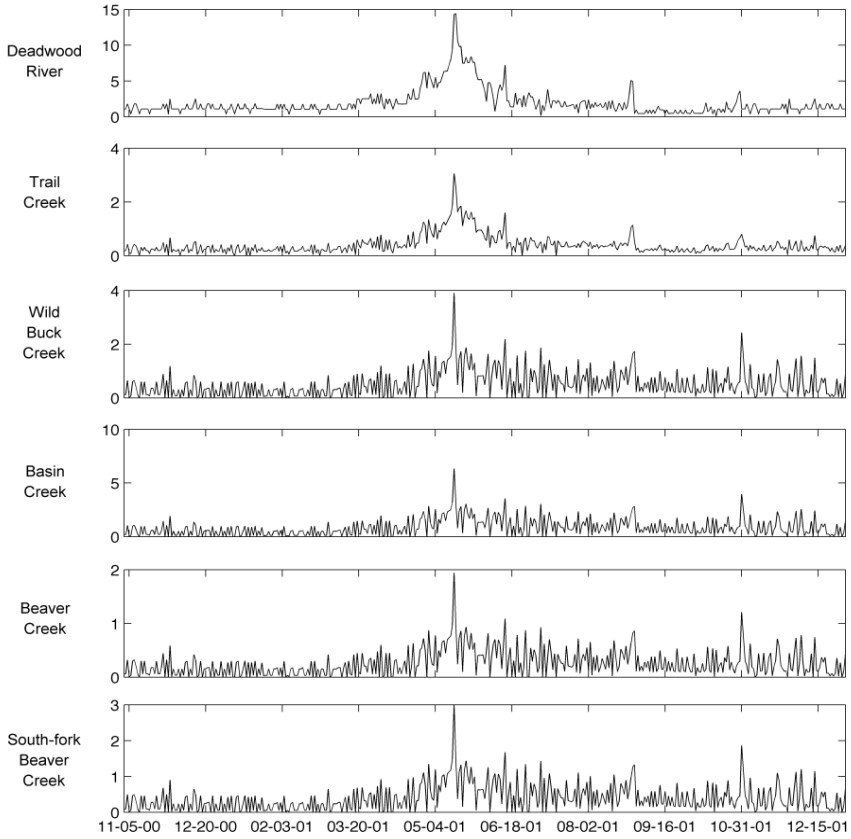


Figure 2-24. Flow rates at the main tributaries to Deadwood Reservoir for the dry BiOp year 2001.

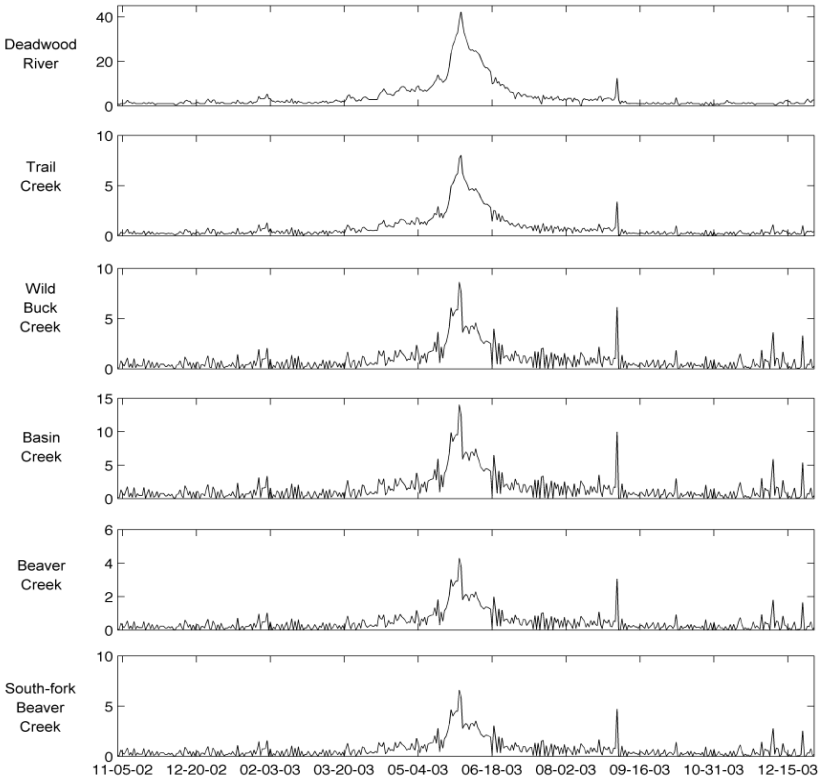


Figure 2-25. Flow rates at the main tributaries to Deadwood Reservoir for the average BiOp year 2003.

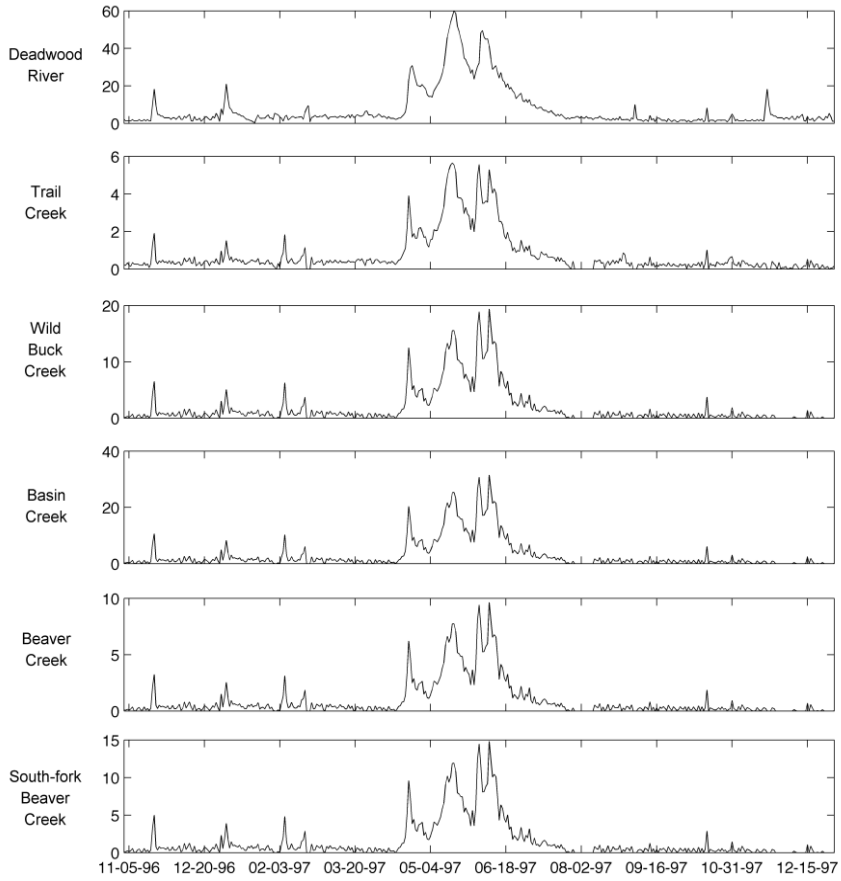


Figure 2-26. Flow rates at the main tributaries to Deadwood Reservoir for the wet BiOp year 1997.

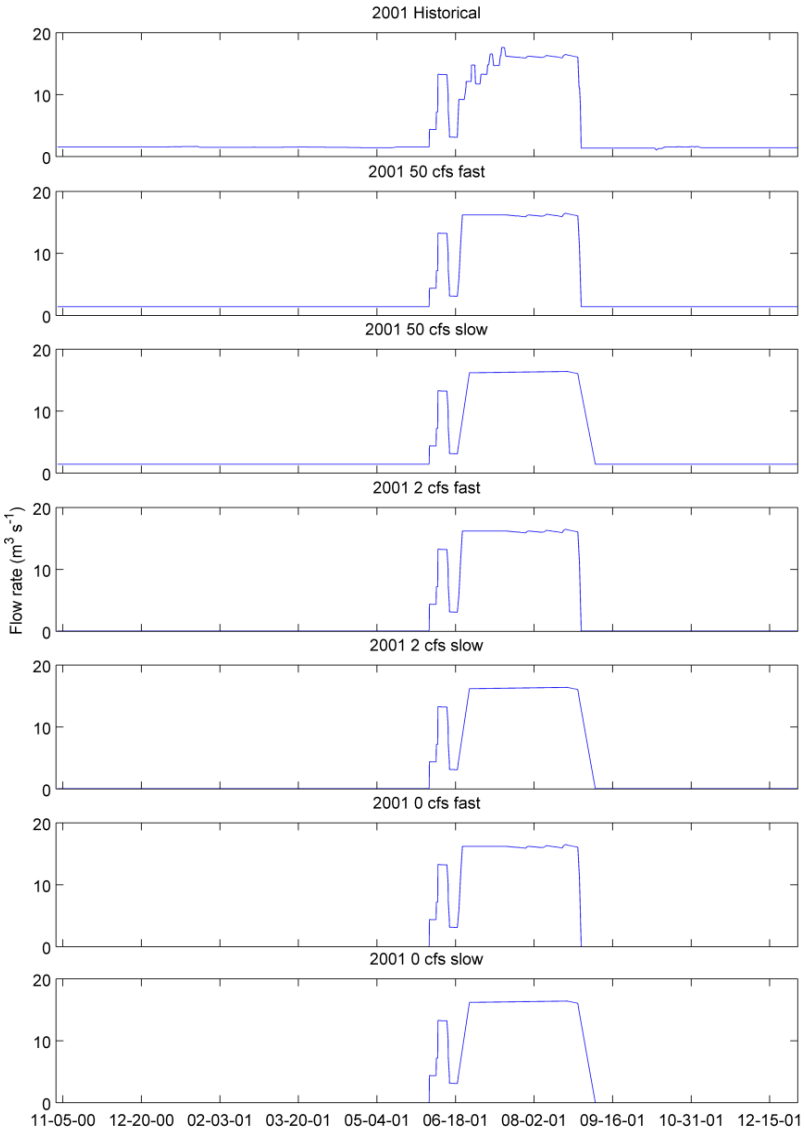


Figure 2-27. Outflow rates at the dam for each operational scenario (dry BiOp year 2001).

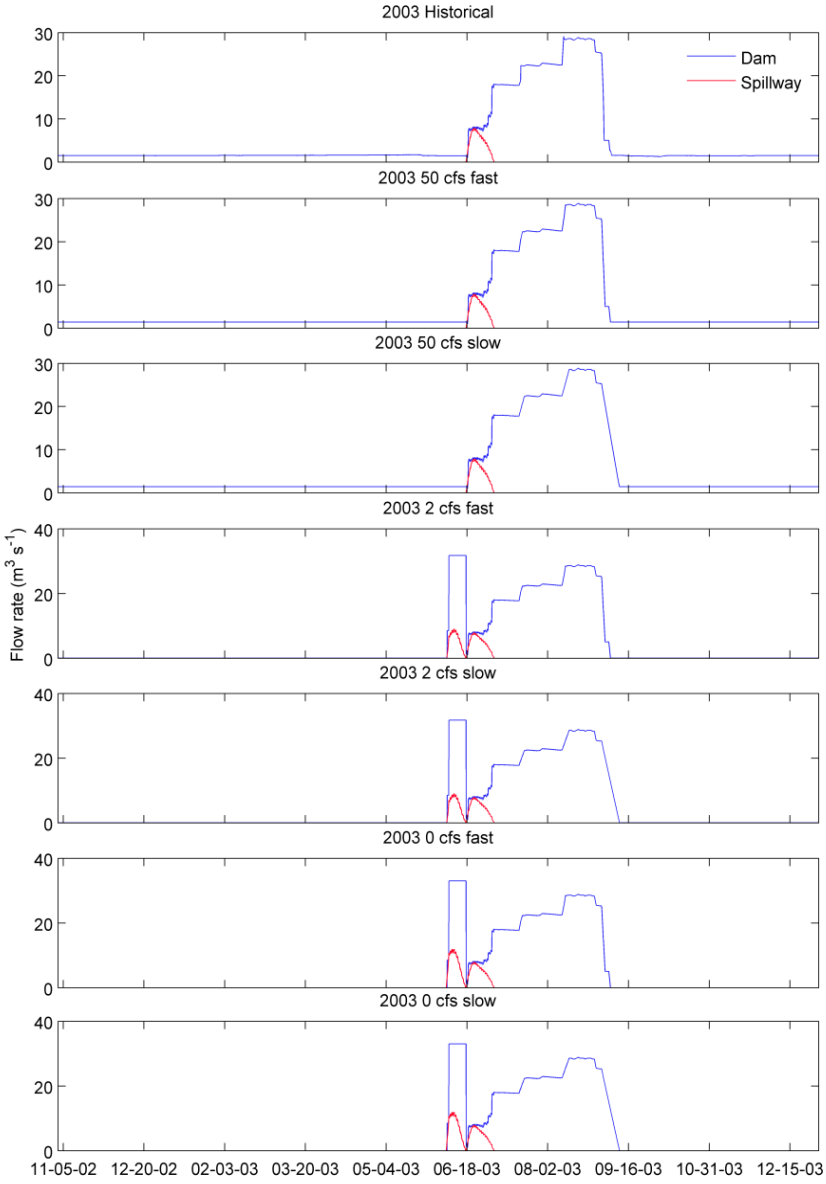


Figure 2-28. Outflow rates at the dam and spillway for each operational scenario (average BiOp year 2003).

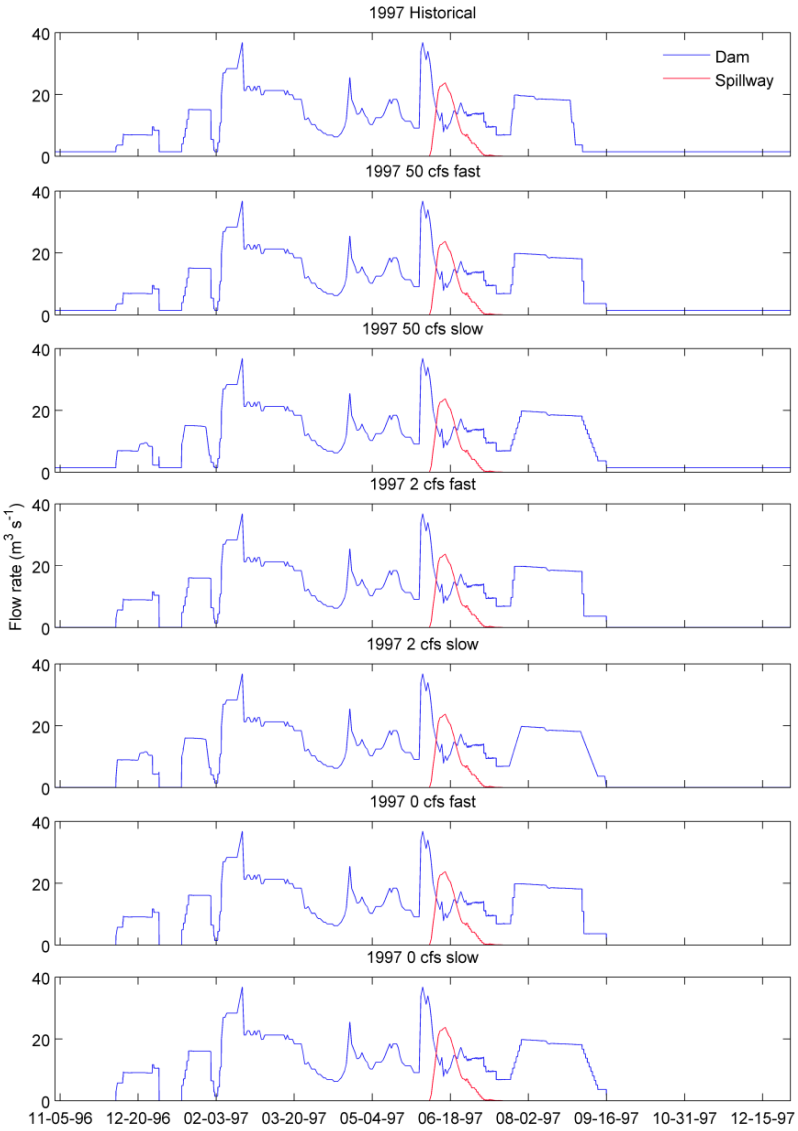


Figure 2-29. Outflow rates at the dam and spillway for each operational scenario (wet BiOp year 1997).

For each year simulated, the results for water temperature are presented at DEA010 (Figure 2-30 through Figure 2-32) and at the dam (Figure 2-33 through Figure 2-35), followed by DO (Figure 2-36 through Figure 2-38), nutrients (Figure 2-37 through Figure 2-47), and chlorophyll *a* (Figure 2-48 through Figure 2-50).

The physical dynamics of Deadwood Reservoir is strongly controlled by the water level variation due to spring inflows and summer withdrawals. Water level changes by up to 15 m (~45 feet) during the year, with peak water levels typically in mid-June, and low water in September. As the withdrawal point is deep in the water column, it has the effect of removing the cooler water from the reservoir during the summer months, with the thermocline (the

region of strongest vertical temperature gradient) progressively drawn down with the water level. DO levels are highest in the spring when the water is coldest. As the water heats and stratifies, DO starts to decrease (particularly in the bottom 10 m of the water column) due to sediment oxygen demand. This continues until the lower layers increase in DO due to mixing of water from above due to the drawdown process.

Figure 2-30 through Figure 2-35 clearly shows the effects of water levels on water temperature at the time of the drawdown. When less water is released from the dam (which was the case for the 2 and 0 cfs scenarios), this leads to higher storage levels, bottom temperatures are kept under 15^{o}C even during summer. This effect is mostly visible for the dry year case (Figure 2-30 and Figure 2-33), when both historical and 50 cfs release rates led to bottom temperatures of ~20^{o}C during summer drawdown. Fast ramping rates seem to be more effective in producing this type of result. In 1997, as the water level was already high in the historical case, the different scenarios produced little visible effect on the water temperatures (Figure 2-32 and Figure 2-35).

The "low DO" region in the bottom waters is highlighted in each image by contours drawn at concentrations of 3 and 6 mg/L (Figure 2-36 through Figure 2-38), considered to be important biological niche indicators for fish. It is clear from the simulations that the water level exerts a strong control on the extent and timing of the low DO region at depth. This is particular apparent, first when comparing the Wet-Historical to the Avg-Historical and Dry-Historical scenarios. Due to the high flows in 1997, the water level was maintained at substantially higher values, resulting in the low DO region persisting until the middle of September, approximately 2 to 3 weeks longer than the other cases. This effect is even more apparent when comparing the scenarios that provided additional carryover (2 and 0 cfs) with the base case for each year (Historical and 50 cfs); where in all cases the DO region was more persistent under high water level conditions.

From a management and operational perspective, a clear tradeoff is apparent from these results. Higher reservoir water levels (wet years or additional carryover from winter) result in cooler bottom waters (Figure 2-30 to Figure 2-35); however, as the duration of stratification is extended, a greater oxygen drawdown occurs, prolonging the period of hypolimnetic hypoxia/anoxia (Figure 2-36 through Figure 2-38). As a consequence, the timing for remineralization of nutrients from the sediments is also extended (Figure 2-39 through Figure 2-47), occurring later into the autumn until the thermal stratification breaks down. This delayed autumn overturn causes nutrients from the hypolimnion to be mixed into the upper water column, which can potentially lead to enhanced primary productivity (Figure 2-48 through Figure 2-50).

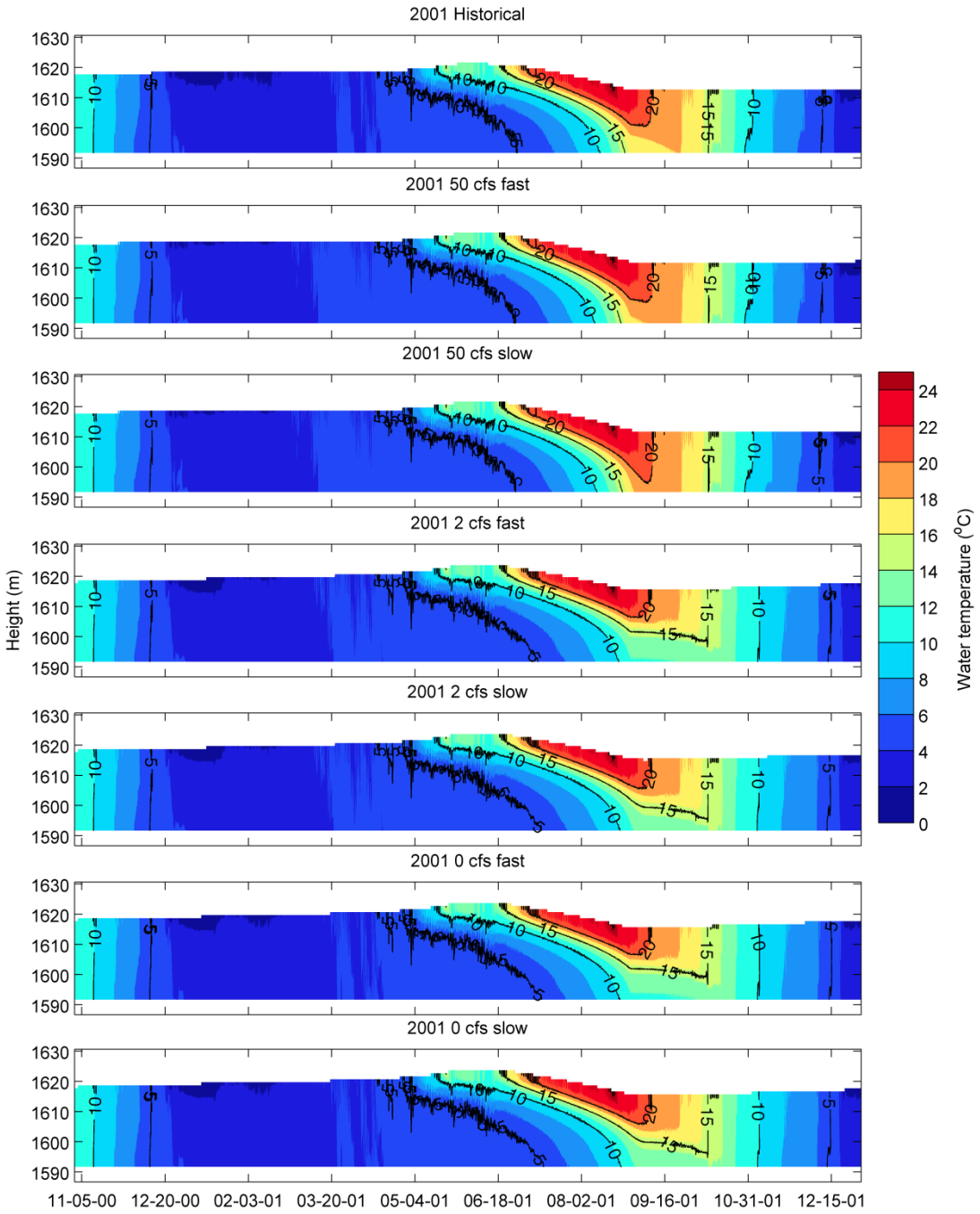


Figure 2-30. Temperature response to the different operational scenarios at station DEA010 (dry BiOp year 2001).

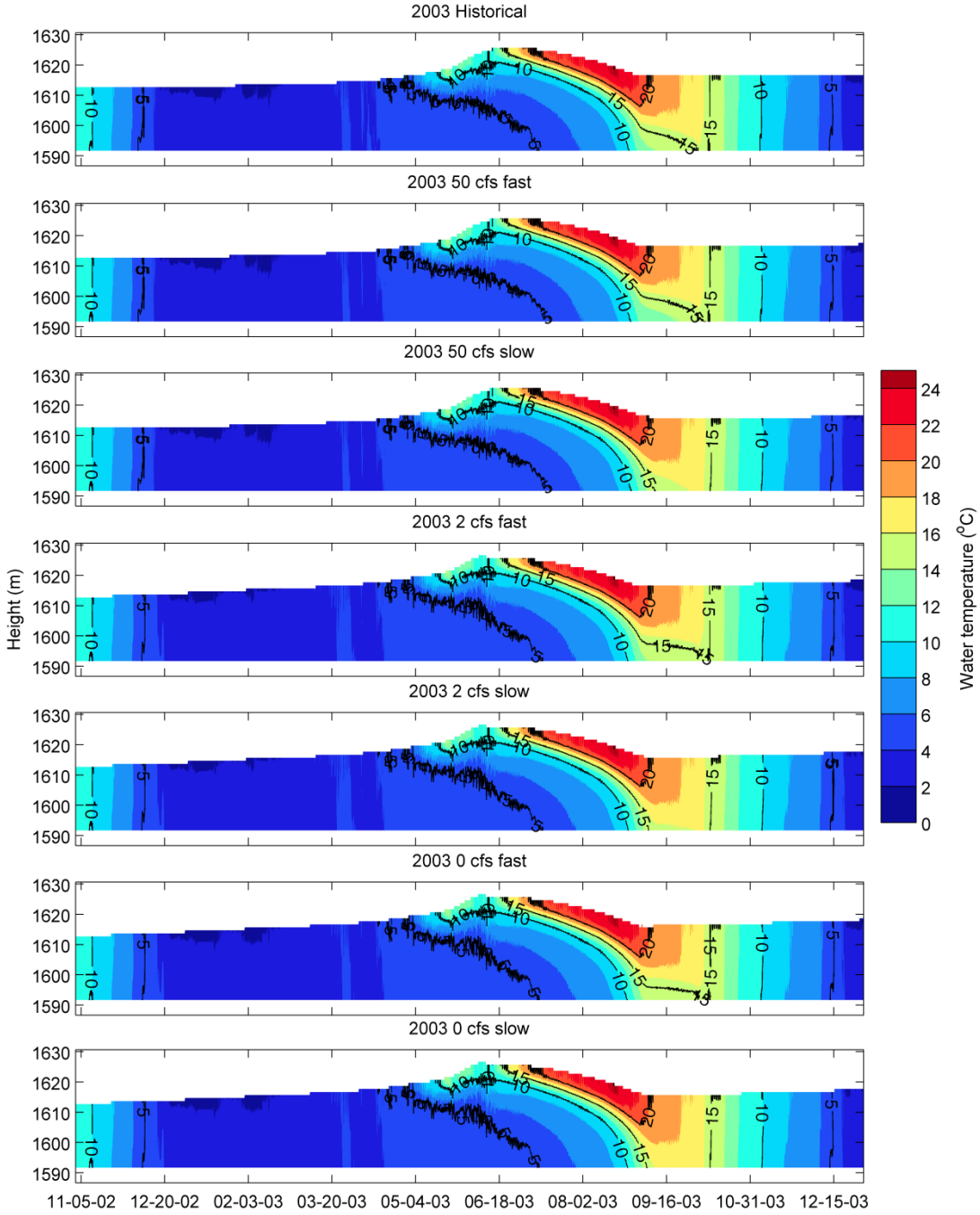


Figure 2-31. Temperature response to the different operational scenarios at station DEA010 (average BiOp year 2003).

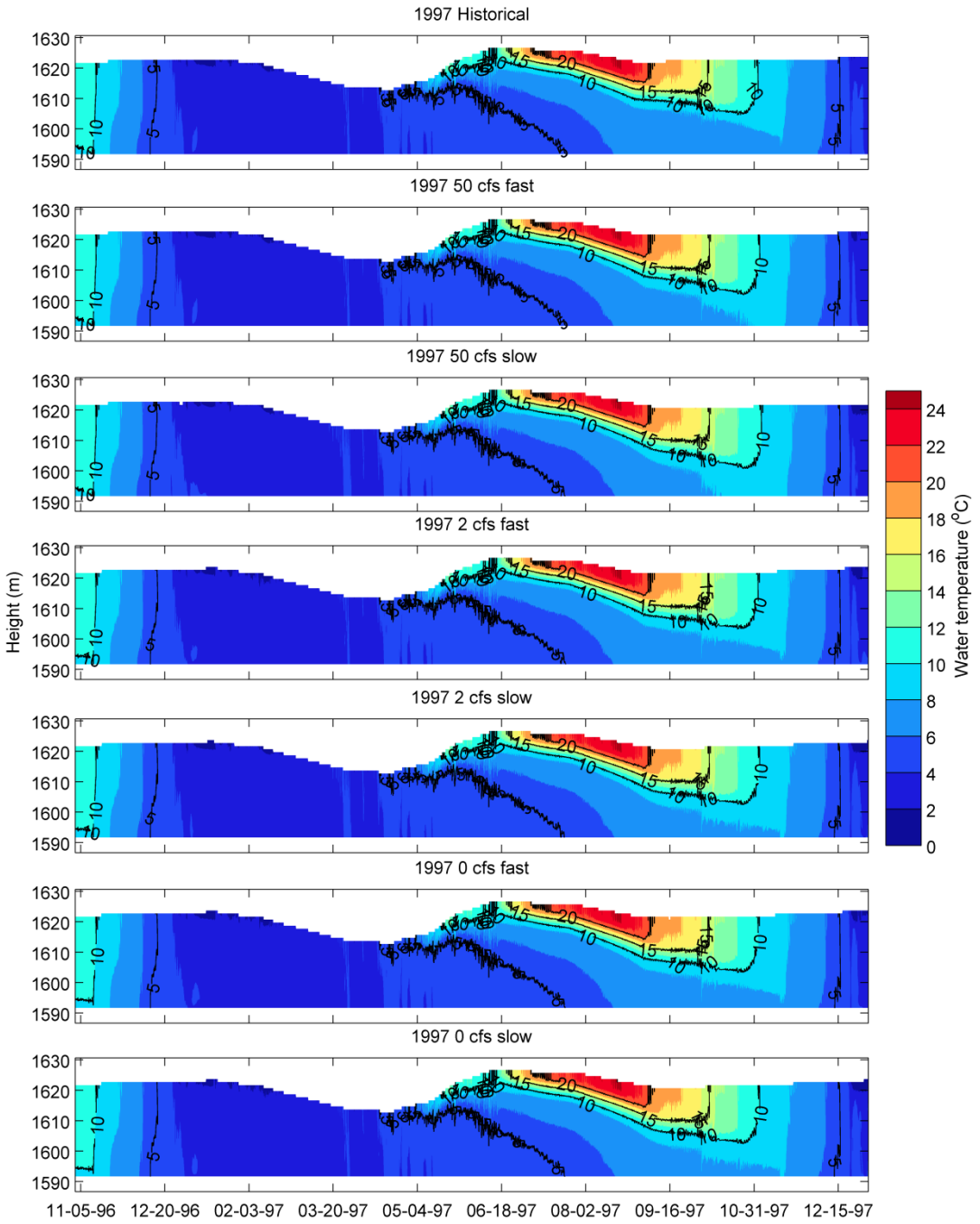


Figure 2-32. Temperature response to the different operational scenarios at station DEA010 (wet BiOp year 1997).

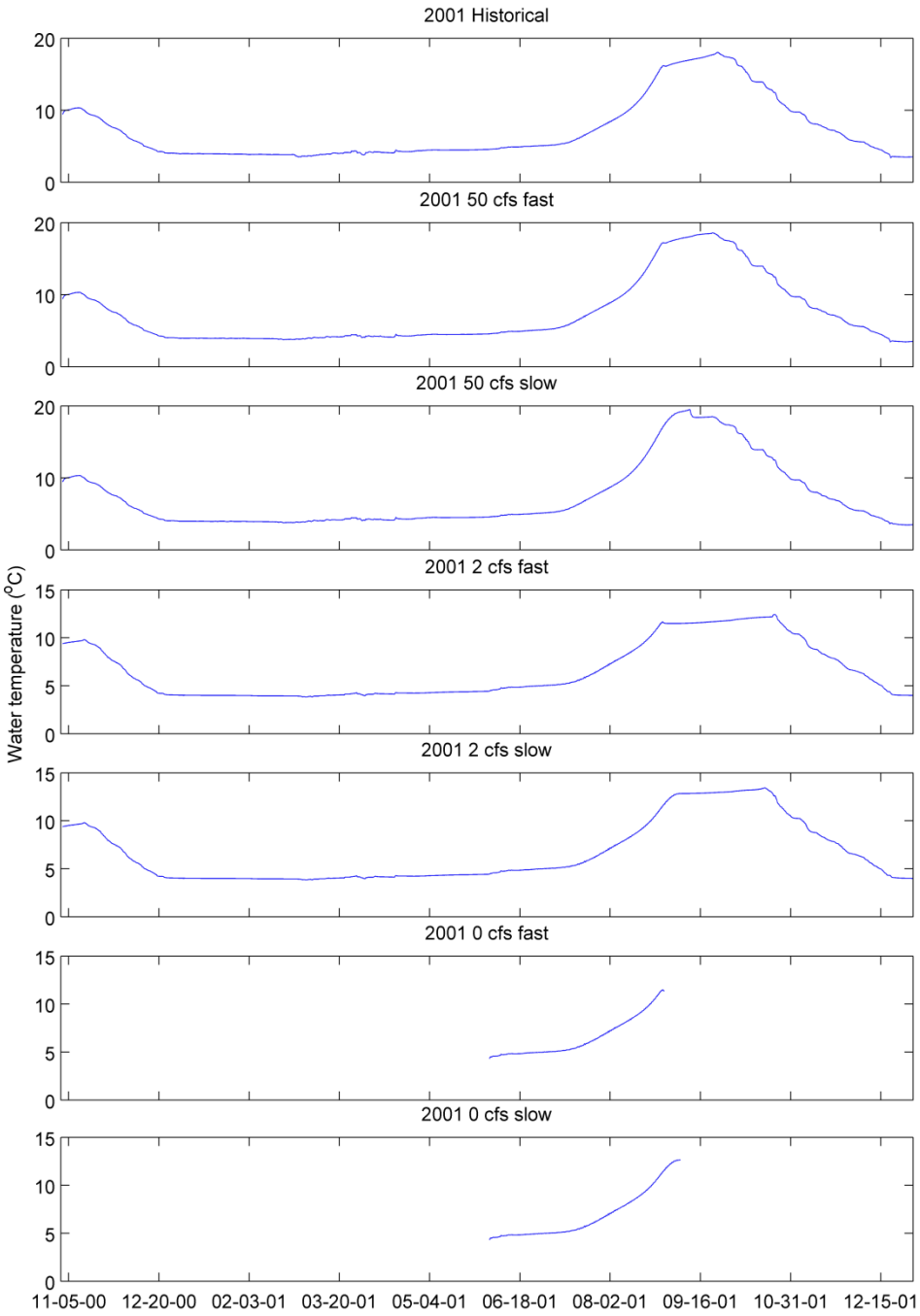


Figure 2-33. Temperature response to the different operational scenarios at the dam (dry BiOp year 2001).

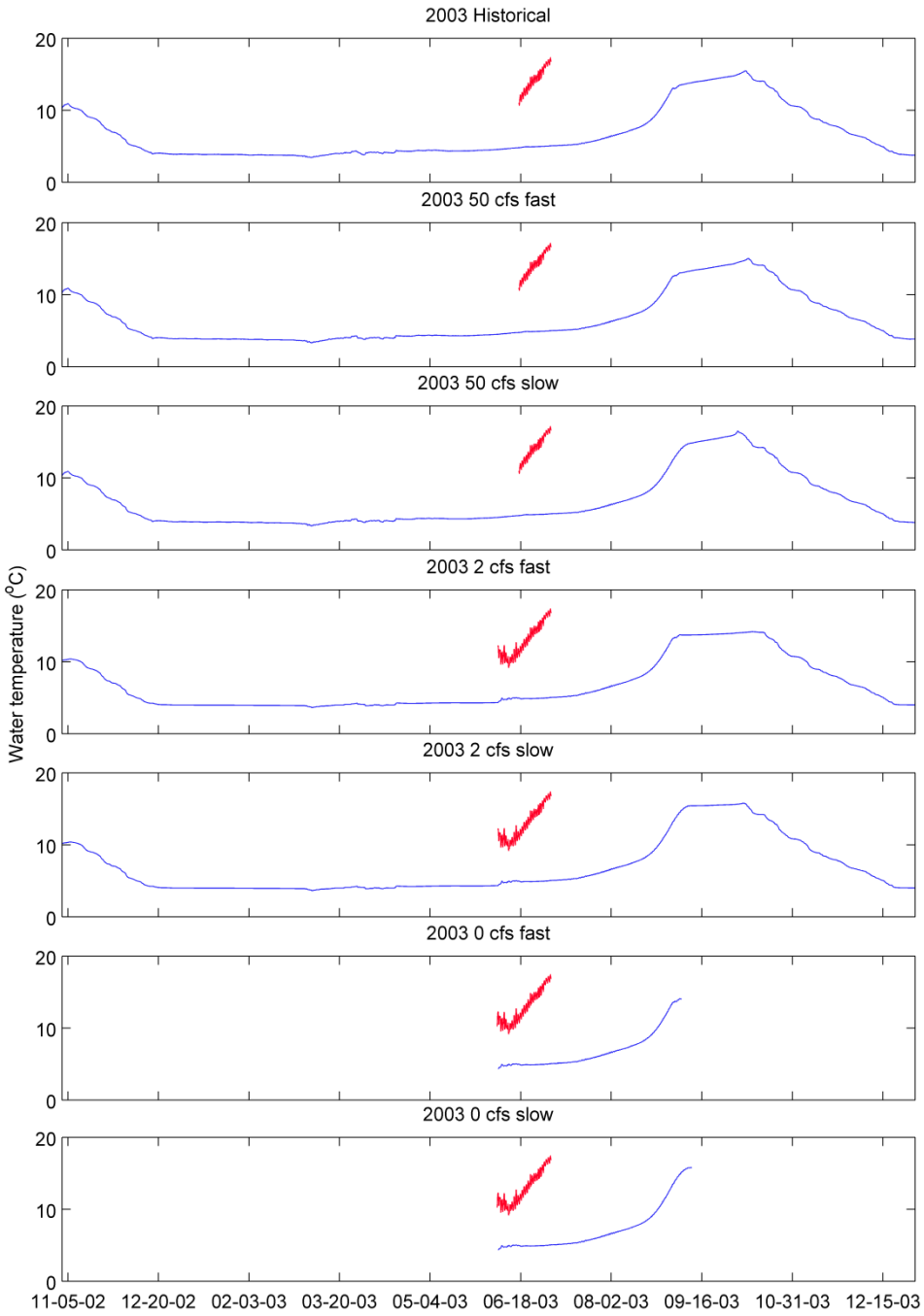


Figure 2-34. Temperature response to the different operational scenarios at station the dam and spillway (average BiOp year 2003).

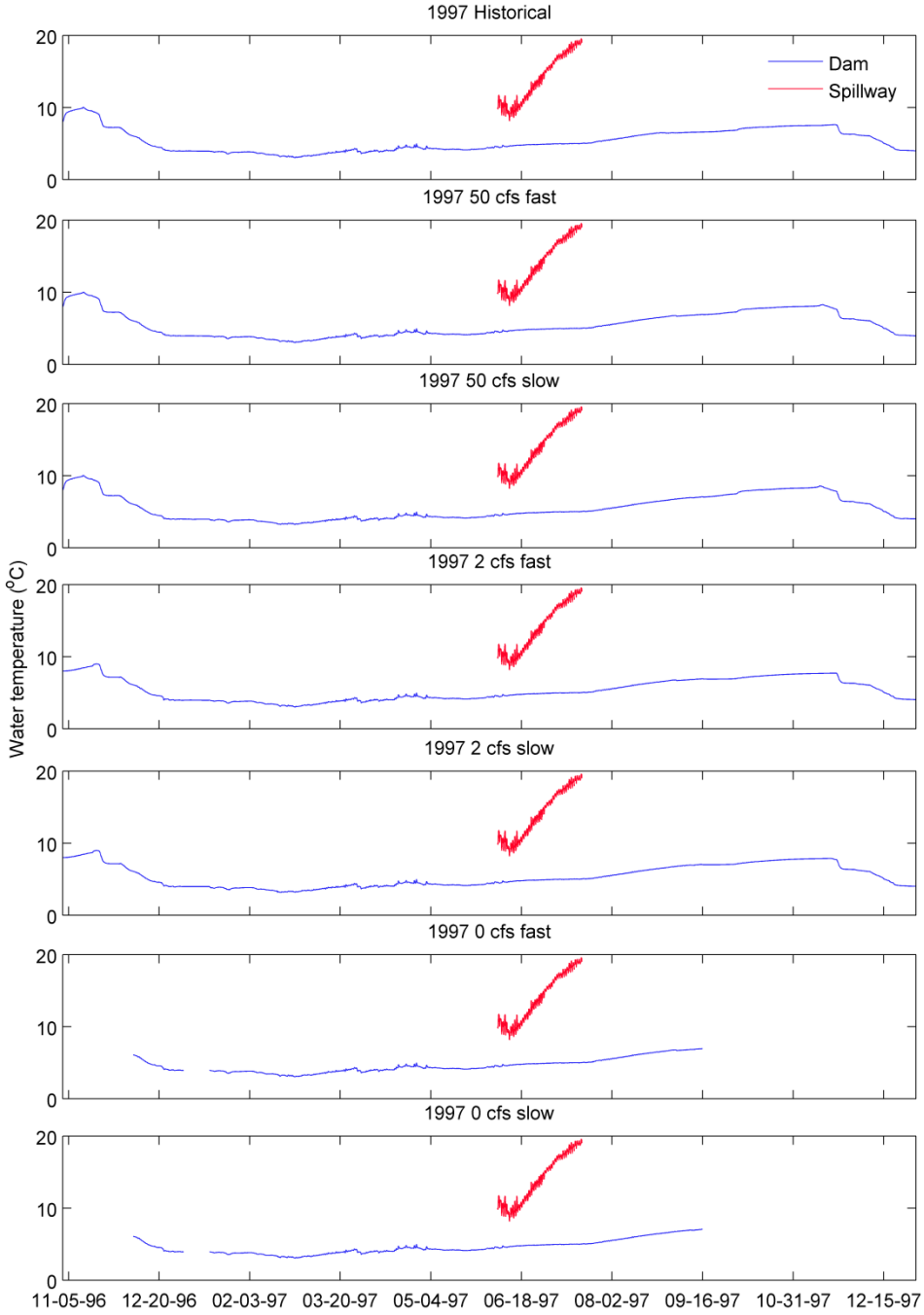


Figure 2-35. Temperature response to the different operational scenarios at the dam and spillway (wet BiOp year 1997).

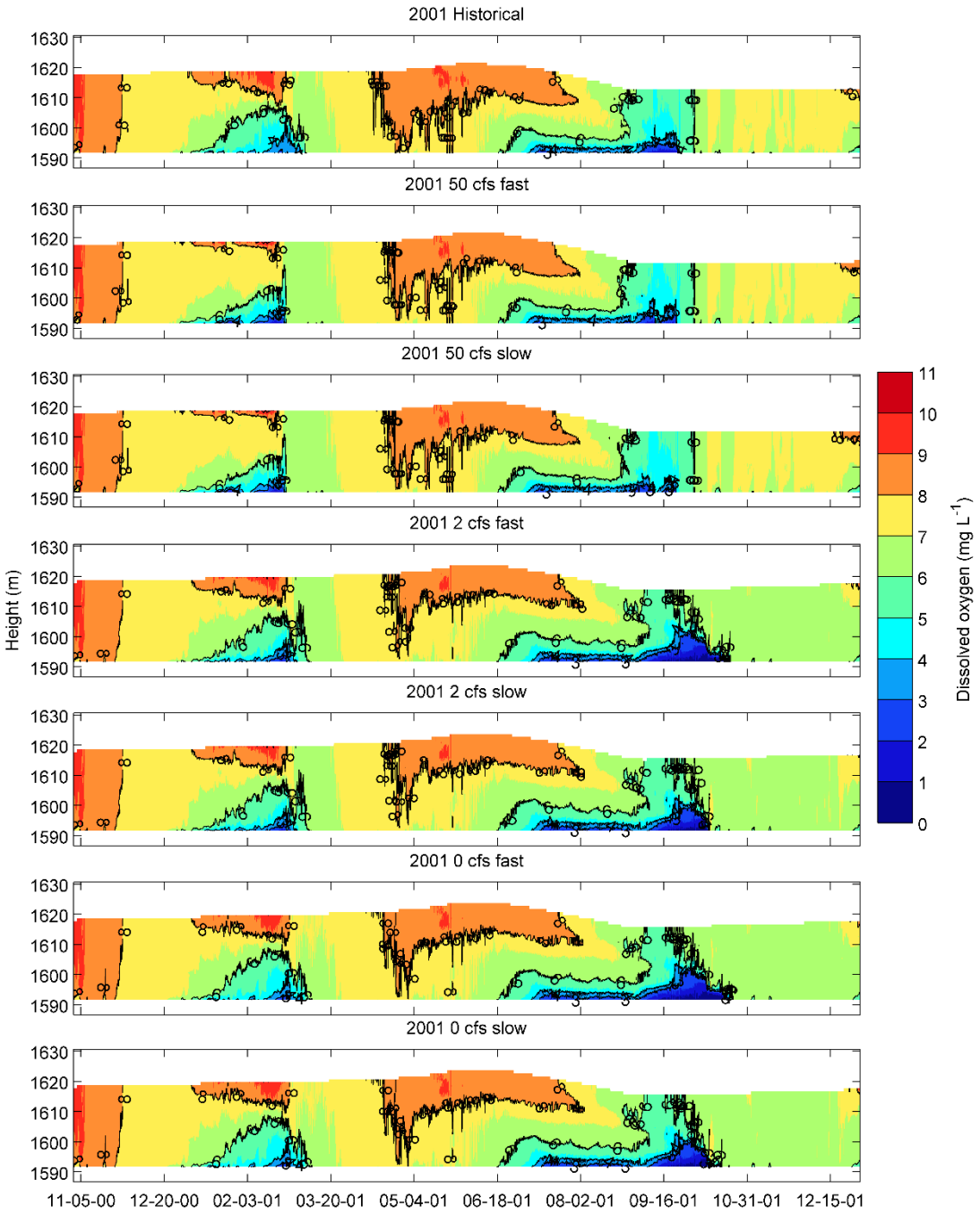


Figure 2-36. DO response to the different operational scenarios at station DEA010 (dry BiOp year 2001).

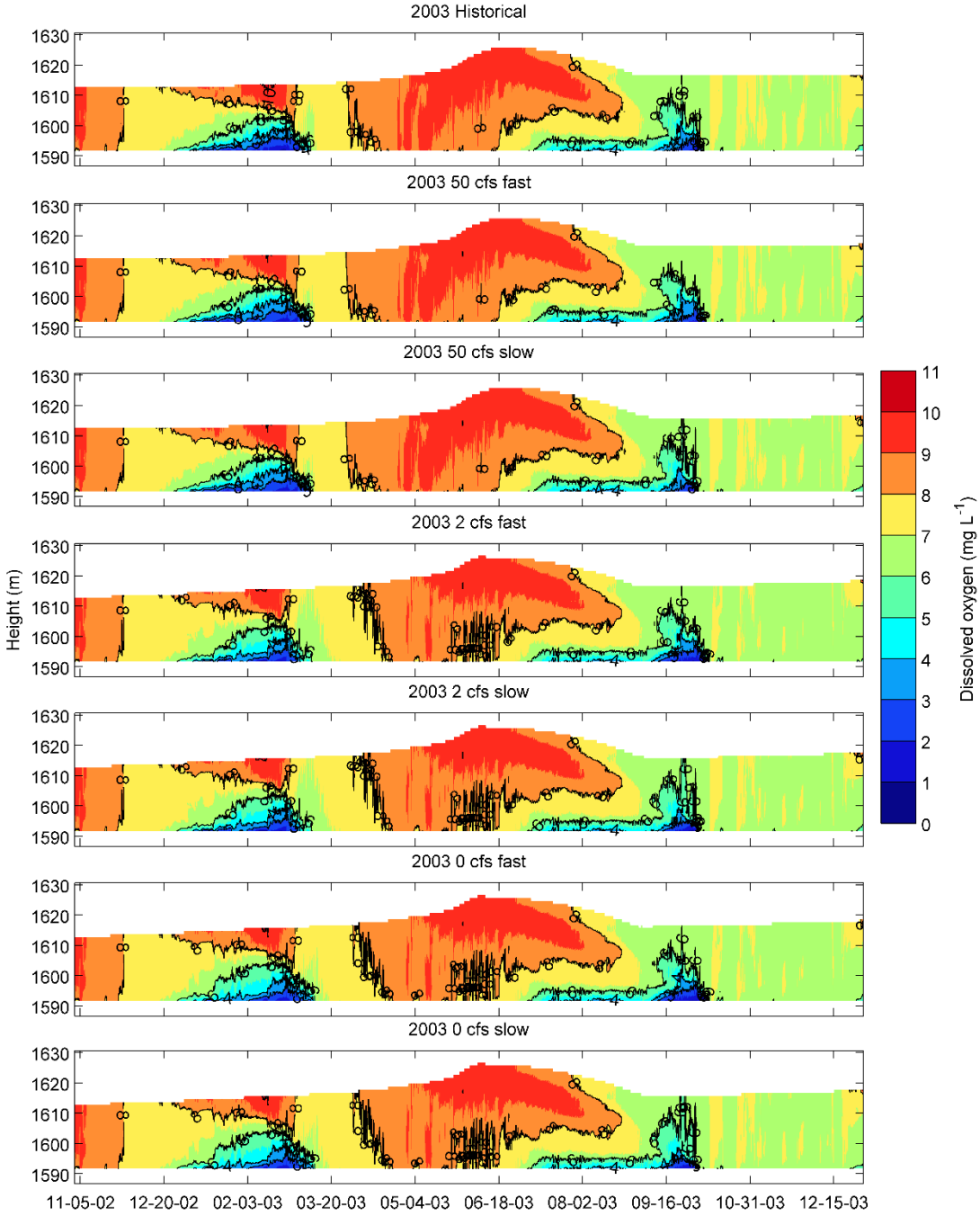


Figure 2-37. DO response to the different operational scenarios at station DEA010 (average BiOp year 2003).

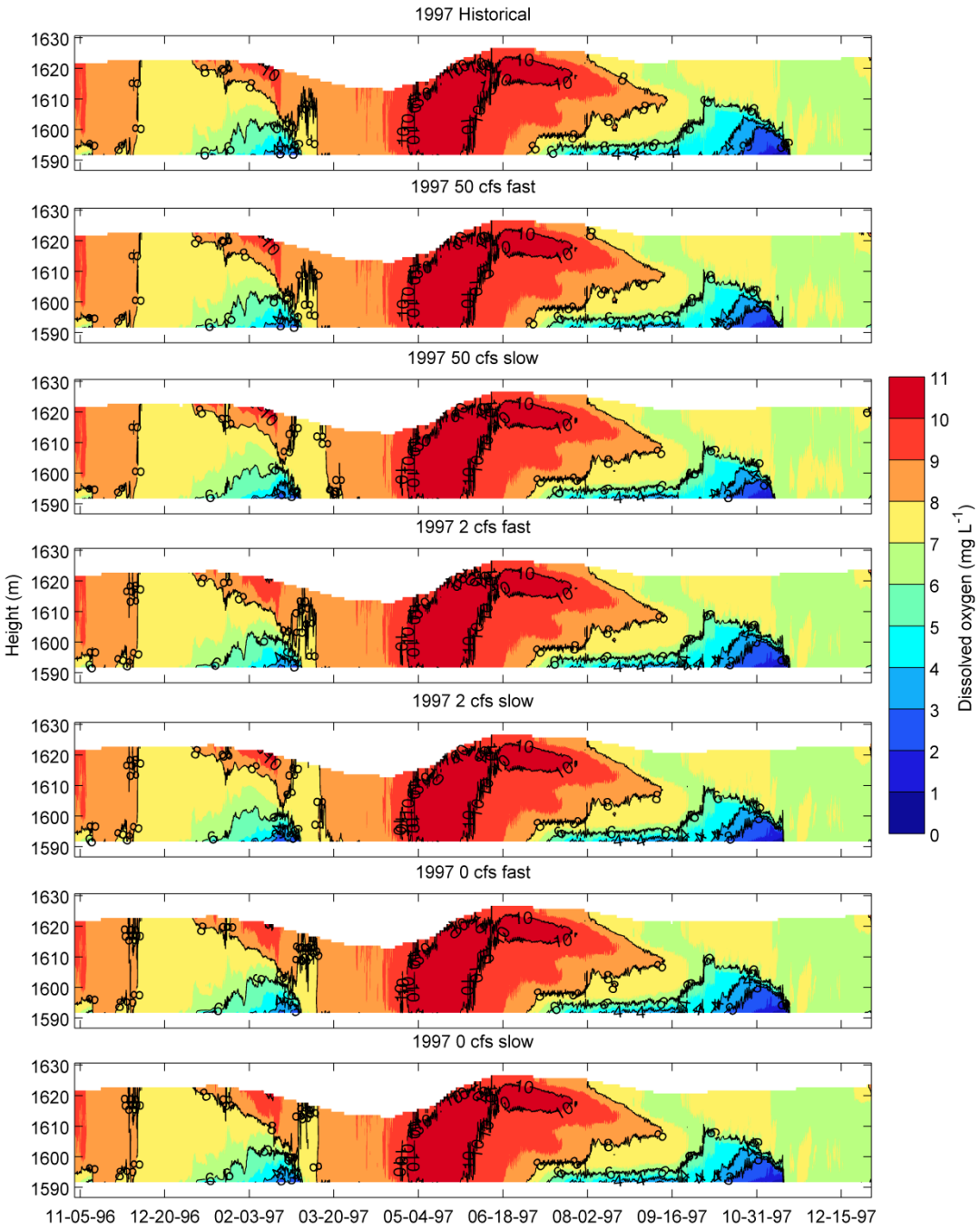


Figure 2-38. DO response to the different operational scenarios at station DEA010 (wet BiOp year 1997).

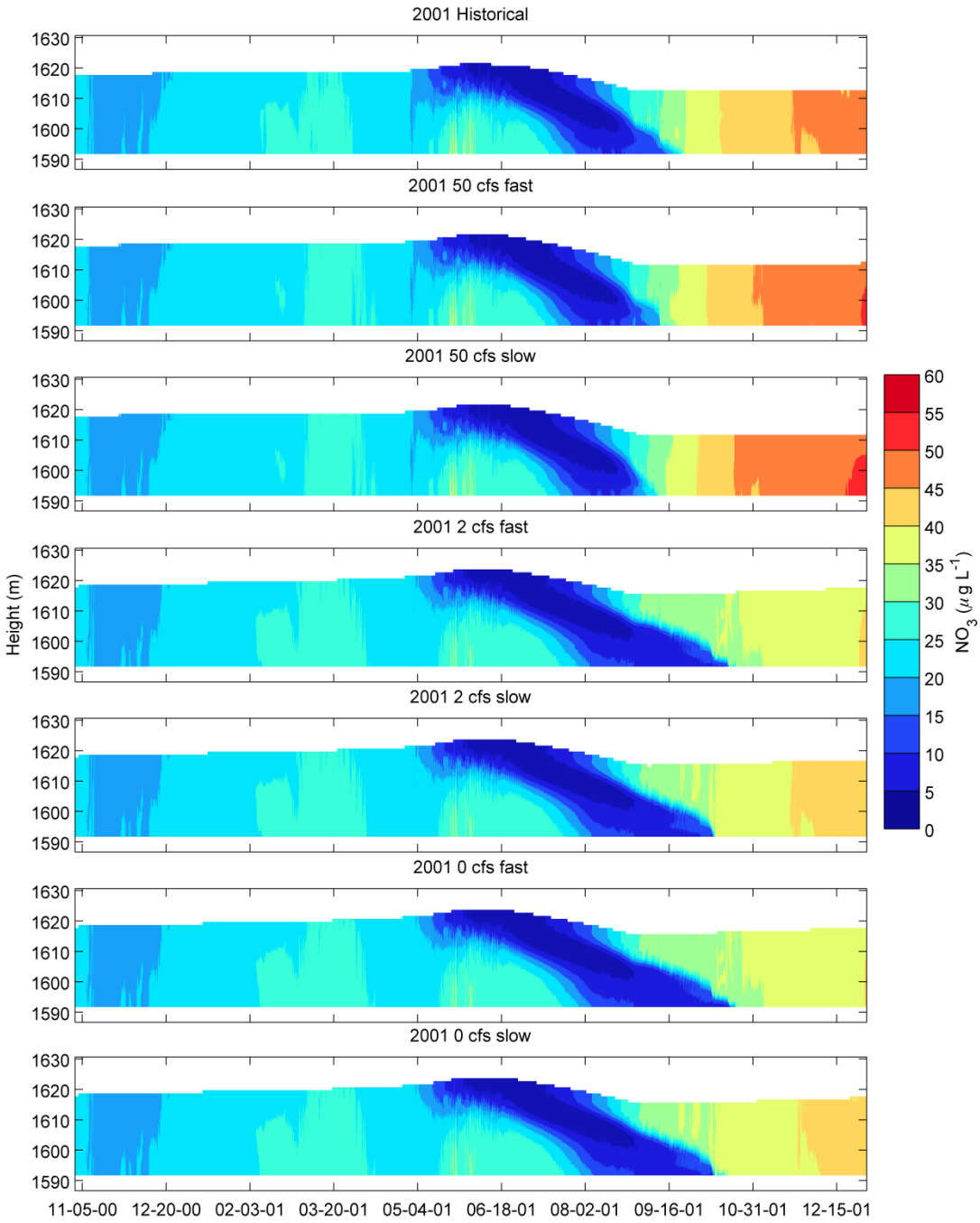


Figure 2-39. NO_3 response to the different operational scenarios at station DEA010 (dry BiOp year 2001).

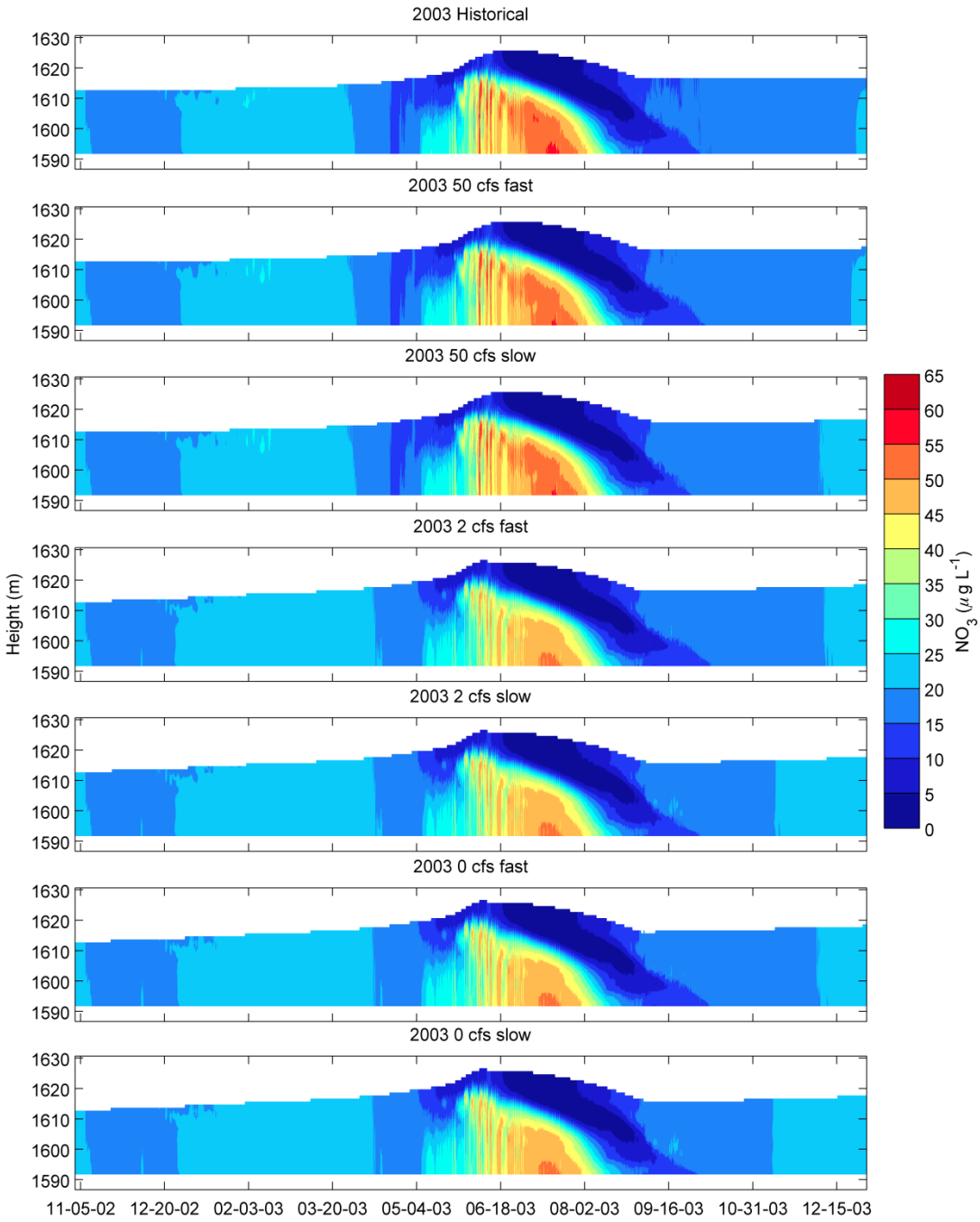


Figure 2-40. NO_3 response to the different operational scenarios at station DEA010 (average BiOp year 2003).

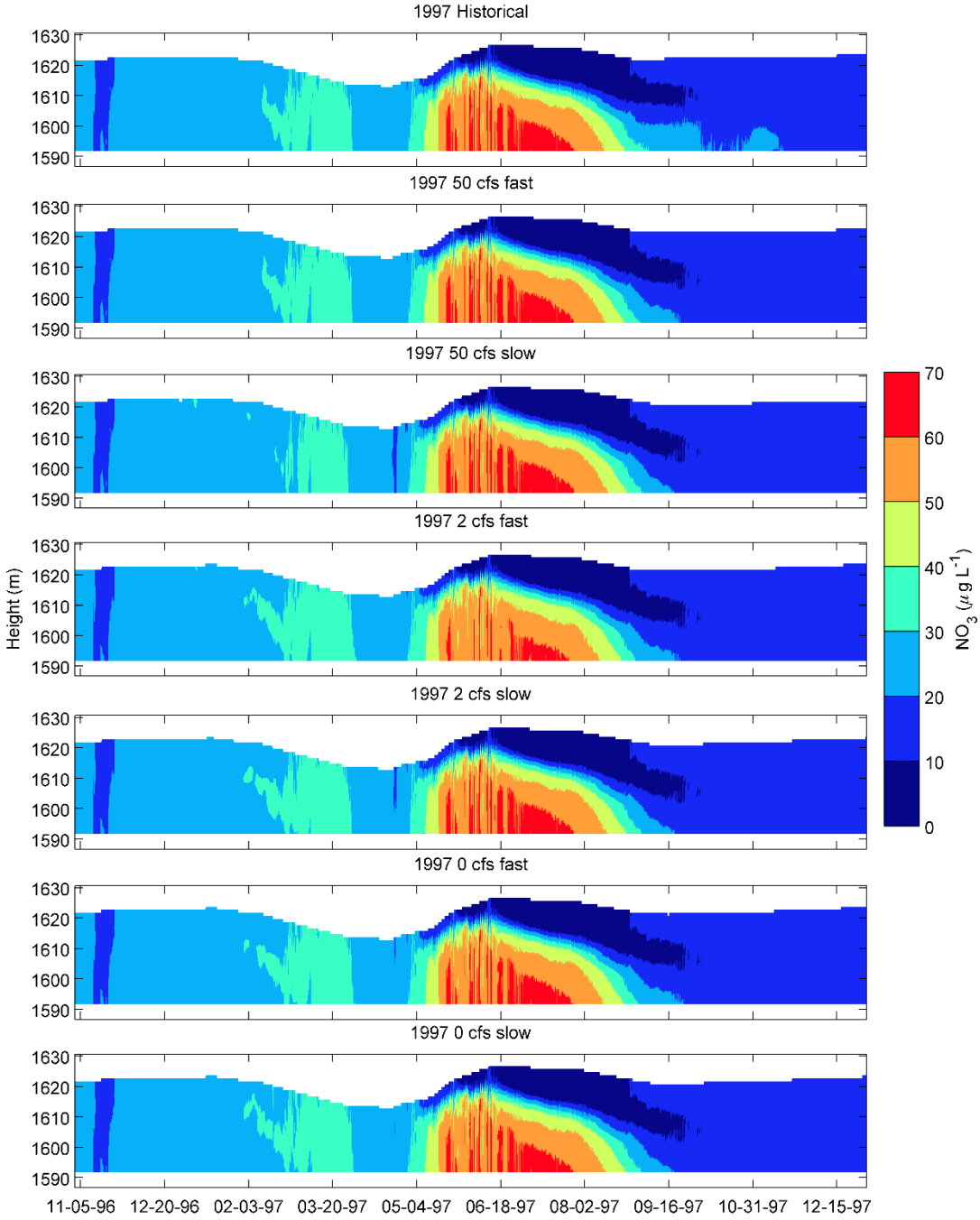


Figure 2-41. NO_3 response to the different operational scenarios at station DEA010 (wet BiOp year 1997).

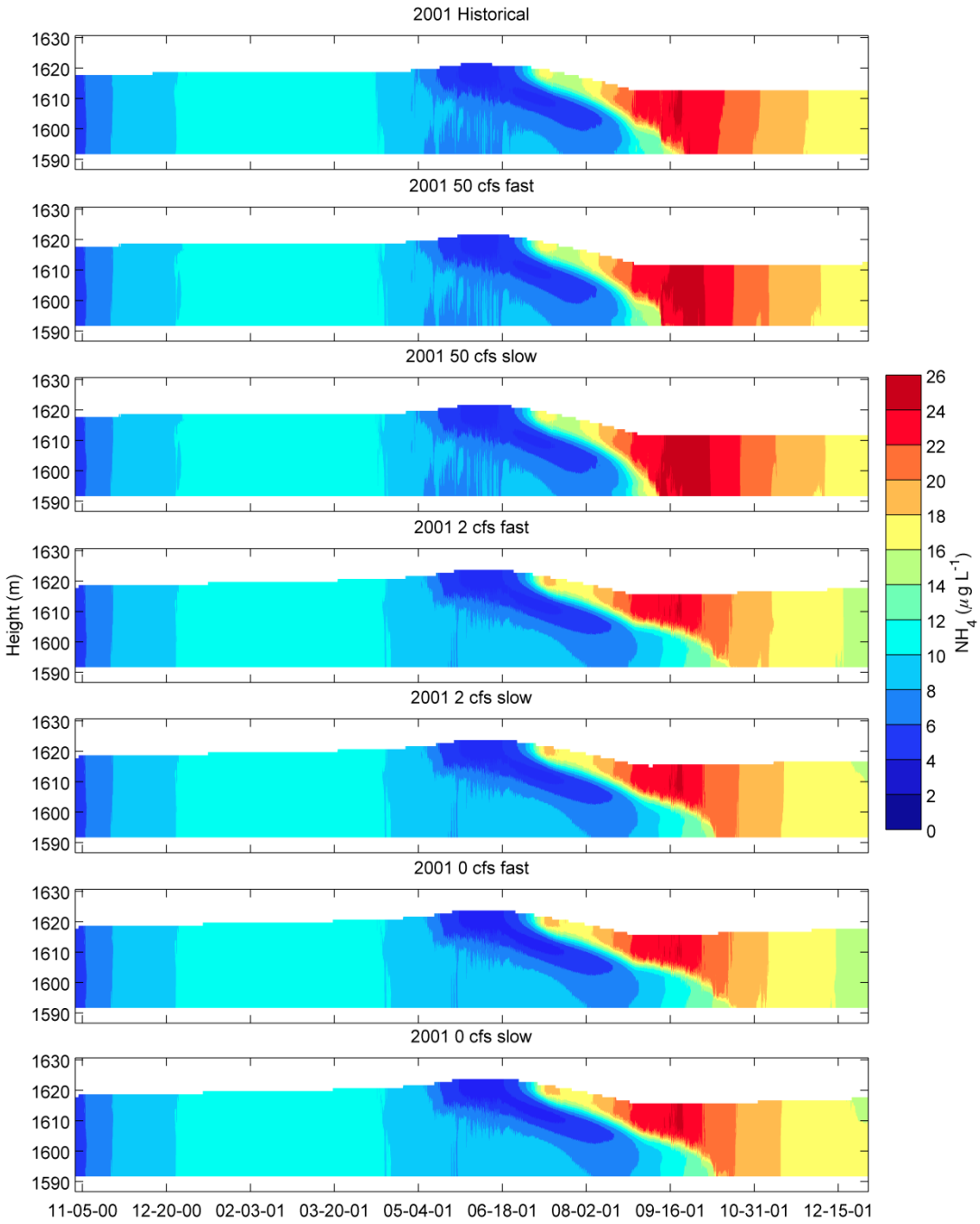


Figure 2-42. NH_4 response to the different operational scenarios at station DEA010 (dry BiOp year 2001).

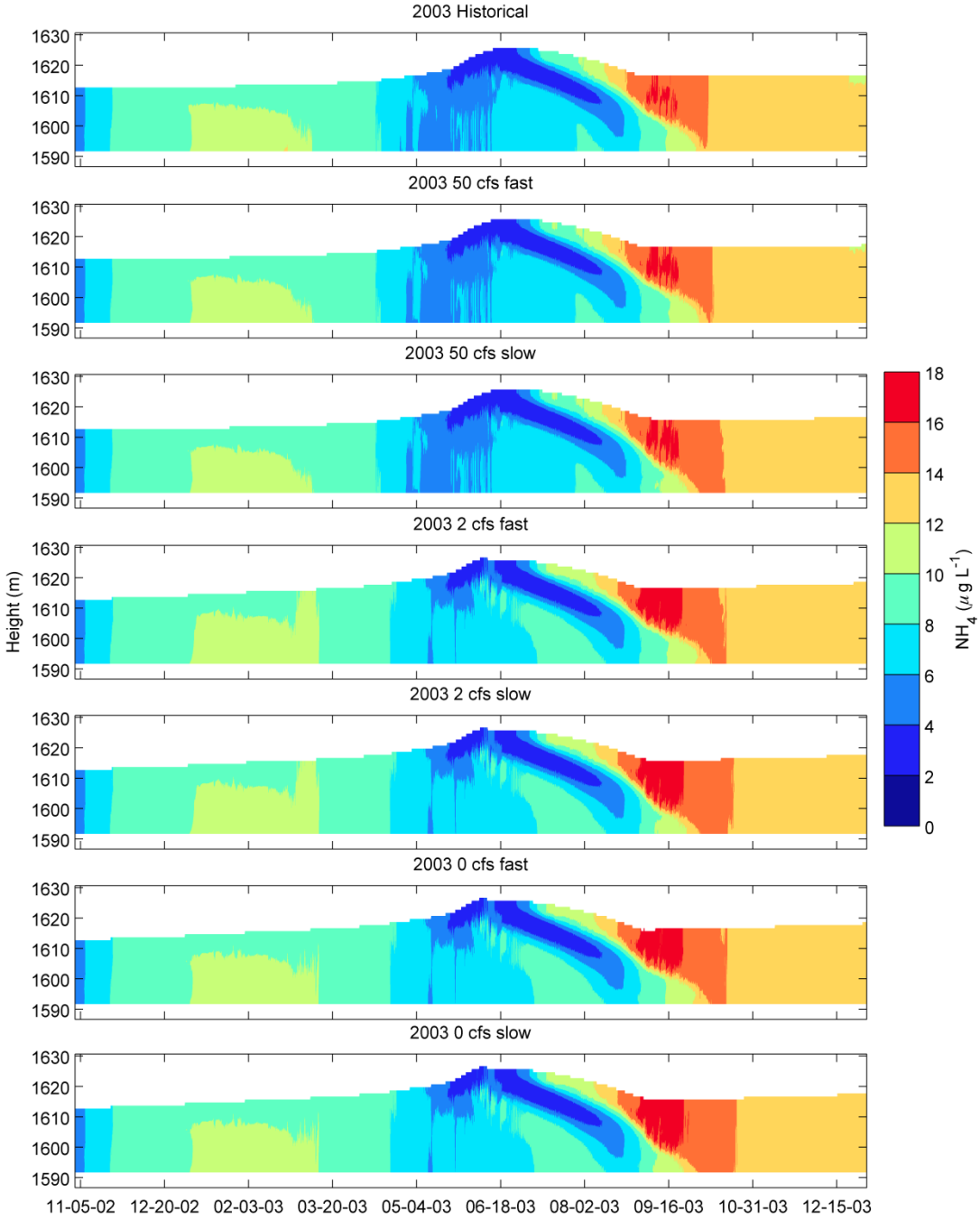


Figure 2-43. NH_4 response to the different operational scenarios at station DEA010 (average BiOp year 2003).

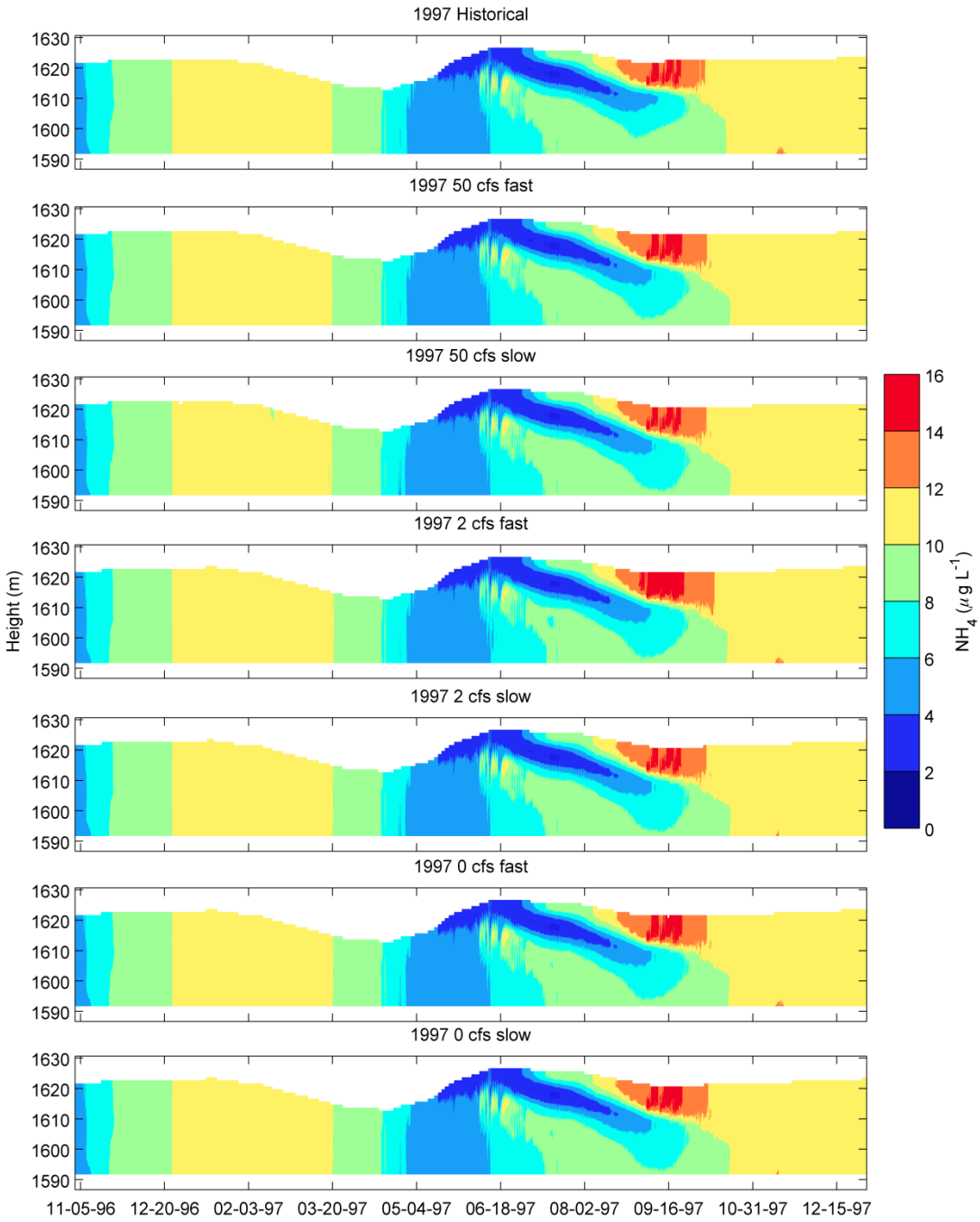


Figure 2-44. NH_4 response to the different operational scenarios at station DEA010 (wet BiOp year 1997).

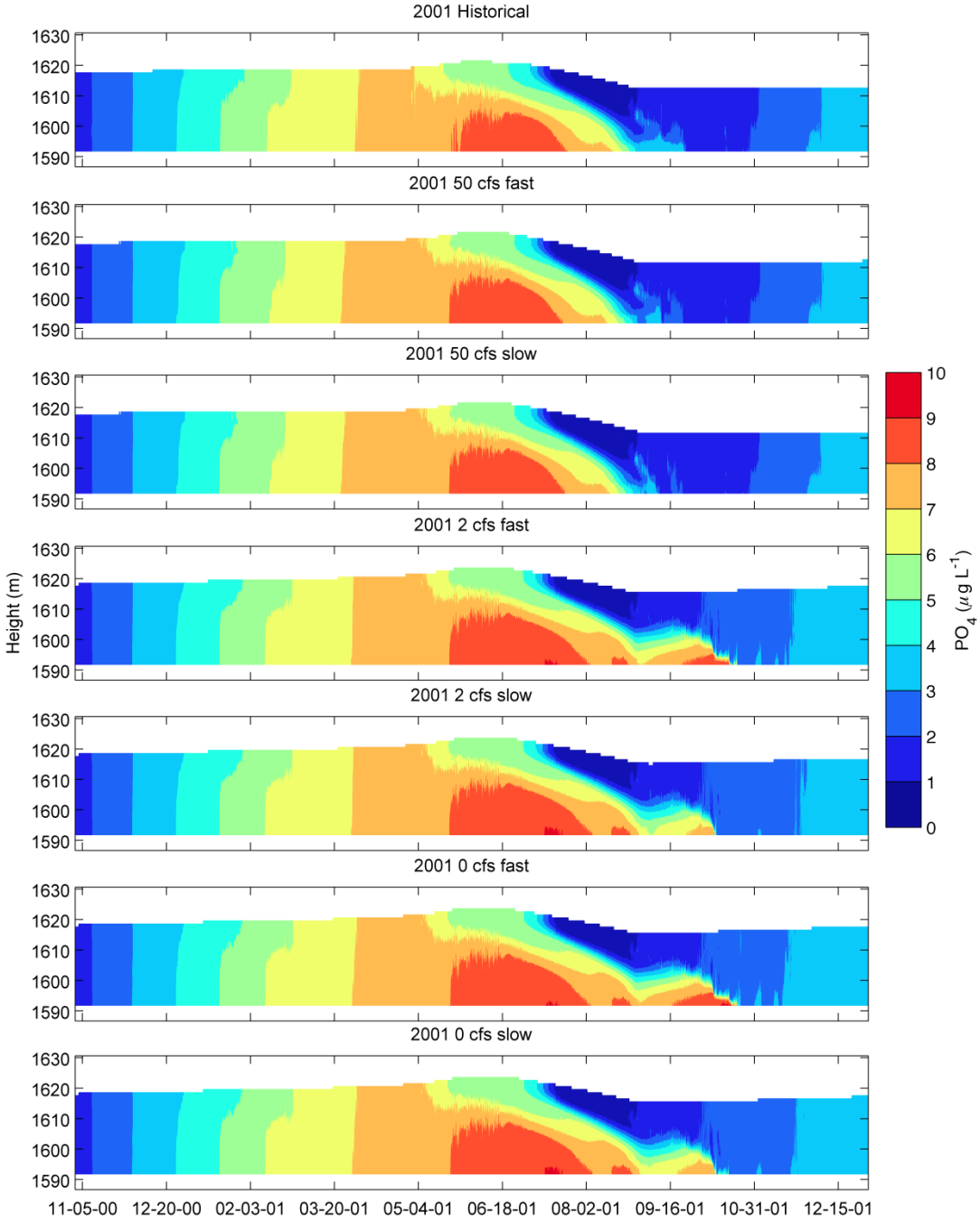


Figure 2-45. PO_4 response to the different operational scenarios at station DEA010 (dry BiOp year 2001).

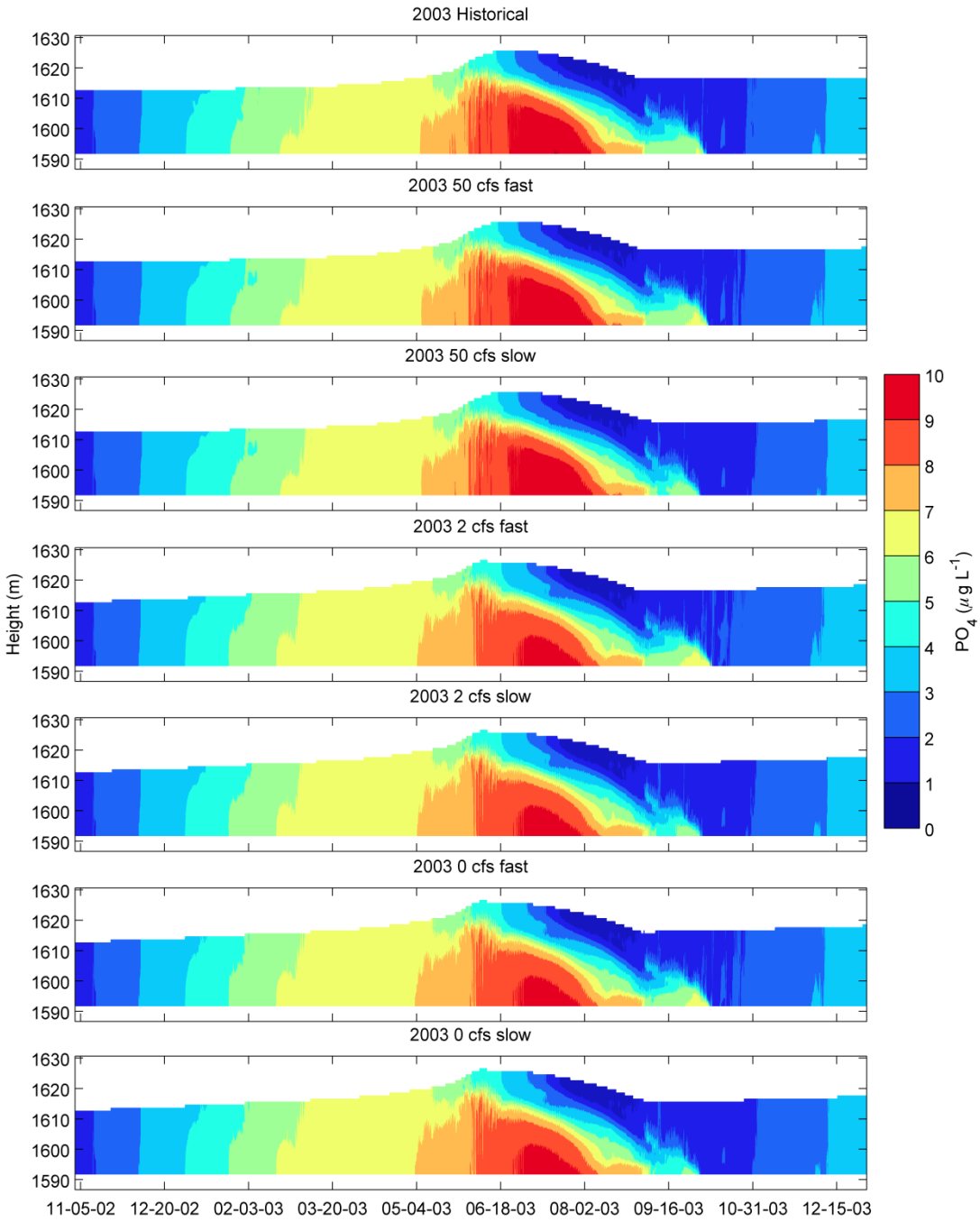


Figure 2-46. PO_4 response to the different operational scenarios at station DEA010 (average BiOp year 2003).

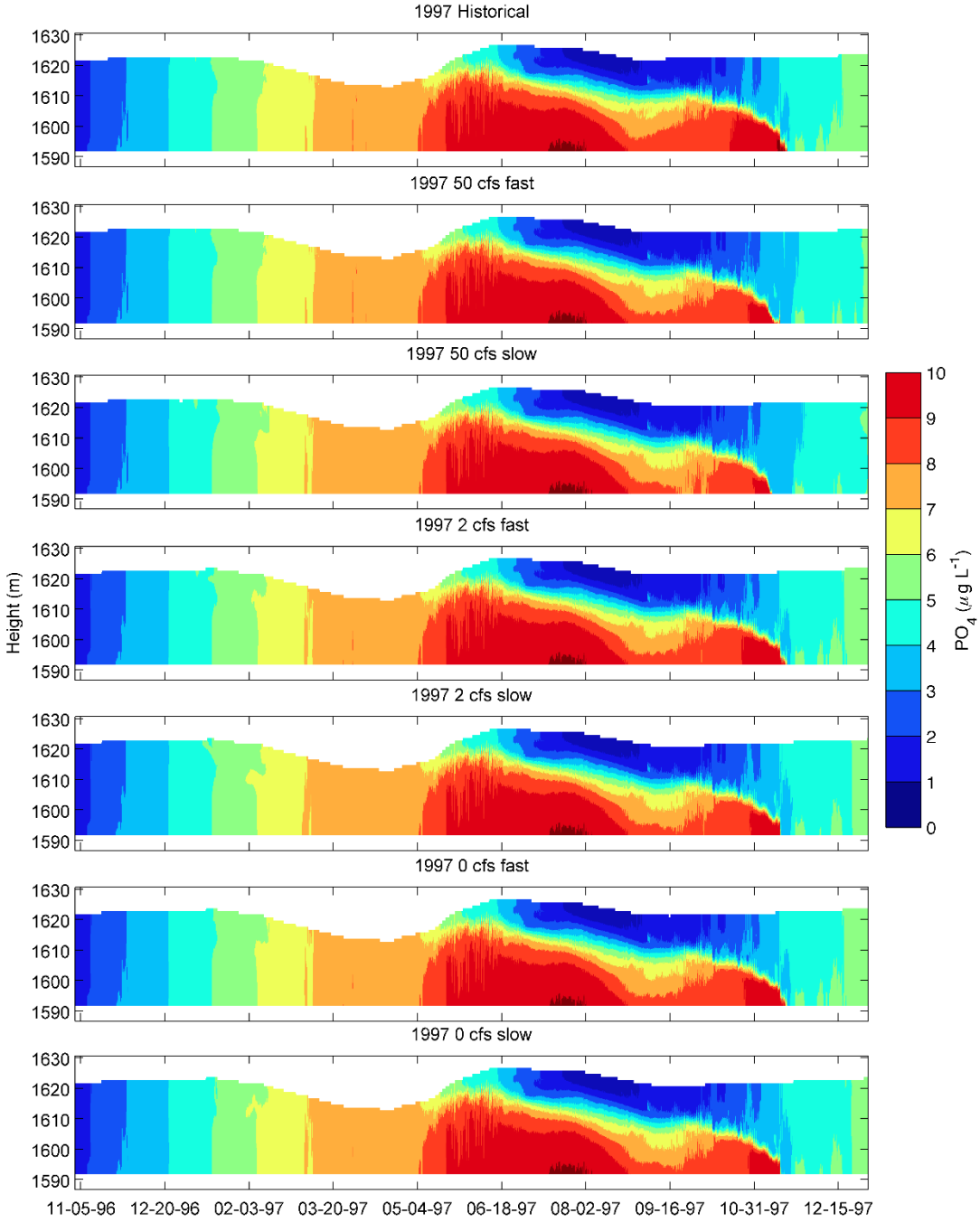


Figure 2-47. PO_4 response to the different operational scenarios at station DEA010 (wet BiOp year 1997).

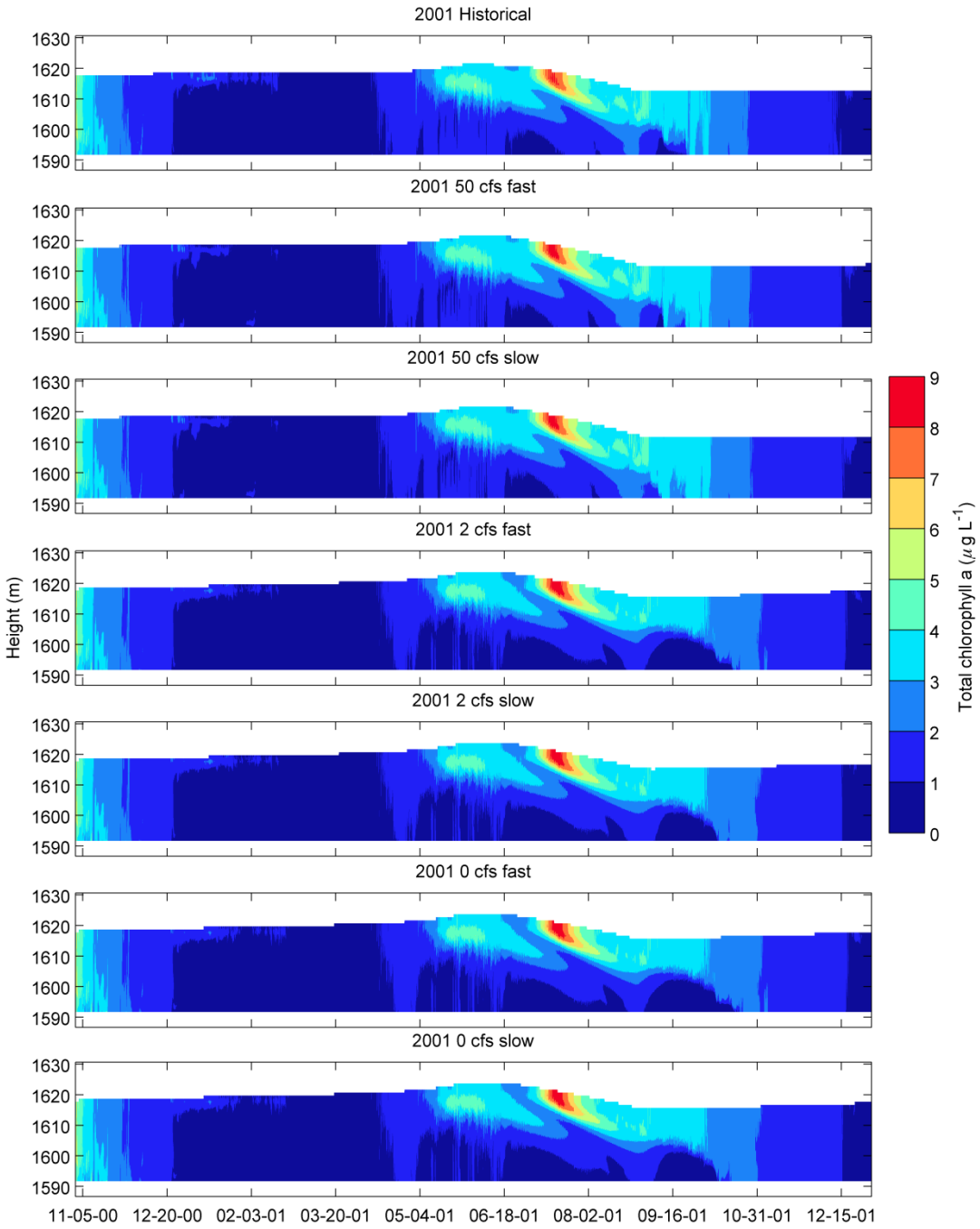


Figure 2-48. Chlorophyll *a* response to the different operational scenarios at station DEA010 (dry BiOp year 2001).

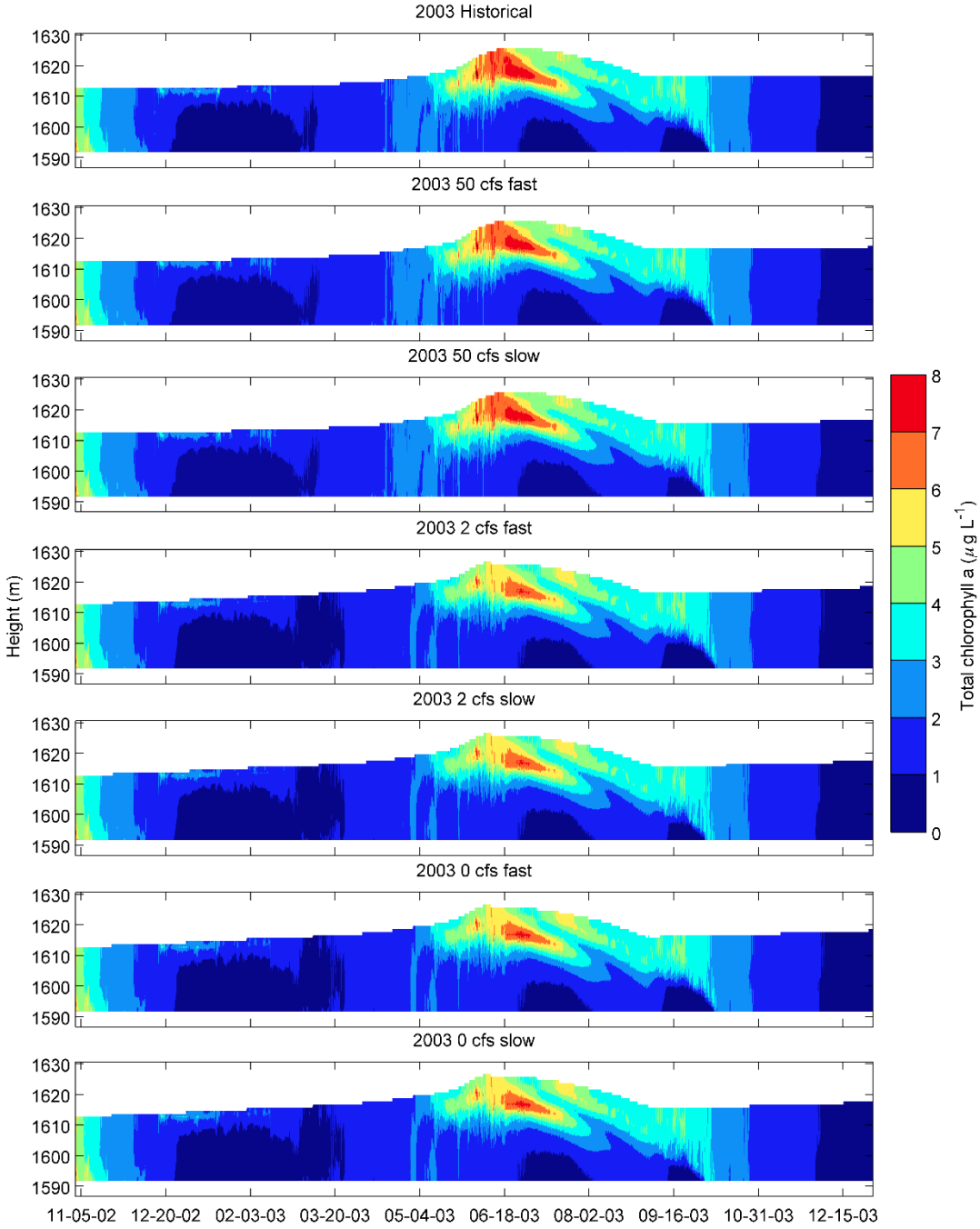


Figure 2-49. Chlorophyll *a* response to the different operational scenarios at station DEA010 (average BiOp year 2003).

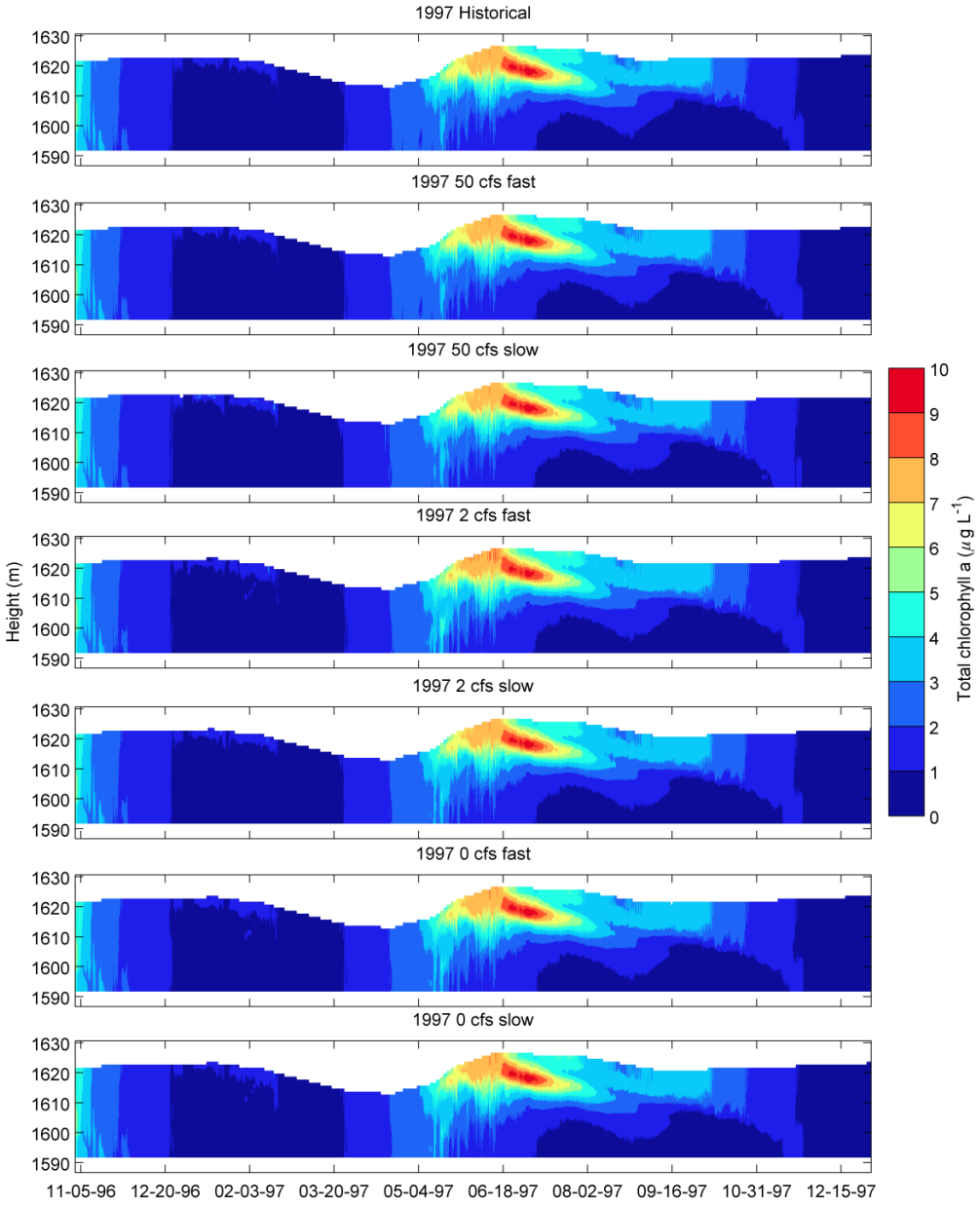


Figure 2-50. Chlorophyll *a* response to different operational scenarios at station DEA010 (wet BiOp year 1997).

2.1.4 Conclusions

This section has shown via numerical simulations that the habitat for Bull Trout could potentially be controlled by altering the timing of the turnover through active management of the discharge through the dam, as water levels play a major role in the physical and ecological conditions of the reservoir. While the minimum bottom temperature in Deadwood Reservoir

is determined exclusively by the river inflow temperature, the volume of cold water at the bottom during summer depends on the stability of the water column, which is influenced by the amount of rainfall during spring that determines the volume of water entering the reservoir, and on the ambient air temperature, which will influence density stratification. A wet spring combined with high air temperatures during summer leads to high water levels and strong density stratification and, thus, a stable water column with a high volume of cold water at the bottom. The temperature of the water that is released through the dam, on the other hand, depends on the discharge rates, as high discharge determines the drawdown for a particular off take structure. Therefore, management actions, via water level manipulation, have the potential to alter both in-reservoir and downstream water quality.

2.2 Limnology and Nutrient Mass Balance in Deadwood Reservoir

2.2.1 Introduction

In response to USFWS 2005 BiOp, Reclamation instituted in 2006 a 5-year investigation of reservoir operations flexibility for Deadwood River and Reservoir. A holistic watershed assessment, coupled with a comparison of several operational scenarios, was used to address the Terms and Conditions for Bull Trout listed in the BiOp. One of the important management tools developed by the investigation was a coupled hydrodynamic-ecological model of Deadwood Reservoir. The ELCOM-CAEDYM 3D model was used to simulate changes in the operation of Deadwood Reservoir in order to assess conformance to the Terms and Conditions of the BiOp (see Section 2.1 for details). The complexity of ELCOM-CAEDYM required collection and evaluation of substantial amounts of physical, chemical, and biological data from Deadwood Reservoir and its tributaries. This section discusses the approach, results, and interpretation of a comprehensive limnological monitoring program conducted in Deadwood Reservoir during water years 2007 through 2011.

2.2.2 Methods

Field Data Collection Program

Reservoir Sampling Stations, Duration, and Frequency

Locations of the reservoir sampling stations on Deadwood Reservoir as well as locations for collection of tributary data are illustrated in Figure 2-51. The frequency and duration for sampling of the five primary reservoir stations during 2007 to 2011 are listed in Table 2-5. Of the five stations listed, DEA010 was sampled most frequently, 60 times, over the 5 years. That station was also the deepest at 35 m; the shallowest station was DEA006 with a depth of

17 m. The other three primary stations (DEA004, DEA014, and DEA016) ranged in depth from 24 to 27 m.

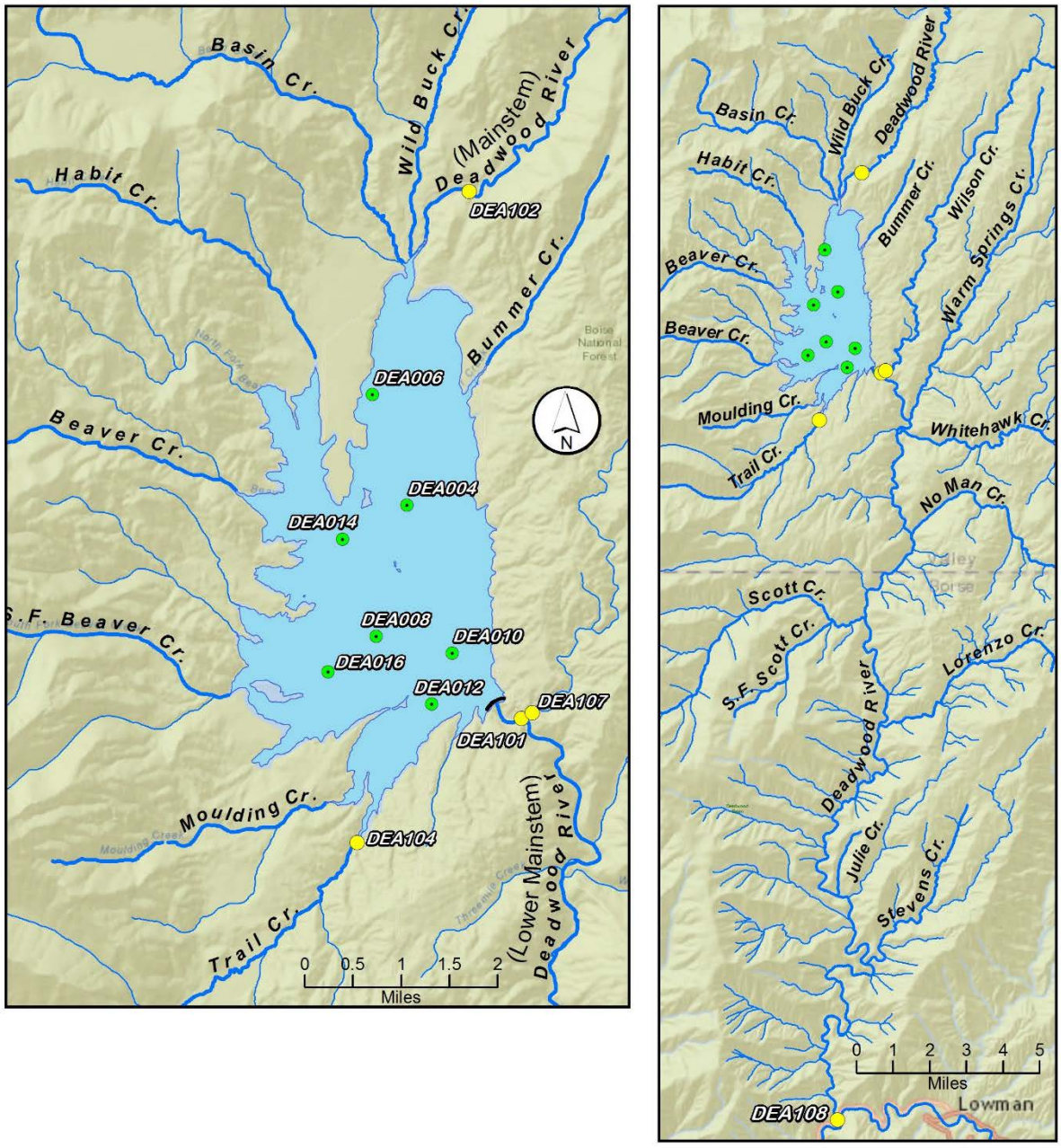


Figure 2-51. Water chemistry and reservoir profile locations (water chemistry also sampled at reservoir profile locations for surface, mid, and bottom water column conditions).

Table 2-5. Frequency and duration of limnological sampling at five primary reservoir stations during water years 2007-2011, Deadwood Reservoir.

Year and Variable	DEA004	DEA006	DEA010	DEA014	DEA016
2007					
Sampled Period	5/23-10/29	5/23-10/29	4/30-10/29	5/29-9/10	5/29-9/10
Frequency	weekly	weekly	weekly	biweekly	biweekly
Number of Samples	22	20	25	10	10
2008					
Sampled Period	6/16-10/6	6/16-10/6	6/5-10/6	6/30-10/6	6/16-10/6
Frequency	biweekly	biweekly	biweekly	biweekly	biweekly
Number of Samples	9	8	11	8	9
2009					
Sampled Period	6/29-9/28	6/29-9/28	6/29-9/28	6/29-9/28	6/29-9/28
Frequency	monthly	monthly	biweekly	monthly	monthly
Number of Samples	4	4	8	4	4
2010					
Sampled Period	7/1-11/4	7/1-9/29	6/3-11/4	7/1-11/4	7/1-9/29
Frequency	monthly	monthly	biweekly	monthly	monthly
Number of Samples	6	4	12	4	3
2011					
Sampled Period	7/7-10/17	7/7-10/17	7/7-10/17	7/7-10/17	7/7-10/17
Frequency	monthly	monthly	biweekly	monthly	monthly
Number of Samples	4	4	8	4	4

Weekly reservoir sampling commenced the first week in May 2007 at four of the seven reservoir stations and concluded the last week in October. The other three stations were sampled on a biweekly basis and over a shorter duration. Reservoir water chemistry samples and a water-column profile were collected through the ice at DEA010 in February 2008. During 2008, biweekly sampling was conducted at five reservoir stations (DEA008 and DEA012 were discontinued) starting the first week in June and concluding the first week in October. Reservoir samples were collected about monthly during 2009 at five stations; sampling began in late June and ended in late September. Sampling began in early June 2010 at only DEA010; sampling began in early July at the other four stations. The final sampling for 2010 concluded in early November; however, only three of the five stations were sampled. The latest start of reservoir sampling among the 5 years was in 2011; not until July 7 were the five stations sampled. Near-monthly sampling concluded on October 17.

Sampled Variables

Reservoir sampling consisted of measurement of secchi-disc transparency and barometric pressure, collection of full-depth water-column profiles (Hydrolab), and collection of water-

quality samples at several depths. Variables measured by reservoir sampling are listed in Table 2-6. Water-quality samples were analyzed by Reclamation's Pacific Northwest Regional Water Quality Laboratory in Boise using analytical procedures and quality assurance practices detailed in Reclamation's Water Quality Manual (Reclamation 2007; 2011).

Table 2-6. Field-measured and laboratory-analyzed water-quality variables for Deadwood Reservoir study, water years 2007–2011.

Water-column profiles and field data	Lab-analyzed water-quality variables
Water temperature	Nitrite+nitrate, dissolved
DO concentration	Ammonia, dissolved
DO percent saturation	Orthophosphate, dissolved
pH	Total phosphorus
Conductivity	Total Kjeldahl nitrogen
Turbidity	Organic carbon, dissolved
Fluorescence	Organic carbon, total
Barometric pressure	Turbidity
Secchi depth	Chlorophyll *a*
Sampling-station depth	Pheophytin-a
	Silica, dissolved

Nutrient samples collected from the reservoir were analyzed for total concentrations of phosphorus and Kjeldahl nitrogen (organic plus ammonia nitrogen) and dissolved concentrations of orthophosphate, nitrite plus nitrate, and ammonia. Analytical detection limits, in µg/L, for 2007 samples were as follows: 100 for Kjeldahl nitrogen; 10 for total phosphorus, dissolved nitrite plus nitrate, and ammonia; and 3 for dissolved orthophosphate. Nutrient analyses were revised in 2008 because the 2007 samples had a preponderance of below-detection limit concentrations for dissolved nitrite plus nitrate and orthophosphate. The revised analytical detection limits, in µg/L, were as follows: 3 for dissolved nitrite plus nitrate and 1 for orthophosphate. The other three nutrient analyses remained at their 2007 analytical detection limits.

Evaluation of the 2007 limnological data also indicated a need for modifications in the sampling and analysis of chlorophyll. In 2007, chlorophyll samples were collected only at the 1 m depth. Beginning in 2008, chlorophyll sampling was modified to collect samples at the 1 m depth as well as at the depth of the fluorescence maxima at most of the reservoir stations. Additionally, the trichromatic spectrophotometric method used in 2007 for chlorophyll *a* analyses was changed in 2008 to an acid-corrected spectrophotometric method, one that yields values for both chlorophyll *a* and pheophytin-a.

Automated Sensors

Although the field data collection program included numerous sampling visits to the reservoir stations about 7 to 8 months of each water year were not sampled because of access limitations, especially in the winter. In order to partly fill in this data gap a system of automated sensors relevant to important reservoir processes was installed in Deadwood Reservoir in the vicinity of DEA010. The LDS consisted of a floating platform of meteorological instruments and a vertically suspended sensor array for measurement of water temperature and DO concentrations. The 40 temperature sensors were equally spaced over the water column's full depth (about 35 m) and recorded temperature every minute. Seven DO sensors also recorded concentration every minute. Five of the DO sensors were suspended within the upper 9 m of the water column in order to track biological productivity. The remaining two tracked DO depletion within the hypolimnion; one was about 1.5 m above the reservoir bottom, the other was 12.5 m higher in the water column. The LDS became operational in July 2007 and, except for routine maintenance and several episodes of sensor malfunction, it recorded and transmitted data nearly continuously over each of the 5 years.

Hydrologic Budgets

Annual hydrologic budgets for Deadwood Reservoir were determined for 2007 through 2010; 2011 was not included because of a paucity of gaged streamflow data. The budgets accounted for the mass of water entering and leaving the reservoir via pathways such as gaged streamflow and ungaged streamflow, precipitation, and evaporation. Such data were essential for computation of nutrient budgets for Deadwood Reservoir. Hydrologic budgets were computed for each water year using the following equation (quantities in cubic meters):

$$R=GI+UI+P-E-GO-CS, \quad (1)$$

where R is the residual; GI is gaged inflow; UI is ungaged inflow; P is precipitation to the reservoir surface; E is evaporation from the reservoir surface; GO is gaged outflow; and CS is change in reservoir storage.

Gaged inflow (GI) was determined as the summation of the Bureau of Reclamation's reported inflows for Deadwood Reservoir's two primary tributaries, Deadwood River (DEA102) and Trail Creek (DEA104). Gaged outflow (GO) was derived from Bureau of Reclamation's long-term gaging station located immediately downstream of Deadwood Dam (DEA101). A later section of this report describes the methods used to obtain inflow data at these three gaged stations.

Ungaged inflow (UI) was estimated as the summation of inflows to the reservoir not delivered by Deadwood River or Trail Creek. The ungaged inflows were determined by multiplying their drainage basin areas by selected unit-runoff coefficients. Unit-runoff coefficients for

gaged inflows for the Deadwood River and Trail Creek were determined using the following equation:

$$RO=Q/A, \quad (2)$$

where RO is a unit-runoff coefficient, in cubic kilometers per square kilometer per year; Q is annual discharge, in cubic meters; and A is drainage area, in square kilometers.

Precipitation, P, to the reservoir surface was determined by multiplying its annual median surface-area by the annual precipitation recorded in the vicinity of Deadwood Reservoir. The nearest long-term climate data was from the SNOTEL station at Long Valley, which was about 35 km west of the reservoir and at an elevation very similar to that of the reservoir. Annual precipitation, in m, recorded for each of the 4 years was as follows: 2007, 0.52; 2008, 0.66; 2009, 0.58; 2010, 0.58. Evaporation (E) from the reservoir surface was determined by multiplying its summer (May through October) median surface-area by 0.76 m, the annual free-water-surface evaporation rate applied by Woods (1997) to nearby Payette Lake, which has a surface elevation very similar to that of the reservoir.

The change in reservoir storage (CS) represents the difference in reservoir contents between the start and finish of a specific water year. CS was determined using reservoir stage data and a tabulation of reservoir contents at specified reservoir stages.

The residual (R) was determined as the difference between gaged outflow and the algebraic sum of inflow and outflow components. The residual includes the errors associated with all budget components and unmeasured components such as groundwater flux and bank-storage flux.

Nutrient Budgets

Annual nutrient budgets for Deadwood Reservoir were determined for 2007 through 2010; the lack of a hydrologic budget for 2011 precluded computation of a 2011 nutrient budget. The budgets accounted for the mass of selected nitrogen and phosphorus compounds entering and leaving the reservoir via pathways such as gaged and ungaged inflows, and atmospheric deposition. Nutrient budgets were calculated using the following equation (quantities in kilograms), which used inflows from the hydrologic budget and nutrient concentration data from several sources.

$$RN=GIN+UIN+AD-GON-CSN, \quad (3)$$

where RN is the nutrient-load residual; GIN is nutrient load of gaged inflow; UIN is nutrient load of ungaged inflow; AD is atmospheric nutrient deposition to the reservoir surface; GON is nutrient load of gaged outflow; and CSN is nutrient load associated with change in reservoir storage.

The primary source of nutrient-concentration data was the tributary sampling program that was conducted during 2007 through 2011 at the reservoir's two primary tributaries, Deadwood River (DEA102) and Trail Creek (DEA104), and the reservoir's outflow (DEA101). The nutrient samples were analyzed at Reclamation's Water Quality Laboratory in Boise for concentrations of total phosphorus, dissolved orthophosphate, total Kjeldahl nitrogen, dissolved nitrite plus nitrate, and dissolved ammonia. A later section of this report describes the methods used to obtain nutrient-concentration data at these three gaged stations.

The nutrient-concentration data and inflow data obtained from the three gaged stations (DEA101, DEA102, and DEA104) were used to compute nutrient loads delivered into or discharged from the reservoir over 2007 through 2010. Load is defined as the quantity of a constituent passing a riverine cross section per unit of time and is calculated as the product of constituent concentration, streamflow, and appropriate conversion factors for measurement units. The computer program FLUX (Walker 1996) uses a variety of multiple-regression models to compute loads using stratified data sets based on relationships between either streamflow and nutrient concentration or time and nutrient concentrations. The model and data-stratification scheme that yields the smallest coefficient of variation, r2, is considered the best estimate of load. FLUX provides numerous diagnostic tools for choosing models and evaluating modeled results.

Nutrient loads from ungaged tributaries to Deadwood Reservoir were computed with the following equation:

$$L=(A)\ (N), \quad (4)$$

where L is annual nutrient load, in kilograms; A is drainage basin area, in square kilometers; and N is nutrient-export coefficient, in kilograms per square kilometer.

The nutrient-export coefficients were for Deadwood River (DEA102) and Trail Creek (DEA104) and were calculated by dividing their respective annual nutrient loads by their drainage area.

Atmospheric input of nutrients to the reservoir surface was estimated using monitoring data from the National Atmospheric Deposition Program's station at nearby Smiths Ferry (Woods 1997). The annual areal deposition rates, in kilograms per square kilometer, were multiplied by reservoir surface area, in square kilometers, to determine the annual load to Deadwood Reservoir. The nutrient load associated with annual change in storage, CS, was determined by multiplying that volume, in cubic meters, by the mean annual nutrient concentration, in micrograms per liter (µg/L), within the reservoir's hypolimnion.

The residual for each nutrient budget was determined as the difference between the nutrient load discharged from the reservoir's outflow (DEA101) and the algebraic sum of nutrient loads upstream of DEA101. The residual includes the errors associated with all budget

components and unmeasured components such as nutrients associated with groundwater flux, bank-storage flux, and flux from bottom sediments (internal fertilization).

2.2.3 Overview of Limnological Determinants of Reservoir Productivity

The data streams generated during 2007–2011 from reservoir and tributary sampling, near-year-round LDS data acquisition, and computed mass balances for water and nutrients, coupled with historic water-quality data (1980–2006) lead to new insights into the interaction of physical, chemical, and biological processes within Deadwood Reservoir. After a brief review of limnological processes, detailed evaluations will be presented regarding the following topics:

- Fate and transport of nutrient loads
- Indicators of elevated reservoir productivity
- DO dynamics and elevated reservoir productivity
- Interactions of limnological processes with hydrodynamic/water-operation variations
- Potential reasons for Deadwood Reservoir's elevated productivity

The fate and transport of water and associated constituents following their delivery into a reservoir are determined by the interactions of a myriad of physical, chemical, and biological processes operating within the reservoir over a wide range of spatial and temporal scales. The outcome of these interactions determines the reservoir's water quality, including its biological productivity, as well as the quantity and nature of constituents discharged downstream.

Among the important physical determinants of reservoir water quality and productivity are morphometry, hydrological loading, thermal stratification, water-column transparency, and the effect of the dam's operational schedule on pool volume and downstream discharge. These factors, in conjunction with chemical and biological ones, determine the magnitude and temporal aspects of the reservoir's water quality and biological productivity.

At its normal full-pool elevation of 1,625.8 m Deadwood Reservoir has a surface area of 12.6 km^2, contains about 190 million m^3, and has a maximum depth of about 35 m. Deadwood Reservoir's morphometry, depicted in Figure 2-52, has several important features: a large, shallow deltaic region near the influent Deadwood River; a highly dissected western and southern shoreline; extensive shallow "islands" mid-lake; and the deepest areas adjacent to Deadwood Dam with its deep outlet structure. The mid-lake shallow "islands" are oriented parallel and west of the thalwag of the pre-impoundment Deadwood River. This orientation may tend to route Deadwood River inflows toward Deadwood Dam; additionally, inflow-induced circulation into the reservoir's western margin may be somewhat restricted.

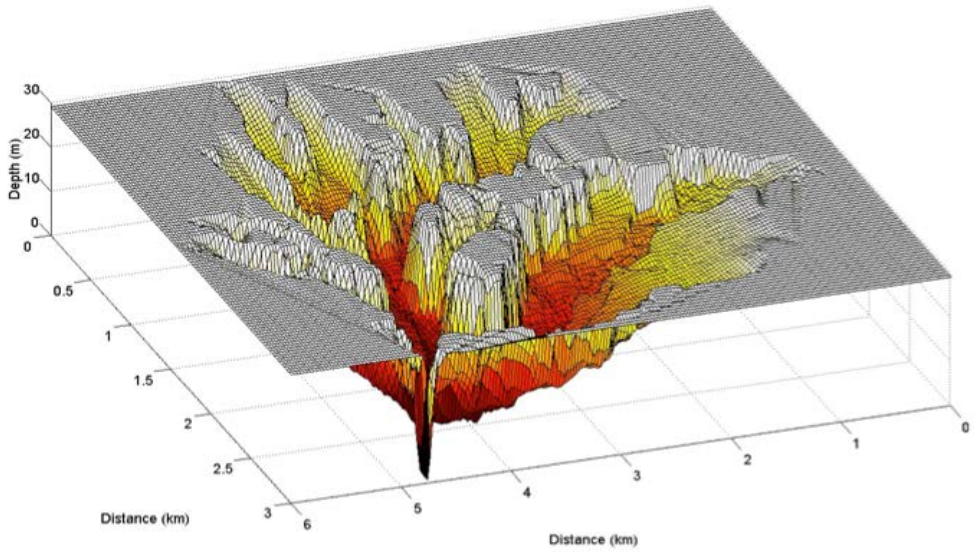


Figure 2-52. Oblique view of Deadwood Reservoir's bathymetry. [Deadwood River inflow at right of diagram, Deadwood Dam at bottom of diagram, Trail Creek inflow at left of diagram and shallow mid-lake islands at center of diagram].

The operation of the reservoir is highly dependent on the magnitude and timing of hydrologic inflows in concert with mandated water deliveries for downstream uses. Deadwood Reservoir receives drainage from about 287 km^2 of mountainous terrain; the maximum elevation in the drainage basin is about 2,650 m (above mean sea level) at Price Peak. The majority of inflow comes from the Deadwood River as the winter snow pack melts in the spring. As discussed previously, these inflows tend to enter the reservoir as interflows, not overflows or underflows. As such, the chemical and biological constituents carried as interflow may have longer residence times in the reservoir, especially if those constituents are associated with sediments. Residence times of dissolved constituents may be shortened if inflow is spilled over the dam. The overwhelming majority of releases from Deadwood Dam are via paired 1.5-m-diameter outlet tunnels with an invert elevation of 1,586.4 m. During the summer, these deep withdrawals entrain mostly hypolimnetic water. As drawdown progresses into late summer, metalimnetic water (and infrequently, epilimnetic water) may be entrained by the deep outlets; drawdown during 2007 did entrain metalimnetic and epilimnetic water.

The rather extensive shallow areas of the reservoir, coupled with an operational range of about 10 m, produce a highly variable percentage of littoral area in relation to reservoir surface area. Deadwood Reservoir's littoral zone is defined here as that with depths less than 10 m, which is about twice the reservoir's median secchi-disc transparency. At full pool, the littoral zone comprises 31% of reservoir surface area, or about 3.9 km^2; at minimum pool, the area increases to about 7.4 km^2. The reservoir's typical operational schedule produces a moving band of littoral zone as water levels rise during spring filling and decline during fall drawdown. Over 2007–2011, the filling phase lasted between 3 weeks (2010) and 3 months

(2011), the full-pool littoral zone lasted between 2 weeks (2009 and 2011) and 5 weeks (2007), drawdown lasted between 5 weeks (2011) and 9 weeks (2007); the remaining 8 months of each year were at minimum pool.

The vertical distribution of water-quality properties and constituents within a reservoir are closely linked to the physical limnological processes of thermal stratification and convective circulation. The major source of heat for establishment of thermal stratification is the solar radiation that impinges upon the reservoir's surface. Wind energy distributes that surface heating into the water column until density differences impede deeper mixing. In reservoirs deep enough to resist full-depth convective circulation, solar heating and wind mixing during the summer vertically segregate the water column into three zones: epilimnion, metalimnion, and hypolimnion. The upper zone, the epilimnion, is the stratum in which most of the reservoir's biological production occurs because light is generally sufficient to drive photosynthetic production of phytoplankton in excess of their respiratory demands. The metalimnion is the stratum of maximum temperature change; density differences may be sufficient to impede settling of detrital material into the lower stratum, the hypolimnion. A thermocline is present within the metalimnion if the vertical rate of temperature change exceeds 1^{o}C/m. The hypolimnion overlies the reservoir's bottom sediments, with their long-term accumulation of detrital material produced both within the reservoir (autochthonous) and delivered from its watershed (allochthonous). During thermal stratification, the hypolimnion is isolated from atmospheric exchange and, as a result, may develop a DO deficit if biological and chemical oxygen demands exceed the oxygen mass available within the hypolimnion at the onset of thermal stratification. During the spring and autumn, solar radiation is less than during the summer and windy conditions are more prevalent. This combination facilitates convective circulation, the process whereby a weakly stratified water column can undergo partial or full-depth vertical mixing when wind energy is sufficient to overcome the thermal gradient. Convective circulation is an important mechanism for the vertical movement of water-quality constituents such as DO, nutrients, and detrital organic carbon.

The biological productivity of the reservoir is closely linked to the influx and processing of the non-conservative nutrient compounds of nitrogen and phosphorus. Subsequent to their delivery into Deadwood Reservoir as dissolved, colloidal, and particulate fractions nitrogen and phosphorus can be involved in a variety of chemical and biological processes. The most important of these processes is the primary productivity of phytoplankton. Phytoplanktonic assimilation of dissolved inorganic nitrogen (nitrite, nitrate, and ammonia) and dissolved orthophosphate converts some of the dissolved fraction to a particulate, organically bound fraction that has several possible fates. Advective transport can physically redistribute the particles within the reservoir, a portion of which may exit via the reservoir's outlet. The particles also can be retained within the water column by turbulence and be subjected to remineralization or uptake by zooplankton grazing. Dissolved and colloidally bound fractions are subject to in-lake sedimentation when converted to particles by processes such as assimilation, precipitation, complexation, and adsorption. Sedimentation delivers the particles

to the lakebed, where they may be subjected to remineralization and possible recycling back into the water column; alternatively, subsequent sedimentation may permanently bury the particles within the lakebed.

The decomposition of detrital organic carbon and particulate-associated nutrients that occurs within or above the reservoir's bed sediments is facilitated by hypolimnetic deoxygenation; this process is often referred to as "internal nutrient loading." Convective circulation aids in redistribution of these nutrients into the reservoir's epilimnion where they may stimulate primary productivity, especially during the spring and autumn months when the reservoir's thermal stratification is weak or absent.

2.2.4 Reservoir Water Quality, 2007 to 2011

Hydrologic Conditions and Reservoir Sampling

A summary of important hydrologic conditions affecting Deadwood Reservoir in each of the 5 sampled years is presented in Table 2-7. These conditions relate to duration and peak discharge of snowmelt runoff and reservoir drawdown, dates of spillage, pool elevation changes, and the time frame encompassed by reservoir sampling.

Table 2-7. Annual hydrologic and water-operations variables during water years 2007 to 2011, Deadwood Reservoir.

Characteristic	2007	2008	2009	2010	2011
Pool elevation (m), prior to snowmelt	1,620	1,617	1,620	1,620	1,621
Start date, snowmelt runoff	early April	late April	late May	mid-May	mid-April
Date, peak snowmelt runoff	early May	mid-May	early June	early June	late June
Peak snowmelt (m^3/s)	21	59.5	39.4	50	39.7
Date range, spillage	5/22-6/25	6/7-7/2	7/5-7/14	6/6-6/17	none
Date range, full pool	mid-May – late June	early June – early July	early July-mid-July	early June – early July	mid-July – late July
Pool elevation (m), end of drawdown	1,613	1,616	1,618.50	1,620	1,618.50
Date range, reservoir sampling	4/30-10/29	6/5-10/6	6/29-9/28	6/3-11/4	7/7-10/17

Snowmelt runoff into the reservoir during 2007 began in early April with the reservoir surface at about 1,620 m; snowmelt runoff peaked at about 21 m^3/s (742 cfs) in early May. During reservoir filling deep withdrawal was augmented with spillage from about May 22 to June 25. Full pool was reached in mid-May and was maintained until late June when drawdown commenced. Drawdown ended in late August at a reservoir elevation of 1,613.2 m. Reservoir sampling spanned May 1 through October 29 and encompassed the hydrologic conditions of near-peak snowmelt inflows, a near-complete fill/drawdown cycle, development and loss of

thermal stratification, depletion of hypolimnetic DO, and reaeration of water column by convective circulation.

In 2008, snowmelt runoff into the reservoir began in late April and peaked in mid-May at about 59.5 m^3/s (2,100 cfs), which was about three times larger than in 2007. Snowmelt began with the reservoir surface at about 1,617 m., which was about 3 m lower than in 2007. Deep withdrawal was augmented with spillage from June 7 to July 2. Full pool was reached in early June and was maintained until early July. Drawdown began in early July and ended in early September at a reservoir elevation of 1,616.6 m, about 3.4 m higher than in 2007. Reservoir sampling (June 5 through October 6) encompassed the hydrologic conditions of late recession of snowmelt runoff, full pool and complete drawdown, development and loss of thermal stratification, depletion of hypolimnetic DO, but not the reaeration of the water column.

Snowmelt runoff began to fill the reservoir during 2009 about a month later than the previous 2 years. The peak of snowmelt runoff, 39.4 m^3/s (1,390 cfs), occurred in early June and was about mid-way between those measured in 2007 and 2008. During reservoir filling deep withdrawal was augmented briefly with spillage from July 5 to 14. Full pool was attained in early July; drawdown commenced 10 days later. Drawdown ended in late August at a reservoir elevation of 1,618.5 m. The late start of reservoir sampling on June 29 missed the filling of the reservoir by snowmelt runoff and the development of thermal stratification. Sampling, which ended on September 28, did encompass the drawdown cycle, the loss of thermal stratification, and the depletion of hypolimnetic DO.

For 2010, snowmelt runoff into the reservoir began in mid-May and peaked in early June at about 50 m^3/s (1,770 cfs). At the start of snowmelt runoff the reservoir surface was at about 1,620 m, typical for winter pool elevations. The normal full pool elevation was reached in early June and was maintained until early July, the start of drawdown. Deep withdrawal was briefly augmented with spillage from June 6 to 17. Drawdown ended in mid-August at a reservoir elevation of 1,618.5 m. Reservoir sampling spanned June 3 through November 4 and encompassed the hydrologic conditions of near-peak snowmelt runoff in early June, full pool and complete drawdown, development and loss of thermal stratification, depletion of hypolimnetic DO, and reaeration of water column by late October.

A sustained period of snowmelt runoff began in mid-April 2011; the peak of 39.7 m^3/s (1,400 cfs) did not occur until late June. The reservoir elevation in early April was 1,621 m. No spill occurred and full pool was almost attained (down 0.3 m) in mid-July. Drawdown began on July 20 and ended on September 11 at a reservoir elevation of 1618.2 m. The start of reservoir sampling was delayed until July 7 because of access problems caused by the prolonged period of snowmelt runoff. Reservoir sampling ended on October 17. The shorter sampling period in 2011 missed the filling of the reservoir by snowmelt runoff and the development of thermal stratification. Sampling did encompass the drawdown cycle, the loss of thermal stratification, the depletion of hypolimnetic DO, and the partial reaeration of the water column.

Reservoir Thermal Structure and Inflow-plume Routing

Thermal stratification had commenced by early May 2007 and was well-established by mid-May. The reservoir's surface temperature on the initial sampling trip, April 30, was 9°C at DEA010. The maximum surface water temperature at DEA010 was 24°C on July 23. Thermal stratification began to weaken in mid-August and was absent by early September. By the final sampling trip on October 9 the reservoir's surface had cooled to 11°C. The inflow plume of the Deadwood River during snowmelt runoff entered the reservoir as an interflow between the depths of 5 to 10 m, as indicated by temperature and specific-conductance profiles. The interflow plume was evident reservoir-wide through early June on the basis of specific conductance variations in the water column in relation to those delivered by snowmelt runoff.

Thermal stratification during 2008 was in progress on the initial sampling trip of June 5 and was well-established by late June. Surface water temperature at DEA010 on June 5 was 10.5°C and increased to a maximum of 21.2°C by July 28. By late August, thermal stratification had begun to weaken and was absent by mid-September. The reservoir's surface temperature on the final sampling trip, October 6, had cooled to 14.3°C. During June, snowmelt runoff from the Deadwood River was evident as an interflowing layer between 5 to 10 m beneath the reservoir surface.

The initial sampling trip on 2009, June 29, found thermal stratification was well-established and the surface temperature at DEA010 was 19.3°C. At DEA010, July 20 had the maximum surface water temperature of 21.6°C. The reservoir surface had cooled to 17.2°C by the final sampling trip, September 28; thermal stratification had weakened considerably but convective circulation had not fully mixed the water column. Snowmelt runoff began about a month later than in 2007 and 2008 but was still evident as an interflow between the 5 and 10-m depth layer.

On the initial sampling trip of June 3, 2010 thermal stratification was established and the surface temperature at DEA010 was 9.8°C. Strong thermal stratification persisted from early June through early September. August 2 had the peak surface temperature of 21.9°C. By late September, thermal stratification was still present but weak. By late October, water-temperature profiles showed the reservoir to be nearly isothermal with a surface temperature of 10.6°C. During June, the reservoir's thermal structure was intruded at about a depth of 10 m by the interflowing Deadwood River.

With reservoir sampling delayed until July 7, the initial profiles for 2011 found thermal stratification was strong and the surface temperature at DEA010 was 20.4°C. The peak surface temperature of 21.2°C was measured on August 8. Snowmelt recession was still underway in early July; the inflowing Deadwood River intruded the reservoir at a depth of about 18 m, which was well beneath the thermocline depth of 4 m. Strong thermal stratification continued

until early September but steadily weakened through mid-October. By the final sampling trip on October 17, the reservoir was nearly isothermal, with a surface temperature of 13°C.

Reservoir Dissolved Oxygen and Percent Saturation

The following discussion of DO concentration and percent saturation pertains to DEA010 in that it was the most consistently sampled reservoir station. Additionally, this station was adjacent to the LDS, which generated copious amounts of data pertaining to water temperature and DO.

DO concentrations during 2007 sampling ranged from 12 to 0.5 mg/L (Table 2-8). High concentrations were measured during July near the thermocline; these high concentrations were often supersaturated (as high as 150%) as a consequence of robust phytoplankton photosynthesis. The 0.5-mg/L concentration was measured near the bottom in early October (in 2006, at the start of the 2007 water year). Near the end of the 2007 water year, near-bottom, DO concentrations had declined to 3.5 mg/L. These low concentrations were eliminated in mid-September by ongoing convective circulation of the water-column as thermal stratification weakened.

Table 2-8. Minimum and maximum DO concentrations, in milligrams per liter, sampled at reservoir station DEA010 during water years 2007-2011, Deadwood Reservoir.
[NB is near bottom sample; T is thermocline sample}

DO	2007	2008	2009	2010	2011
Minimum					
Concentration (mg/L)	0.5	2.4	2.1	0.7	2.9
Date of Occurrence	early Oct.	early Oct.	late Sept.	late Sept.	mid-Oct.
Depth Zone	NB	NB	NB	NB	NB
Maximum					
Concentration (mg/L)	12	12.2	11.8	11.1	11.1
Date of Occurrence	late July	late July	mid-July	early June	mid-Aug.
Depth Zone	T	T	T	3-m depth	T

DO sampling during 2008 included through-the-ice sampling performed in late February at DEA010. This winter sampling obtained important water-quality data never before available for Deadwood Reservoir. Perhaps most significant was the measurement of substantial hypoxia in the hypolimnion. DO concentration and percent saturation near the bottom were, respectively, 3.5 mg/L and 32%. Prior to the onset of winter ice-cover the reservoir had circulated and fully reaerated, on the basis of DO concentrations from the LDS. The February hypoxia indicated that the reservoir experienced substantial oxygen demand while under winter ice cover. During summer sampling in 2008 the range of DO concentrations was from 2.4 to 12.2 mg/L, slightly wider than in 2007 (Table 2-8). The peak concentration of 12.2 mg/L (a saturation of 150%) was measured in late July near the thermocline. Saturations

greater than 100% persisted near the thermocline from mid-July to early September. The concentration of 2.4 mg/L (a saturation of 26%) was measured near the bottom on October 6, the final date of reservoir sampling.

DO concentrations during 2009 ranged from 2.1 to 11.8 mg/L (Table 2-8). The high concentration was measured in mid-July near the thermocline. The lowest concentration was saturated at only 23% and was measured near the bottom on September 28, the last day of reservoir sampling.

During 2010, DO concentrations ranged from 0.7 to 11.1 mg/L (Table 2-8). The peak concentration was measured in early June near the reservoir surface. DO saturations greater than 100% (supersaturation) persisted from early June through late September, often near the thermocline. The peak supersaturation, 123%, was measured near the thermocline in early July. The concentration of 0.7 mg/L (a saturation of 7.4%) was measured near the bottom in late September, prior to water-column circulation. Reservoir sampling continued until November 4 and verified LDS profiles of water temperature and DO, both indicated that full-depth convective circulation and reaeration occurred in late October.

In the final year of reservoir sampling DO concentrations ranged from 2.9 to 11.1 mg/L (Table 2-8). The maximum was measured in mid-August near the thermocline whereas the minimum was measured on October 17 near the bottom. Supersaturated DO concentrations were measured near the thermocline during early July and mid-August, but near the surface during mid-September. The final sampling trip on October 17 measured a nearly isothermal water column that had been reaerated to within about 5 m of the reservoir bottom.

Automated Sensors for Water Temperature and Dissolved Oxygen

Difficulty of access owing to extreme winter conditions meant that the reservoir was not sampled for 7 to 8 months of each year. This yearly gap was monitored for important reservoir processes using a system of automated sensors installed in Deadwood Reservoir in the vicinity of DEA010. The LDS consisted of a floating platform of meteorological instruments and a vertically suspended sensor array for measurement of water temperature and DO concentrations.

In addition to the insights gained from LDS data collected outside of reservoir sampling, LDS data collected during reservoir sampling was used to assess both the persistence of supersaturated DO concentrations near the thermocline and the extent of hypolimnetic deoxygenation during periods of thermal stratification. Reservoir sampling often encountered these significant water-quality features; however, the variable frequency of reservoir sampling (weekly, biweekly, or monthly) left long unsampled periods. To illustrate, Figure 2-53 graphs the DO concentrations measured by the seven vertically arrayed sensors for the period July 2007 through December 2009. The upper five sensors (do1-do5) clearly illustrate the very dynamic behavior of DO concentrations within the reservoir's upper water column (near-

surface to 9-m depth). Variations in hypolimnetic DO concentrations were tracked by sensors do6 and do7, the latter lies about 1 m above the reservoir's bottom.

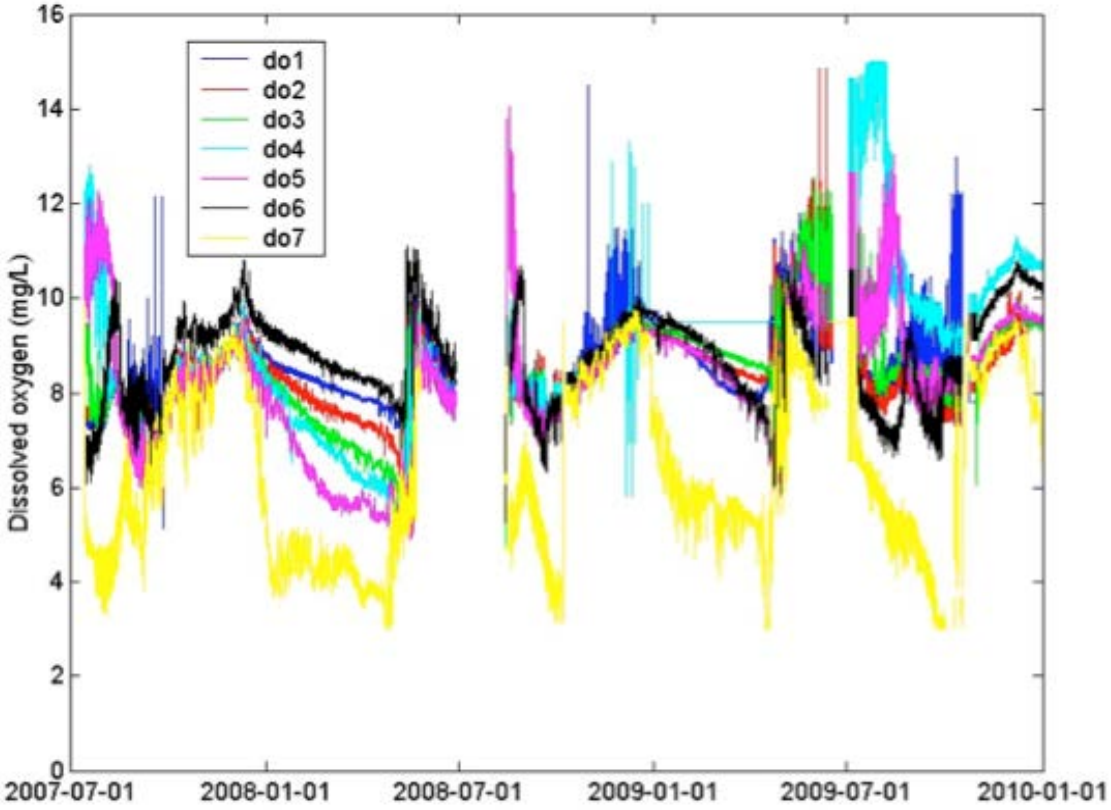


Figure 2-53. Variations in DO concentrations, in milligrams per liter, over July 2007 through December 2009, as measured by seven vertically arrayed sensors on LDS near reservoir station DEA010, Deadwood Reservoir.

In 2007, reservoir sampling began on April 30; however, the LDS did not start measuring DO until early July. From that date, until about mid-August, the LDS revealed persistent supersaturated conditions near the thermocline. The weakening of thermal stratification after late August curtailed supersaturation. Late August also marked the occurrence of minimum, near-bottom DO concentrations (3.5 mg/L) from the LDS. The start of convective circulation in early September began reaeration of the hypolimnion. By early October, hypolimnetic DO was about 8 mg/L.

Following the end of reservoir sampling in 2007 (late October) and to mid-December, data from the LDS indicated cooling water temperatures under near-isothermal conditions and ongoing reaeration of the water column to about 8.5 mg/L. However, by late December near-bottom DO concentrations had declined to 5.5 mg/L; that decline continued to about 4 mg/L by late April of 2008. Convective circulation and reaeration of the upper water column

commenced in early May; however, the onset of thermal stratification in mid-May precluded complete reaeration of the hypolimnion.

Reservoir sampling, which commenced on June 5 2008, and the LDS both revealed a lack of supersaturation near the thermocline during June. The LDS was inoperative from late June to mid-August; reservoir sampling indicated the presence of supersaturation from mid-July to late August. With the restart of the LDS in mid-August the thermocline region was found to be supersaturated until late August. By early September, convective circulation of the epilimnion had curtailed supersaturation.

Reservoir sampling ended on October 6, 2008 with convective circulation underway, but with near-bottom DO concentrations still as low as 2.4 mg/L. From mid-October to mid-December the reservoir cooled, the water column became isothermal, and reaeration to about 8 mg/L had occurred. Unlike 2007, in 2008 the upper several meters of the reservoir experienced near-daily pulses of DO to 110% saturation from late October to mid-December. By mid-January near-bottom DO concentrations had declined to 6 mg/L and continued to decline to 3 mg/l by mid-April 2009. Convective circulation commenced in late April and raised near-bottom DO concentrations to about 6 mg/L. Concurrently, near-surface concentrations pulsed to about 11 mg/L. Thermal stratification was underway by early May and prevented complete reaeration of the hypolimnion.

Prior to becoming inoperative from early June to mid-July the LDS indicated supersaturation near the thermocline in the first few days of June 2009. With its restart in mid-July, the LDS measured persistence supersaturation near the thermocline from mid-July to mid-September; Figure 2-54 illustrates one day of such conditions in July, with supersaturation at about 132%. By the end of reservoir sampling on September 28, temperature and DO stratification were still present, but supersaturated conditions had migrated to the near-surface strata.

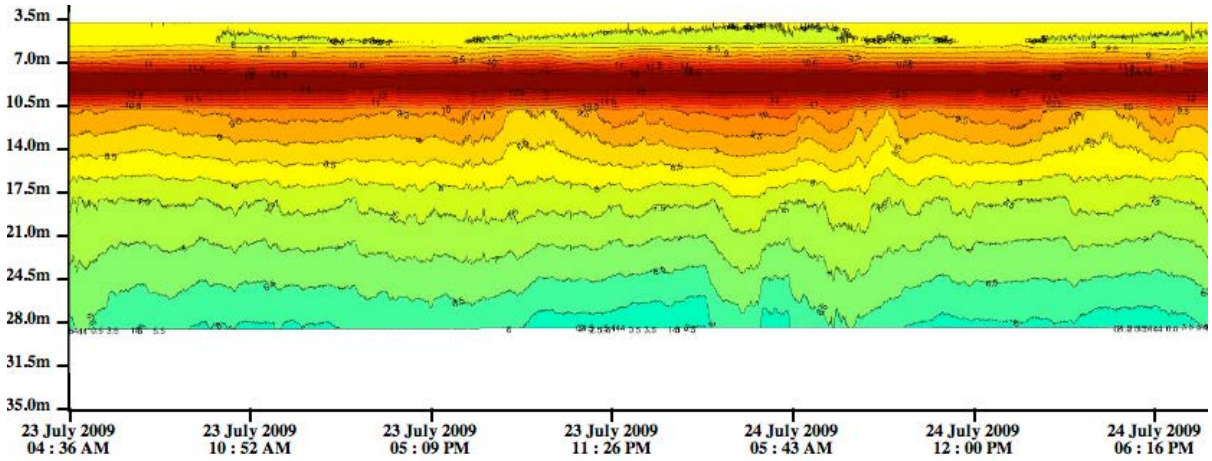


Figure 2-54. Persistent occurrence of supersaturated DO concentrations, in milligrams per liter, in vicinity of thermocline (about 9-m depth), as measured by LDS sensors on July 23-24, 2009, Deadwood Reservoir. DO values are represented by colors; red signifies the highest value and decreases along the color gradient to blue which signifies the lowest values.

By mid-October, convective circulation was in progress but DO remained stratified, with near-bottom concentrations of about 2 mg/L. The first two weeks of October had near-surface pulses of DO as high as 145-percent saturation. Unfortunately, the LDS was inoperative from mid-to-late October. Upon restarting in late October, the LDS indicated that hypolimnetic DO had been reaerated to about 8 mg/L. Operational problems with the LDS continued through December; the upper water-column data were missing. Therefore, the occurrence of DO pulses could not be monitored from mid-October through December 2009. The hypolimnion had been reaerated to about 9 mg/L by early December. Near-bottom DO concentrations had declined to 7 mg/L by late January 2010 and continued to decline to about 3.5 mg/L by late April. Robust convective circulation had reaerated the water column to 8.5 mg/L in early May; near-surface pulses of DO attained 115% saturation. Thermal stratification was established by mid-May and robust phytoplankton production was evident within the epilimnion, but not as near-surface pulses anymore.

During reservoir sampling in 2010 (June 5 to November 4) the LDS was inoperative from early June to early September. The LDS did measure supersaturation near the thermocline during the latter half of May. Commencing in early September and to late September the LDS did not encounter supersaturation near the thermocline. Supersaturation commenced in late September, but was expressed in daily surges near the reservoir's surface. Full-depth convective circulation did not occur until late October; over much of October DO concentrations near the bottom had declined to less than 1 mg/L.

November 4, 2010 marked the latest termination of reservoir sampling over the 5 years. A few days prior the reservoir had experienced full-depth circulation and reaeration. The months of October into mid-December exhibited the most-sustained DO pulsing of the 5 years. On

almost a daily basis the upper several meters of the reservoir attained daytime DO saturations as high as 130%; saturations declined to about 75% during the night (Figure 2-55). Even though water temperatures had fallen to about 5°C by early December the reservoir maintained robust phytoplankton productivity into late December. Mid-December's near-bottom DO concentration of 8 mg/L had declined to 6 mg/L by mid-January 2011. That had declined further to 3.5 mg/L by late April. From mid-April to late May convective circulation and thermal stratification had commenced. In the same period, robust phytoplankton production produced near-surface DO saturations as high as 130% during the day and as low as 75% at night. The same pattern of supersaturation continued through much of June.

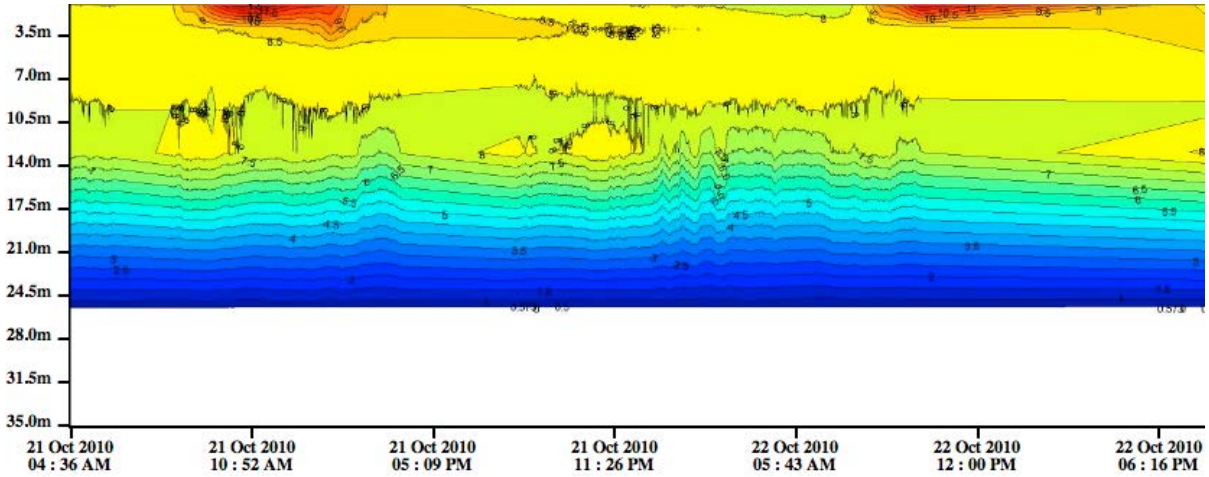


Figure 2-55. Near-daily pulses of supersaturated DO concentrations, in milligrams per liter, measured near surface by LDS during October 21-22, 2010, Deadwood Reservoir. [Note that DO concentrations from surface to bottom ranged from 13.5 to 0.5 mg/L.]

In 2011, prolonged snowmelt runoff delayed the start of reservoir sampling to July 7, the latest of the 5 years. That sampling trip found that supersaturation had migrated from the near-surface strata to the thermocline. A day later the LDS became inoperative, that continued until late August. With the restart of the LDS on August 25 the presence of supersaturation near the thermocline was revealed; this continued until mid-September when it was curtailed by convective circulation of the upper water column. Reservoir cooling continued into October and resulted in full-depth convective circulation on October 18, one day after the final reservoir sampling trip. DO concentrations in the lower hypolimnion had declined to less than 1 mg/L in early October; by mid-October they had been increased to about 2.5 mg/L by convective circulation and partial reaeration of the hypolimnion. On October 19, following full-depth convective circulation, daily surface pulses of supersaturated DO commenced. The LDS was removed from the reservoir on October 28; the pulses, some as high as 130% saturation, were ongoing on that day.

Reservoir pH

The following discussion of pH pertains to DEA010 in that it was the most consistently sampled reservoir station. Over the 5 years of sampling, reservoir pH values ranged from a minimum of 6.0 (September 2009) to a maximum of 9.5 (July 2011). Minimum pH values in each year were measured near the reservoir bottom, often near the end of drawdown and prior to convective circulation of the water column. Maximum pH values in each year were consistently associated with the thermocline and supersaturated DO concentrations. In general, pH ranged from 7 to 8 in the majority of the water column.

Reservoir Secchi-disc Transparency

The following discussion of secchi-disc transparency pertains to the five reservoir sampling stations (Table 2-9). The overall range of the 91 readings of secchi-disc transparency in 2007 was 2.4 to 6.3 m. In 2008, the 43 readings ranged from 3.1 to 7.3 m. Only five readings were made in 2009; they ranged from 3.9 to 5.7 m. Twenty-two readings were taken in 2010; they ranged from 2.6 to 9.2 m. The last year of sampling included 20 readings that ranged from 2.5 to 4.8 m. Median values of secchi-disc transparency among the 5 years had a narrow range, from 4 to 5 m (Table 2-9).

Table 2-9. Statistical comparison of secchi-disc transparency, in meters, at the five primary reservoir stations during water years 2007-2011, Deadwood Reservoir.

Year	Number of Samples	Minimum	Maximum	Median
2007	91	2.4	6.3	4.4
2008	43	3.1	7.3	5
2009	5	3.9	5.7	4.8
2010	22	2.6	9.2	4.2
2011	20	2.5	4.8	4

Reservoir Nutrients

The following discussion of nutrient concentrations pertains to DEA010 in that it was the most consistently sampled reservoir station. A summary of nutrient concentrations for near-surface, mid-depth, and near-bottom samples at DEA010 is presented in Table 2-10.

Table 2-10. Concentration ranges, in µg/L, of selected nutrients from near-surface (NS), mid-depth (MD), and near-bottom (NB) samples at reservoir station DEA010 during water years 2007-2011, Deadwood Reservoir.

Nutrient and Depth Zone	2007	2008	2009	2010	2011
Total Phosphorus					
NS	<10-28	<10-25	<10-15	<10-24	<10-19
MD	<10-27	<10-35	<10-20	<10-16	<10-18
NB	<10-40	16-76	<10-34	<10-66	15-53
Diss. Orthophosphate					
NS	<3	<1-1	<1	<1-2	<1-2
MD	<3-4	<1-5	<1-1	<1	<1-3
NB	<3-12	<1-18	<1-5	<1-26	<3-20
Total Kjeldahl Nitrogen					
NS	80-240	110-210	140-190	140-270	130-220
MD	100-230	<100-330	100-180	110-150	130-180
NB	80-270	130-340	100-180	100-210	230-260
Diss. Nitrite+Nitrate					
NS	<10	<3-20	<3	<3-9	<3-11
MD	<10	<3-50	<3-37	<3-9	<3-14
NB	<10-10	<3-53	28-120	<3-50	<10-18
Diss. Ammonia					
NS	<10-20	<10-30	<10-10	<10-10	<10-30
MD	<10-20	<10-20	<10-40	<10-10	<10-30
NB	<10-50	<10-160	<10-40	<10-20	<10-100

Total phosphorus. Over the 5 sampled years, concentrations of total phosphorus in the near-surface and mid-depth samples had a relatively narrow range, from <10 to 35 µg/L. Near-bottom concentrations ranged wider, from <10 to 76 µg/L. Both of the highest concentrations were measured in 2008. Total phosphorus concentrations at the two upper sampled depths were often below detection until enriched hypolimnetic water mixed into the upper water column during the late summer and autumn. The highest concentrations in each year were measured near the bottom prior to full-depth convective mixing.

Dissolved orthophosphate. Near-surface and mid-depth concentrations of dissolved orthophosphate were at or below their detection limits for most samples. The peak concentration for those two depths was 5 µg/L, which was measured in 2008. Near-bottom concentrations were also often below detection; however, a peak concentration of 26 µg/L was measured in 2010. The elevated near-bottom concentrations occurred in late summer and autumn prior to full-depth convective circulation.

***Total Kjeldahl nitrogen*.** The overall concentration range for total Kjeldahl nitrogen for the 5 sampled years was 80 to 340 µg/L. Concentration differences among the three sampled depths were more muted than those for the phosphorus concentrations just discussed. The minimum concentration was measured in 2007 in both near-surface and near-bottom samples. The maximum concentration of 340 µg/L was measured near the bottom in 2008, but a mid-depth sample of the same year was nearly the same, 330 µg/L.

Dissolved nitrite plus nitrate. Similar to dissolved orthophosphate, concentrations of dissolved nitrite plus nitrate were often at or below detection in near-surface and mid-depth samples. However, mid-depth samples did reach concentrations between 37 and 50 µg/L in early summer of 2008 and 2009, likely as a result of interflow of Trail Creek snowmelt runoff, which was enriched with nitrite plus nitrate resultant from forest fires. Near-bottom concentrations of dissolved nitrite plus nitrate became enriched due to hypolimnetic decomposition processes over the summer and autumn. Concentrations as high as 120 µg/L were reached in 2009.

***Dissolved ammonia*.** The majority of dissolved ammonia concentrations were at or below the detection limit of 10 µg/L at the three sampled depths. Concentrations as high as 40 µg/L were measured in near-surface and mid-depth samples as a result of water-column circulation in the autumn. The near-bottom sample in early October of 2008 had the peak concentration of dissolved ammonia, 160 µg/L.

Reservoir Chlorophyll *a* and Phytoplankton

Chlorophyll *a*

The following discussion of chlorophyll *a* concentrations pertains to DEA010 in that it was the most consistently sampled reservoir station. A summary of chlorophyll *a* concentrations for near-surface and fluorescence-maxima samples at DEA010 is presented in Table 2-11.

Table 2-11. Statistical comparison of chlorophyll *a* concentrations, in µg/L, from near-surface (NS) and fluorescence maxima (FM) samples at reservoir station DEA010 during water years 2007-2011, Deadwood Reservoir.

Year	Depth Zone	Number of Sample	Minimum	Maximum	Median
2007	NS	23	0.6	9.5	2.4
	FM	0			
2008	NS	5	<3	2.2	1.5
	FM	5	<3	15.9	6
2009	NS	4	<2.7	4.2	<2.7
	FM	4	2	8.8	7.1
2010	NS	6	1.5	7.1	4.1
	FM	1	9.2	9.2	9.2
2011	NS	4	1.9	8.1	3.6
	FM	3	2.8	16.2	8.1

Chlorophyll *a* concentrations were sampled only at the 1-m depth during 2007; concentrations ranged from 0.6 µg/L (mid-May) to 9.5 µg/L (early October). Chlorophyll *a* was relatively uniform over much of the summer and then began to increase from mid-September until early October. The autumn increase was attributable to two circulation-related processes; movement of nutrient-enriched hypolimnetic water into the surface layer and mixing of the enriched chlorophyll layer from near the thermocline. The enriched chlorophyll near the thermocline was indicated by supersaturated DO concentrations and spikes in fluorescence (a surrogate measure for chlorophyll). The 2007 protocol for collection of chlorophyll *a* samples only at the 1-m depth did not quantify the chlorophyll *a* layer near the thermocline that had been indicated by the combination of elevated fluorescence, supersaturation of DO, and high pH.

The 2008 sampling program collected chlorophyll *a* samples at both the 1-m depth and at the depth of maximum fluorescence. The analytical results were very instructive in that, on average, the chlorophyll *a* concentrations at the 1-m depth were only about one-third of those measured at the fluorescence maxima. The ranges in chlorophyll *a* concentrations at the two depths were as follows: <3 to 2.2 µg/L at the 1-m depth and <3 to 15.9 µg/L at the fluorescence maxima. The minimum concentrations were both sampled in early October; the 1-m depth maximum was sampled in early June whereas the 15.9 µg/L concentration was sampled in late August. Note that the concentration of the 1-m sample that was associated with the 15.9 µg/L concentration was only 2.1 µg/L.

Chlorophyll *a* samples taken in 2009 at the 1-m depth ranged in concentration from <2.7 µg/L (mid-July) to 4.2 µg/L (mid-August). Four deep samples were obtained in 2009 at DEA010; their concentrations ranged from 2 to 8.8 µg/L. The two mid-August samples had the maximum concentrations.

In 2010, chlorophyll *a* samples at the 1-m depth ranged from 1.5 µg/L (early August) to 7.1 µg/L (late September). Only one sample was obtained at the fluorescence maxima, during early August. That sample's chlorophyll *a* concentration was 9.2 µg/L whereas its associated near-surface sample was only 1.5 µg/L.

The 2011 results for chlorophyll sampling included 4 samples at the 1-m depth and 3 at the fluorescence maxima. The former ranged from 1.9 µg/L (early July) to 8.1 µg/L (mid-September), whereas the latter ranged from 2.8 µg/L (mid-October) to 16.2 µg/L (mid-August). The largest fluorescence-maxima sample of mid-August was associated with a 1-m sample concentration of 4 µg/L.

Among the 5 sampled years, the median concentrations of chlorophyll *a* (Table 2-11) at the 1-m depth of reservoir station DEA010 ranged from 1.5 µg/L (2008) to 4.1 µg/L (2010). Median concentrations at the fluorescence maxima were larger and ranged from 6 µg/L (2008) to 9.2 µg/L (2010). That 2010 sample was obtained in early August and was the only fluorescence maxima sample of that year.

Phytoplankton

Phytoplankton samples were collected from the upper water column of the five primary reservoir stations on six occasions in 2008 (mid-July to early September) and nine times in 2009 (mid-June to late September). Based on all the measurements (15 sampling dates and 5 stations), the community was dominated by the filamentous *cyanobacteria Anabaena spiroides*, which constituted 48% of the biovolume (Table 2-12). The large, motile dinoflagellate *Ceratium hirundinella* contributed 23%; several diatom species of the genus *Fragilaria* contributed 11%. Summing across groups, those contributing more than 5% of the biovolume were cyanobacteria (51%), dinoflagellates (24%), diatoms (15%), and cryptophytes (8%). Note, however, that the main dinoflagellate species *Ceratium hirundinella* was present in only 10% of samples, thus the biovolume associated with this species was highly skewed to only a few, highly abundant, measurements.

Table 2-12. Dominant phytoplankton from 2008–2009 samples, Deadwood Reservoir. [Percent biovolume is summed across the 15 sampling dates and 5 stations. Percent occurrence is percentage of samples in which that particular species occurred.]

Name	Group	percent biovolume	Percent occurrence
Anabaena spiroides	Cyanobacteria	47.92%	100%
Ceratium hirundinella	Dinoflagellate	23.18%	10%
Fragilaria sp.	Diatom	10.51%	74%
Cryptomonas sp.	Cryptophyte	3.92%	93%
Ochromonas sp.	Cryptophyte	3.53%	17%
Aphanothece clathrata	Cyanobacteria	2.67%	48%
Synedra sp.	Diatom	2.20%	41%
Asterionella sp.	Diatom	2.03%	66%
Sphaerocystis sp.	Chlorophyte	1.27%	5%
Gymnodinium sp. (small)	Dinoflagellate	0.83%	33%
Rhodomonas lacustris var. nannoplanctica	Cryptophyte	0.36%	90%
Synura sp.	Chrysophyte	0.25%	2%
Phormidium sp.	Cyanobacteria	0.23%	43%
Rhodomonas sp.	Cryptophyte	0.20%	24%

Spatial Comparability among Reservoir Sampling Stations

Much of the foregoing presentation of the results of reservoir sampling during 2007–2011 focused on reservoir station DEA010 for a number of reasons. Of the five primary reservoir stations, DEA010 was sampled most frequently, it was the deepest station, it was adjacent to the LDS, and it was closest to Deadwood Dam's deep release structures and spillway. Three of the reservoir stations (DEA006, DEA004, and DEA010) were located along the eastern side of the reservoir, which contained the thalwag of the pre-impoundment Deadwood River; the other two stations (DEA014, DEA016) were located along the western side of the reservoir (earlier Figure 2-51). The spatial comparability among the five stations for selected limnological variables was assessed with a series of water-column profiles and a table of constituent concentrations for near-surface and near-bottom water-quality samples.

The spatial comparability of water-temperature profiles among the five stations for late July 2007, mid-August 2009, and mid-September 2011 was quite good (Figure 2-56, Figure 2-57, and Figure 2-58). The July and August profiles were taken during well-established thermal stratification and indicate very similar depths of maximum temperature change within the metalimnion. The September profiles show weakened thermal stratification at the five stations; the shallowest, DEA006, had undergone more extensive convective circulation.

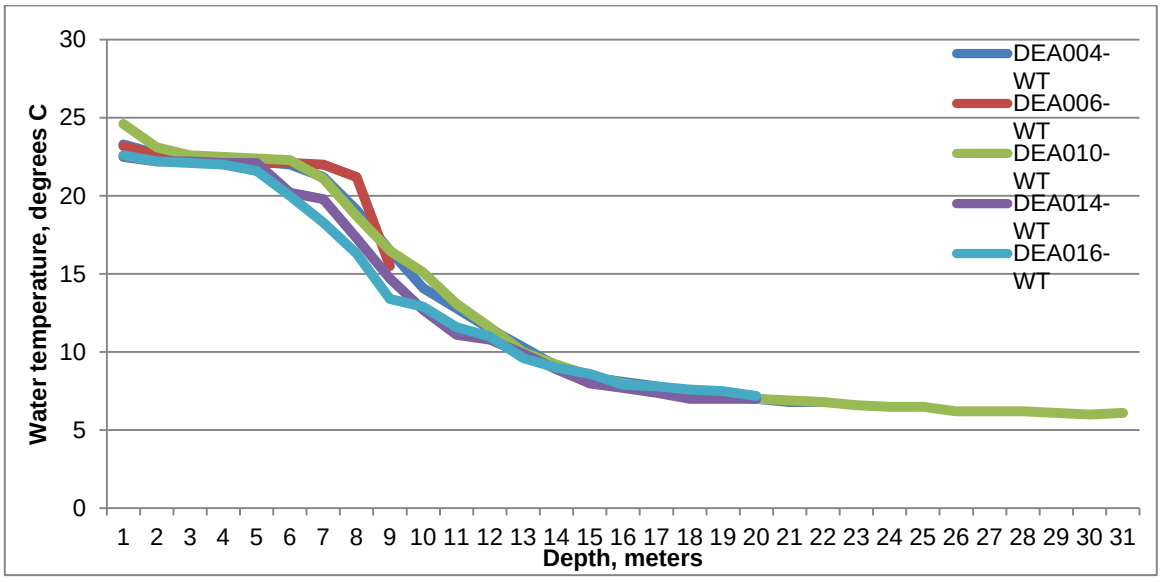


Figure 2-56. Spatial comparability of water-temperature (WT) profiles, in degrees Celsius, over the full depths, in meters, of the five primary reservoir stations for July 30, 2007, Deadwood Reservoir.

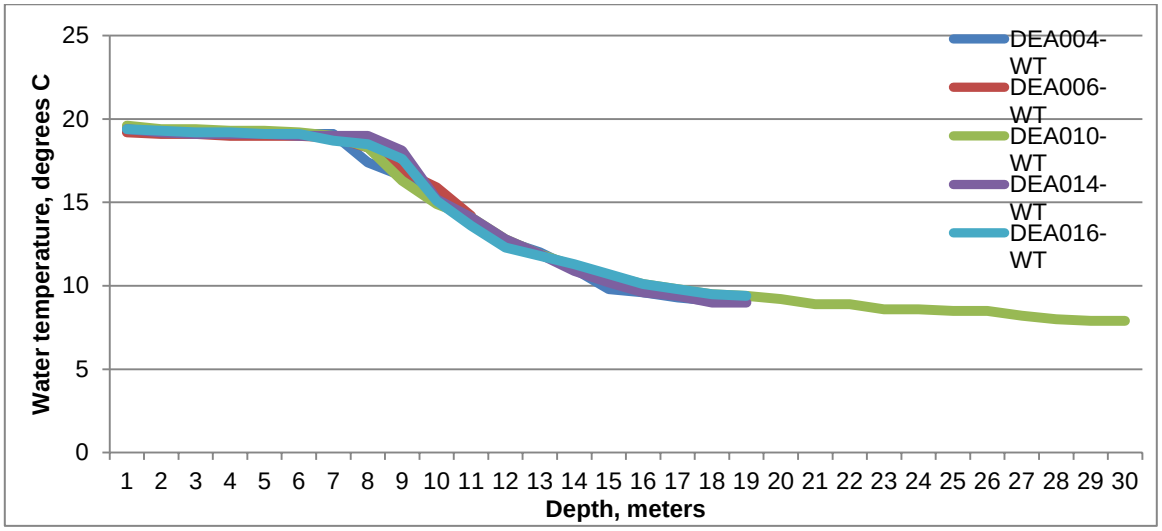


Figure 2-57. Spatial comparability of water-temperature (WT) profiles, in degrees Celsius, over the full depths, in meters, of the five primary reservoir stations for August 17, 2009, Deadwood Reservoir.

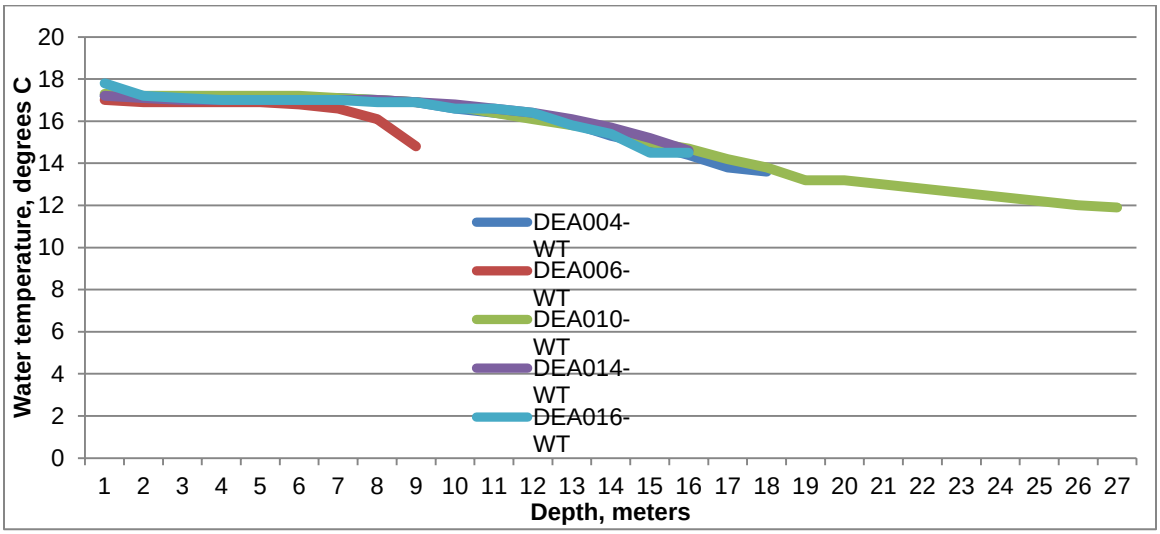


Figure 2-58. Spatial comparability of water-temperature (WT) profiles, in degrees Celsius, over the full depths, in meters, of the five primary reservoir stations for September 19, 2011, Deadwood Reservoir.

The spatial comparability of DO concentration profiles among the five stations for the three sampling dates was more variable than for water-temperature profiles (Figure 2-59, Figure 2-60, and Figure 2-61). Except for DEA006, the late July profiles in 2007 exhibited metalimnetic DO surges to about 12 mg/L and depletion of hypolimnetic DO down to between 4 and 5 mg/L (Figure 2-59). The profiles for mid-August 2009 (Figure 2-60) had similar patterns to those for July 2007. Again, the DO profile for DEA006 had no metalimnetic surge or substantial hypolimnetic depletion. Hypolimnetic DO concentrations at the four deeper stations ranged from 4 to 5 mg/L. The mid-September 2011 profiles were more variable, probably in response to weakened thermal stratification (Figure 2-61). Station DEA006 had convectively mixed, as indicated by uniform DO concentrations over its full depth. The previously measured metalimnetic surges of DO were absent from the five stations. Two stations, one on the reservoir's western side (DEA014) and the other on the eastern side (DEA004), exhibited rapid declines in hypolimnetic DO; their near-bottom DO concentrations were down to about 2.5 to 3 mg/L. The hypolimnetic decline in DO at the deepest station, DEA010, was more gradual than at DEA014 and DEA004, but its near-bottom DO concentration was comparable to theirs. The remaining station, DEA016, had undergone some convective circulation as evidenced by partial reaeration of its near-bottom DO concentration. Both DEA010 and DEA016 were located closest to Deadwood Dam's deep outlet structure which, until early September, had been releasing hypolimnetic water during reservoir drawdown; that process had likely drafted cold hypolimnetic water from these two reservoir stations.

An important observation about hypolimnetic DO concentrations is their similarity among the four deeper reservoir stations. Even though DEA010 was at least 10 m deeper than DEA004,

DEA014, and DEA016, all had similar DO depletion within several meters of their bottom sediments. That comparability indicates that sediment oxygen demand was the primary mechanism for hypolimnetic DO depletion and that it was operational throughout much of the reservoir's deeper regions.

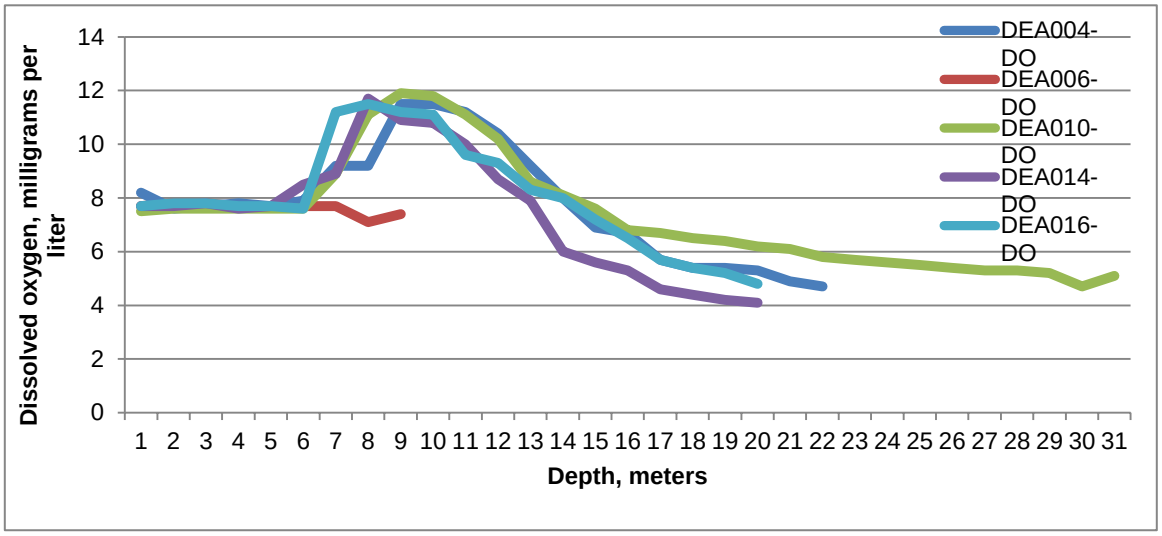


Figure 2-59. Spatial comparability of DO concentration profiles, in milligrams per liter, over the full depths, in meters, of the five primary reservoir stations for July 30, 2007, Deadwood Reservoir.

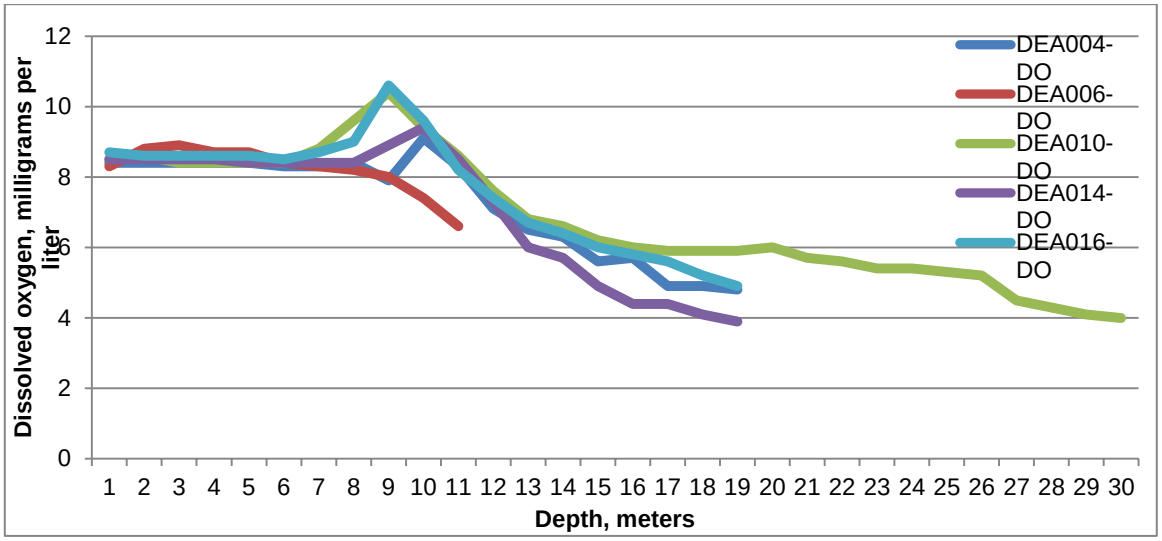


Figure 2-60. Spatial comparability of DO concentration profiles, in milligrams per liter, over the full depths, in meters, of the five primary reservoir stations for August 17, 2009, Deadwood Reservoir.

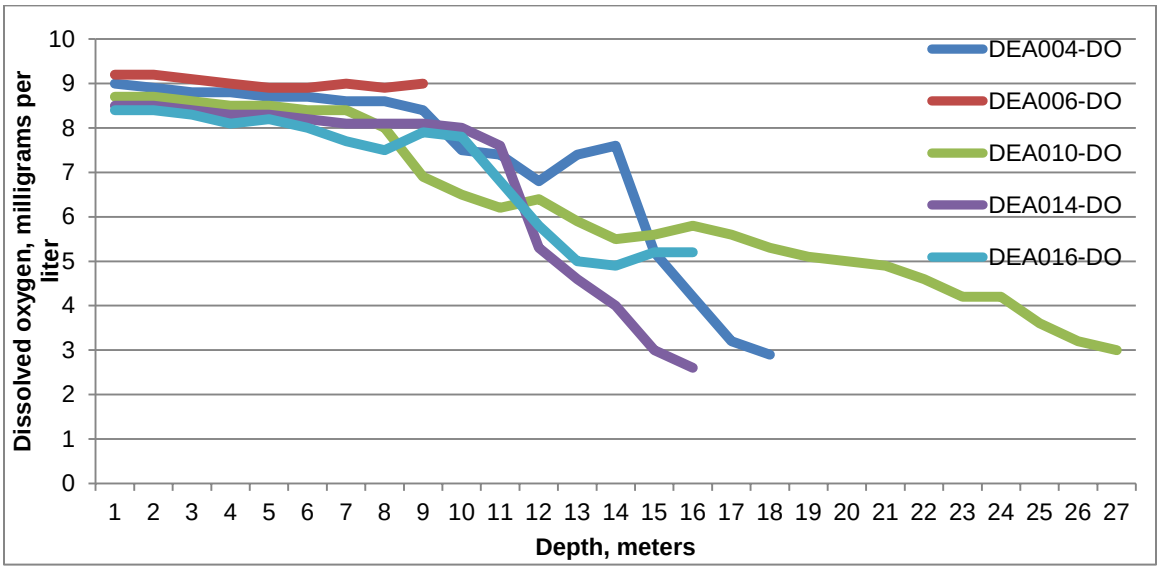


Figure 2-61. Spatial comparability of DO concentration profiles, in milligrams per liter, over the full depths, in meters, of the five primary reservoir stations for September 19, 2011, Deadwood Reservoir.

The spatial comparability of concentrations of two nutrients and chlorophyll *a* in near-surface samples was assessed for four sampling dates (Table 2-13). Near-surface concentrations of chlorophyll *a* were comparable among the five stations on each of the sampling dates. Near-surface samples of total phosphorus and dissolved nitrite plus nitrate were very similar in concentration among the five reservoir stations on each sampling date, except in one instance. On July 14, 2008, reservoir station DEA014 had a total phosphorus concentration between 2 and 6 times higher than the other four stations. A possible explanation may relate to time-lagged watershed inputs from a large forest fire that impacted the southern and western portions of the reservoir's watershed during 2006. Total-phosphorus samples during July of 2008 from Trail Creek (DEA104), which was nearly enveloped by the 2006 fire, were about equal to the concentration measured at DEA014 on July 14.

Near-bottom samples of total phosphorus and dissolved nitrite plus nitrate were less comparable among the five reservoir stations than were their near-surface concentrations (Table 2-13). The higher variability may be due, in part, to the fact that reservoir station DEA006 is much shallower than the other four and is closest in proximity to the influent Deadwood River. Thus, DEA006 is more prone to convective circulation, which reduces its propensity to suffer hypolimnetic DO depletion and consequent increases in hypolimnetic nutrient concentrations. Among the four deeper stations, near-bottom dissolved nitrite plus nitrate concentrations were less variable than those for total phosphorus.

Table 2-13. Spatial comparability of nutrient and chlorophyll *a* concentrations, in µg/L, measured for near-surface (NS) and near-bottom (NB) samples on four dates (July 14, 2008; August 12, 2009; July 1, 2010; and September 19, 2011) at the five primary reservoir stations, Deadwood Reservoir. [TP is total phosphorus, DN+N is dissolved nitrite plus nitrate]

Date and Water-Quality Variable	DEA004	DEA006	DEA010	DEA014	DEA016
7/14/2008 Concentrations, µg/L					
TP, NS	20	25	<10	61	34
TP, NB	27	18	39	52	34
DN+N, NS	<3	<3	<3	<3	<3
DN+N, NB	30	6	34	38	46
Chlorophyll *a*, 1-meter	2.3	2.1	2.1	1.9	1.9
8/12/2009 Concentrations, µg/L					
TP, NS	16	12	15	16	14
TP, NB	19	19	22	22	15
DN+N, NS	<3	<3	<3	<3	<3
DN+N, NB	20	<3	39	34	25
Chlorophyll *a*, 1-meter	3.5	2.7	4.2	3	3.4
7/1/2010 Concentrations, µg/L					
TP, NS	14	<10	10	<10	11
TP, NB	<10	12	56	<10	<10
DN+N, NS	14	10	9	9	9
DN+N, NB	10	11	10	14	12
Chlorophyll *a*, 1-meter	1.9	3	5.1	2.7	2.5
9/19/2011 Concentrations, µg/L					
TP, NS	20	20	19	18	18
TP, NB	40	18	53	54	26
DN+N, NS	8	8	7	5	5
DN+N, NB	9	8	10	7	6
Chlorophyll *a*, 1-meter	10.2	10.2	8.1	8.9	7.9

2.2.5 Hydrologic and Nutrient Budgets, 2007 – 2010

Hydrologic Budgets

Hydrologic budgets for Deadwood Reservoir for 2007–2010 are listed in Table 2-14. The largest total inflow, 244 million m^3 (197,800 acre-feet), was in 2008; the smallest, 171.8 million m^3 (139,300 acre-feet), was in 2007. Inflows in each of the 4 years were dominated by the Deadwood River (gaged station DEA102). Ungaged inflows accounted for about a third of total inflow in each year; whereas the other gaged inflow, Trail Creek (DEA104), accounted for about 10% of total inflow. Direct precipitation to the reservoir surface was the smallest inflow component, at 2.5% or less. More than 95% of total outflow was discharge through

Deadwood Dam, which was measured at the gaged station DEA101, Deadwood River. Evaporation from the reservoir surface accounted for less than 5% of total outflow.

When the difference between total inflow and total outflow is adjusted for change in storage over a water year the resulting residual can be used to assess the reasonableness of the hydrologic budget. The residuals for 2007-2009 represented 3.6%, or less, of total inflow. In 2010 the residual was 11.8% of the total inflow of 229.5 million m^3 (186,100 acre-feet). As such, the hydrologic budgets for 2007-2009 are very reasonable; the one for 2010 is reasonable.

Table 2-14. Hydrologic budgets for water years 2007-2010, Deadwood Reservoir. [Volumes in million cubic meters; percent of total inflow or total outflow].

Budget Components	2007	2008	2009	2010
	Volume (Percent of Total)	Volume (Percent of Total)	Volume (Percent of Total)	Volume (Percent of Total)
INFLOW				
Deadwood River	97.5 (56.8)	146.4 (60.0)	114.4 (53.6)	126.3 (55.0)
Trail Creek	15.0 (8.7)	18.1 (7.4)	21.7 (10.2)	21.9 (9.5)
Ungaged inflows	55.1 (32.1)	74.4 (30.5)	72.0 (33.7)	75.8 (33.0)
Precipitation	4.2 (2.4)	5.1 (2.1)	5.3 (2.5)	5.5 (2.5)
OUTFLOW				
Deadwood River	201.0 (96.3)	202.0 (96.0)	180.0 (95.6)	187.0 (95.3)
Evaporation	7.8 (3.7)	8.3 (4.0)	8.3 (4.4)	9.3 (4.7)
SUMMARY				
Total inflow	171.8	244	213.4	229.5
Total outflow	208.8	210.3	188.3	196.3
Change in storage	-39.4	24.8	17.5	6.1
Residual	2.4	8.9	7.6	27.1

Nutrient Budgets

Nutrient budgets for total phosphorus, dissolved orthophosphate, total organic nitrogen, and dissolved inorganic nitrogen are listed for Deadwood Reservoir in Table 2-15 through Table 2-18, respectively, for 2007–2010. Over the 4 years, the largest nutrient input to the reservoir was 31,450 kilograms (kg) of total organic nitrogen in 2008; the smallest nutrient input was 1,021 kg of dissolved orthophosphate in 2009.

Total Phosphorus

The input of total phosphorus to Deadwood Reservoir (Table 2-15) was dominated by the Deadwood River, which accounted for between 48.3 and 71.8% of the total. The next largest

input, between 17 and 34.9%, was from ungaged inflows. The combination of the remaining two inputs, Trail Creek and atmospheric deposition, accounted for between 11.2 and 18.1% of the total.

The largest input of total phosphorus (5,869 kg) was in 2008; the smallest input of 4,272 kg occurred in 2009. The largest outflow of total phosphorus (4,358 kg) also occurred in 2008, but 2010 had the smallest outflow at 2,658 kg. The residuals for each year's total phosphorus budget were positive and ranged from 356 to 1,756 kg. The positive residuals indicate that the reservoir retained more total phosphorus than it released via Deadwood Dam. These retentions, calculated as residual divided by total inflow, ranged from about 8% in 2009 to about 39% in 2010.

Table 2-15. Total phosphorus budgets for water years 2007-2010, Deadwood Reservoir. [Mass in kilograms; percent of total inflow].

Budget Components	2007	2008	2009	2010
	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)
INFLOW				
Deadwood River	2,136 (48.3)	4,216 (71.8)	2,649 (62.0)	2,899 (64.6)
Trail Creek	511 (11.6)	433 (7.4)	513 (12.0)	469 (10.4)
Ungaged inflows	1,542 (34.9)	1,000 (17.0)	850 (19.9)	840 (18.7)
Atmos. Deposition	230 (5.2)	220 (3.8)	260 (6.1)	280 (6.3)
OUTFLOW				
Deadwood River	3,410	4,358	3,653	2,658
SUMMARY				
Total inflow	4,418	5,869	4,272	4,488
Total outflow	3,410	4,358	3,653	2,658
Change in storage	-394	495	263	74
Residual	1,402	1,016	356	1,756
(Res./Inflow) x 100	31.7	17.3	8.3	39.1

Dissolved Orthophosphate

Inputs of dissolved orthophosphate to Deadwood Reservoir (Table 2-16) were much smaller than those for total phosphorus. As with total phosphorus, the Deadwood River was the dominant contributor of dissolved orthophosphate in each of the 4 years; inputs ranged from 48.7 to 61% of total inputs. Ungaged inputs were the second largest source of dissolved orthophosphate for the reservoir and ranged in percentage contribution from 22.8 to 36.7%. Trail Creek contributed a larger percentage of dissolved orthophosphate (12.6 to 21.2%) than it did of total phosphorus (7.4 to 12%). Atmospheric deposition to the reservoir surface was less than 3% of total inputs.

The largest input of dissolved orthophosphate occurred in 2007 (1,280 kg); the smallest (1,021) in 2009. Outflows of dissolved orthophosphate through Deadwood Dam ranged from 467 kg in 2008 to 749 kg in 2009. As with total phosphorus, the residuals for dissolved orthophosphate were positive in each of the 4 years, indicative of retention by Deadwood Reservoir. Retention of dissolved orthophosphate ranged from about 25% in 2009 to about 60% in 2008.

Table 2-16. Dissolved orthophosphate budgets for water years 2007-2010, Deadwood Reservoir. [Mass in kilograms, percent of total inflow]

Budget Components	2007	2008	2009	2010
	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)
INFLOW				
Deadwood River	623 (48.7)	757 (61.0)	506 (49.6)	552 (50.8)
Trail Creek	161 (12.6)	183 (14.8)	216 (21.2)	223 (20.5)
Ungaged inflows	470 (36.7)	275 (22.8)	270 (26.4)	280 (25.8)
Atmos. Deposition	26 (2.0)	25 (1.4)	29 (2.8)	31 (2.9)
OUTFLOW				
Deadwood River	614	467	749	620
SUMMARY				
Total inflow	1,280	1,240	1,021	1,086
Total outflow	614	467	749	620
Change in storage	-39	25	18	12
Residual	705	748	254	454
(Res./Inflow) x 100	55.1	60.3	24.9	41.8

Total Organic Nitrogen

The Deadwood River delivered between 52.2 and 72.7% of the reservoir's input of total organic nitrogen; the largest mass, 22,870 kg, was delivered in 2008 (Table 2-17). Of the total input of total organic nitrogen, ungaged inflows delivered between 15.9 and 30.4% whereas Trail Creek delivered between 6.1 and 12.6%. Atmospheric deposition of total organic nitrogen represented between 5.3 and 8.8% of the total input.

Among the 4 years the largest input of total organic nitrogen was 31,450 kg in 2008; the smallest was 20,020 kg in 2007. Annual outputs of total organic nitrogen ranged from 25,440 kg (2007) to 35,540 kg (2008). Unlike total phosphorus and dissolved orthophosphate, more total organic nitrogen was released through Deadwood Dam than was received by the reservoir, especially in 2008 and 2009. Negative residuals occurred in 2008 and 2009; these indicated the reservoir discharged about 126% of what it received in total organic nitrogen. Comparable masses of total organic nitrogen were received and discharged in 2007 and 2010.

Table 2-17. Total organic nitrogen budgets for water years 2007-2010, Deadwood Reservoir (mass in kilograms, percent of total Inflow).

Budget Components	2007	2008	2009	2010
	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)
INFLOW				
Deadwood River	10,450 (52.2)	22,870 (72.7)	15,870 (64.0)	15,660 (59.6)
Trail Creek	1,714 (8.6)	1,921 (6.1)	2,457 (9.9)	3,315 (12.6)
Ungaged inflows	6,093 (30.4)	5,000 (15.9)	4,500 (18.2)	5,200 (20.0)
Atmos. Deposition	1,730 (8.8)	1,650 (5.3)	1,960 (7.9)	2,050 (7.8)
OUTFLOW				
Deadwood River	25,440	35,540	29,000	26,110
SUMMARY				
Total inflow	20,020	31,450	24,790	26,280
Total outflow	25,440	35,540	29,000	26,110
Change in storage	-5,516	4,211	2,453	952
Residual	94	-8,302	-6,665	-777
(Res./Inflow) x 100	0.5	-26.4	-26.9	-3

Dissolved Inorganic Nitrogen

The dominance of the Deadwood River as a nutrient source was amended by dissolved inorganic nitrogen inputs to the reservoir. In 2007 and 2009, ungaged inflows delivered a larger percentage of dissolved inorganic nitrogen than did the Deadwood River (Table 2-18); however, the Deadwood River was the dominant source in 2008 and 2010. The combination of the two sources accounted for between 53.1 and 64.8% of dissolved inorganic nitrogen inputs to the reservoir. The percentage contributions of dissolved inorganic nitrogen from Trail Creek were larger than its contributions for the other three nutrients; Trail Creek's contributions ranged from 14.5 to 30.5%. Atmospheric deposition of dissolved inorganic nitrogen also was a larger contributor, ranging from 13.5 to 20.7%.

The largest input of dissolved organic nitrogen to the reservoir was 7,500 kg in 2010, whereas the smallest was 4,111 kg in 2007. The largest discharge of dissolved inorganic nitrogen (12,260 kg) was in 2009; the following year had the smallest (5,760 kg). The residuals for 2007-2009 were negative and indicated substantial releases of dissolved inorganic nitrogen in relation to inputs. In particular, 2009 released more than twice the dissolved inorganic nitrogen that it received. With its positive residual, 2010 was the exception; it retained about 21% of the dissolved inorganic nitrogen it received.

Table 2-18. Dissolved inorganic nitrogen budgets for water years 2007-2010, Deadwood Reservoir (mass in kilograms, percent of total inflow).

Budget Components	2007	2008	2009	2010
	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)	Mass (Percent of Total)
INFLOW				
Deadwood River	1,222 (29.7)	1,629 (30.7)	1,278 (21.8)	2,720 (36.2)
Trail Creek	596 (14.5)	1,361 (25.7)	1,782 (30.5)	1,764 (23.5)
Ungaged inflows	1,443 (35.1)	1,500 (28.3)	1,830 (31.3)	2,010 (26.8)
Atmos. Deposition	850 (20.7)	810 (15.3)	960 (16.4)	1,010 (13.5)
OUTFLOW				
Deadwood River	7,022	8,176	12,620	5,760
SUMMARY				
Total inflow	4,111	5,300	5,850	7,500
Total outflow	7,022	8,176	12,620	5,760
Change in storage	-1,182	619	1,050	135
Residual	-1,729	-3,495	-7,820	1,610
(Res./Inflow) x 100	-42.1	-65.9	-103.4	21.4

Fate and Transport of Nutrient Loads

The fuel for Deadwood Reservoir's biological productivity emanated primarily from nutrients transported into Deadwood Reservoir from its watershed and airspace. During 2007-2010, large differences in the magnitudes of inflow and outflow nutrient loads were quantified with the FLUX model (Table 2-15 through Table 2-18). Within the Summary sections of these four tables are three important quantities: change in storage, residual, and the percentage the residual was of total inflow. The variations in Deadwood Reservoir's retention or discharge (positive or negative residuals) of phosphorus and nitrogen compounds were indicative of numerous watershed and limnological processes. Some of these variations were due to nutrients generated within the reservoir (autochthonous), instead of those delivered to the reservoir from its watershed (allochthonous). These processes, and their effects upon nutrient retention, had important relations to the reservoir's cyclic interaction of nutrients, productivity, and DO dynamics.

Nutrient loads, inflow. The annual magnitudes and ranks of influent nutrient loads and associated streamflows are listed in Table 2-19. Annual differences in volume of streamflow delivered from the reservoir's watershed largely account for the differences in nutrient inflows. That is especially true with regard to nutrients associated with abiotic or biotic materials, which tend to be positively correlated with streamflow. In contrast, dissolved nutrients generally have a negative correlation with streamflow because of the dilutional nature of

snowmelt runoff. As listed in Table 2-19, the ranks of streamflow magnitude over the 4 years agreed well with the ranks of inflow loads of total phosphorus and total organic nitrogen; six of the eight comparisons were of equal rank. The ranks of the two dissolved nutrients, orthophosphate and inorganic nitrogen, were more variable; only one of the eight comparisons were of equal rank.

Table 2-19. Quantities and ranks of water volumes and nutrient loading masses for inflow and outflow during water years 2007-2010, Deadwood Reservoir. [Volume in million cubic meters; mass in kilograms; TP is total phosphorus; DOP is dissolved orthophosphate; TON is total organic nitrogen; DIN is dissolved inorganic nitrogen; rank 1 is lowest value, rank 4 is highest].

Variable	2007	2008	2009	2010
INFLOW				
Volume--Rank	172--1	244--4	213--2	230--3
TP Mass--Rank	4,420--2	5,870--4	4,270--1	4,490--3
DOP Mass--Rank	1,280--4	1,240--3	1,020--1	1,090--2
TON Mass--Rank	20,000--1	31,400--4	24,800--2	26,300--3
DIN Mass--Rank	4,110--1	5,300--2	5,850--3	7,500--4
OUTFLOW				
Volume--Rank	209--3	210--4	188--1	196--2
TP Mass--Rank	3,410--2	4,360--4	3,650--3	2,660--1
DOP Mass--Rank	614--2	467--1	749--4	620--3
TON Mass--Rank	25,400--1	35,500--4	29,000--3	26,100--2
DIN Mass--Rank	7,020--2	8,180--3	12,600--4	5,760--1

Part of the variability in influent nutrient loading, especially those for the two dissolved nutrients, can be accounted for with watershed processes other than streamflow. Several large forest fires occurred within or near the reservoir's watershed in 2006 and 2007. The Rattlesnake Fire of 2006 started in mid-August and was finally suppressed in early November. That fire burned much of the watershed west and south of Deadwood Reservoir, especially in the vicinity of Trail Creek. The following year the Monumental Fire began in mid-July and was suppressed in late September. That fire burned in the upper watershed of the Deadwood River north of the reservoir. Two smaller fires, the Lucky Fire and the Lightning Fire, burned near Trail Creek's watershed in 2007.

A well-documented effect of forest fires has been the increase in nutrient loads delivered to receiving waters such as streams, lakes, and reservoirs (Tiedemann et al. 1979). Fires can affect a watershed's nutrient balance in four principal ways: removal of nutrients (loss of vegetation), redistribution of nutrients as ash, temporary disruption of normal nutrient cycling processes, and increased flow of water and nutrients to the soil mantle. Combustion renders nitrogen and phosphorus compounds contained in vegetation more available for transport to receiving waters via various pathways; however, nitrogen transport is generally larger than for

phosphorus because of the adsorption of phosphorus to soil particles. Several processes enhance the transport of nitrogen to receiving waters. Nitrogen in redeposited ash is readily leachable and moves into the soil mantle where it can be transported as surface or subsurface runoff. A fire's destruction of vegetation reduces uptake of soil nitrogen and thus may increase runoff of nitrogen into receiving waters. An additional source of both nitrogen and phosphorus to receiving waters is that contained in the large amounts of fire retardant often used to suppress forest fires (Woods 1997).

Tributary water-quality samples from Deadwood Reservoir's two gaged tributaries, Deadwood River inflow (DEA102) and Trail Creek (DEA104) clearly indicated large increases in concentrations of dissolved inorganic nitrogen and smaller increases in dissolved orthophosphate during and following the Rattlesnake Fire of 2006 and the Monumental Fire of 2007 (Figure 2-62 and Figure 2-63). Trail Creek's dissolved inorganic nitrogen concentrations responded much more strongly to the two fires than did those in the Deadwood River inflow; additionally, the increased concentrations in Trail Creek lagged over several years after the two fires (Figure 2-62). The two largest concentrations of dissolved inorganic nitrogen, 203 and 254 µg/L, in Trail Creek were associated with the two largest snowmelt runoff peaks in 2008 and 2010. Likewise, the largest concentration in Deadwood River inflow, 116 µg/L, occurred with the 2010 snowmelt runoff peak. As expected, the increased concentrations of dissolved orthophosphate were less dramatic than those of nitrogen and did not lag as long (Figure 2-63). The large spike in dissolved orthophosphate in early October 2006 was associated with a concurrent spike in streamflow. As with nitrogen, the snowmelt peak of 2008 served to flush large amounts of dissolved orthophosphate out of Trail Creek and into Deadwood Reservoir. The fire-affected concentrations of dissolved inorganic nitrogen in Trail Creek were substantially larger than those in the Deadwood River inflow; however, the mass of this nutrient transported to Deadwood Reservoir from the Deadwood River was about 150% larger than from Trail Creek because of the larger volume of streamflow delivered by the Deadwood River inflow.

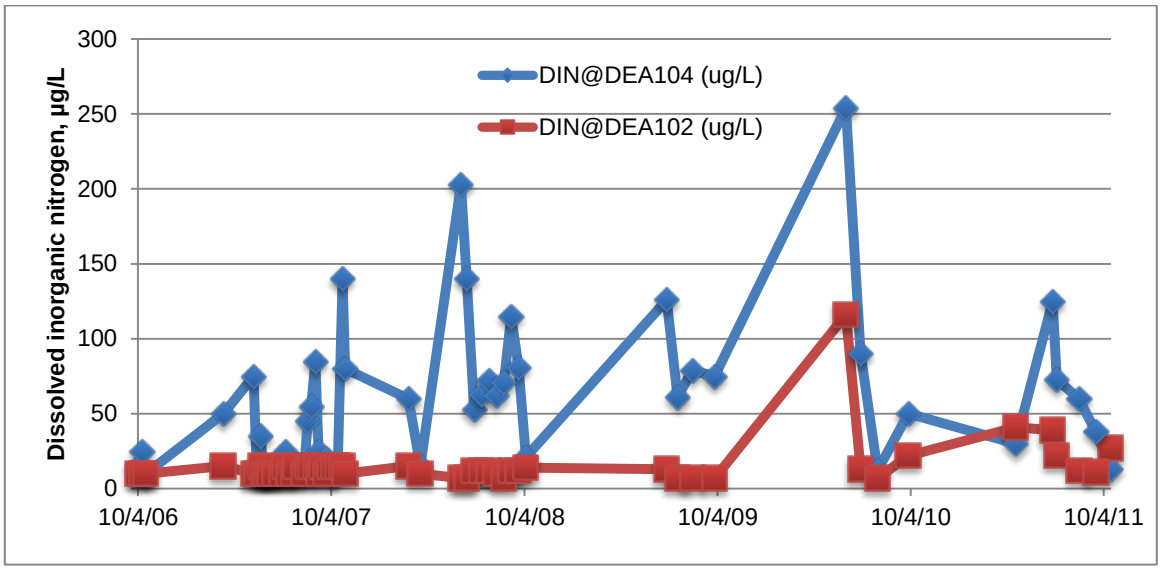


Figure 2-62. Concentrations of dissolved inorganic nitrogen (DIN), in µg/L, during water years 2007-2011 at two inflows: Deadwood River (DEA102) and Trail Creek (DEA104), Deadwood Reservoir.

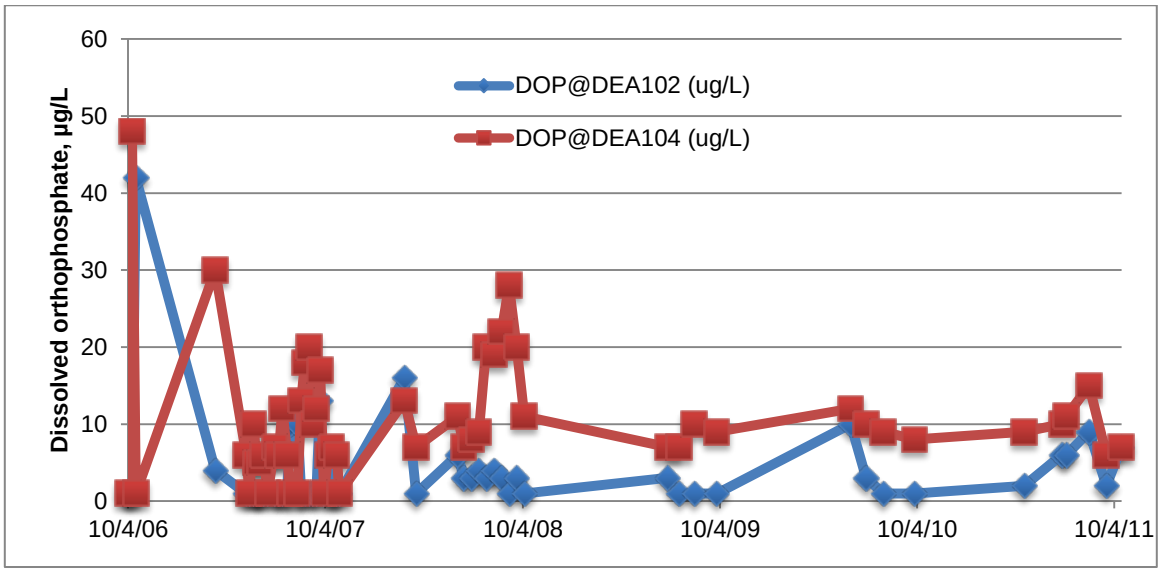


Figure 2-63. Concentrations of dissolved orthophosphate (DOP), in µg/L, during water years 2007-2011 at two inflows: Deadwood River (DEA102) and Trail Creek (DEA104), Deadwood Reservoir.

The water-quality impacts of the Rattlesnake and Monumental Fires on Deadwood Reservoir were similar to those experienced by Payette Lake, which is about 85 km northwest of Deadwood Reservoir. About one-half of Payette Lake's 373 km^2 watershed was burned in the autumn of 1994, just at the start of a 3-year limnological study of Payette Lake (Woods 1997). Woods had sufficient information to estimate a five-fold increase in dissolved inorganic

nitrogen transport from Payette Lake's watershed into Payette Lake; negligible changes were determined for dissolved orthophosphate. The mass of ash-derived dissolved inorganic nitrogen was two orders of magnitude larger than that attributable to fire retardant used to suppress the fires. The limnological study measured hypolimnetic concentrations of dissolved inorganic nitrogen; they were between two and four times larger than pre-fire concentrations. Importantly, the increased hypolimnetic concentrations persisted for about 4 years before they were finally flushed from Payette Lake.

Nutrient loads, outflow. The annual magnitudes and ranks of nutrient loads and associated streamflows discharged from Deadwood Reservoir are listed in Table 2.15. Unlike inflow loads, annual differences in volume of reservoir discharge were poorly correlated with nutrient outflows. The ranks of streamflow magnitude agreed with the ranks of outflow loads of total phosphorus and total organic nitrogen in only three of the eight comparisons. Ranks for dissolved orthophosphate and inorganic nitrogen loads were not correlated with ranks for reservoir discharge volume.

Outflow nutrient loads were poorly correlated with reservoir discharge volume because the masses of nutrients within the reservoir varied temporally under the influences of a variety of watershed-based (allochthonous) and within-reservoir (autochthonous) processes. Again, many of these processes were associated with the reservoir's cyclic interaction of nutrients, productivity, and DO dynamics.

One of the most significant processes that added nutrients to the reservoir was the decomposition and remineralization of organic matter within the reservoir's hypolimnion. As noted earlier in the discussion of the LDS data, the reservoir experienced lengthy periods of low hypolimnetic DO concentrations in the autumn and winter. The effects on nutrient recycling of adequate versus deficient hypolimnetic DO concentrations are illustrated in Figure 2-64 and Figure 2-65. Convective circulation in September 2007 reaerated the reservoir's hypolimnion from a low of 3.3 mg/L in early September to 8.2 mg/L by mid-October (Figure 2-64). The elevated concentrations of dissolved orthophosphate and inorganic nitrogen in the hypolimnion during early September were reduced substantially as reaeration progressed. The net effect was to reduce the mass of the two nutrients available for release from the reservoir. In contrast, the hypolimnetic mass of the two nutrients increased substantially from August to October 2011 as hypolimnetic DO concentrations declined to about 2.5 mg/L (Figure 2-65).

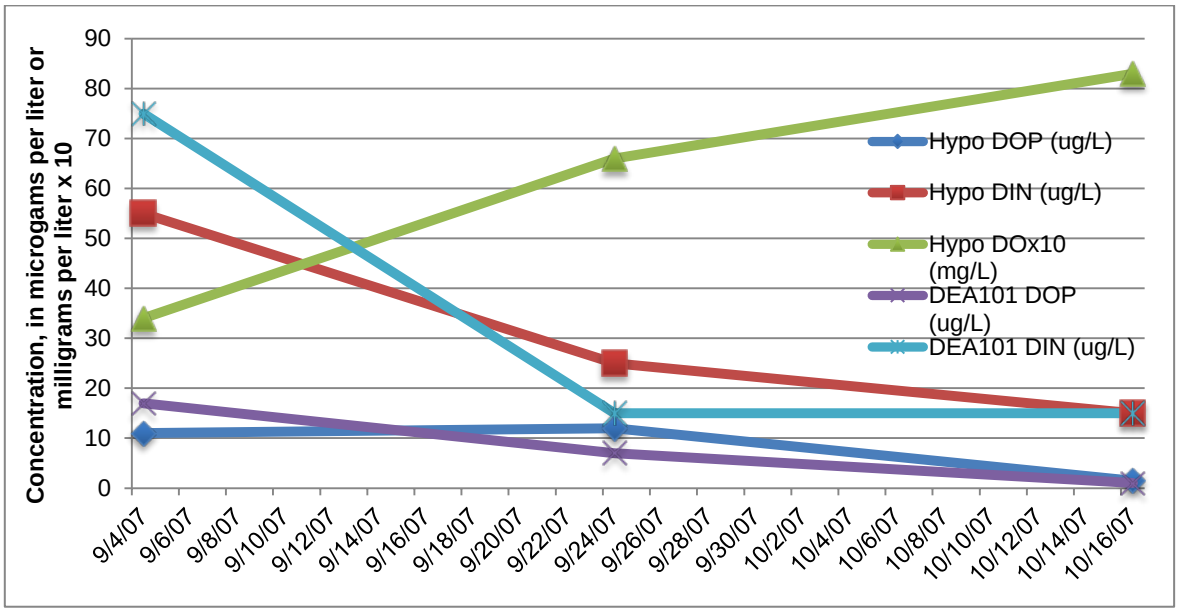


Figure 2-64. Comparison of concentrations, in µg/L, of dissolved orthophosphate (DOP) and dissolved inorganic nitrogen (DIN), and concentrations, in milligrams per liter x 10, of DO in hypolimnion (Hypo) of reservoir station DEA010 and reservoir outlet station DEA101 during early September to mid-October of 2007, Deadwood Reservoir.

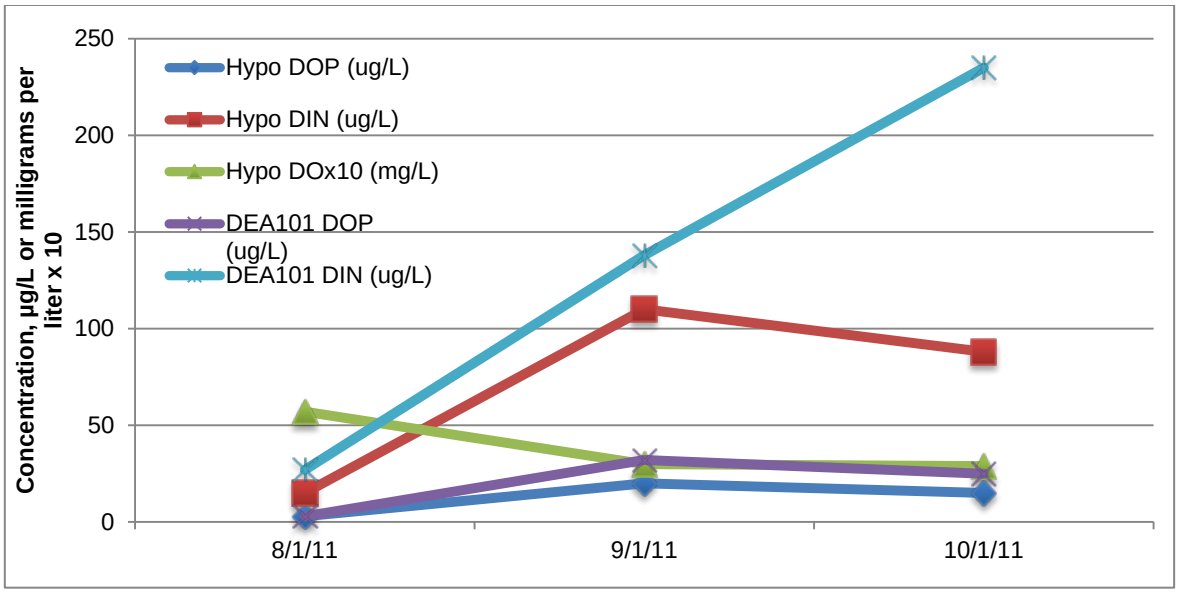


Figure 2-65. Comparison of concentrations, in µg/L, of dissolved orthophosphate (DOP) and dissolved inorganic nitrogen (DIN), and concentrations, in milligrams per liter x 10, of DO in hypolimnion (Hypo) of reservoir station DEA010 and reservoir outlet station DEA101 during early August to early October of 2011, Deadwood Reservoir.

The wintertime effects of hypolimnetic deoxygenation provided an important source of nutrients for the spring phytoplankton blooms that commenced with water-column circulation as winter ice-cover was lost from the reservoir. These effects were well-illustrated by water-quality samples taken in late February 2008 at reservoir station DEA010 and at the reservoir's outlet (DEA101). The February 27 reservoir samples were taken about mid-way through that winter's four months of deoxygenation. DO concentration near the reservoir bottom was 3.5 mg/L. Dissolved nutrient concentrations near the bottom were elevated as follows: inorganic nitrogen 80 µg/L and orthophosphate, 7 µg/L. Samples at DEA101 on February 27 were very similar to those taken near the reservoir bottom. Follow-up samples at DEA101 on March 20 showed further increases in nutrient concentrations; hypolimnetic deoxygenation had now been in progress for more than three months. Dissolved nutrient concentrations at DEA101 on March 20 were as follows: inorganic nitrogen 110 µg/L and orthophosphate, 13 µg/L.

The availability of LDS DO data during the winter revealed that under-ice hypolimnetic deoxygenation occurred in each of the 5 years of this project. And, except for the autumn of 2007, persistent hypolimnetic deoxygenation was present in the autumn months. Hypolimnetic deoxygenation and nutrient recycling were closely linked in Deadwood Reservoir and provided an important explanation for some of the variability in the mass of nutrient loads discharged from Deadwood Reservoir (Table 2-19).

Although of lesser magnitude than hypolimnetic deoxygenation, an additional source of variability was attributable to fire-related inputs of dissolved inorganic nitrogen to Deadwood Reservoir. The relation between dissolved inorganic nitrogen inputs from Trail Creek and hypolimnetic concentrations at reservoir station DEA010 is illustrated in Figure 2-66. Note that the moderate to large spikes in hypolimnetic concentrations around October of each year were mainly due to nutrient recycling caused by hypolimnetic deoxygenation. Because the months of June through August had not yet experienced severe hypolimnetic deoxygenation, the influences of the Trail Creek inputs were more noticeable. During the summer of 2007 hypolimnetic concentrations of dissolved inorganic nitrogen ranged from 10 to 35 µg/L (median of 15 µg/L). The ranges for the summers of 2008 and 2009 were, respectively, 6 to 63 µg/L (median of 38 µg/L) and 48 to 79 µg/L (median of 79 µg/L). The summers of the final 2 years had median concentrations less than 20 µg/L. The apparent lack of influence of the 250-µg/L spike in Trail Creek on the summer hypolimnion during 2010 was related to flushing of dissolved inorganic nitrogen during 2010's large snowmelt runoff.

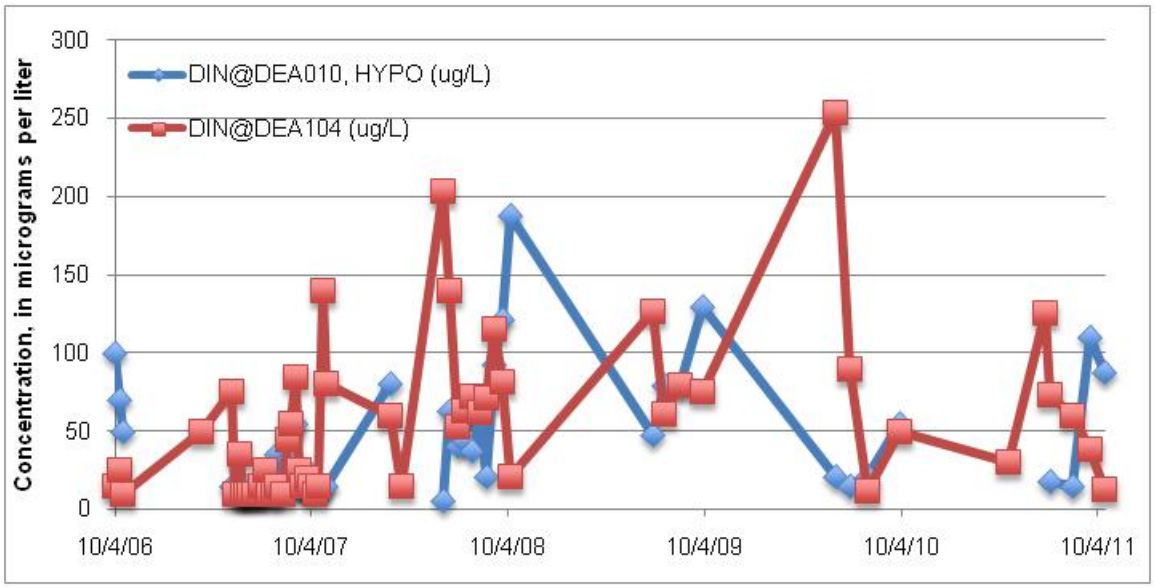


Figure 2-66. Comparison of concentrations of dissolved inorganic nitrogen (DIN) during water years 2007-2011 in hypolimnion (HYPO) of reservoir station DEA010 and in Trail Creek (DEA104), Deadwood Reservoir.

***Nutrient loads, temporal aspects*.** Evaluation of the FLUX model outputs (Table 2-15 through Table 2-18) revealed that two periods, snowmelt runoff and drawdown, accounted for the majority of annual inputs or outputs of nutrients for the reservoir. As shown in Figure 2-68, 48.2% (2130/4420 kg) of the total phosphorus inflow in 2007 was delivered during snowmelt runoff (early April to mid-June), but only 7.6% (337/4420 kg) was delivered during drawdown (late June to early September). Conversely, only 12.8% (438/3410 kg) of total-phosphorus outputs occurred during snowmelt runoff, whereas drawdown accounted for 60% (2050/3410 kg) of the annual total-phosphorus output from the reservoir. The elevated streamflows delivered to the reservoir during snowmelt runoff was the primary reason for the large percentage of total phosphorus delivery during that period. However, only a small portion of the snowmelt-runoff load of total phosphorus was output from the reservoir because the dam was in low-release mode in order to fill the reservoir. Drawdown reversed the scenario for total phosphorus loads; streamflow inputs were near their annual minima whereas discharge through the dam was at its annual maxima. The other three nutrients behaved similarly as can be seen in Figure 2-67 for dissolved orthophosphate and Figure 2-68 for total organic nitrogen and dissolved inorganic nitrogen. The FLUX model outputs indicated that the temporal relation of input and output loads during snowmelt runoff and drawdown were comparable over 2007–2010.

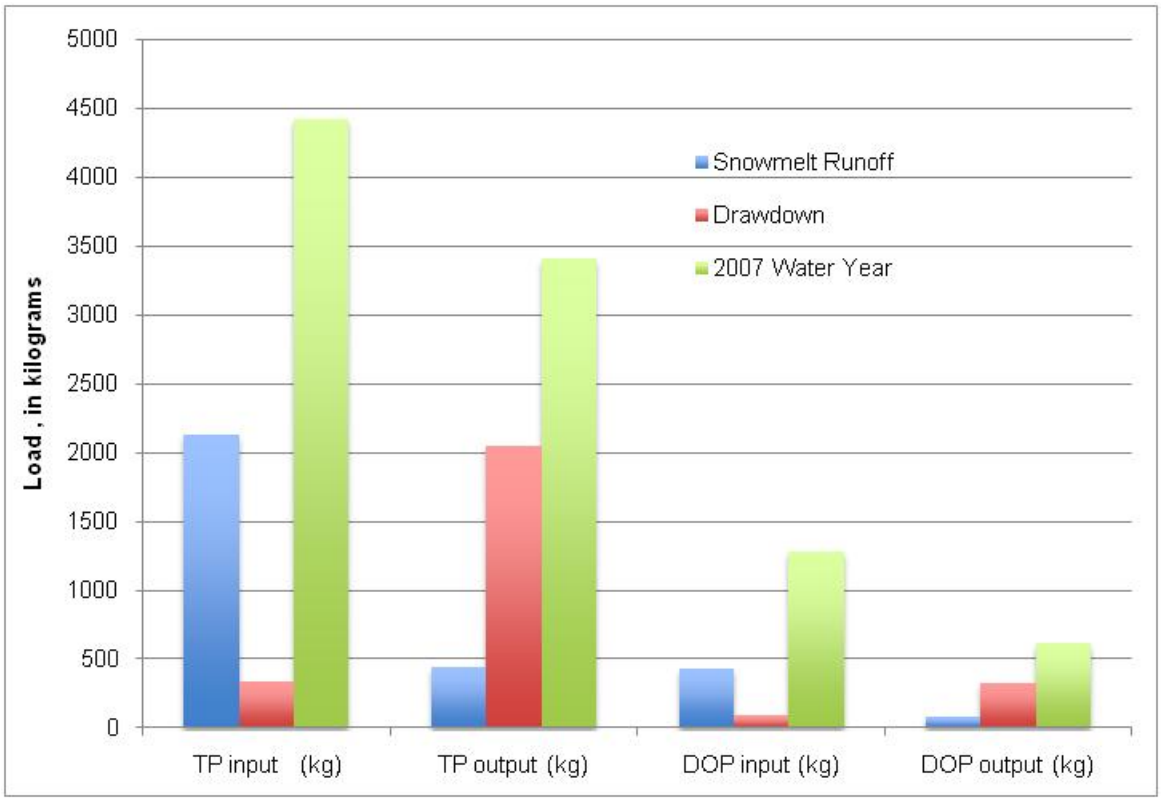


Figure 2-67. Partitioning of input and output loads, in kilograms, of total phosphorus (TP) and dissolved orthophosphate (DOP) during snowmelt runoff and drawdown during 2007 water year, Deadwood Reservoir.

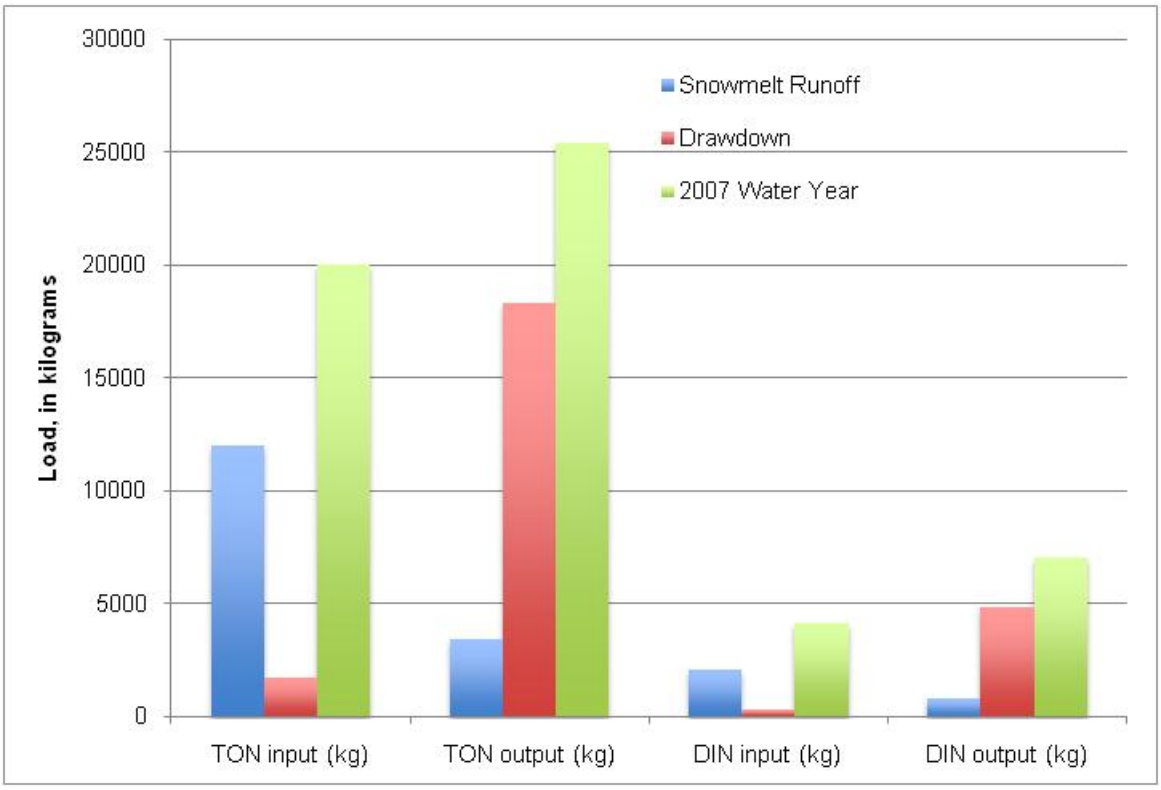


Figure 2-68. Partitioning of input and output loads, in kilograms, of total organic nitrogen (TON) and dissolved inorganic nitrogen (DIN) during snowmelt runoff and drawdown during 2007 water year, Deadwood Reservoir.

2.2.6 Reservoir Productivity, 2007 to 2011

Indicators of Elevated Reservoir Productivity

The review of historical limnological data, in conjunction with water-quality data gathered by the field data collection program and by the automated sensors on the LDS, found that Deadwood Reservoir was more biologically productive than expected for a high-elevation reservoir situated in a relatively undeveloped drainage basin. The basis for that conclusion is evident in Table 2-20, which lists four water-quality variables that have been extensively used to assess enhanced biological productivity, or eutrophication. The four variables primarily focus on organic matter production (phytoplankton primary production) and decomposition and their effects on DO dynamics in the reservoir. Calendar year comparisons for 2007–2011 are listed in Table 2-20; 2007–2011 comparisons are also listed for August in that historical data for the four variables was available only in July or August. The data in the table are based on DEA010 in that the majority of historic water-quality data was sampled in the vicinity of that reservoir station.

Table 2-20. Selected indicators of reservoir productivity derived from historic samples (1980-2006) and the 2007-2011 reservoir-sampling program at Deadwood Reservoir.

Date	Minimum Hypolimnetic DO, mg/L	Maximum DO Saturation, mg/L	Chlorophyll *a* at 1-m depth, µg/L	Maximum pH within euphotic zone
July, 1980	NS	NS	4.6	NS
July, 1981	NS	125	4.2	NS
August, 1981	4.8	NS	1.3	8.5
August, 1984	5.3	113	11.6	8.7
July, 1997	6.4	149	3.3	8.3
August, 2000	1	146	0.9	7.6
August, 2002	4.3	111	NS	8
August, 2006	3.5	110	2.3	9
August, 2007	6	100	1.7	8.1
August, 2008	3.8	132	2.1	8.9
August, 2009	3.9	131	4.2	8.7
August, 2010	0.7	123	7.1	8.9
August, 2011	5.7	136	4	9.3
2007	3.5	150	9.5	9
2008	4	151	4.1	9
2009	2.1	152	4.8	8.9
2010	0.7	123	7.1	8.9
2011	2.9	136	8.1	9.6

The 1980–2006 historic data in Table 2-20 revealed that even as early as the 1980s Deadwood Reservoir had low DO concentrations in its hypolimnion during the summer. Conversely, its upper water-column often was supersaturated with DO, a consequence of robust photosynthetic production by phytoplankton. Elevation of pH into the range of 8 to 9 also indicated robust phytoplankton production related to uptake of carbon for photosynthesis. Except for the 11.6-µg/L concentration of chlorophyll measured in August 1984, the other summer chlorophyll concentrations were not particularly high. Compared to the historic August data, the 2007–2011 data for August had similar ranges for each of the four variables (Table 2-20).

The annual data in Table 2-20 revealed that 2007-2011 had strong indications of eutrophication. Hypolimnetic concentrations of DO in 2007 and 2010, respectively, were as low as 0.5 and 0.7 mg/L, or nearly anoxic. Supersaturation of DO was as high as 150-152% in 2007–2009. Euphotic-zone pH was as high as 9.6 in 2011. The maximum chlorophyll *a* concentration at the 1-m depth reached 9.5 µg/L in 2007. The near-year-round operation of

the LDS during 2007-2011 verified the existence of two important eutrophication indicators: 1) the persistence of supersaturated DO in the reservoir's upper water column over the summer, and 2) the development of substantial hypolimnetic DO deficits in both the late summer/early fall and under winter ice-cover.

Another significant indicator of the reservoir's enhanced biological productivity was provided by the addition of chlorophyll sampling near the fluorescence maxima beginning in 2008. Although the maximum chlorophyll *a* concentrations listed in Table 2-20 for the 1-m depth were moderately elevated, those shown in Figure 2-69, which include the fluorescence-maxima samples, more clearly show the elevation of biological productivity. Over 2007–2011, median concentrations of chlorophyll *a* near the surface and at the fluorescence maxima often differed by a factor of between 1.5 and 3 within each year. Over the 5 sampled years, the maximum concentrations near the surface ranged from 4.8 µg/L (2009) to 10.2 µg/L (2011); those at the fluorescence maxima ranged from 9.2 µg/L (2010) to 28.8 µg/L (2011).

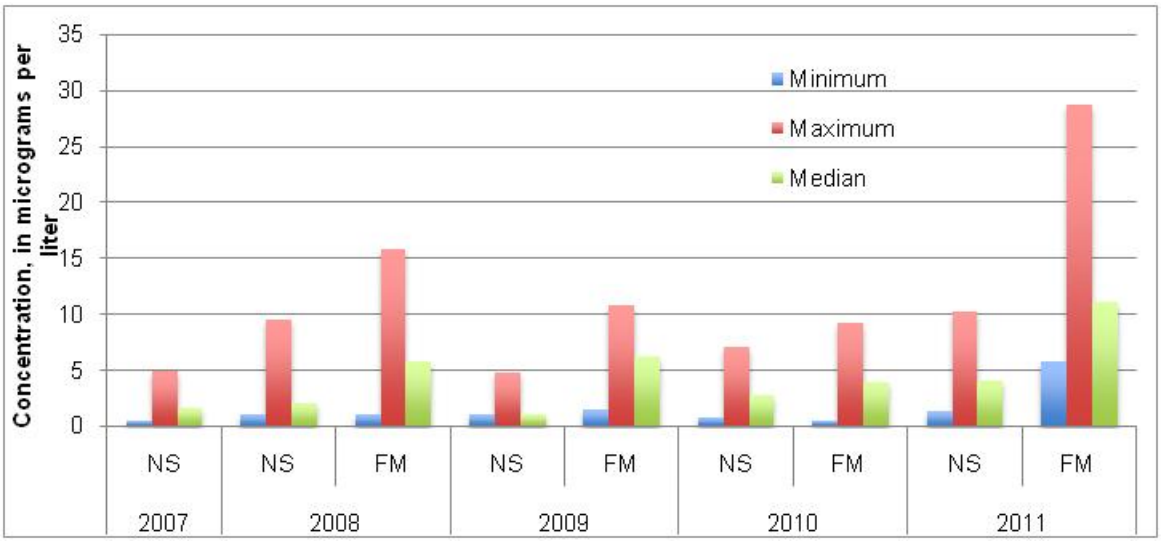


Figure 2-69. Statistical comparison of chlorophyll *a* concentrations, in µg/L, from near-surface (NS) and fluorescence maxima (FM) samples at the five primary reservoir stations during water years 2007-2011, Deadwood Reservoir.

The statistical comparisons in Figure 2-69 blend the 178 near-surface and 51 fluorescence-maxima samples and obscure some of the extremes contained in individual comparisons. Table 2-21 lists those dates on which fluorescence-maxima samples exceeded 10 µg/L of chlorophyll *a*; the associated chlorophyll *a* concentration for the near-surface sample is also listed. Of the 14 comparisons, all but one occurred in samples collected during July and August. The single exception had the smallest difference between chlorophyll samples (7.7 versus 10.4) and occurred the final day of sampling (October 17, 2011), which was characterized by isothermal conditions and water-column circulation. The other 13

comparisons often differed by a factor of between 4 and 9 and were measured during well-developed thermal stratification.

Table 2-21. Comparisons of chlorophyll *a* concentrations, in µg/L, from near-surface (1-m depth) samples associated with fluorescence maxima samples exceeding 10 µg/L at four of the five primary reservoir stations during water years 2008–2011, Deadwood Reservoir.

Station	Date	– *a* concentration, µg/L	
		1-m depth	Fluorescence maxima
DEA004	7/29/08	1.9	15.7
	8/18/11	4.3	17.1
DEA010	7/29/08	1.5	13.3
	8/25/08	2.1	15.9
	7/7/11	1.9	10.7
	8/18/11	4.0	16.2
DES014	7/29/08	1.9	13.6
	7/7/11	1.9	11.5
	8/18/11	4.5	28.8
	10/7/11	7.7	10.4
DEA016	7/29/08	1.7	13.6
	7/20/09	<2.7	11.7
	7/7/11	2.1	11.7
	8/18/11	4.1	20.9

Dissolved Oxygen Dynamics and Elevated Reservoir Productivity

Deadwood Reservoir's elevated biological production was directly linked to wide fluctuations in DO concentrations measured in the reservoir. Supersaturation of the upper water column was common in the summer and fall months, whereas deoxygenation of the hypolimnion prevailed in the fall and winter months. Hypolimnetic deoxygenation was also directly linked to elevated biological productivity via the important feedback loop among nutrients, productivity, and DO dynamics. The augmentation of nutrient recycling within the hypolimnion supplied non-watershed-derived nutrients for reservoir primary production via convective circulation. Hypolimnetic deoxygenation also supplied nutrients and organic carbon for release through Deadwood Dam into the Deadwood River downstream of Deadwood Reservoir. Several lines of evidence provide additional insight into the

limnological processes associated with the feedback loop among nutrients, productivity, and DO dynamics.

The large amount of littoral zone contributed to the important feedback loop among biological productivity, nutrient cycling, and DO dynamics in several ways. The biological productivity of the reservoir was dominated by phytoplankton photosynthesis (primary productivity); that source was augmented by primary productivity of benthic algae within the littoral zone. During reservoir filling, reservoir productivity may not have been increased much by benthic-algae productivity because of the transient nature of newly established littoral zone. However, the detrital organic matter remaining after senescence of benthic algae may have enhanced reservoir productivity during and after drawdown. At the initiation of drawdown in mid-summer, extensive areas of the littoral zone progressively became dewatered; decay of the stranded benthic algae may have contributed nutrients back into the reservoir via several pathways. These pathways included subsurface flow through lakebed sediments, gravitational drainage from recently dewatered surficial sediments, wave erosion, and precipitation-induced flows over exposed lakebed sediments. These additions of nutrients to the reservoir during drawdown may help explain increased phytoplankton productivity (higher chlorophyll *a* concentrations and supersaturation of DO) measured in the autumn and early winter. Such enhancement of late-season productivity contributed to the oxygen demand placed on the reservoir as it went into winter ice-cover.

The DO data recorded by the LDS during the winter months, when the reservoir was ice-covered, provided important insight into processes affecting the reservoir's productivity during the following spring and summer months. The persistence of hypolimnetic deoxygenation that started in December and continued into April of most sampled years was one of the more important findings of the limnological study of the reservoir. A time-series of the saturation of DO during late July 2007 through April 2008, as measured by the LDS, is very illustrative of DO dynamics over the water column (Figure 2-70). During late July the reservoir was still thermally stratified and robust phytoplanktonic photosynthesis produced saturations between 85 and 125% in the upper water column (sensors DO1-DO5); however, saturations within the hypolimnion were less than 55%. With the loss of thermal stratification and the commencement of full-depth convective circulation in mid-August saturations rapidly increased within the hypolimnion in response to reaeration; however, saturations declined in the upper water column in response to deeper circulation of phytoplankton populations. By early October the entire water column was saturated at about 70%. Saturations continued to gradually decline through April 2008, with the exception of near-bottom saturations. Sensor DO7 demonstrated a substantial decline in saturation at depth over the period of winter ice-cover. That sensor depicted a rapid increase in saturation near the end of April 2008, possibly in response to deep circulation of oxygenated water; the other six sensors were unaffected. The declines in saturation during winter ice-cover for all the sensors indicated an abundance of DO demand throughout the water column, although that demand was largest near the reservoir bottom. What is missing from Figure 2-70 is the occurrence of surges of saturations greater

than 100% during late autumn and early winter that were recorded by the LDS in each year of 2008-2011, 2007 was the only sampled year in which they failed to occur.

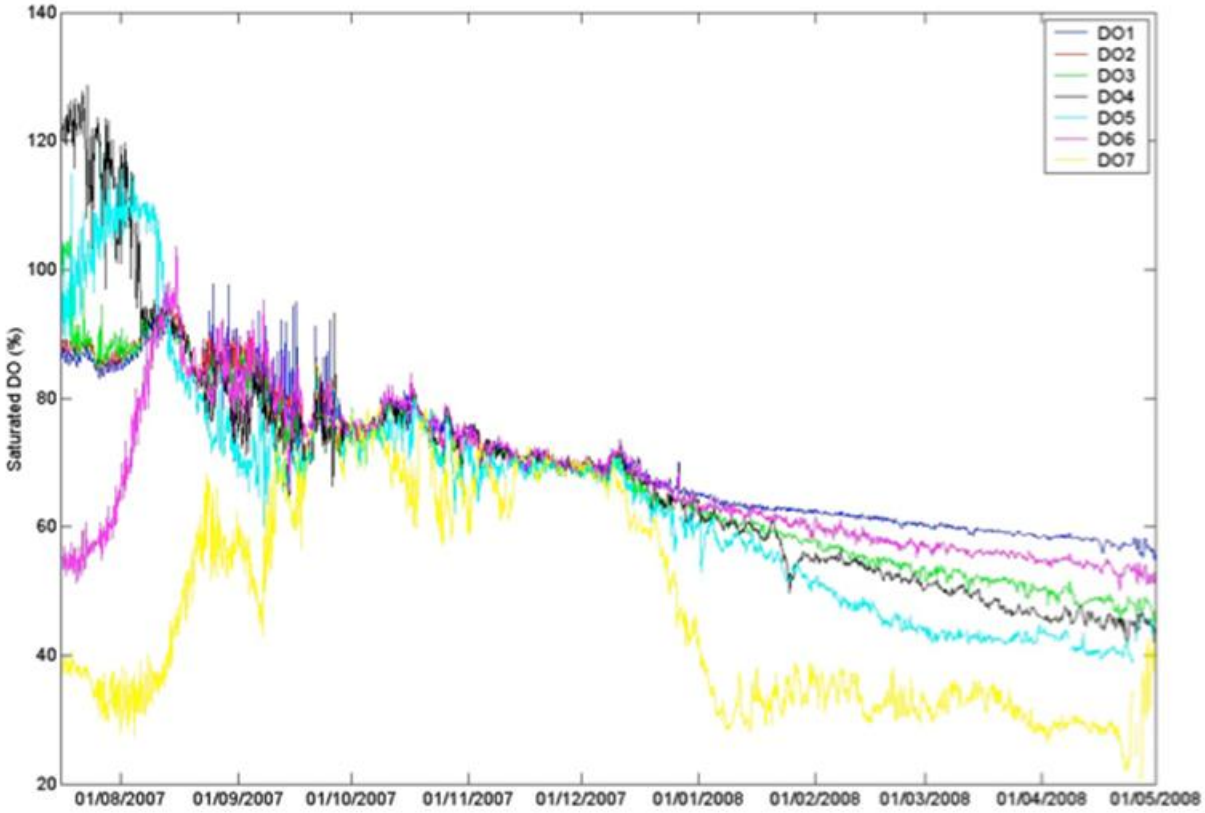


Figure 2-70. Variations in saturation of DO concentration, in percent, during August 2007 through April 2008 as recorded by DO sensors on LDS instrument moored near reservoir station DEA010, Deadwood Reservoir. [Sensors DO1-DO5 monitored reservoir surface to 9-meter depth, DO6 was 14 meter above reservoir bottom, and DO7 was 1.5 meter above reservoir bottom].

The effects of wintertime hypolimnetic deoxygenation were evident in water-quality samples taken in 2008 at DEA010 on February 27 and at the reservoir's outlet (DEA101) on February 27 and March 20. The February 27 reservoir samples were taken about mid-way through that winter's four months of deoxygenation. Near the reservoir bottom, DO concentration and percent saturation were, respectively, 3.5 mg/L and 32%; near-surface and mid-depth concentrations were greater than 8 mg/L. Nutrient concentrations, in µg/L, near the bottom were elevated as follows: dissolved nitrite plus nitrate, 40; dissolved ammonia, 40; dissolved orthophosphate, 7; and total phosphorus, 18. Samples at DEA101 on February 27 were very similar to those taken near the reservoir bottom except that the total phosphorus concentration had increased to 37 µg/L. The March 20 samples at DEA101 showed further increases in nutrient concentrations as deoxygenation had been in progress for more than three months. Nutrient concentrations, in µg/L, were as follows: dissolved nitrite plus nitrate, 70; dissolved

ammonia, 40; dissolved orthophosphate, 13; and total phosphorus, 41. In conclusion, the availability of winter LDS oxygen data, coupled with the February and March nutrient samples, revealed an important source of nutrients for the spring phytoplankton blooms that commenced with water-column circulation in late April-early May as winter ice-cover was lost from the reservoir.

Interactions of Limnological Processes with Hydrodynamic/Water-operations Variations

Now that one of Deadwood Reservoir's more important limnological topics, the cyclic interaction among nutrients, productivity, and DO dynamics, has been evaluated in some detail, a summary of that interaction seems in order before proceeding to another major topic. That second topic relates to variations in hydrodynamic processes and water operations and their effects upon the cyclic interaction among nutrients, productivity, and DO dynamics over 2007–2011. The combined evaluation of these two important topics can be used to better understand within-reservoir variations in water quality and, consequently, variations in water quality discharged through Deadwood Dam into the downstream Deadwood River.

Summary of cyclic interaction. The fuel for Deadwood Reservoir's biological productivity largely emanated from nutrients, especially nitrogen and phosphorus, delivered by the reservoir's watershed. The timing and magnitude of these nutrient deliveries, or loads, were closely tied to variations in streamflow, especially those delivered during snowmelt runoff. Two large forest fires within, or near, the reservoir's watershed augmented nutrient loads via runoff and ash deposition. An additional nutrient source came from decomposition of benthic algae produced within the reservoir's littoral zone. The reservoir's watershed-based and littoral-zone-based nutrient loads were supplemented by internal nutrient recycling, which was most active in late autumn/early winter and under winter ice cover. Internal nutrient recycling occurred within the DO-deficient hypolimnion, especially within a few meters of the reservoir's bottom sediments. The hypolimnetic DO deficit was a direct consequence of the reservoir's robust phytoplanktonic primary production, which produced the organic, nutrient-rich detrital "rain" that settled through the reservoir's water column while consuming DO during decomposition. In contrast to the consumption of DO in the hypolimnion, robust phytoplanktonic primary productivity generated supersaturated levels of DO within the reservoir's upper water column, often at the thermocline during the summer months. During the spring and autumn, the linkage between nutrient supply and primary production was highly dependent on the physical limnological process of convective circulation, which delivered internally recycled nutrients into the reservoir's upper water-column.

As the summary illustrates, the cyclic interaction among nutrients, productivity, and DO dynamics, was complex and dependent upon an array of physical, chemical, and biological processes. These processes need to be compared among 2007–2011 to elucidate the most important influences on Deadwood Reservoir's biological productivity and water quality.

Temporal aspects of thermal stratification, convective circulation, and DO dynamics. Several important differences between 2007 and the other 4 years are evident in Table 2-22; the onset of weakened thermal stratification, the date of minimum hypolimnetic DO, and the date of hypolimnetic reaeration occurred between 2 and 6 weeks earlier in 2007. The most consistent delay was for hypolimnetic reaeration; during 2008-2011 it occurred 6 weeks later than in 2007. The effects of longer thermal stratification and the consequent delay in hypolimnetic reaeration are readily apparent in Figure 2-71; the loss of hypolimnetic DO was greater in 2008–2011 than in 2007, by as much as 4 mg/L. The mid-August onset of weakened thermal stratification in 2007 was coincident with the final 2 to 3 weeks of reservoir drawdown. This interaction of a limnological process with reservoir water-operations resulted in the entrainment of metalimnetic and epilimnetic water, in addition to hypolimnetic water, by the reservoir's deep outlet structures. As a result, the water temperatures discharged through Deadwood Dam were about 6°C higher in 2007 than in the other 4 years (Table 2-22).

Table 2-22. Limnological characteristics related to thermal stratification, DO dynamics, and outflow water temperatures during water years 2007–2011, Deadwood Reservoir.

Characteristic	2007	2008	2009	2010	2011
Start of strong thermal stratification	mid-May	mid-June	early June	early June	early June
Start of weakened thermal stratification	mid-Aug	late Aug	early Sept	late Sept	mid-Sept
Period of minimum hypolimnetic DO	early Sept	early Oct	late Sept	mid-Oct	mid-Oct
Period of hypolimnetic reaeration	mid-Sept	late Oct	late Oct	late Oct	late Oct
Outflow temperature (C)					
Maximum	18	12.3	11.7	12.5	12.4
Depth of equal temp. at DEA010	isothermal	26 m.	26 m.	17 m.	25 m.
Period of maximum	early Sept	early Oct	late Sept	mid-Sept	mid-Oct

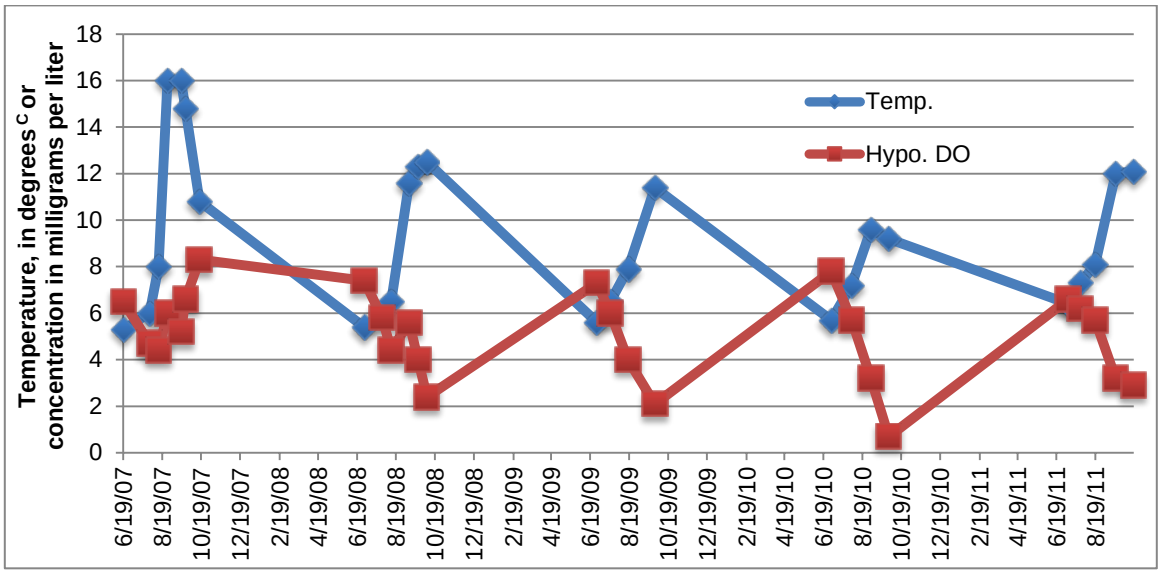


Figure 2-71. Temporal variation in hypolimnetic (near-bottom) water temperatures, in degrees Celsius, and DO concentrations, in milligrams per liter, from mid-June 2007 to late September 2011 at reservoir station DEA010, Deadwood Reservoir.

The earlier onset of convective circulation and hypolimnetic reaeration in 2007 were a consequence of another important difference between 2007 and the other 4 years. As shown in Figure 2-72, the reservoir's pool elevation, and hence its volume, at the end of drawdown were less in 2007. Compared to 2008, pool elevation was 3.5-m lower; compared to 2009–2011, it was 5.3-m lower. The lower pool elevation in 2007 was the result of more water being discharged from the reservoir than was received; 2007 was the only one of the 5 years in which the volume of discharge was substantially larger than inflow volume (Figure 2-73).

The pronounced variations in mean daily inflows (Figure 2-74) to Deadwood Reservoir during water years 2007–2011 required Reclamation to adjust reservoir outflows (Figure 2-74) to accommodate snowmelt runoff and to provide adequate reservoir volume to satisfy downstream water allocations. Reclamation's water operations in response to hydrologic variability during 2007−2011 resulted in the pool-elevation variations shown in Figure 2-72. Mean daily inflows were largest during snowmelt runoff whereas reservoir drawdown produced the largest outflows. During the first 4 years, drawdown commenced during the middle to later stages of the snowmelt-recession hydrograph; however, drawdown commenced in 2011 near the start of snowmelt, which was more prolonged than in the other years.

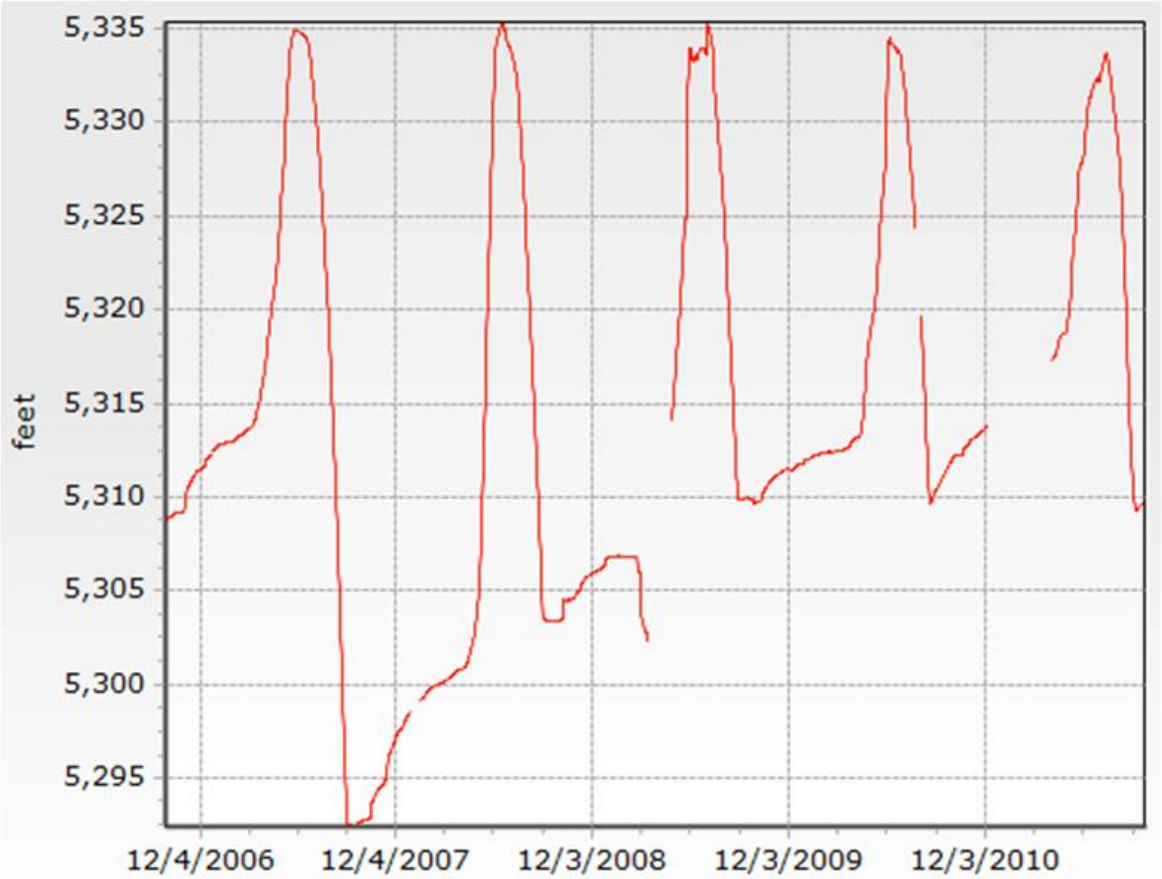


Figure 2-72. Daily variation in reservoir surface elevation, in feet above mean sea level, for water years 2007−2011, Deadwood Reservoir. [Normal full pool elevation is 5334 feet].

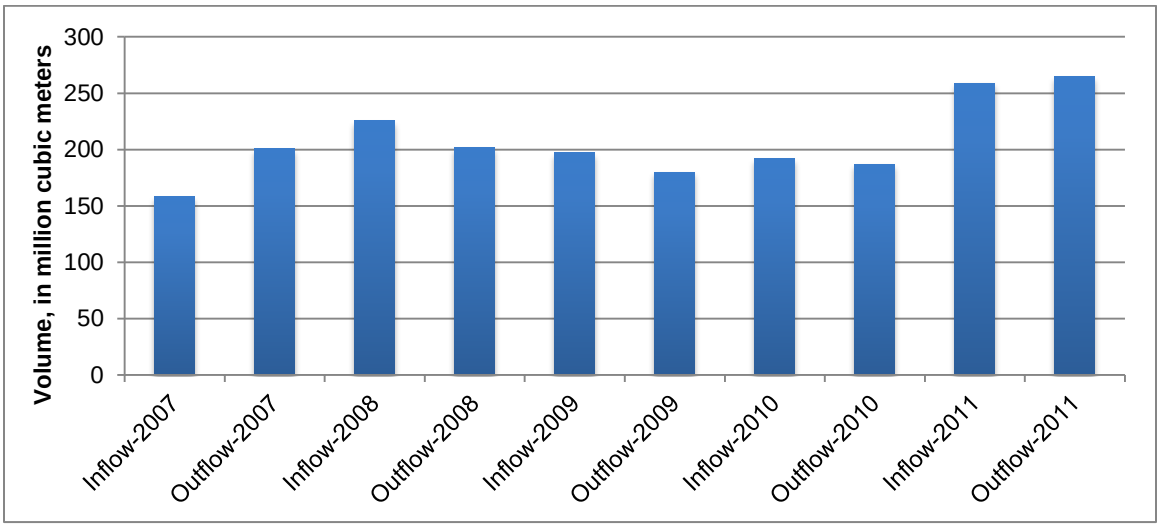


Figure 2-73. Volume of inflow and outflow, in million cubic meters, for water years 2007−2011, Deadwood Reservoir.

In addition to its influence on water-operations decisions, such as post-drawdown pool volumes, the hydrologic variability of reservoir inflows affected the magnitude and timing of nutrient loads delivered to the reservoir from its watershed (Table 2-19). For the two sediment-associated nutrients, total phosphorus and total organic nitrogen, larger inflow volumes generally equated to larger nutrient loads. However, that correlation was much weaker for the two dissolved nutrients, orthophosphate and inorganic nitrogen, both of which are important nutrients for phytoplanktonic primary productivity. However, evaluation of variations in nutrient concentrations in the reservoir's upper water column (Table 2-10) led to the conclusion that reservoir primary productivity was not robustly correlated with watershed-derived nutrient loads.

That weak correlation was overshadowed by other interactions among chemical and biological processes, which were under the temporal and spatial influences of physical processes such as thermal stratification and convective and advective circulation.

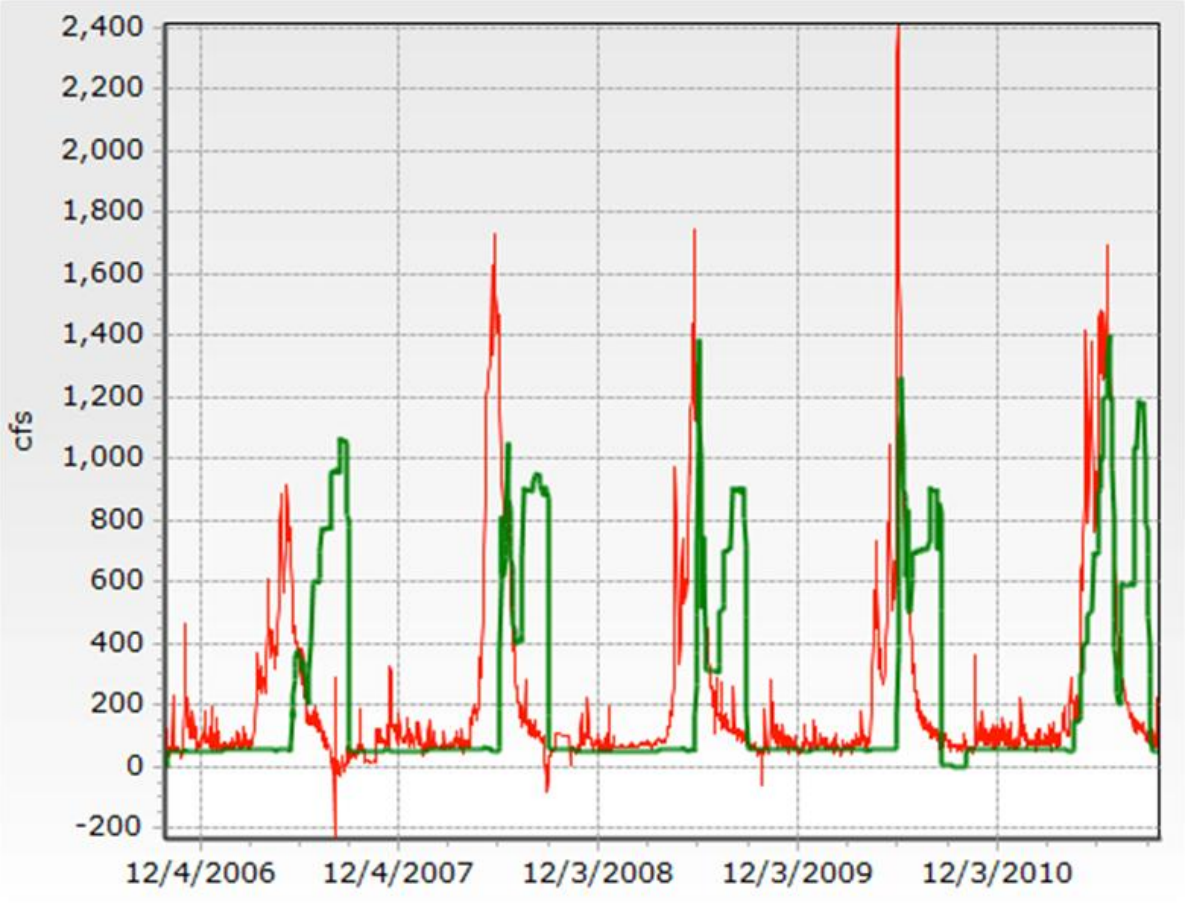


Figure 2-74. Hydrographs of mean daily inflow (calculated) and outflow, in cubic feet per second, for water years 2007−2011, Deadwood Reservoir. [Inflow calculated as outflow adjusted for change in reservoir contents]. (Note: red series is inflow volume; green series is outflow volume.)

Phytoplankton and reservoir processes. Valuable insight into the role of biological processes on phytoplanktonic primary productivity came from interpretation of the first-ever phytoplankton samples collected in Deadwood Reservoir (Table 2-12). Phytoplanktonic utilization of nutrients was augmented in Deadwood Reservoir by phytoplankton capable of nitrogen fixation, buoyancy regulation, and motility. The dominance of cyanobacteria (also known as blue-green algae) in the 2008−2009 phytoplankton analyses was an unexpected result. The major component of the cyanobacterial dominance was *Anabaena spiroides*, a filamentous algae capable of fixing atmospheric nitrogen via a heterocyst. Importantly, this algal species also contains gas vesicles, which aid buoyancy control and limit sedimentation losses in stratified environments. *Anabaena spiroides* is typically found in lakes and reservoirs with low nitrogen content as its nitrogen-fixing capability provides a competitive advantage. This species remained prevalent throughout the sampling period in both years (Figure 2-75). *Ceratium hirundinella* is a large, motile, dinoflagellate species with the ability to perform large diurnal vertical migrations in order to access nutrients and light; this gives it a competitive advantage in stratified environments. As such, it typically appears in late summer in stratified lakes (Alexander and Imberger 2009). *Ceratium hirundinella* appeared in the Deadwood data set in the late summer in both years (Figure 2-75). Diatoms were generally present in the early part of the stratification during the spring period. The diatom assemblage consisted of *Fragilaria, Asterionella* and *Synedra* species, with the *Synedra* species approximately 10 times larger based on biovolume. Numerous cryptophyte species were prevalent in the data, including species of *Cryptomonas, Ochromonas* and *Rhodomonas*, and were relatively persistent through the sampling period. Later in the stratification period, increasing concentrations of the large dinoflagellate Ceratium hirundinella and the small spherical cyanobacteria *Aphanothece clathrata* were observed. These species are known to prevail after extended periods of vertical stratification in nutrient-rich environments, and so their appearance towards the end of summer was expected.

The presence in Deadwood Reservoir of phytoplankton species capable of buoyancy regulation and fixation of atmospheric nitrogen helped explain the occurrence of late-fall and early-winter surges of photosynthetic activity, as evidenced by supersaturation in the reservoir's upper water column (Figure 2-57). Another persistent feature in Deadwood Reservoir was its deep-lying chlorophyll maxima during the summer (Figure 2-56); these have been observed in many well-stratified lakes with adequate water-column transparency (Pick et al. 1984).

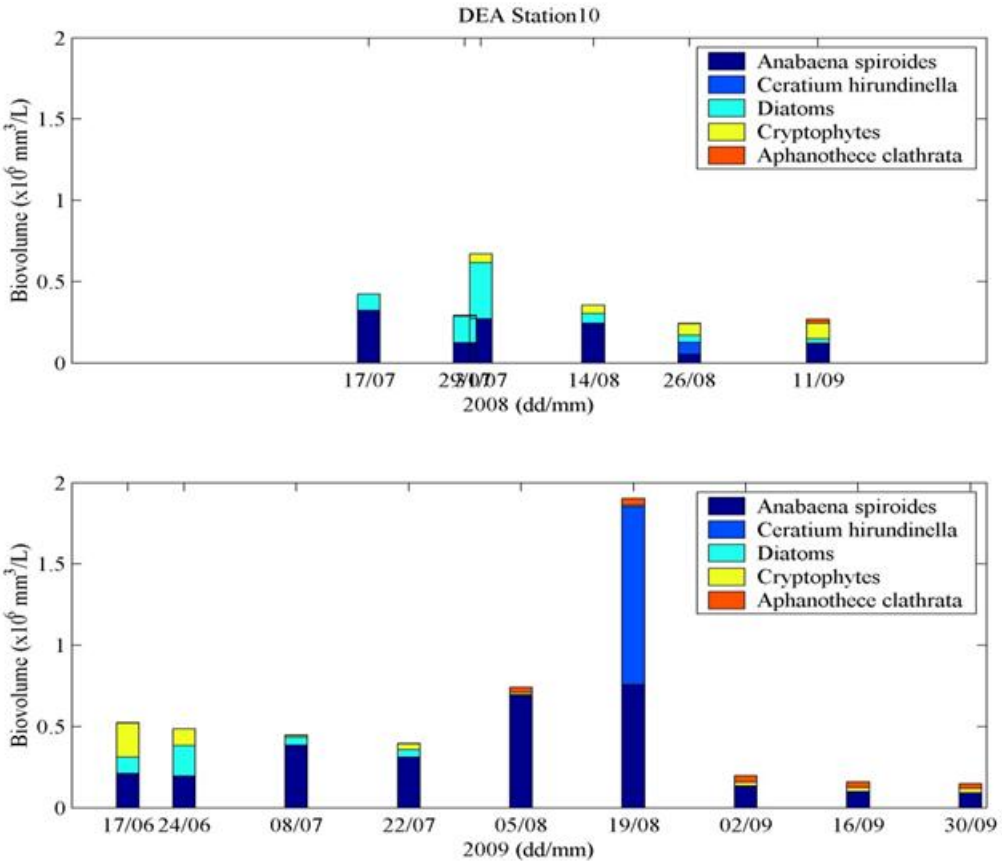


Figure 2-75. Biovolume of dominant species/groups at reservoir station DEA010 during mid-July to early September of 2008 and mid-June to late September of 2009, Deadwood Reservoir.

Temporal aspects of nutrient utilization and reservoir productivity. The among-year comparability of reservoir productivity, represented by chlorophyll *a*, was somewhat masked in earlier tables and figures because sampled periods varied over 2007–2011. Reservoir sampling had ended 3 to 4 weeks after drawdown (2008 and 2009), whereas in the other 3 years it had ended between 6 and 8 weeks after drawdown. Therefore, chlorophyll *a* concentrations during July through August (Figure 2-76) were examined to assess reservoir productivity over the 5 years. In each of the 5 years these two months had similar reservoir conditions; they were thermally stratified, had episodes of supersaturated DO near their thermoclines, and DO depletion was underway in their hypolimnia.

Readily apparent in Figure 2-76 is that median chlorophyll *a* concentrations for near-surface samples were much lower than those for fluorescence-maxima samples. An upward trend was apparent for near-surface samples; a two-fold difference existed between the smallest (2007) and largest (2011) median concentrations. Fluorescence-maxima samples in 2008 and 2011

had the largest median chlorophyll *a* concentrations; however, the lower values in 2009 and 2010 obscured the potential upward trend.

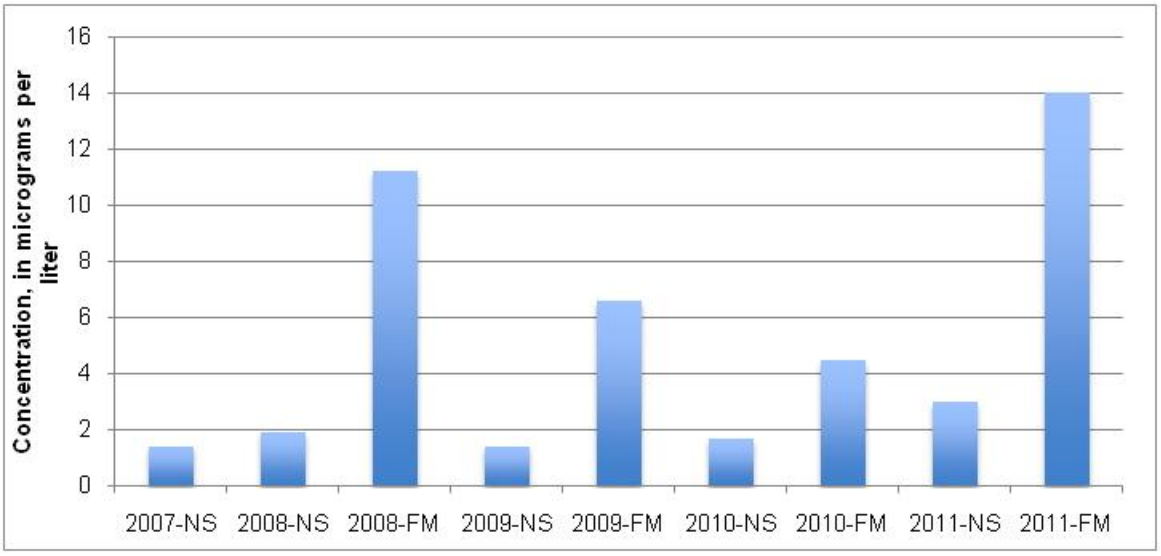


Figure 2-76. Median concentrations, in µg/L, of chlorophyll *a* from near-surface (NS) and fluorescence maxima (FM) samples at the five primary reservoir stations during July through August of water years 2007−2011, Deadwood Reservoir.

The increases in reservoir productivity depicted in Figure 2-76 likely resulted from a combination of reservoir processes that augmented the reservoir's efficiencies for nutrient utilization and nutrient recycling. The reservoir's larger post-drawdown volumes in 2008−2011 increased its ability to utilize its late-season nutrient supply to augment late-season primary productivity. More effective utilization of late-season nutrients resulted from the aforementioned presence of phytoplankton capable of nitrogen fixation, buoyancy regulation, and motility. The generation of organic matter just prior to winter ice-cover provided more detrital material for under-ice recycling of nutrients that would then be available to fuel spring and summer primary production. A relevant difference among the 5 years was that only in 2007 did the combination of lower pool volume and earlier convective circulation result in the drafting of nutrients and chlorophyll *a* from the entire water column. An important consequence was that 2007 did not generate post-drawdown, near-surface surges of primary productivity.

Potential Reasons for Deadwood Reservoir's Elevated Productivity

Switching to a more speculative mode, there is a dearth of quantitative data with which to track the long-term nature of nutrient loads to Deadwood Reservoir and its biological responses to such loads. However, there are a number of lines of evidence that may be used to develop a hypothesis about how Deadwood Reservoir achieved its elevated levels of biological productivity.

With completion of Deadwood Dam in 1931 Deadwood Reservoir received its first influx of nutrients during its initial filling in 1932. The initial years for new reservoirs have often been quite biologically productive in response to inundation of nutrient-rich terrestrial soils and vegetation. Beginning in 1932, winter releases from the reservoir into the Deadwood River were minimal; this mode of water operation continued for about 60 years, until 1992. From 1993 to present, a minimum winter flow of 1.4 m^3/s (50 cfs) has been released from the reservoir. The 60 years of minimal winter releases had the potential for the reservoir's bed sediments to accumulate nutrient and organic carbon inputs received prior to winter ice-cover. If hypolimnetic deoxygenation was prevalent in some portion of those 60 years, then nutrient recycling under ice cover could have produced robust phytoplankton blooms in the spring. Several indicators of elevated productivity, previously listed in Table 2-16, showed that between 1981 and 1984 the reservoir had reduced hypolimnetic DO concentrations, supersaturation in its upper water column, and chlorophyll *a* concentrations as high a 11.6 µg/L.

In addition to nutrient and organic carbon inputs commonly associated with forested watersheds, Deadwood Reservoir has harbored large populations of salmonid fishes, including kokanee salmon (*Oncorhynchus nerka*). Kokanee populations had become large enough in the reservoir to cause stunted growth; chemical treatments have been used several times to reduce Kokanee Salmon populations. Kokanee salmon die after tributary spawning; their carcasses are subject to predation and decomposition, the latter of which provided an additional source of nutrients and organic carbon to Deadwood Reservoir. As with some other nutrient sources, such as annual deposition of tree pollen, these likely represented small percentages of watershed-derived nutrient loads; however, these nutrient sources may have had a cumulative impact, especially if held in the reservoir over winter.

The previous discussion of the Rattlesnake and Monumental Fires of 2006 and 2007 clearly showed that those fires had measurable water-quality impacts on Deadwood Reservoir. On the basis of U.S. Forest Service fire maps for 1908−2007 (Prisciandaro 2012) the Rattlesnake and Monumental Fires were the largest fires to occur within and near Deadwood Reservoir's watershed since its impoundment in 1931. No large fires occurred within the reservoir's watershed from 1930 to 1980; however, several large fires occurred within about 25 km of the reservoir during that period. From 1980 through 2005 several large fires occurred within that 25-km radius; those outside of the reservoir's watershed were to the southwest and south, but one to the northeast was situated within the upper reach of the Deadwood River. The likely water-quality impacts to Deadwood Reservoir from most of these fires were caused by deposition of wind-blown ash. The one large fire in the reservoir's upper watershed prior to 2006 may have delivered time-lagged inflows of nutrients to the reservoir such as occurred with the Rattlesnake and Monumental Fires of 2006 and 2007.

One of the more significant impacts on the reservoir's productivity likely relates to long-term water-level management. The effects of higher water-surface elevations following reservoir

drawdown have been a major focus of preceding discussions of the cyclic interactions among nutrients, productivity, and DO dynamics. These effects may not have been restricted to 2007-2011. For 1990−2011, post-drawdown reservoir elevations have ranged between 1,610 and 1,622 m; elevations higher than 1,620 m were measured for 1995−1999. In 11 of those 22 years, elevations were higher than 1,618 m. Half of the remaining years had elevations between 1,614 m and 1,618 m; which were higher than the elevation of 1,613.2 m measured for 2007. Over the past decade (2002 to 2011), 4 years had post-drawdown elevations equal to or larger than 1,618 m, elevations in eight of those years exceeded 1,614 m.

Therefore, the hypothesis to address Deadwood's Reservoir's higher-than-expected biological productivity, which was in evidence in the early 1980's, combines the frequent incidence of post-drawdown reservoir elevations in excess of 1,618 m with the reservoir's highly efficient utilization and recycling of its allochthonous and autochthonous nutrient sources.

2.2.7 Conclusions

Much of the variation in Deadwood Reservoir's biological productivity was influenced by hydrologic variations in reservoir volume during the autumn and early winter months. However, this hydrologic influence was not direct, but was exercised through the cyclic interaction among nutrients, productivity, and DO dynamics. Major consequences of larger reservoir volumes at the end of late-summer drawdowns were delays in convective circulation, resultant from delayed weakening of thermal stratification, and lengthened periods of hypolimnetic DO depletion. These delays increased nutrient recycling within the water column, especially near the reservoir bottom. When convective circulation finally did commence, recycled nutrients were transported into the upper water column to fuel late-season surges of phytoplanktonic primary productivity. The organic carbon and biota-based nutrients resultant from late-season productivity added to the oxygen demands carried into winter. Under winter ice-cover organic detrital material was decomposed and recycled back into bio-available nutrients. With the loss of ice cover in the spring these internally generated nutrients were convectively circulated into the productive upper water-column and joined those watershed-derived nutrients delivered by snowmelt runoff. A large portion of these co-mingled nutrients was retained in the reservoir during late spring and early summer because water-operations required small releases through Deadwood Dam in order to fill the reservoir with snowmelt runoff. With the onset of summer thermal stratification, often established during reservoir filling, robust phytoplanktonic primary productivity commenced, producing organic carbon and biota-based nutrients that settled through the water column to fuel the reservoir's hypolimnetic oxygen demand. Over the summer months, the cyclic interaction of nutrients, productivity, and DO demand set the stage for a repeat of post-drawdown conditions, the magnitude of which was closely allied with post-drawdown reservoir volume.

The foregoing depiction of spring and autumn increases of phytoplanktonic primary productivity is common to dimictic (two episodes of convective circulation), temperate lakes

and reservoirs. Where Deadwood Reservoir deviated somewhat from this model was its efficiency in utilization of late-season nutrients to produce additional organic matter prior to onset of winter conditions and ice cover. The accumulation of organic matter from summer and late-season primary productivity resulted in substantial depletion of hypolimnetic DO that resulted in efficient recycling of nutrients over the winter. The reservoir's robust rates of photosynthetic primary productivity (defined as the rate of carbon fixation per unit time per area or volume) were apparent from lines of evidence such as elevated chlorophyll *a* concentrations and persistent supersaturation near the summer thermocline, post-drawdown surges of supersaturation in the upper water column, substantial hypolimnetic DO deficits in autumn and winter, and elevated pH levels in association with supersaturation. Despite these high rates of primary productivity, the reservoir's annual primary production (defined as the mass of carbon fixed per unit area over a year) was likely damped by the lengthy period of winter ice cover.

2.3 Effects of Reservoir Operations on Phytoplankton Production and Energy Available to Bull Trout in Deadwood Reservoir

2.3.1 Introduction

Reservoir operations can affect fish growth and survival in the reservoir through changes in temperature, DO, toxins, food availability, habitat space, and habitat connectivity. Direct effects of temperature and oxygen on Bull Trout in the Deadwood Reservoir are addressed elsewhere in this report. The purpose of this section is to describe the potential for reservoir operations to influence Bull Trout indirectly through effects on the aquatic foodweb.

We used natural abundance stable isotopes to describe energy pathways from phytoplankton to fish in the Deadwood Reservoir foodweb. Carbon and nitrogen, which are major nutrients for fish, occur in more than one stable isotopic form (e.g., ^{13}C and ^{12}C, ^{15}N and ^{14}N). The ratio of the heavy to light isotope of an element in a food source provides it with an isotope signature that may be used to trace its movement through a food chain (Peterson and Fry 1987; Kling et al. 1992; Michener and Schell 1994). Isotope signatures of consumers reflect their diet plus trophic fractionation (i.e., the change in isotope ratio between diet and consumer). If trophic fractionation is known, isotope ratios can be used to estimate trophic level and energy sources for consumers. A benefit of stable isotope studies is that stable isotopes reflect broader time scales, generally weeks to months, than do gut contents or direct observations of feeding (Fry

and Sherr 1984). Stable isotope studies are particularly appealing for systems like the Deadwood Reservoir, where there is little quantitative information on fish populations.

Fish species in the Deadwood Reservoir include Bull Trout (*Salvelinus fontinalis*), kokanee (*Oncorhynchus nerka*), Rainbow Trout (*Oncorhynchus mykiss*), Mountain Whitefish (*Prosopium williamsoni*), Redside Shiner (*Richardsonius balteatus*), Dace (*Rhinichthys spp*.), and Sculpin (*Cottus spp*.). Westslope Cutthroat Trout (*Oncorhynchus clarki lewisi*) were stocked by Idaho Department of Fish and Game (IDFG) until 1998 and a reproducing population remains. Resident fall Chinook salmon (*Oncorhynchus tshawytscha*) also were stocked until 1998, but only a few adults have been observed during recent years. In 2009, fingerling fall Chinook were stocked by IDFG at a rate of four fish per hectare (5,200 fish) Butts et al. 2009). Fall Chinook were not captured during this study and will not be considered.

Quantitative population estimates are lacking for most fish species in the Deadwood Reservoir, with the exception of Kokanee, the dominant species. Hydroacoustic, trawl, gillnet, and tributary weir studies were done during 2000–2010 by IDFG and Reclamation. Although there is high uncertainty associated with population size estimates, these studies reveal a robust yet highly variable population of Kokanee. Hydroacoustic survey estimates range from approximately 100,000–1,800,000 Kokanee in the reservoir from 2000 through 2009. The Kokanee population shows density dependent growth with high inter-annual variability in abundance, size structure, and length-at-maturity (Butts et al. 2009). Kokanee provide abundant forage for Bull Trout in the Deadwood Reservoir. In turn, kokanee are principally zooplanktivores and derive their energy from phytoplankton-based energy pathways (Clark 1999; Vidergar 2000; Figure 2-77).

Reservoir operations can influence primary production, which in turn can affect production of Bull Trout via the aquatic foodweb. We applied the modeling approach of Saito (1999) and Saito et al. (2001) to describe links between reservoir operations, phytoplankton production, and energy available for Bull Trout production in the Deadwood Reservoir. The hydrodynamic and aquatic ecological models ELCOM and CAEDYM were used to describe physical, chemical, and biological components of the Deadwood Reservoir and predict how reservoir conditions change with alternative reservoir operations. Trophic linkages from phytoplankton to fish were quantified using stable isotope analysis and information on trophic transfer efficiencies gathered from the scientific literature. Finally, net phytoplankton energy available for each operational scenario was propagated through the modeled foodweb to estimate growth potential for Bull Trout and other fish.

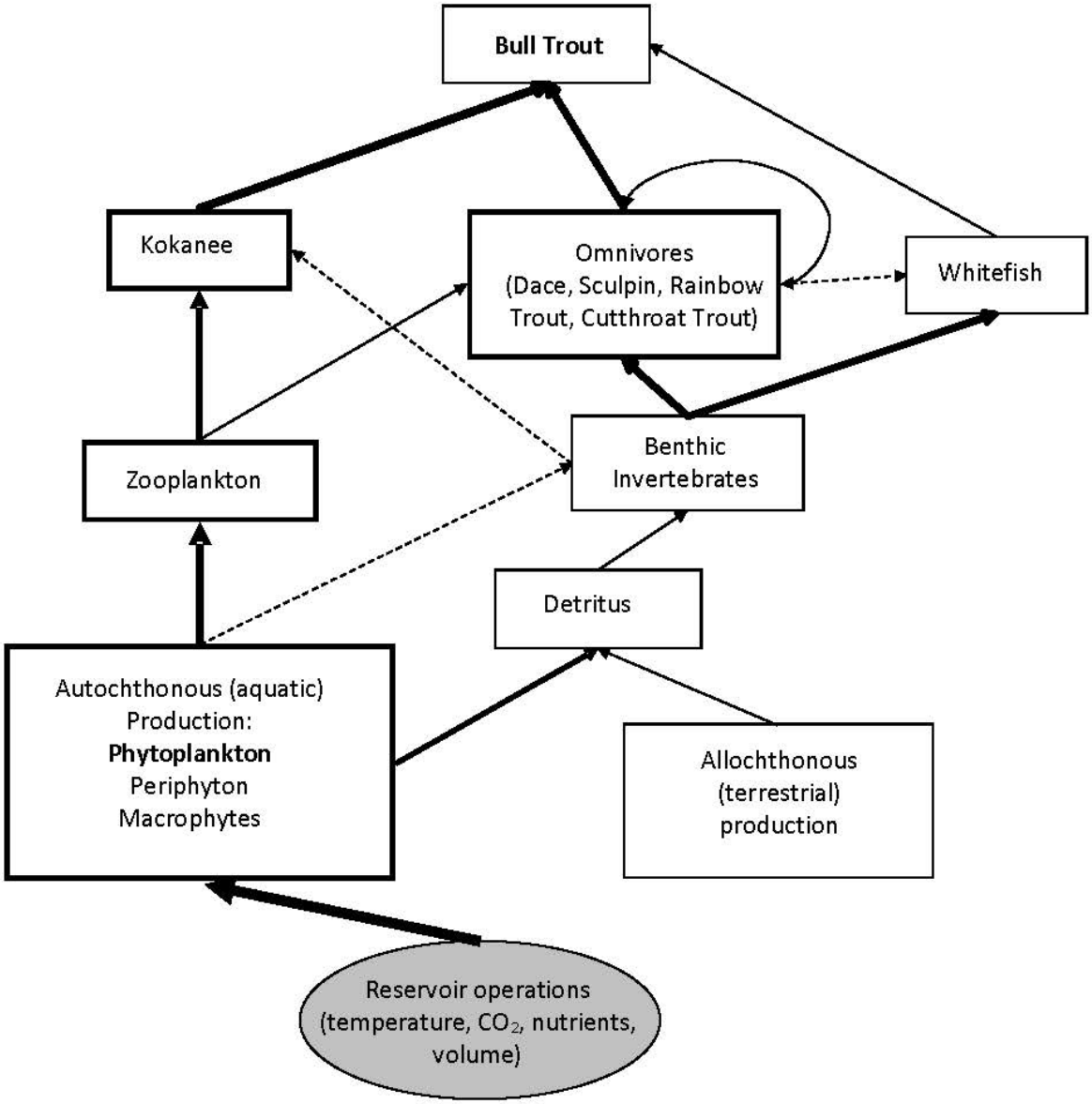


Figure 2-77. Conceptual model of the Deadwood Reservoir foodweb. Arrow thickness represents a-priori expectations for relative importance of trophic pathway for energy transfer. Dashed lines indicate linkages that may not contribute significantly to energy transfer through the foodweb.

2.3.2 Methods

Limnological Model

ELCOM v2.2 (Hodges and Dallimore 2012) and CAEDYM v3.2 (Hipsey et al. 2012) were used to model the Deadwood Reservoir in three dimensions. ELCOM and CAEDYM are dynamically coupled and include comprehensive process representation of density stratification, flow, thermal structure, major elemental cycles (C, N, P, Si, and DO), inorganic suspended solids, and phytoplankton dynamics. CAEDYM state variables occur in water column, benthic, and sediment components. Application of ELCOM-CAEDYM to the Deadwood Reservoir is detailed in Section 2.1.

We used ELCOM-CAEDYM to simulate phytoplankton production for multiple scenarios of reservoir operations for dry, average, and wet water years (Table 2-23). Hydrological conditions from 2001, 2003, and 1997 were used to calibrate the model for dry, average, and wet conditions, respectively. Field data for calibration and validation of ELCOM-CAEDYM were collected in a reservoir and tributary monitoring program from 2007 – 2011 (detailed in Section 2.1 and Chapter 3). The phytoplankton groups configured were those typically used in ELCOM-CAEDYM for temperate lakes: dinoflagellates, N-fixing freshwater cyanobacteria, cryptophytes, and freshwater diatoms. Phytoplankton dynamics included growth, metabolic losses (respiration, natural mortality, and excretion), grazing, and movement (re-suspension, settling, vertical migration). Phytoplankton growth was influenced by light, nutrients (N, P, and Si), and temperature; carbon was assumed to be non-limiting.

We ran simulations for 14 months, from November 1 through December 31 of the following year. We computed algal biomass (µg chl-a/m3) every two minutes with hourly output. We reported chlorophyll *a* (µg chl-a/L) and applied a constant carbon to chlorophyll ratio to report in units of carbon. Net primary production (NPP) of phytoplankton was reported as gross primary production minus respiration. Total lake NPP was divided by the whole- lake or epilimnion volume and surface area (obtained from ELCOM-CAEDYM) to get volumetric (g C/m3) and areal (g C/m2) NPP. Because essentially all production occurred in the epilimnion, results for whole-lake versus epilimnion NPP were very similar and so only whole-lake results were reported.

To determine phytoplankton production under different operational scenarios, we integrated total, areal, and volumetric NPP over each day using MATLAB. The integration produced daily, and when summed, annual values of algal production. For each simulation, the annual values were for the second year (January 1 to December 31). We reported annual energy available due to phytoplankton net production in units of energy (J), using average relationships for carbon-to-mass (Wetzel 1983) and energy-to-mass (Cummins and Wuycheck 1971; Equation 1):

$$P_{phyto}(\mathrm{J}) = P_{phyto}(g\ C)\left(\frac{1\ g\ AFDM}{0.53\ g\ C}\right)\left(\frac{4991\ cal}{1\ g\ AFDM}\right)\left(\frac{4.184\ J}{1\ cal}\right)$$

where P_phyto is annual net phytoplankton production reported in J and grams C, and 4991 cal/g AFDM represents an average for Cyanobacteria, dinoflagellates, and diatoms, which were the dominant phytoplankton groups.

Table 2-23. Deadwood Reservoir operational scenarios for which phytoplankton production was simulated.

Scenario Number	Background Conditions from BiOp	T&C - 3a, 3b,3e Winter Reservoir Release	River Modeling Timeframe	T&C - 3d,3c Spring Ramp Up	T&C - 3c Fall Ramp Down
	Dry (2001)				
1	Historical	Historical	11/1/00-12/31/01	Historical Actual	Historical Actual
2	0 ac-ft carry over	50 cfs	11/1/00-12/31/01	Fast	Fast
3	"	"	5/27/01- 9/12/01	Slow	Slow
4	17280 ac-ft carry over	2 cfs	11/1/00-12/31/01	Fast	Fast
5	"	"	5/27/01- 9/12/01	Slow	Slow
6	18000 ac-ft carry over	0 cfs	11/1/00-12/31/01	Fast	Fast
7	"	"	5/27/01- 9/12/01	Slow	Slow
8	Natural Flows	Natural Flows	11/1/00-12/31/01	Natural Hydrograph	Natural Hydrograph
	Average (2003)				
9	Historical	Historical	11/1/02-12/31/03	Historical Actual	Historical Actual
10	0 ac-ft carry over	50 cfs	11/1/02-12/31/03	Fast	Fast
11	"	"	7/11/03-9/30/03	Slow	Slow
12	17280 ac-ft carry over	2 cfs	11/1/02-12/31/03	Fast	Fast
13	"	"	7/11/03-9/30/03	Slow	Slow
14	18000 ac-ft carry over	0 cfs	11/1/02-12/31/03	Fast	Fast
15	"	"	7/11/03-9/30/03	Slow	Slow
16	Natural Flows	Natural Flows	11/1/02-12/31/03	Natural Hydrograph	Natural Hydrograph
	Wet (1997)				
17	Historical	Historical	11/1/96-12/31/97	Historical Actual	Historical Actual
18	0 ac-ft carry over	50 cfs	11/1/96-12/31/97	Fast	Fast
19	"	"	7/18/97-9/30/97	Slow	Slow
20	17280 ac-ft carry over	2 cfs	11/1/96-12/31/97	Fast	Fast
21	"	"	7/18/97-9/30/97	Slow	Slow
22	18000 ac-ft carry over	0 cfs	11/1/96-12/31/97	Fast	Fast
23	"	"	7/18/97-9/30/97	Slow	Slow
24	Natural Flows	Natural Flows	11/1/96-12/31/97	Natural Hydrograph	Natural Hydrograph

Stable Isotope Analysis

We sampled organisms for stable isotopes at five sites in the reservoir (DEA004, DEA006, DEA010, DEA014, and DEA016; Figure 2-78) from June to September 2009. We collected zooplankton, benthic invertebrates, periphyton, and macrophytes biweekly and collected terrestrial vegetation monthly. Fish were sampled opportunistically in space and time as they were collected for other studies. Isotopic values for phytoplankton, detritus, and terrestrial insects were estimated.

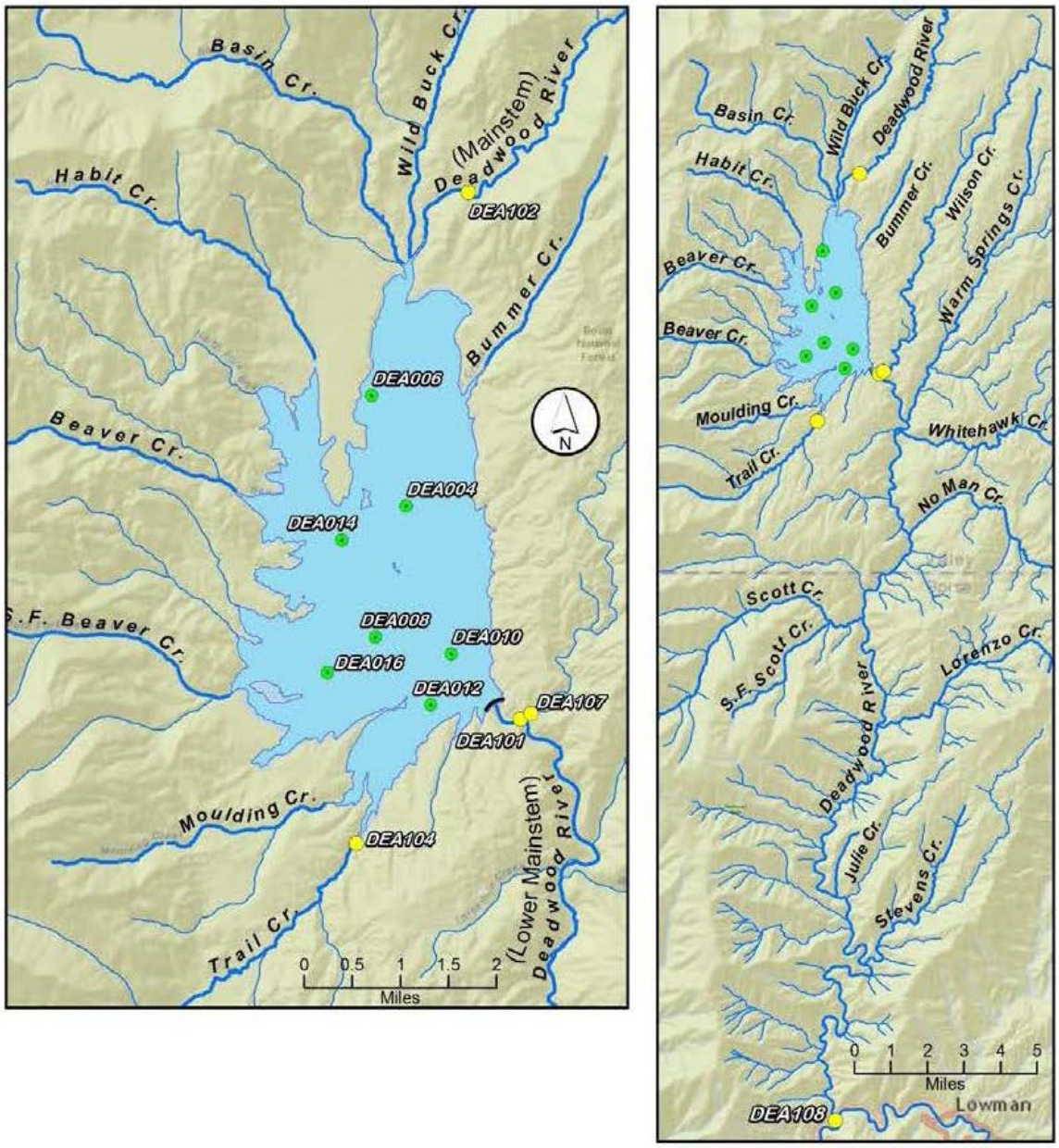


Figure 2-78. Deadwood Reservoir and River with sampling sites for the ELCOM-CAEDYM and foodweb – energy transfer models.

Zooplankton

We pulled an 80 µm net vertically from one meter above the substrate to the water surface at approximately one meter per second, recording the duration and depth of the tow. We transported live zooplankton to the laboratory in cool, filtered lake water. Within 24 hours, we picked 300–400 *Daphnia* spp. individuals from each sample using a pipet and a dissecting microscope. We held the *Daphnia* spp. for 24 hour in filtered lake water for evacuation of gut contents and then rinsed them with deionized water. This protocol for zooplankton was determined using a preliminary study, which indicated that both $\delta^{13}C$ and $\delta^{15}N$ differed significantly between herbivorous Daphnia, zooplanktivorous Calanoid copepods, and bulk net samples (Figure 2-79 and Figure 2-80). By hand-picking Daphnia, we ensured that stable isotope values would represent herbivores without contamination from zooplanktivorous zooplankton.

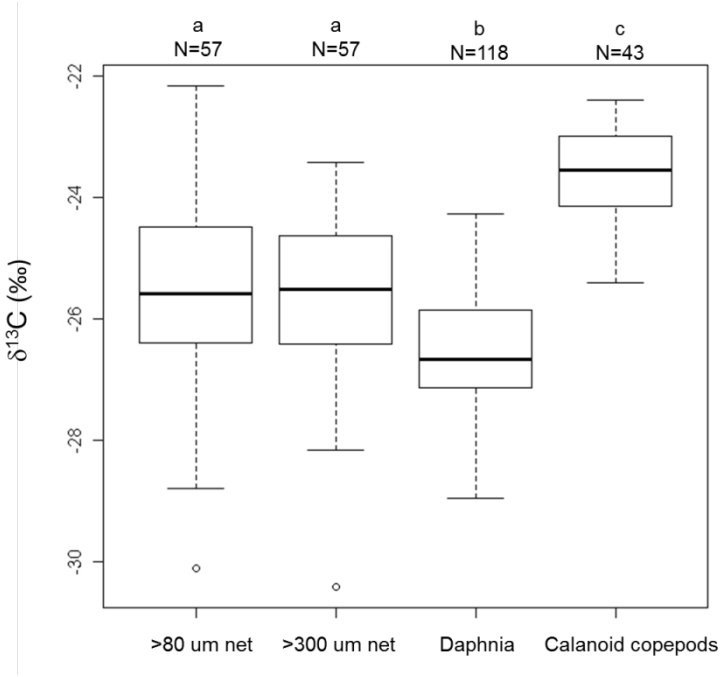


Figure 2-79. $\delta^{13}C$ for bulk zooplankton net samples (using 80 µm or 300 µm nets), *Daphnia* spp. and Calanoid copepods. Letters indicate significant differences between groups (p<0.001) and N is sample size.

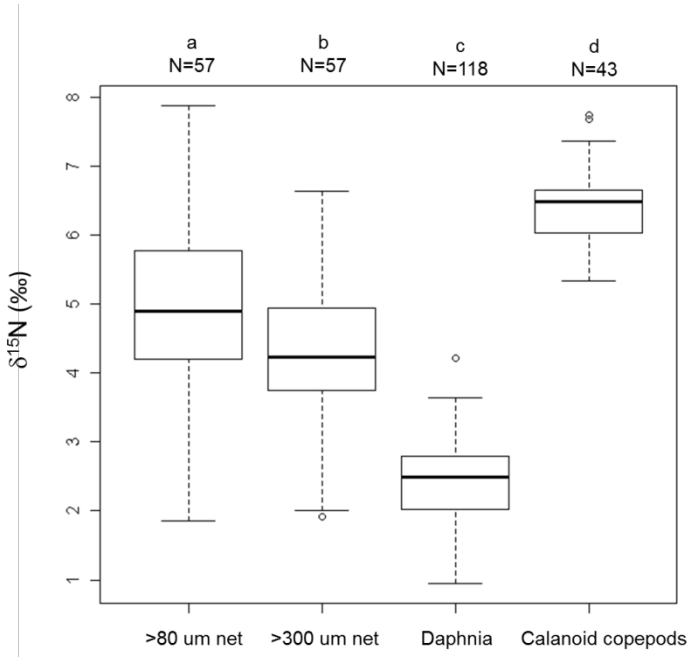


Figure 2-80. $\delta^{15}N$ for bulk zooplankton net samples (using 80 um or 300 μm nets), *Daphnia* spp. and Calanoid copepods. Letters indicate significant differences (p<0.001) and N is sample size.

Benthic Macroinvertebrates

We collected benthic macroinvertebrates with a Ponar dredge in deep water and a D-net in littoral areas, rinsed samples on a 500 μm sieve, and removed debris. We held macroinvertebrates for 24 hours in deionized water for gut evacuation and then froze them individually. At the laboratory, we thawed and identified invertebrates to family. Large invertebrates were analyzed individually and small invertebrates were pooled for analysis.

Periphyton and Macrophytes

We collected periphyton and, in the rare instances we could find them, macrophytes, monthly from littoral areas closest to each sampling site. We picked macrophytes by hand and removed periphyton from substrates (rocks, logs, submerged vegetation) using a stiff-bristled brush. Samples were frozen within 4 hours of collection.

Terrestrial Vegetation

Terrestrial plant samples were collected from riparian areas adjacent to the littoral sites. We picked leaves from dominant species, rinsed them with deionized water, and froze them within 8 hours of collection.

Fish

Reclamation biologists provided tissues from approximately five individuals of each species captured during fish surveys in the reservoir from June to October in 2009. Researchers took a non-lethal dorsal muscle biopsy using a five millimeter dermal punch (Rounick and Hicks 1985; Pinnegar and Polunin 1999; Tyus et al. 1999), swabbed the wound with Betadine, and placed the fish in fresh water to recover before release. Small (< 100 ml) individuals of non-listed species were killed and dorsal muscle was sampled by dissection. We froze fish tissues within 6 hours of collection.

Stable isotope measurement. After laboratory preparation, samples were dried at 50°C for 24 hours, ground to powder, and weighed into tins. Samples were combusted and analyzed for $^{13}C/^{12}C$ and $^{15}N/^{14}N$ on a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK) at the University of California at Davis Stable Isotope Facility. A sample's deviation of molar ratios from standards was reported as $\delta^{13}C$ and $\delta^{15}N$ (‰; Equation 2).

$$\boldsymbol{\delta_{sample} = \left(\frac{R_{sample} - R_{standard}}{R_{standard}}\right) \times 1000} \qquad \textbf{(2)}$$

where $R_C = {}^{13}C/{}^{12}C$ and $R_N = {}^{15}N/{}^{14}N$. Standards are the limestone Pee Dee belemnite (Boutton 1991) for C and N_2 in air for N (Shearer and Kohl 1993). We sent blind standards (EDTA with known $\delta^{13}C$ and $\delta^{15}N$) and blanks at a rate of 15% for quality assurance. The analytical laboratory interspersed their own laboratory standards that were calibrated against NIST Standard Reference Materials (IAEA-N1, IAEA-N2, IAEA-N3, USGS-40, and USGS-41). The long term standard deviation is 0.2 ‰ for $\delta^{13}C$ and 0.3 ‰ for $\delta^{15}N$ for laboratory standards and standard deviations for the blind EDTA standards were within 0.5 ‰ for $\delta^{13}C$ and 0.7 ‰ for $\delta^{15}N$ for all analytical batches.

Phytoplankton, detritus, and terrestrial insect signatures. Stable isotope values for phytoplankton, detritus, and terrestrial insects ("target" foodweb components) were estimated, due to high temporal variability or inadequate sample sizes for direct estimation. The general method for estimation of target taxa was to use published, quantitative relationships between target and benchmark taxa in other systems with published data (method detailed in Saito 1999).

For phytoplankton, measured isotopic values for *Daphnia* spp. in the Deadwood Reservoir and trophic fractionation factors ($\Delta\ \delta^{13}C$ and $\Delta\delta^{15}N$) were used to estimate $\delta^{13}C$ and $\delta^{15}N$ for

phytoplankton ("baseline signature" approach of Vander Zanden et al. 1999). Phytoplankton were assumed to be one trophic level below *Daphnia* spp. (Equation 3):

$$\delta^{13}C_{phyto} = \delta^{13}C_{Daphnia} - \Delta\,\delta^{13}C \quad (3)$$

where $\Delta\,\delta^{13}C$ was estimated for herbivorous invertebrates (McCutchan et al. 2003; McGrath 2004) and $\delta^{13}C_{Daphnia}$ was calculating using hand-picked *Daphnia* spp. transported live to the laboratory in 2009, because *Daphnia* frozen before analysis had elevated $\delta^{15}N$ (Table 2-24).

Isotopic values for benchmark taxa (mayflies, chironomids, and Rainbow Trout) measured in both Deadwood Reservoir and other reference locations were used to estimate $\delta^{13}C$ and $\delta^{15}N$ for target taxa (periphyton and detritus) at Deadwood. The average difference in isotopic value, or isotopic distance, between benchmark and target groups from reference studies was assumed to equal the isotopic distance between benchmark and target taxa at Deadwood Reservoir (Saito 1999).

Table 2-24. Values used to estimate stable isotope signatures for phytoplankton in the Deadwood Reservoir. Trophic fractionation coefficients are from McGrath (2004).

	Deadwood Target Organism	Deadwood Benchmark Organism	Mean Benchmark Measured Value	Sample Size	Trophic Fractionation ($\Delta\delta$)Value	Estimated Isotope Signature for Deadwood Target
$\delta^{13}C$	Phytoplankton	*Daphnia*	-25.71	56	0.41	-26.12
$\delta^{15}N$	Phytoplankton	*Daphnia*	2.60	56	2.37	0.23

Reference isotopic distances were calculated using published studies and the average value for all studies was used to estimate isotopic value for periphyton and detritus (Equation 4; Table 2-25).

$$\delta^{13}C_{target,\,Deadwood} = \delta^{13}C_{benchmark,\,Deadwood} - (\delta^{13}C_{benchmark,\,Reference} - \delta^{13}C_{target,\,Reference}) \quad (4)$$

where $\delta^{13}C_{target,\,Deadwood}$ is the estimated carbon signature for periphyton or detritus at Deadwood, $\delta^{13}C_{benchmark,\,Deadwood}$ is the measured carbon signature for the benchmark taxa (mayflies, chironomids) at Deadwood, $\delta^{13}C_{benchmark,\,Reference}$ is the measured carbon signature for the same benchmark taxa at a reference location, and $\delta^{13}C_{target,\,Reference}$ is a measured carbon signature for the periphyton or detritus at the reference location. The same procedure was used for nitrogen isotopes.

Table 2-25. Reference values used to estimate average $\delta^{13}C$ and $\delta^{15}N$ for periphyton and detritus in the Deadwood Reservoir. Target organisms at Deadwood were periphyton or detritus, for which $\delta^{13}C$ and $\delta^{15}N$ had to be estimated. Benchmark organisms were those for which measurements were available for both Deadwood Reservoir and reference studies. Details on this benchmark approach for estimation can be found in Saito (1999).

Isotope	Deadwood Target Organism	Literature Reference	Location	Benchmark Organism	Literature Value for Benchmark Organism	Literature Value for Target Organism	Deadwood Measurement for Benchmark Organism	Deadwood Estimate for Target Organism
$\delta^{13}C$	Periphyton	Angradi 1994	Colorado R, Arizona	chironomid	-32.30	-33.50	-29.70	-30.90
$\delta^{13}C$	Periphyton	Bunn et al 1989	Alik Lake, Quebec	chironomid	-21.50	-17.80	-29.70	-26.00
$\delta^{13}C$	Periphyton	Estep and Vigg 1985	Pyramid Lake, Nevada	chironomid	-23.00	-23.00	-29.70	-29.70
$\delta^{13}C$	Periphyton	Gu et al 1997	Smith Lake, Alaska	chironomid	-26.50	-30.80	-29.70	-34.00
$\delta^{13}C$	Periphyton	Gu et al 1997	Smith Lake, Alaska	mayfly	-25.00	-30.80	-20.50	-26.30
$\delta^{13}C$	Periphyton	Junger and Planas 1994	Laflamme Cr, Quebec	chironomid	-29.20	-28.50	-29.70	-29.00
$\delta^{13}C$	Periphyton	Junger and Planas 1994	De l'Aqueduc Cr, Quebec	chironomid	-25.60	-25.15	-29.70	-29.25
$\delta^{13}C$	Periphyton	Peterson et al 1993	Tundra river ecosystem	chironomid	-24.80	-29.20	-29.70	-34.10
$\delta^{13}C$	Periphyton	Peterson et al 1993	Tundra river ecosystem	mayfly	-30.90	-29.20	-20.50	-18.80
$\delta^{13}C$	Periphyton	Rau 1980	Lake Findlay, Washington	chironomid	-29.60	-34.60	-29.70	-34.70
$\delta^{13}C$	**Periphyton**	**AVERAGE**						**-29.28**
$\delta^{15}N$	Periphyton	Angradi 1994	Colorado R, Arizona	chironomid	10.30	7.00	6.01	2.71
$\delta^{15}N$	Periphyton	Estep and Vigg 1985	Pyramid Lake, Nevada	chironomid	6.50	5.00	6.01	4.51
$\delta^{15}N$	Periphyton	Gu et al 1997	Smith Lake, Alaska	chironomid	-1.30	5.00		
$\delta^{15}N$	Periphyton	Gu et al 1997	Smith Lake, Alaska	mayfly	2.00	5.00	2.55	5.55
$\delta^{15}N$	Periphyton	Peterson et al 1993	Tundra river ecosystem	chironomid	1.90	1.90	6.01	6.01
$\delta^{15}N$	Periphyton	Peterson et al 1993	Tundra river ecosystem	mayfly	3.30	1.90	2.55	1.15
δ15N	**Periphyton**	**AVERAGE**						**3.99**
$\delta^{13}C$	Detritus	Angradi 1994	Colorado R, Arizona	chironomid	-32.30	-27.60	-29.70	-25.00
$\delta^{13}C$	Detritus	Angradi 1994	Colorado R, Arizona	RBT	-23.70	-27.60		
$\delta^{13}C$	Detritus	Bunn et al 1989	Alik Lake, Quebec	chironomid	-21.50	-26.50	-29.70	-34.70
$\delta^{13}C$	Detritus	Gu et al 1997	Smith Lake, Alaska	chironomid	-26.50	-26.60	-29.70	-29.80
$\delta^{13}C$	Detritus	Gu et al 1997	Smith Lake, Alaska	chironomid	-26.50	-28.00	-29.70	-31.20
$\delta^{13}C$	Detritus	Gu et al 1997	Smith Lake, Alaska	mayfly	-25.00	-26.60	-20.50	-22.10
$\delta^{13}C$	Detritus	Gu et al 1997	Smith Lake, Alaska	mayfly	-25.00	-28.00	-20.50	-23.50
$\delta^{13}C$	Detritus	**AVERAGE**						**-27.72**
$\delta^{15}N$	Detritus	Angradi 1994	Colorado R, Arizona	chironomid	10.30	3.70	6.01	-0.59
$\delta^{15}N$	Detritus	Angradi 1994	Colorado R, Arizona	Rainbow trout	5.60	3.70		
$\delta^{15}N$	Detritus	Gu et al 1997	Smith Lake, Alaska	chironomid	-1.30	-1.30	6.01	6.01
$\delta^{15}N$	Detritus	Gu et al 1997	Smith Lake, Alaska	chironomid	-1.30	-4.80	6.01	2.51
$\delta^{15}N$	Detritus	Gu et al 1997	Smith Lake, Alaska	mayfly	2.00	-1.30	2.55	-0.75
$\delta^{15}N$	Detritus	Gu et al 1997	Smith Lake, Alaska	mayfly	2.00	-4.80	2.55	-4.25
$\delta^{15}N$	Detritus	Harrinton et al 1998	Bingo Brook, Vermont	mayfly	2.37	-0.21	2.55	-0.03
$\delta^{15}N$	Detritus	Harrinton et al 1998	West Branch, Vermont	mayfly	3.07	0.19	2.55	-0.33
$\delta^{15}N$	Detritus	Harrinton et al 1998	Bethel-Gilead, Vermont	mayfly	4.62	0.22	2.55	-1.85
$\delta^{15}N$	Detritus	Harrinton et al 1998	Peavine, Vermont	mayfly	6.43	4.70	2.55	0.82
$\delta^{15}N$	Detritus	Harrinton et al 1998	First Branch, Vermont	mayfly	8.39	1.91	2.55	-3.93
$\delta^{15}N$	Detritus	Harrinton et al 1998	Third Branch, Vermont	mayfly	10.00	1.33	2.55	-6.12
$\delta^{15}N$	Detritus	**AVERAGE**						**-0.77**

Fish Diet Analysis

We described diets of fish species in the Deadwood Reservoir by review of relevant literature and analysis of gut contents from fish collected in the reservoir. For fish that were sampled for stable isotopes, stomach contents were collected by gastric lavage and preserved in 70% ethanol. Individual prey with an intact head and thorax were identified and counted. Invertebrates typically were identified to family. Prey with complex identifying characteristics (Diptera, Gastropoda, Hirudinea and Oligochaeta) were identified to order. Prey fish were identified to species. Partially-digested prey were identified to the lowest practical level of taxonomic resolution. Samples with large numbers of small prey (e.g., zooplankton, dipteran larvae) were subsampled. Inorganic matter (sand, plastic), plants (terrestrial vegetation, macrophytes, algae, mosses), and amorphous organic detritus were noted but were not quantified. Gut contents were analyzed for abundance and prey category mass.

Foodweb – Energy Transfer Model Initial Diet Matrix

We constructed an initial diet matrix to assign potential food sources for consumers based on a literature review and gut content analysis of fish in the Deadwood Reservoir. Basal resources included phytoplankton, benthic algae, detritus, and terrestrial invertebrates; macrophytes were excluded from the foodweb model due to their scarcity in the reservoir and likelihood that they did not contribute significantly to the aquatic foodweb.

In the initial diet matrix, all potential food resources contributed equally to the diet of a consumer (Table 2-26). The initial diet matrix was used to estimate $\delta^{13}C$ and $\delta^{15}N$ for each consumer based on measured or estimated $\delta^{13}C$ and $\delta^{15}N$ in all potential food resources for that consumer (Equations 5, 6, and 7):

$$\delta^{13}C_i^{'} = \sum_{j=1}^{n}\left[f_j^{'}\left(\delta^{13}C_j + \Delta_C^{'}\right)\right] \quad \textbf{(5)}$$

$$\delta^{15}N_i^{'} = \sum_{j=1}^{n}\left[f_j^{'}\left(\delta^{15}N_j + \Delta_N^{'}\right)\right] \quad \textbf{(6)}$$

$$\sum_{j=1}^{n} f_j^{'} = 1 \quad \textbf{(7)}$$

where $\delta^{13}C_i^{'}$ is the estimated carbon signature of consumer *i*, $\delta^{15}N_i^{'}$ is the estimated nitrogen signature of consumer *i*, $\delta^{13}C_j$ is the observed carbon signature of food resource *j*; $\delta^{15}N_j$ is the observed nitrogen signature of food resource *j*; $\Delta_C^{'}$ and $\Delta_N^{'}$ are trophic fractionation factors for ^{13}C and ^{15}N; $f_j^{'}$ is the estimated proportion of diet of consumer *i* that is food resource *j*; and *n* is the total number of food resources in the diet. Trophic fractionation factors were estimated using published values from controlled diet studies (McCutchan et al. 2003; McGrath 2004; Table 2-27).

Table 2-26. Initial diet matrix for consumers and food resources in Deadwood Reservoir. Potential foods for a consumer are shaded blue or purple; white cells are not considered to be food resources for that consumer. Food resources were not assigned for grey cells (i.e., for basal resources). Initial values reflect an equal energy contribution of all potential food sources for a consumer. Blue cells were constrained to a maximum percent contribution of energy for a food resource to a consumer (Table 5). Purple cells were not constrained (i.e., maximum contribution could be 100%). BT = Bull Trout, RB = Rainbow Trout, CT = Cutthroat Trout, KOK = kokanee, MWF = Mountain Whitefish, SF = small fish (Redside Shiner, dace, sculpin), CLA = cladocerans, COP = copepods, BMI = benthic macroinvertebrates (including taxa such as Chaoborus spp. that have pelagic stages), PHY = phytoplankton, BALG = benthic algae, DET = detritus, TER = terrestrial invertebrates.

Food Resources	Consumers									Producers / Basal Resources			
	BT	RB	CT	KOK	MWF	SF	CLA	COP	BMI	PHY	BALG	DET	TER
BT	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RB	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CT	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KOK	0.13	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MWF	0.13	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SF	0.13	0.17	0.17	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CLA	0.00	0.17	0.17	0.33	0.25	0.17	0.00	0.50	0.00	0.00	0.00	0.00	0.00
COP	0.00	0.00	0.00	0.33	0.25	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BMI	0.13	0.17	0.17	0.33	0.25	0.17	0.00	0.00	0.33	0.00	0.00	0.00	0.00
PHY	0.00	0.00	0.00	0.00	0.00	0.17	1.00	0.50	0.00	0.00	0.00	0.00	0.00
BALG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
DET	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.33	0.00	0.00	0.00	0.00
TER	0.13	0.17	0.17	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-27. Trophic fractionation factors ($\Delta\delta^{13}C$ and $\Delta\ \delta^{15}N$) used for estimating diet proportions for consumers in the Deadwood Reservoir. Trophic fractionation was estimated as the average for all consumer classes, using published values from controlled diet studies (McCutchan et al. 2003; McGrath 2004).

Consumer class	Diet class	$\Delta\ \delta^{13}C$	$\Delta\ \delta^{15}N$
invertebrate	plant	0.41	2.37
invertebrate	animal	0.27	2.11
fish	animal	1.73	3.80
Average		**0.80**	**2.76**

Proportional Contribution of Food Resources to Consumers

To estimate the proportional contribution of each food resource to each consumer in the foodweb, we calculated an iterative solution of a non-linear optimization model following the approach proposed by Saito (1999) and Saito et al. (2001). The optimization algorithm minimized the sum of squared errors between the expected and observed values for $\delta^{13}C$ and $\delta^{15}N$ for all consumers simultaneously (Equations 8 – 9):

$$SSE_{\delta^{13}C} = \sum_{j=1}^{n} \left(\delta^{13}C_j - \delta^{13}C_j^{'}\right)^2 \qquad \textbf{(8)}$$

$$SSE_{\delta^{15}N} = \sum_{j=1}^{n} \left(\delta^{15}N_j - \delta^{15}N_j^{'}\right)^2 \qquad \textbf{(9)}$$

where the terms are the same as for Equations 4 – 6. The objective function is therefore (Equation 10):

$$SSE_{\delta^{13}C} + SSE_{\delta^{15}N} = 0 \qquad \textbf{(10)}$$

The optimization was done using the Solver module in Microsoft Excel, starting with the initial diet matrix with uniform diet proportions for all potential food resources for each consumer (Table 2-26). The cumulative diet proportion for each consumer was constrained to equal 1.0. Other constraints placed on the optimization solution reflected expected attributes of the foodweb (e.g., cannibalism accounts for less than 20% of the diet of Bull Trout; Table 2-28). Options specified for the Solver module were:

- Solving method = GRG Nonlinear; a generalized, reduced gradient, nonlinear optimization

- Unconstrained variables are non-negative
- Constraint precision = 0.0001
- The percentage by which the objective function can differ from the optimal value and still be considered acceptable was set at 5%
- Random seed = 13513
- Population size = 100
- Convergence criterion (the minimum relative change between iterations before the algorithm stops) = 0.001
- Forward differencing used to estimate partial derivatives of the objective and constraint functions

Table 2-28. Constraints on the proportion of diet that a potential food resource can provide to a consumer. Constraints equal to zero are shown as clear cells in Table 2-26. Constraints were assigned after review of relevant literature and analysis of gut contents for fish collected from Deadwood Reservoir.

Consumer	Food Resource	Constraint (for each food resource)
Bull Trout	Bull Trout	≤ 0.20
Rainbow Trout	Kokanee, Mountain Whitefish, or small fish	≤ 0.50
Cutthroat Trout	Kokanee, Mountain Whitefish, or small fish	≤ 0.50
Small fish	Small fish	≤ 0.20

After diet proportions were estimated by optimization, they were used to estimate trophic position for consumers (Vander Zanden et al. 1999; Vander Zanden and Rasmussen 1996; Equation 11):

$$TP_i = \sum_{j=1}^{n} \left[f_j (TP_j + 1) \right] \qquad \textbf{(11)}$$

where TPi is the estimated trophic position of consumer i, f_j is the proportion of diet of consumer i due to food resource j, TPj is the estimated trophic position of food resource j, and n is the total number of food resources in the diet of consumer j. We assumed a trophic position of 1 for phytoplankton, benthic algae and detritus, and 2.5 for terrestrial insects (Post 2002; Saito 1999). For Bull Trout, cannibalism occurred at low rates (20% or less of diet); these instances created circular references in the equation and were removed. To estimate trophic position for these cases, diet proportions were reweighted to include feeding only at lower trophic levels, resulting in small underestimates of trophic position.

Estimating Potential for Fish Production

After solving for the proportion of diet that each food resource contributed to each consumer, we estimated the proportion of energy for each consumer that ultimately derived from phytoplankton energy. This calculation equaled the sum of all potential pathways by which phytoplankton was directly or indirectly consumed by a group, assuming 10% energy transfer efficiency from one trophic level to the next (Begon et al. 1996; DeAngelis 1992; Slobodkin 1968).

To determine the relative energy derived from phytoplankton for each consumer, we performed a set of calculations given 100 J of phytoplankton energy available to each primary consumer (Figure 2-81).

To investigate the effects of reservoir operations on phytoplankton energy available to higher trophic levels, we linked the foodweb – energy transfer model to phytoplankton predictions from ELCOM-CAEDYM. We asked the question, "What potential biomass of Bull Trout could be supported by phytoplankton production under different scenarios of reservoir management?" We estimated the wet biomass of fish that could be supported by phytoplankton production for the various scenarios of reservoir operations (Equation 12):

$$\boldsymbol{Biomass_i = \Delta E_{phyto}\left(\frac{ET_i}{ED_i}\right)} \quad \textbf{(12)}$$

where $Biomass_i$ is the estimated wet biomass of fish species *i* (g), ΔE_{phyto} is the annual net phytoplankton production for the whole lake (J), ET_i the energy transfer coefficient from phytoplankton to species i, and ED_i is the energy density of species *i* (J/g). Energy density estimates were obtained from the literature (Table 2-29).

Assume Consumer Group X has three trophic pathways to phytoplankton:

Group X diet proportions = 0.15 Group Y1 + 0.85 Group Y2

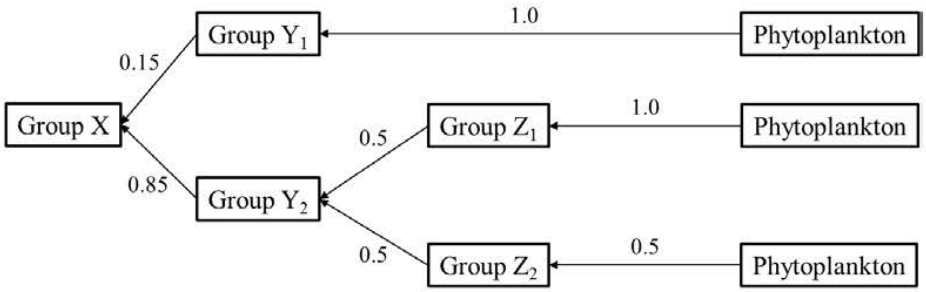
Group Y1 diet proportions = 1.0 Phytoplankton

Group Y2 diet proportions = 0.5 Group Z1 + 0.5 Group Z2

Group Z1 diet proportions = 1.0 Phytoplankton

Group Z2 diet proportions = 0.5 Phytoplankton

In an energy flow diagram, this can be shown as:



For this example, the proportion of 100 J of phytoplankton energy available to each primary consumer group, assuming 10% trophic transfer efficiency, equals:

(Group X energy from 100J of phytoplankton) =

$$
\begin{aligned}
&0.1 \times (\\
&\quad 0.15 \times \\
&\quad\quad 0.1 \times (1.0 \times 100\text{J}) + \\
&\quad 0.85 \times \\
&\quad\quad 0.1 \times (\\
&\quad\quad\quad (0.5 \times (0.1 \times 1.0 \times 100\text{J})) + \\
&\quad\quad\quad (0.5 \times (0.1 \times 0.5 \times 100\text{J}) \\
&\quad\quad) \\
&) \\
&= 0.214\ \text{J}
\end{aligned}
$$

For this example, the ultimate consumer of interest, Group X, has 0.214 J of energy available that ultimately derived from phytoplankton production.

Figure 2-81. Example calculation of relative energy derived from phytoplankton for a consumer. This example is for illustrative purposes and the data are fictitious.

Table 2-29. Energy density parameters used to convert phytoplankton energy into potential biomass for major fish species in Deadwood Reservoir.

Target Species	Reference Species Used	Energy Density (J/g)	Reference
Bull Trout	Bull Trout	6140	Mesa et al. 2013
Rainbow Trout	Rainbow Trout	5763	Hanson et al. 1997
Cutthroat Trout	Rainbow Trout	5763	Hanson et al. 1997
Kokanee	Kokanee	5233	Hyatt et al. 2011
Mountain Whitefish	Rainbow Trout	5763	Hanson et al. 1997
Small fish	Chrosomus spp. (Hanson); Cyprinids (Mazur)	5006, 7093 (mean used)	Hanson et al. 1997, Mazur 2004

2.3.3 Results and Discussion

Limnological Model

Annual NPP per unit area ranged from 238.2 to 297.5 g C/m2/y (Figure 2-82). We examined NPP both areally and volumetrically, and as expected for a northern temperate lake, most production occurred from April through October (Figure 2-83). There was little difference in daily and annual NPP between operational scenarios (Figure 2-84 through Figure 2-86), but hydrological conditions influenced whole-lake NPP strongly (Figure 2-83). Differences in daily and annual NPP between fast and slow ramping scenarios were negligible; therefore, results for only the fast ramping scenarios are shown.

For a given operational scenario, production for wet years was 134 – 156% of that for dry years. The largest difference in NPP between wet and dry years was for simulations of 50 cfs winter releases due to early depletion of reservoir in dry years, markedly decreasing production during the summer months. The timing of production also differed with hydrological condition, with productivity peaking later in the summer during dry water years compared to wet and average years (Figure 2-83). This change in timing of phytoplankton availability could potentially exert bottom-up effects on higher trophic levels including fish.

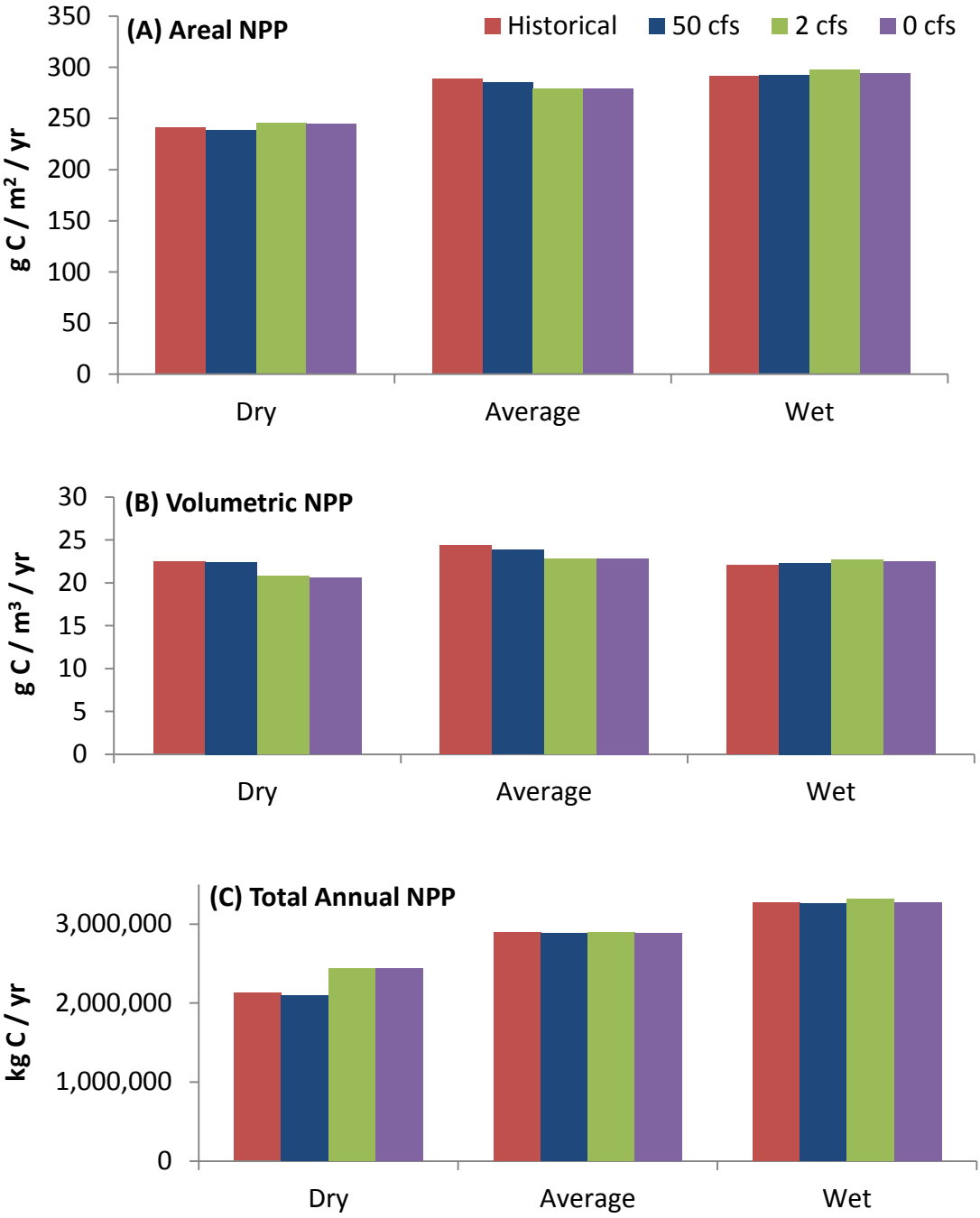


Figure 2-82. (A) Areal phytoplankton production (g C/m2/yr), (B) Volumetric phytoplankton production (g C/m3/yr), and total (whole reservoir) phytoplankton production (kg C / yr) in the Deadwood Reservoir for simulations representing alternative operational scenarios.

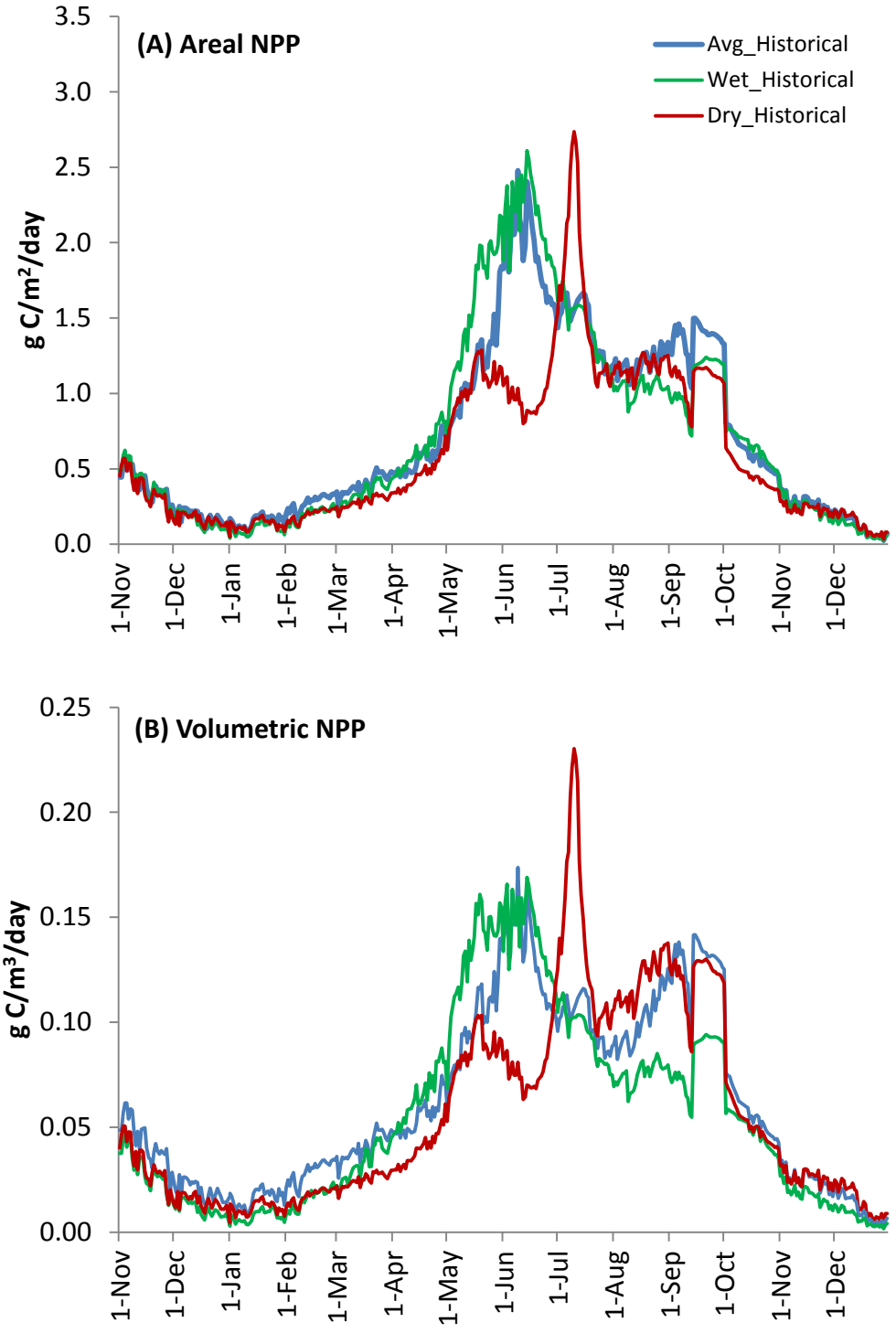


Figure 2-83. (A) Areal (g C/m2/day) phytoplankton production and (B) Volumetric phytoplankton production (g C/m3/day) for "historical" reservoir operations under dry (2001; Simulation 1), average (2003; Simulation 9), and wet (1997; Simulation 17) conditions. Simulations were run from November 1 to December 31 of the following year.

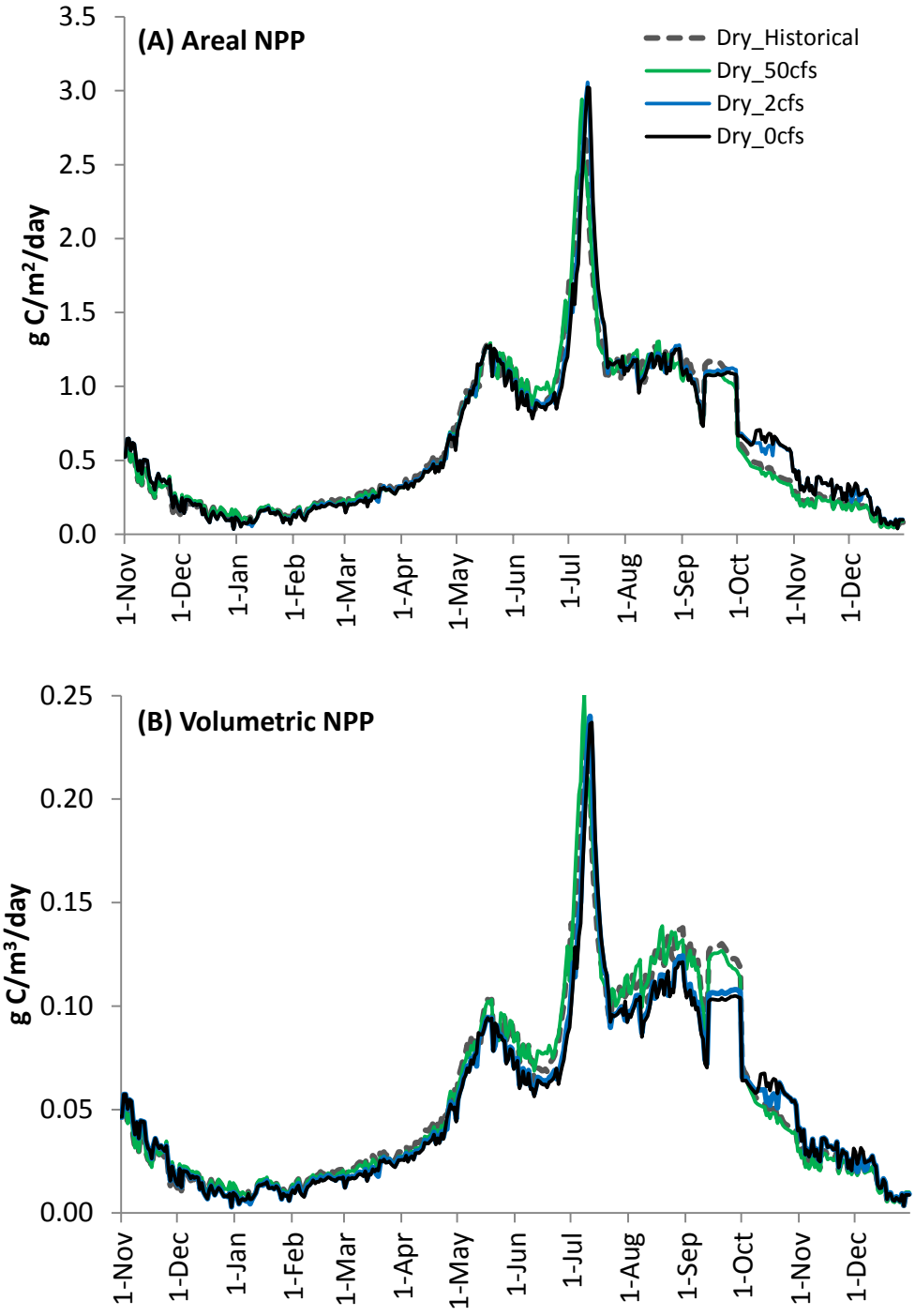


Figure 2-84. (A) Areal (g C/m^2/day) phytoplankton production and (B) Volumetric phytoplankton production (g C/m^3/day) in the Deadwood Reservoir for simulations of historical (Simulation 1), 50 cfs (Simulations 2/3), 2 cfs (Simulation 4/5), and 0 cfs (Simulation 6/7) winter release rates for a dry water year. Simulations were run from November 1 to December 31 of the following year. Differences in phytoplankton production between fast and slow ramping rates were negligible.

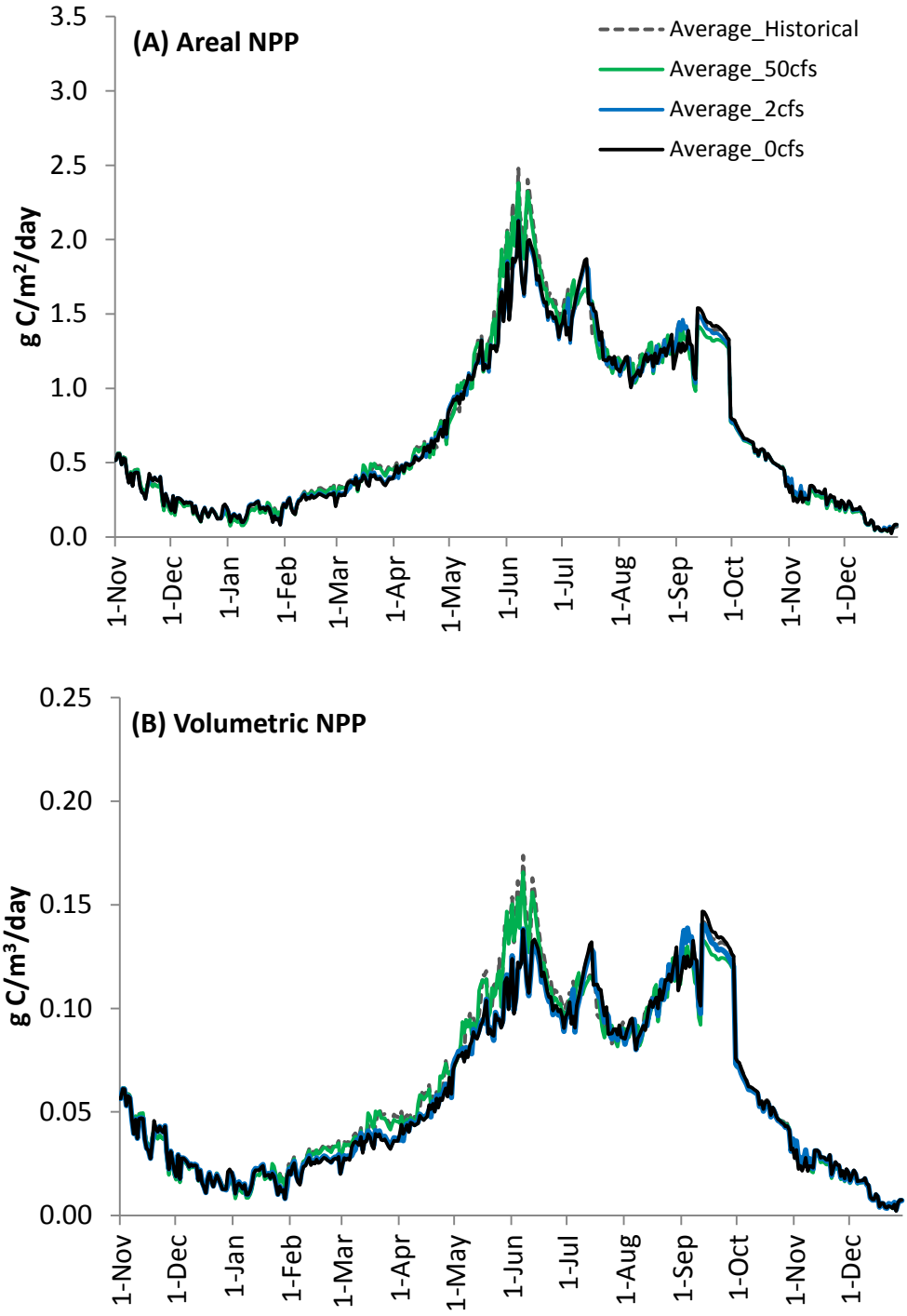


Figure 2-85. (A) Areal (g C/m^2/day) phytoplankton production and (B) Volumetric phytoplankton production (g C/m^3/day) in the Deadwood Reservoir for simulations of historical (Simulation 9), 50 cfs (Simulations 10/11), 2 cfs (Simulation 12/13), and 0 cfs (Simulation 14/15) winter release rates for an average water year. Simulations were run from November 1 to December 31 of the following year. Differences in phytoplankton production between fast and slow ramping rates were negligible.

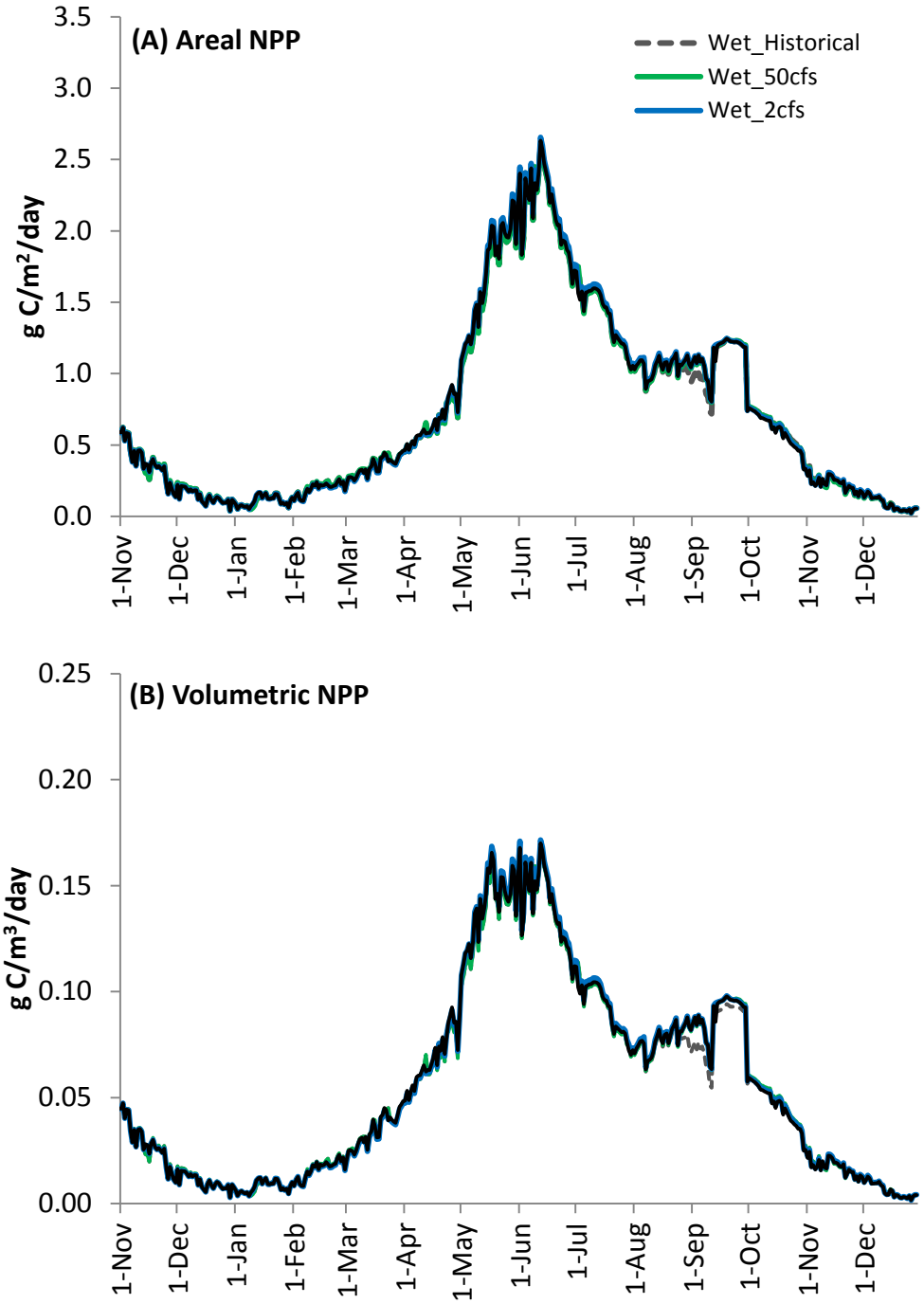


Figure 2-86. (A) Areal (g C/m^2/day) phytoplankton production and (B) Volumetric phytoplankton production (g C/m^3/day) in the Deadwood Reservoir for simulations of historical (Simulation 17) 50 cfs (Simulations 18/19), 2 cfs (Simulation 20/21), and 0 cfs (Simulation 22/23) winter release rates for a wet water year. Simulations were run from November 1 to December 31 of the following year. Differences in phytoplankton production between fast and slow ramping rates were negligible.

C and N Stable Isotopes for Foodweb Components

Separation of $\delta^{13}C$ and $\delta^{15}N$ between basal energy sources in the Deadwood Reservoir permits the use of stable isotope to trace energy flow from phytoplankton to consumers (Figure 2-87 and Figure 2-88). Stable isotope ratios for the major groups of organisms (autotrophs, invertebrates, and fishes) fell into expected ranges with reasonable levels of variation in $\delta^{13}C$ and $\delta^{15}N$. This variation likely reflects seasonal, ontogenetic, intraspecific, and interspecific variability in feeding, as well as sampling variability. Variation in $\delta^{15}N$ among consumer groups reflects predictable increases with progression up the food chain (Petersen and Fry 1987; Kling et al. 1992).

Many consumers do not have $\delta^{13}C$ values between those reported for autotrophic energy sources (e.g., phytoplankton, terrestrial vegetation) in the reservoir (Figure 2-87). Potential explanations include: 1) large trophic fractionations causing positive shift in $\delta^{13}C$ at higher trophic levels; 2) phytoplankton $\delta^{13}C$ values were more positive during seasons outside of the June to October sampling period; and 3) phytoplankton samples were contaminated with carbon of terrestrial origin and so the measured $\delta^{13}C$ does not reflect that of pure phytoplankton. Methodological challenges with obtaining pure phytoplankton samples lend support to the third hypothesis but do not exclude other explanations. Ultimately, we avoided uncertainties related to phytoplankton sampling and purification by estimating phytoplankton $\delta^{13}C$ and $\delta^{15}N$ using the baseline signature approach (Vander Zanden et al. 1999).

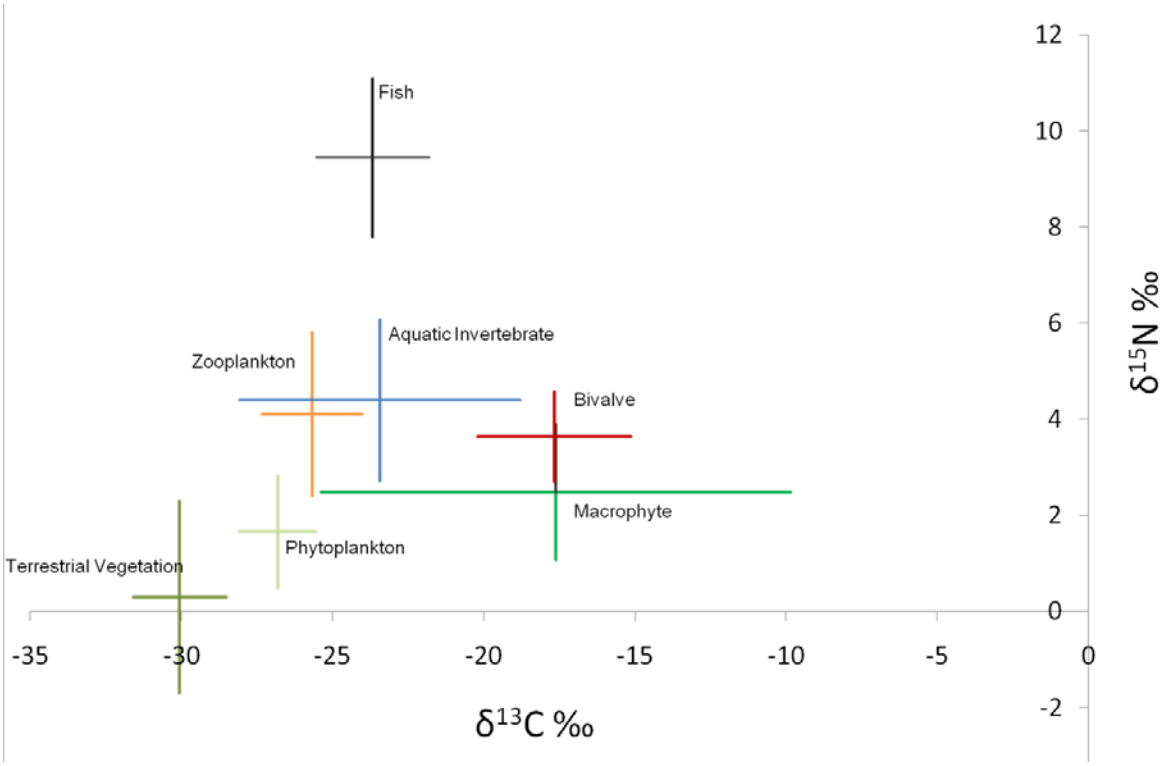


Figure 2-87. Mean (± SD) $\delta^{13}C$ and $\delta^{15}N$ for all samples collected in Deadwood Reservoir (fish, n = 149; aquatic invertebrates, n = 250; zooplankton, n = 364; bivalve, n = 14; phytoplankton, n = 41; terrestrial vegetation, n = 55; macrophyte, n = 5). Samples were collected in the 2009 field season, except fish (2008 – 2010) and zooplankton (2008 – 2009). Not all samples were used in the foodweb – energy transfer model, e.g., macrophytes and bivalves were excluded because they were assumed to not contribute significantly to the reservoir foodweb.

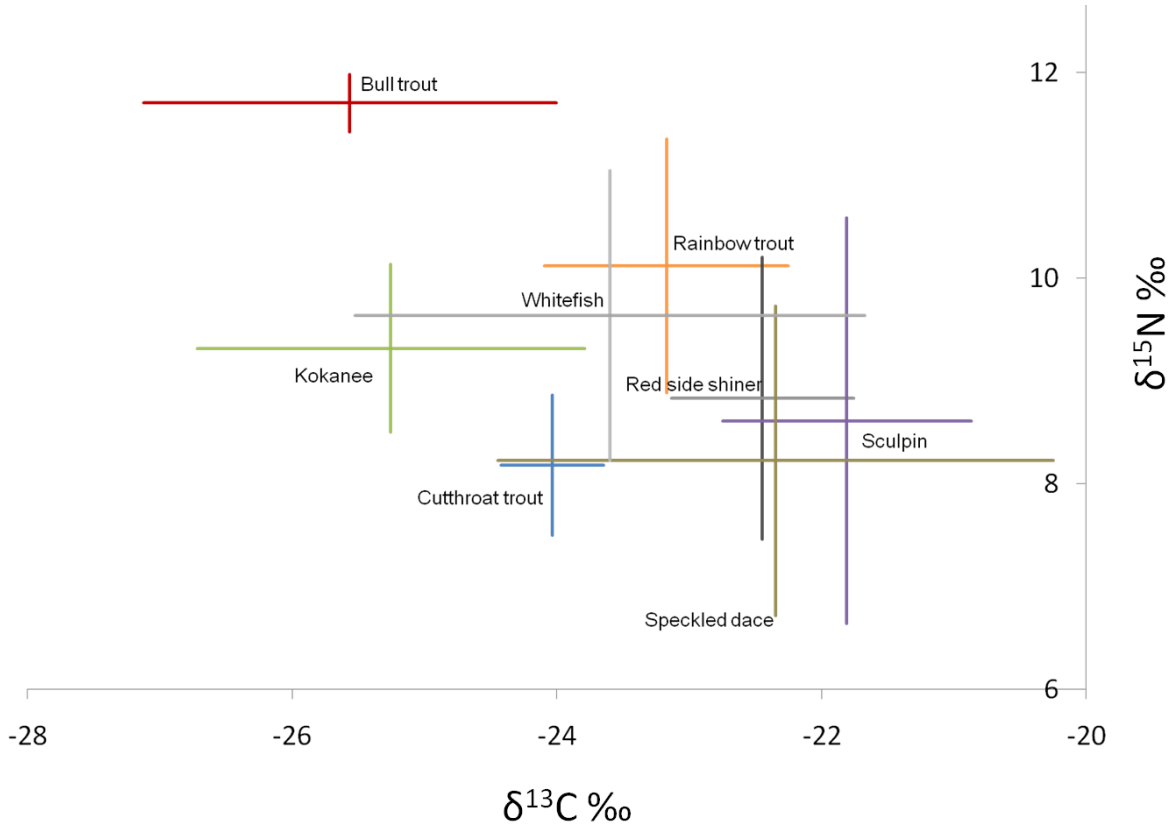


Figure 2-88. Mean (± SD) $\delta^{13}C$ and $\delta^{15}N$ for fish in Deadwood Reservoir (Bull Trout, n = 15; Rainbow Trout, n = 47; Cutthroat Trout, n = 8; Mountain Whitefish, n = 29; Speckled Dace, n = 18; Redside Shiner, n = 11; sculpin, n = 7).

Fish Diets

We analyzed fish gut contents for fish that were captured using a variety of methods including electrofishing, Fyke net, gill net, hook and line, minnow trap, trap net, and trawl. Fish may have been held in traps for up to 24 hours in some cases, and so samples were not always high quality or representative of recent feeding. Taken together, however, analysis of gut contents and review of published literature provided ample information on fish diets to structure and constrain the foodweb – energy transfer model. Total length of fish sampled for gut contents is reported, though some fish had empty guts so the effective sample size was smaller (Figure 2-89).

Fish gut contents generally confirmed expectations of feeding behavior. One notable exception was that we did not find identifiable kokanee in Bull Trout stomachs. Bull Trout primarily consumed fish and fish eggs, but prey fish often were partially digested and unidentifiable. Although we did not find kokanee in Bull Trout stomachs in this study, kokanee predation may still occur. For example, Bull Trout may consume recently hatched kokanee that are migrating to the reservoir during late winter (Vidergar 2000). Identifiable

prey in Bull Trout stomachs included dace, Redside Shiner, and invertebrates including chironomids, stoneflies, and terrestrial caddisflies (Figure 2-90). Table 2-30 provides a list of all items found in gut contents and taxon codes.

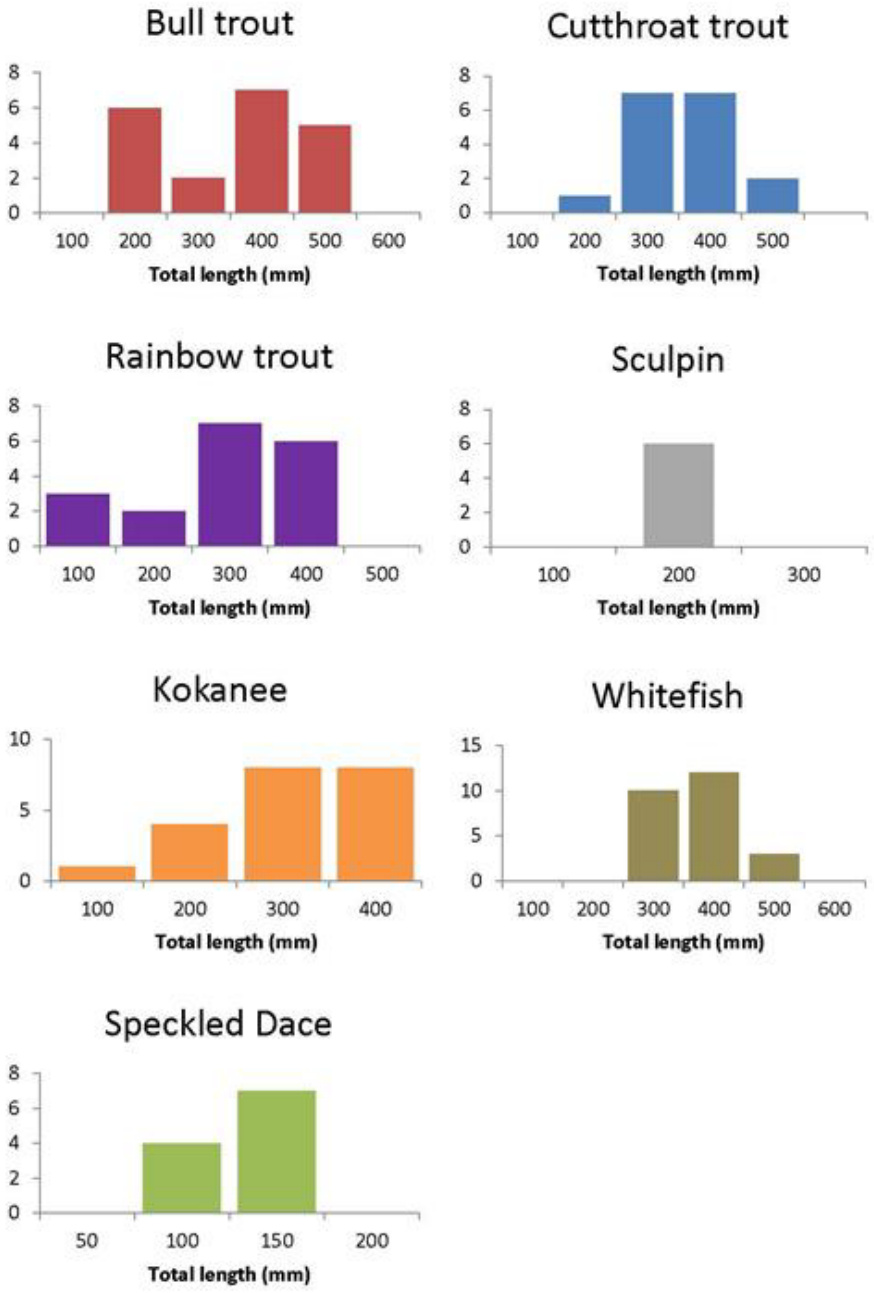


Figure 2-89. Total lengths of fish in Deadwood Reservoir sampled for gut contents. Numbers on x-axis denote upper length of length-frequency bin.

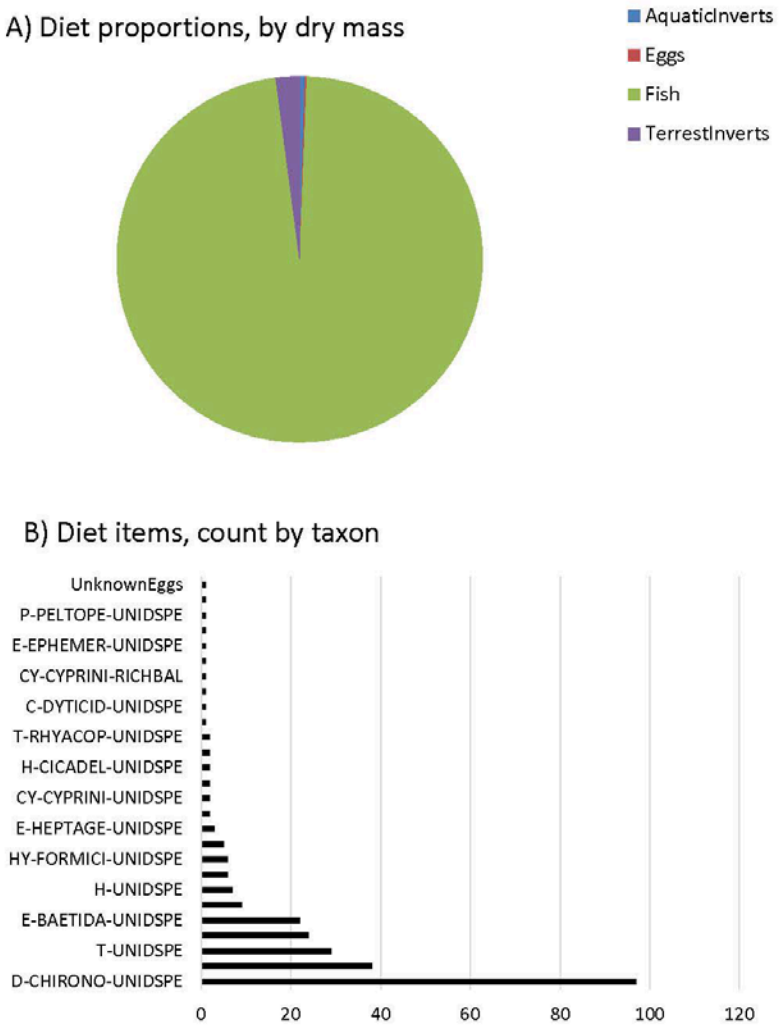


Figure 2-90. Gut contents of Bull Trout in Deadwood Reservoir (n=14). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

Table 2-30. List of fish gut content taxon codes. Taxon codes are comprised of the following: the first 1-2 capitalized letters are the first letters of "Order," next 6 letters are the first 6 letters of "Family," next 4 letters are the first 4 letters of "Genus, last 3 letters are the first 3 letters of "Species."

Taxon Code	Common Name	Order	Family
AC-HYDRACA-UNIDSPE	Water Mite	Arachnida	Hydracarina
AR-UNIDSPE	spider	Araneae	Incomplete
A-UNIDSPE	amphipod	Amphipoda	incomplete
B-BIVALVE-UNIDSPE	Clam	Bivalve	incomplete
C-AMPHIZO-AMPHSPE	Beetle	Coleoptera	Amphizoidae
C-DYTICID-UNIDSPE	Beetle	Coleoptera	Dyticidae
C-HYDROPH-UNIDSPE	Beetle	Coleoptera	Hydrophilidae
CL-CALANOI-UNIDSPE	Zooplankton	Calanoida	incomplete
CL-CYCLOPO-UNIDSPE	Zooplankton	Cyclopoida	incomplete
CL-DAPHNII-DAPHSPE	Zooplankton	Cladocera	Daphniidae
CL-HOLOPED-HOLOGIB	Zooplankton	Cladocera	Holopedidae
CL-LEPTODO-LEPTKIN	Zooplankton	Cladocera	Leptodoridae
CO-COLLEMB-SMINSPE		Collembola	Collembola
C-UNIDSPE	beetle	Coleoptera	Incomplete
CY-CYPRINI-UNIDSPE	Fish	Cypriniformes	Cyprinidae
CY-UNIDSPE	Fish	Cypriniformes	incomplete
D-CERATOP-UNIDSPE	Fly	Diptera	Ceratopogoniidae
D-CHIRONO-UNIDPUP	Fly	Diptera	Chironomid
D-CHIRONO-UNIDSPE	Fly	Diptera	Chironomidae
D-EMPIDID-UNIDSPE	Fly	Diptera	Empididae
D-SIMULII-UNIDSPE	Fly	Diptera	Simuliidae
D-TIPULID-UNIDSPE	Fly	Diptera	Tiplulidae
D-UNIDPUP	Fly	Diptera	Incomplete
E-AMELETI-UNIDSPE	Mayfly	Ephemeroptera	Ameletidae
E-BAETIDA-BAETSPE	Mayfly	Ephemeroptera	Baetidae
E-BAETIDA-UNIDSPE	Mayfly	Ephemeroptera	Baetidae
E-EPHEMER-DRUNSPE	Mayfly	Ephemeroptera	Ephemerellidae
E-EPHEMER-UNIDSPE	Mayfly	Ephemeroptera	Ephemerellidae
E-HEPTAGE-CINYSPE	Mayfly	Ephemeroptera	Heptageniidae
E-HEPTAGE-UNIDSPE	Mayfly	Ephemeroptera	Heptageniidae
E-INCOMPL-UNIDSPE	Mayfly	Ephemeroptera	Incomplete
E-UNIDSPE	mayfly	Ephemeroptera	Incomplete
FishEgg	eggs		
G-UNIDSPE	snail	Gastropoda	Incomplete
H-APHIDID-UNIDSPE	Aphid	Hemiptera	Aphididae

Taxon Code	Common Name	Order	Family
H-CICADEL-UNIDSPE	cicada	Hemiptera	Cicadellidae
H-CORIXID-UNIDSPE	water boatman	Hemiptera	Corixidae
HD-UNIDSPE	leech	Hirudinea	incomplete
HO-UNIDSPE	homopterid	Homoptera	incomplete
H-UNIDSPE	N/A	Hemiptera	Incomplete
HY-APIDAE-UNIDSPE	bee	Hymenoptera	
HY-FORMICI-UNIDSPE	Ant	Hymenoptera	Formicidae
HY-UNIDSPE		Hymenoptera	incomplete
HY-VESPIDA-UNIDSPE	Wasp	Hymenoptera	Vespidae
L-UNIDSPE	moth	Lepidoptera	incomplete
M-SIALIDA-UNIDSPE	Dobson fly	Megaloptera	Sialidae
NE-UNIDSPE	unknown	Neuroptera	incomplete
OD-UNIDSPE	Dragonfly	Odonata	incomplete
OR-UNIDSPE	Grasshopper	Orthoptera	incomplete
O-UNIDSPE	worm	Oligochaeta	incomplete
P-CHLOROP-UNIDSPE	Stonefly	Plecoptera	Chloroperlidae
P-NEMOURI-UNIDSPE	Stonefly	Plecoptera	Nemouridae
P-PELTOPE-UNIDSPE	Stonefly	Plecoptera	Peltoperlidae
P-PERLIDA-UNIDSPE	Stonefly	Plecoptera	Perlidae
P-PTERONA-UNIDSPE	Stonefly	Plecoptera	Pteronarcydae
P-UNIDSPE	Stonefly	Plecoptera	Incomplete
SC-COTTIDA-UNIDSPE	Fish	Scorpaeniformes	Cottidae
T-BRACHYC-UNIDSPE	Caddisfly	Trichoptera	Brachycentridae
T-GLOSSOS-UNIDSPE	Caddisfly	Trichoptera	Glossosomatidae
TH-UNIDSPE		Thysanoptera	incomplete
T-HYDROPS-UNIDSPE	Caddisfly	Trichoptera	Hydropsychidae
T-LEPIDOS-UNIDSPE	Caddisfly	Trichoptera	Lepidostomatidae
T-LEPTOCE-UNIDSPE	Caddifly	Trichoptera	Leptoceridae
T-LIMNEPH-UNIDSPE	Caddisfly	Trichoptera	Limnephilidae
T-PHILOPO-UNIDSPE	Caddisfly	Trichoptera	Philopotamidae
T-RHYACOP-RHYASPE	Caddisfly	Trichoptera	Rhyacophilidae
T-UENOIDA-UNIDSPE	Caddisfly	Trichoptera	Uenoidae
T-UNIDSPE	Caddisfly	Trichoptera	Incomplete
Unknown Eggs	eggs		

The diet of Cutthroat Trout (n=12) was dominated by eggs and terrestrial ants (*Formicidae spp*.). Cutthroat Trout also consumed a variety of aquatic invertebrates, especially chironomids (Figure 2-91). Rainbow Trout (n=12) were omnivores, consuming aquatic invertebrates, fish, terrestrial invertebrates, and a small number of eggs (Figure 2-92). Fish consumed by Rainbow Trout included Redside Shiner and "unidentifiable" Cyprinids, which may also have been Redside Shiner. Kokanee (n=12) diets were dominated by Daphnia spp. (Figure 2-93). Both whitefish (n=12) and speckled dace (n=12) consumed aquatic invertebrates, with smaller proportions of terrestrial invertebrates and eggs (Figure 2-94 and Figure 2-95). Longnose dace (n=1), Redside Shiner (n=1), and sculpin (n=6) gut contents consisted entirely of aquatic invertebrates (Figure 2-96 through Figure 2-98). In addition to aquatic insects, sculpin consumed zooplankton (*Daphnia spp*). Chironomid larvae tended to be a particularly important food resource, constituting the most numerous items in gut contents for Rainbow Trout, Whitefish, Kokanee, and Longnose Dace. In turn, chironomid larvae eat algae, detritus, or other invertebrates, depending on species.

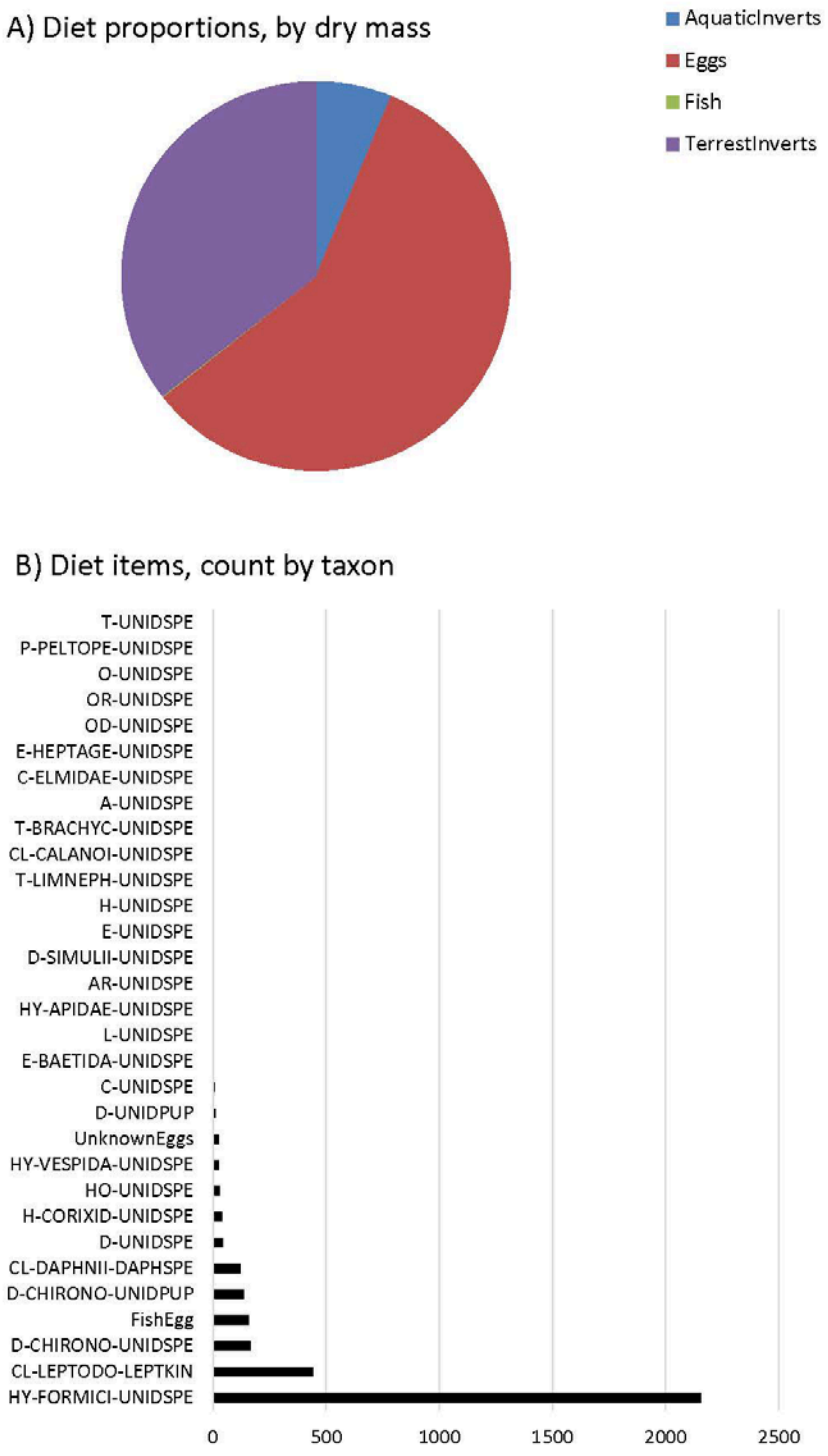


Figure 2-91. Gut contents of Cutthroat Trout in Deadwood Reservoir (n=12). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

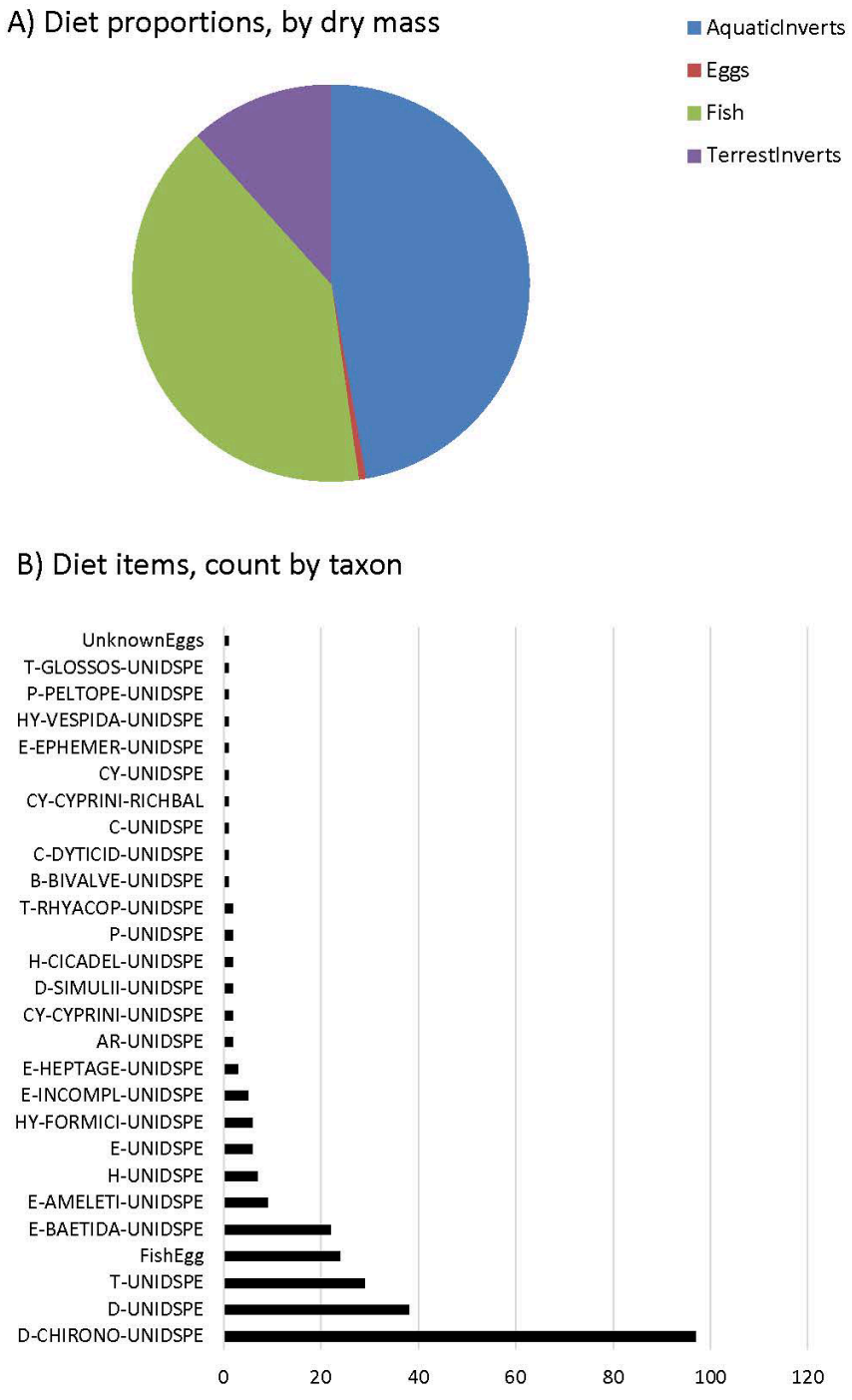


Figure 2-92. Gut contents of Rainbow Trout in Deadwood Reservoir (n=12). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

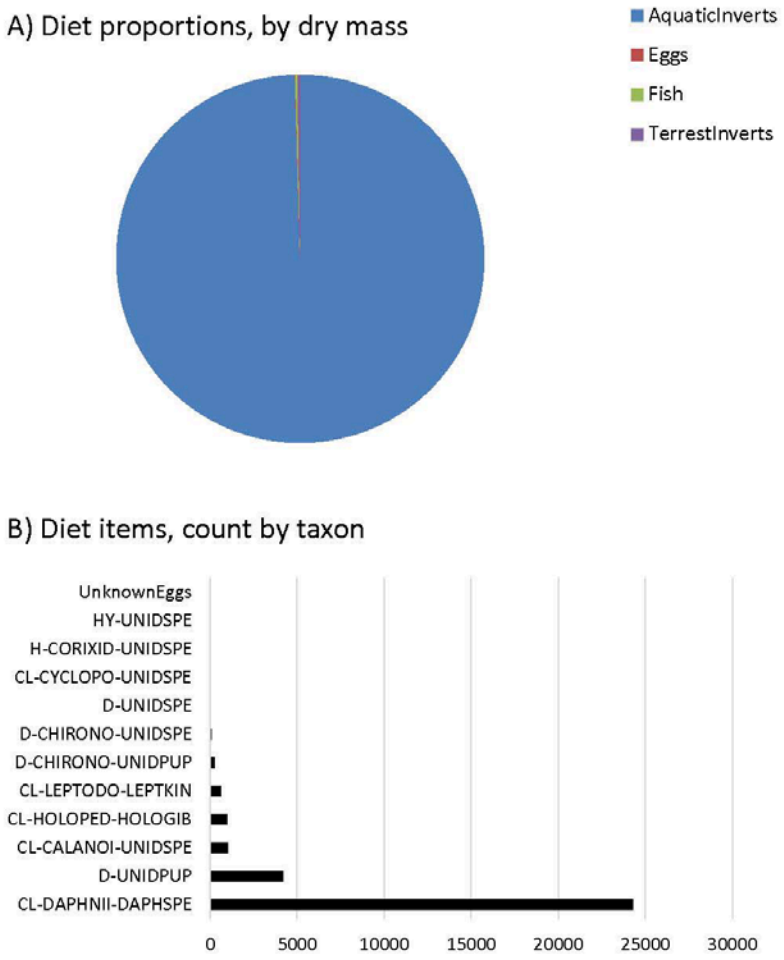


Figure 2-93. Gut contents of kokanee in Deadwood Reservoir (n=12). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

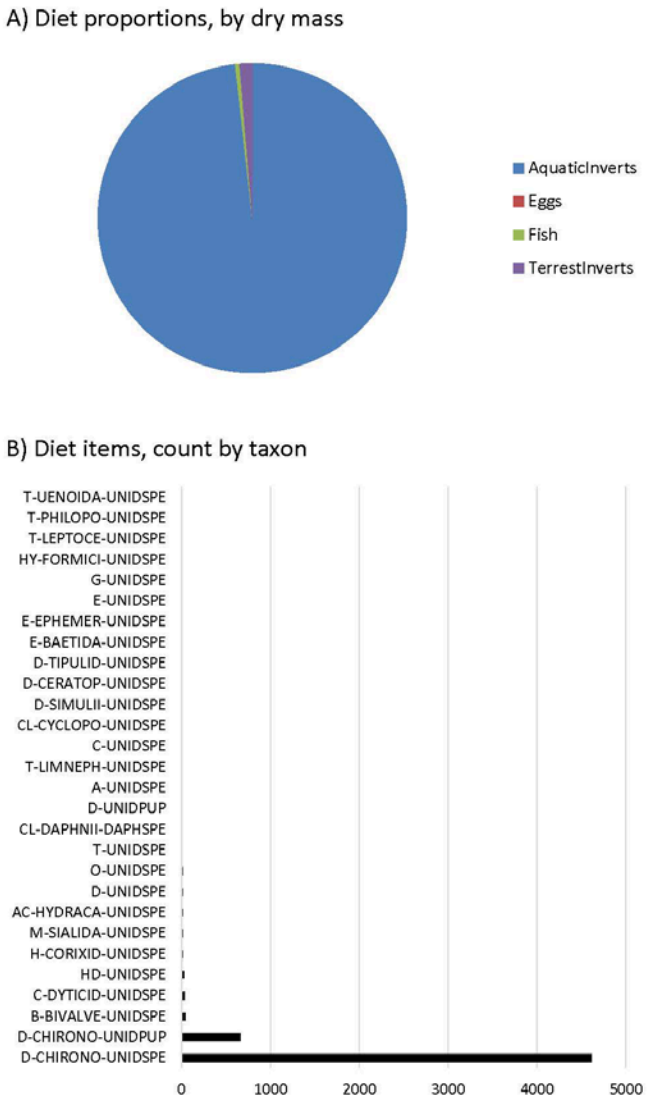


Figure 2-94. Gut contents of whitefish in Deadwood Reservoir (n=12). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

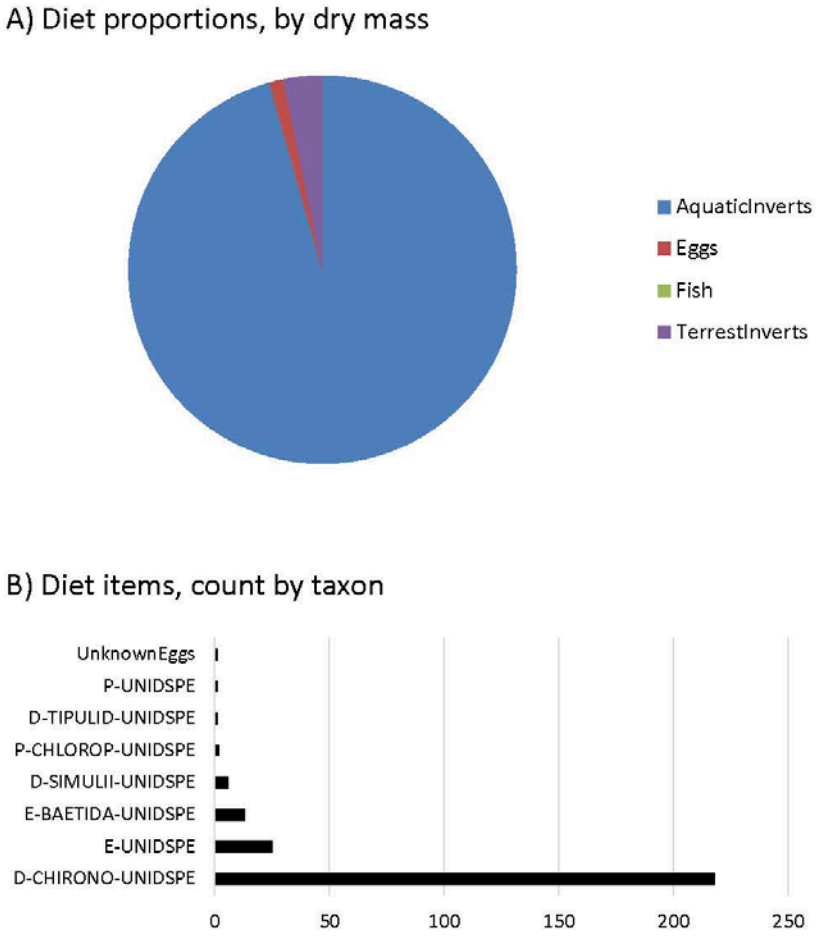


Figure 2-95. Gut contents of Speckled Dace in Deadwood Reservoir (n=12). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

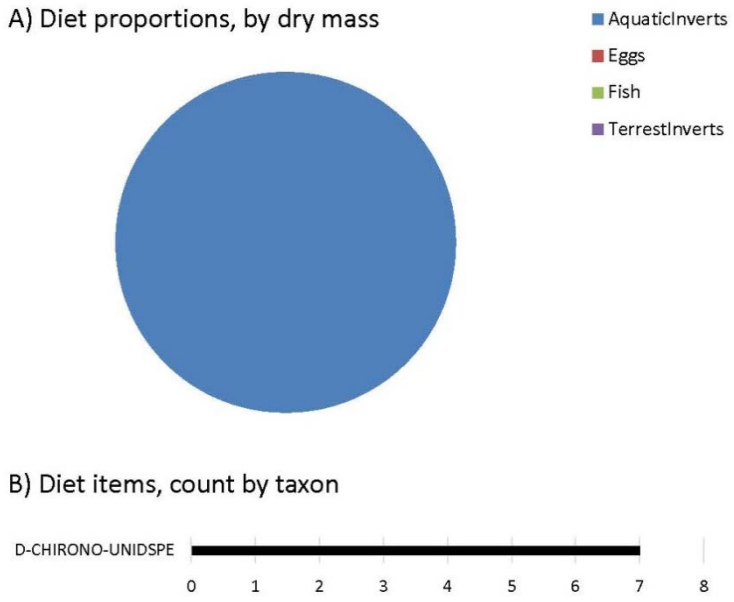


Figure 2-96. Gut contents of Longnose Dace in Deadwood Reservoir (n=1). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

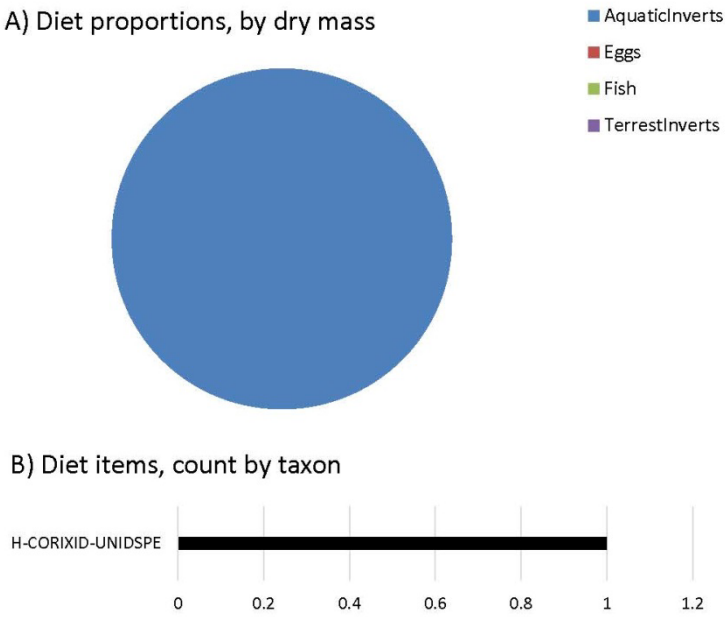


Figure 2-97. Gut contents of Redside Shiner in Deadwood Reservoir (n=1). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

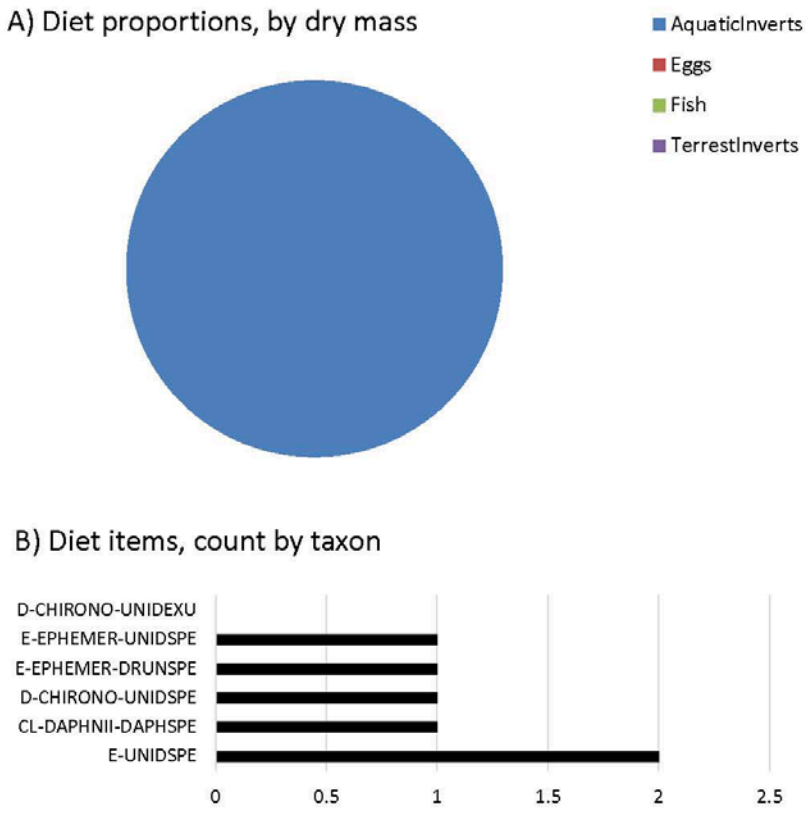


Figure 2-98. Gut contents of sculpin in Deadwood Reservoir (n=6). A) Proportional contribution of major diet categories (aquatic invertebrates, fish, fish or amphibian eggs, terrestrial invertebrates) by dry mass. B) Count of diet items by taxon. Taxon codes are in Table 2-30.

Estimating Potential for Fish Production under Alternative Operational Scenarios

Solver converged to a global solution with an objective function of 6.13 (‰)^2. The optimization solution predicted the proportional contribution of each food resource to the diet of a consumer, which is shown in a final diet matrix (Table 2-31). Using these diet proportions, we estimated trophic position and phytoplankton-derived energy available for each consumer (Table 2-32), and calculated potential for production of fish biomass (Table 2-33).

As expected, kokanee were highly dependent on phytoplankton production and a large potential biomass (~100,000 – 160,000 kg) of Kokanee was supported. Mountain Whitefish had a very small dependence on phytoplankton production. This is because Whitefish did not utilize Cladocera at all in the final foodweb matrix, although gut content analysis showed a few Daphnia spp. in their gut contents. Rainbow Trout, Cutthroat Trout, and small fish had intermediate dependencies on phytoplankton production (Table 2-31through Table 2-33).

Table 2-31. Final diet matrix showing energy contribution of potential food sources to consumers in Deadwood Reservoir. Potential foods for a consumer are shaded blue or purple; white cells are not considered to be food resources for that consumer. Blue cells were constrained to a maximum percent contribution of energy for a food resource to a consumer (Table 2-27). Purple cells were not constrained (i.e., maximum contribution could be 100%). Final values reflect a global solution to the objective function set in the optimization routine. BT = Bull Trout, RB = Rainbow Trout, CT = Cutthroat Trout, KOK = Kokanee, MWF = Mountain Whitefish, SF = small fish (Redside Shiner, Dace, Sculpin), CLA = cladocerans, COP = copepods, BMI = benthic macroinvertebrates (including taxa such as Chaoborus spp. that have pelagic stages), PHY = phytoplankton, BALG = benthic algae, DET = detritus, TER = terrestrial invertebrates.

Food Resources	Consumers									Producers / Basal Resources			
	BT	RB	CT	KOK	MWF	SF	CLA	COP	BMI	PHY	BALG	DET	TER
BT	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KOK	0.80	0.21	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MWF	0.00	0.19	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SF	0.00	0.23	0.03	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CLA	0.00	0.06	0.34	0.28	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00
COP	0.00	0.00	0.00	0.72	0.86	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BMI	0.00	0.15	0.17	0.00	0.00	0.49	0.00	0.00	0.34	0.00	0.00	0.00	0.00
PHY	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00
BALG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
DET	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
TER	0.12	0.16	0.19	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-32. Optimization model results for the Deadwood Reservoir foodweb. Observed values for $\delta^{13}C$ and $\delta^{15}N$ (‰) were measured or estimated for organisms from Deadwood Reservoir. Expected values were calculated assuming equal contribution of all potential food sources to the diet of a consumer. Sums of squared differences (SSE) were for observed minus expected $\delta^{13}C$ and $\delta^{15}N$. Trophic level was calculated using optimization predictions of diet for each consumer. Energy flow (J) is the energy transferred from 100 J of phytoplankton energy available to primary consumers.

	$\delta^{13}C$			$\delta^{15}N$				
Group Name	**Observed**	**Expected**	**SSE**	**Observed**	**Expected**	**SSE**	**Trophic Level**	**Energy Flow**
Bull Trout	-25.59	-24.41	1.39	11.72	11.97	0.06	3.9	0.052
Rainbow Trout	-23.07	-23.07	<0.001	10.11	10.12	<0.001	3.6	0.119
Cutthroat Trout	-24.03	-24.04	<0.001	8.18	8.18	<0.001	3.2	0.337
Kokanee	-25.26	-23.60	2.77	9.32	8.14	1.40	3.4	0.635
Mountain Whitefish	-23.46	-22.94	0.27	9.5	9.05	0.20	3.3	0.009
Small fish	-22.22	-22.41	0.04	8.49	8.56	0.01	3.2	0.424
Cladocerans	-26.44	-26.44	0	2.56	2.56	0	2	10
Copepods	-23.64	-23.64	0	6.42	6.42	0	2.5	5
Benthic macro-invertebrates	-23.23	-23.23	0	4.35	4.35	0	2.0	0
Phytoplankton	-26.12	-26.12	0	0.23	0.23	0	1.0	100
Benthic Algae	-29.28	-29.28	0	3.99	3.99	0	1.0	---
Detritus	-27.72	-27.72	0	-0.77	-0.77	0	1.0	---
Terrestrial invertebrates	-24.49	-24.49	0	5.33	5.33	0	3.9	---

Table 2-33. Potential fish biomass supported by annual net primary production (NPP) of phytoplankton in Deadwood Reservoir. Potential fish biomass was simulated for alternative scenarios of reservoir operations for dry, average, and wet water years.

Scenario		Annual NPP (kg C/yr)	Annual Phytoplankton Energy Produced (J)	Phytoplankton Energy Available to Bull Trout (J)	Potential Biomass Supported by Annual Phytoplankton Production (kg)					
					Bull Trout	Rainbow Trout	Cutthroat Trout	Kokanee	Mountain Whitefish	Small Fish
Dry										
1	Historical	2,130,257	8.39335E+13	43,645,418,911	7,108	17,331	49,081	101,849	1,230	58,823
2/3	50 cfs	2,092,525	8.24468E+13	42,872,360,862	6,982	17,024	48,212	100,045	1,209	57,781
4/5	2 cfs	2,436,688	9.60071E+13	49,923,691,680	8,131	19,824	56,142	116,500	1,407	67,284
6/7	0 cfs	2,437,712	9.60474E+13	49,944,667,720	8,134	19,833	56,165	116,549	1,408	67,313
Average										
9	Historical	2,891,010	1.13908E+14	59,231,978,600	9,647	23,521	66,609	138,222	1,670	79,829
10/11	50 cfs	2,886,488	1.13729E+14	59,139,338,335	9,632	23,484	66,505	138,005	1,667	79,705
12/13	2 cfs	2,890,976	1.13906E+14	59,231,295,167	9,647	23,520	66,608	138,220	1,670	79,829
14/15	0 cfs	2,882,249	1.13562E+14	59,052,486,278	9,618	23,449	66,407	137,803	1,665	79,588
Wet										
17	Historical	3,268,528	1.28782E+14	66,966,714,746	10,907	26,592	75,307	156,271	1,888	90,254
18/19	50 cfs	3,254,083	1.28213E+14	66,670,750,394	10,858	26,475	74,974	155,580	1,879	89,855
20/21	2 cfs	3,314,475	1.30592E+14	67,908,088,559	11,060	26,966	76,366	158,468	1,914	91,523
22/23	0 cfs	3,270,529	1.28861E+14	67,007,701,914	10,913	26,608	75,353	156,367	1,889	90,309

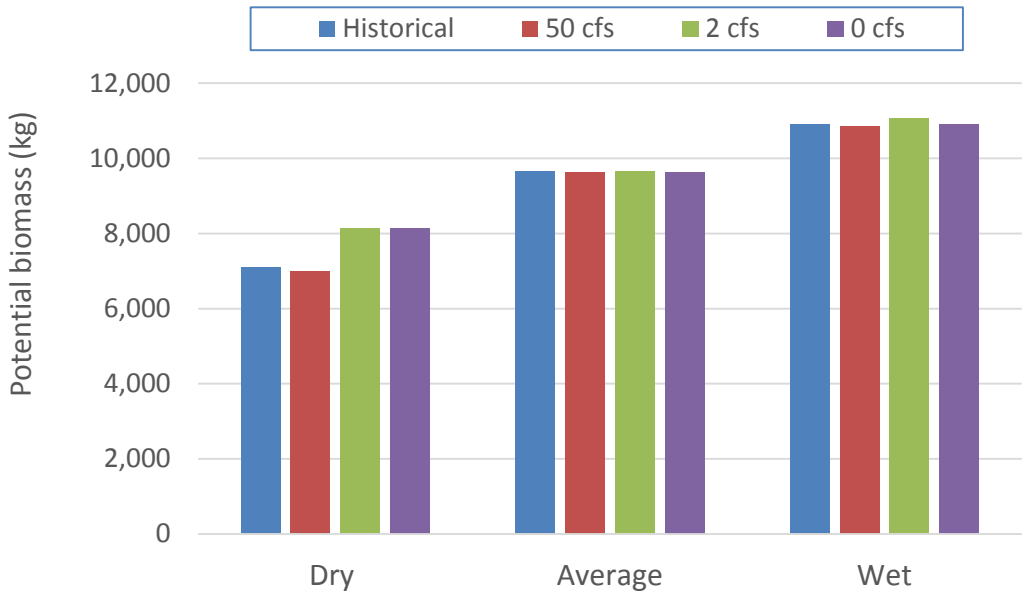


Figure 2-99. Potential biomass of Bull Trout supported by phytoplankton for alternative scenarios of reservoir operations. For other fish species, the percent difference in potential fish biomass between scenarios is the same as shown here, but the values on the y-axis differ (Table 2-32) due to varying reliance on phytoplankton energy among consumers.

The potential for Bull Trout production ranged from ~7,000 – 11,000 kg/yr among scenarios (Table 2-33; Figure 2-99). Reservoir operations had little effect on potential biomass of Bull Trout and other fish for average and wet water years. For dry water years, the potential for Bull Trout production for 0- and 2-cfs winter release scenarios was approximately 15% higher than for 50 cfs and historic winter release scenarios (Figure 2-99).

An assumption inherent with our approach is that the proportion of a consumer's biomass that ultimately derives from phytoplankton does not vary among reservoir operational scenarios. In other words, Bull Trout populations are uniformly limited by food under divergent operational scenarios and background conditions. Note that Figure 2-99 is equivalent to Figure 2-82 with a different y-axis, because the calculations used to convert phytoplankton to fish production can be distilled into a simple conversion factor for each fish species. Another important consideration is that Bull Trout in the Deadwood Reservoir are adfluvial, spawning in tributaries where offspring rear for 1 to 2 years before migrating to the reservoir (Vidergar 2000). The response variable "potential for Bull Trout production" should be viewed broadly as growth potential for fish while in the reservoir.

2.3.4 Summary and Conclusions

Simulation results showed that for average and wet hydrological conditions, reservoir operations had little to no effect on phytoplankton energy available to Bull Trout. For dry years, Bull Trout potential production was ~15% higher for low winter release (0 or 2 cfs) scenarios than for higher (50 cfs or historic) winter release scenarios. To maximize potential for Bull Trout production in the reservoir, our results suggest implementing low winter releases during dry years. Of course, this recommendation should be weighed with other considerations including effects on Bull Trout and their prey base in the regulated river downstream.

Quantitative estimates of Bull Trout population size in the Deadwood Reservoir are not available; however, fishery surveys over the past decade indicate that the population is far smaller than what the results of this study suggest could be supported given the reservoir food base. Put simply, food is not limiting Bull Trout populations in the Deadwood Reservoir. Support for this conclusion is given by the abundance of forage fish and the observation that Bull Trout in the reservoir have good body condition. Other mechanisms that may limit Bull Trout populations include direct effects of reservoir operations on temperature, DO, and migration barriers, particularly in dry hydrological conditions. In addition, spawning or rearing habitat in tributaries could limit adfluvial populations. The results of this study indicate that an increase in food available to Bull Trout in Deadwood Reservoir probably will not be utilized until other limiting factors are addressed.

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Chapter 3 EVALUATION OF RIVER CONDITIONS

3.1 Physical Conditions in the Deadwood River in Response to Reservoir Operations

3.1.1 Introduction

Study Site: Lower Deadwood River, Idaho

The Deadwood River is located in the Central Idaho batholith and drains the mountainous area around Deadwood Summit. Historically, the river ran from its peak elevations (2,650 m) in the basin, for approximately 64 kilometers (km) to its confluence with the South Fork Payette River (Figure 3-1). Since 1931, the river has been separated into two distinct reaches by the Deadwood Dam and Reservoir complex. The reservoir is operated for irrigation storage and flood control. The dam does not generate hydropower except for a small system to power remote communications for dam operation and data transmission. The dam does not have the capability for selective withdrawal (the ability to release water from various depths in the reservoir). Deadwood Dam and Reservoir are at an elevation of 1,625.8 meters (m) (normal, non-spill reservoir capacity) and has a capacity of 154,000 acre-feet when full.[1] The Deadwood River above Deadwood Dam (upper Deadwood River) flows unimpeded approximately 26 km from Deadwood Summit (2,091 m) to the Reservoir. In the spring, snowmelt throughout the basin contributes large and significant amounts of flow to the river.

[1] Source: Reclamation

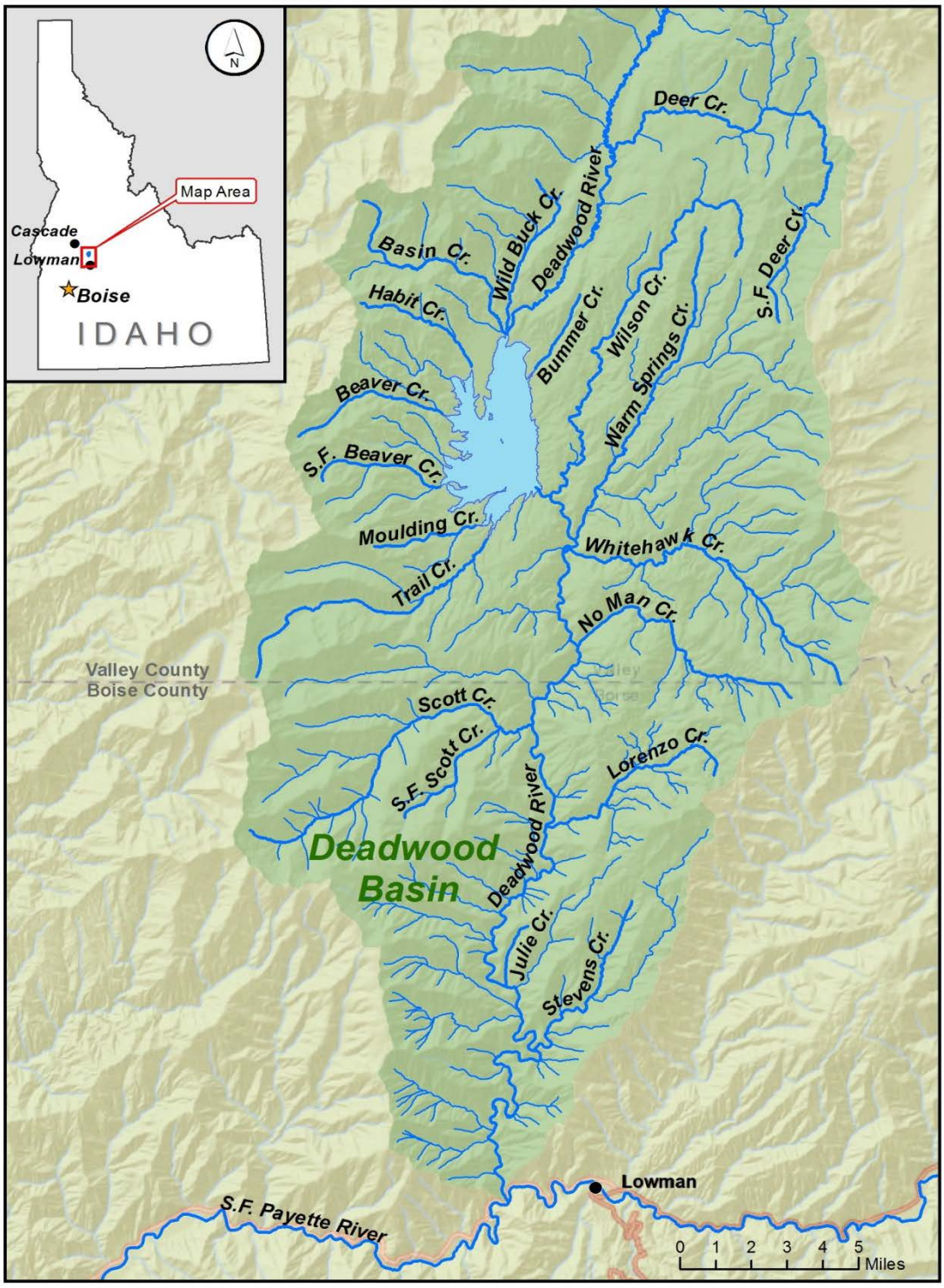


Figure 3-1. Portion of the Deadwood watershed referenced in this report including the Deadwood River and major contributing tributaries below Deadwood Dam. Deadwood River basin is highlighted in green.

Below Deadwood Dam, the lower Deadwood River flows from an elevation of 1,584 m approximately 38 km to the confluence with the South Fork Payette River, at an elevation of 1,128 m. The lower river is a mountainous canyon river that is mostly confined, with limited floodplain features. The relatively steep hill slopes and canyon like nature of the basin limit the amount and duration of sunlight that is able to reach the river. The total watershed area (both above and below the dam) is approximately 614 square kilometers (km^2). Precipitation is snow dominated, with an average of 72.2 centimeters (cm) near the reservoir[2] and 140 cm at Deadwood Summit.[3]

Within the classification system defined by Montgomery and Buffington (Montgomery and Buffington 1997; 1998), the Deadwood River below Deadwood Dam is an alluvial reach with bedrock controls limiting lateral development and migration. It predominately has reaches characteristic of plane bed or pool riffle morphology, however, noteworthy step pool features (Montgomery and Buffington 1997) exist, especially higher in the system. Over recent history the dam and reservoir have created a sediment disconnect between the upper and lower river, with all fine sediment from the upper basin being trapped within the reservoir, in turn reducing the availability of fine sediments to the lower river. As such, the general substrate of the river below the dam is abnormally large, being dominated by boulders and large cobbles. Studies have classified the lower Deadwood River as a Rosgen B2 stream type, which are fundamentally described as moderately entrenched streams with gradients of 2 to 4% and bed forms dominated by boulder materials (Rosgen 1994; 1996).

The lower Deadwood River, on average, is approximately 30 m wide and runs with a slope of approximately 1.2% (Figure 3-2). The local gradient of the river changes noticeably with geomorphic controls, and areas of significantly steeper slopes exist.

[2] Source: NRCS Idaho Snotel Site #423 – Cozy Cove
[3] Source: NRCS Idaho Snotel Site #439 – Deadwood Summit

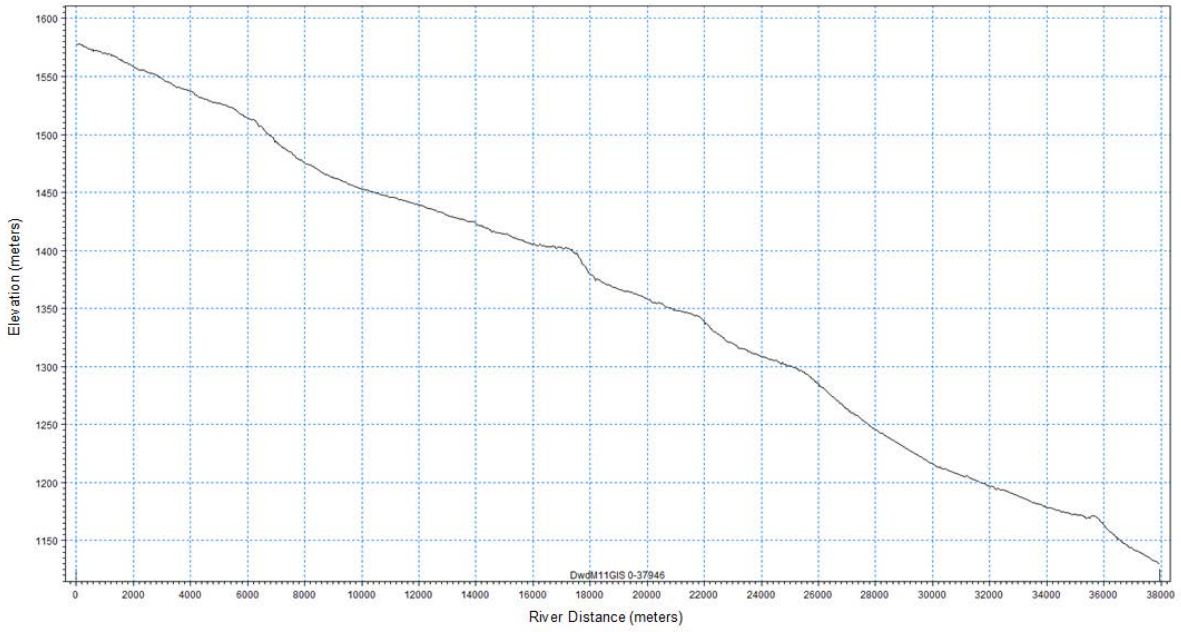


Figure 3-2. Longitudinal profile of lower Deadwood River.

Historic Flow Conditions

The U.S. Geological Survey (USGS) has maintained a flow gage below Deadwood Dam since its construction was completed in 1931 (USGS gage no. 13236500, with rudimentary measurements available prior to construction). The gage is situated approximately 300 meters downstream from Deadwood Dam, and thus measures the combined flow through the dam outlets and spillway (when applicable). Deadwood Dam is operated primarily for irrigation needs throughout South Western Idaho, as the Deadwood River flows into the Payette River system and eventually to the Snake River in Eastern Oregon. As such, the timing and magnitude of flows are significantly altered from the natural flow regime, most notably by reducing normal spring runoff and saving the majority of that water to be discharged in the summer months for irrigation demand. Figure 3-3 shows the daily mean discharge hydrograph from Deadwood Dam, averaged from 1994 until present. Figure 3-4 shows the estimated unregulated inflow hydrograph to the reservoir (based on change in elevation of reservoir water surface and using established reservoir storage tables), averaged from 1994 until present. Note, in Figure 3-3, the reduction in peak discharge below the dam caused by flow regulation, as well as the shift away from spring runoff (mid-April to June) to irrigation releases in July and August. Such irrigation releases offer sustained unnaturally high discharges to the river system at a time when flows naturally recede and approach base flow. This, in turn, significantly impacts the thermal regime of the river throughout the year.

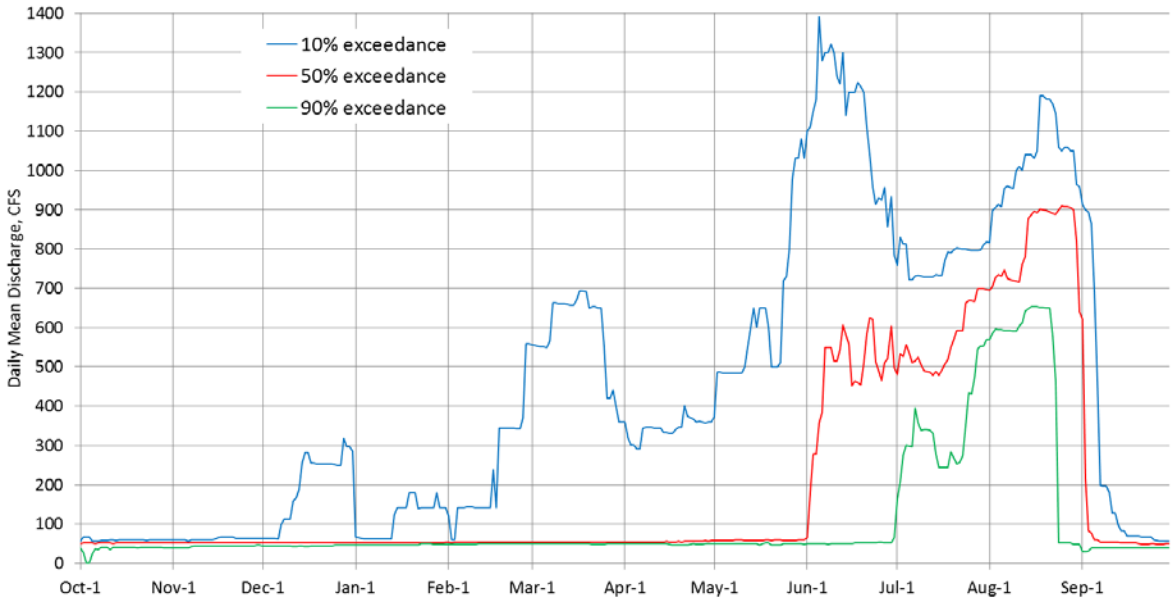


Figure 3-3. Summary hydrograph of Deadwood Dam release from 1994–2012.

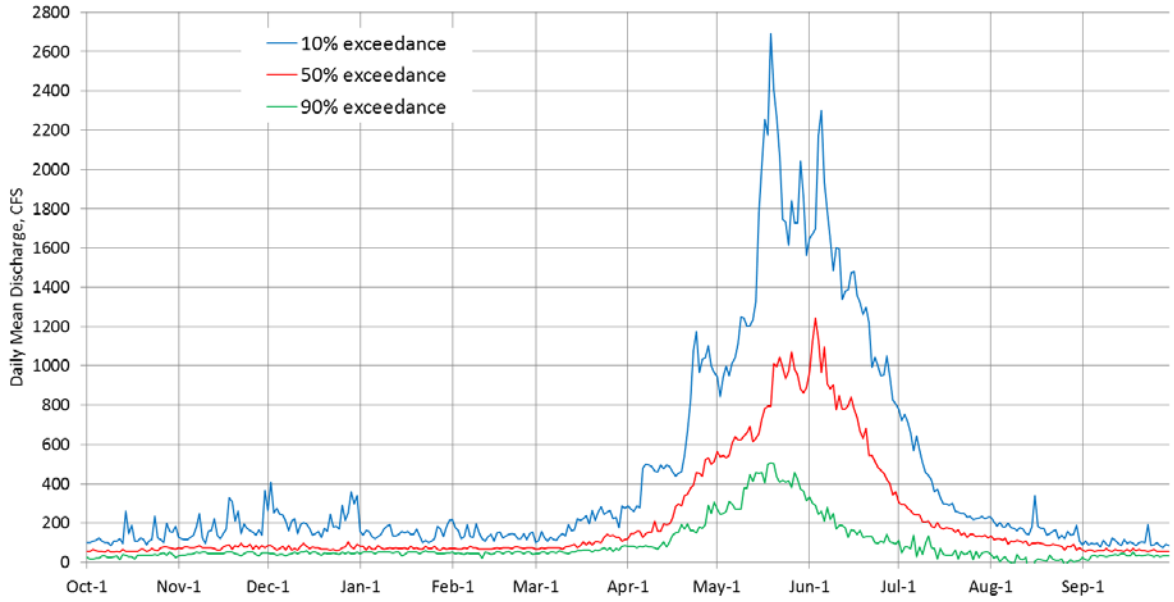


Figure 3-4. Summary hydrograph of unregulated inflow estimate to Deadwood Reservoir from 1994–2012.

The water temperature below Deadwood Dam has been recorded since the end of 1997. Figure 3-5 shows the thermal regime of daily mean temperatures released below Deadwood Dam. To provide a sense of how the dam's altered thermal regime differs from the natural

regime of the watershed, Figure 3-6 shows the thermal regime of the Deadwood River above the reservoir (limited data available: July 2010–August 2011 only), and select tributaries located less than 1 km up or downstream from the dam. Note the shift in magnitude and timing during the non-winter months, and the freezing or near-freezing behavior in the winter.

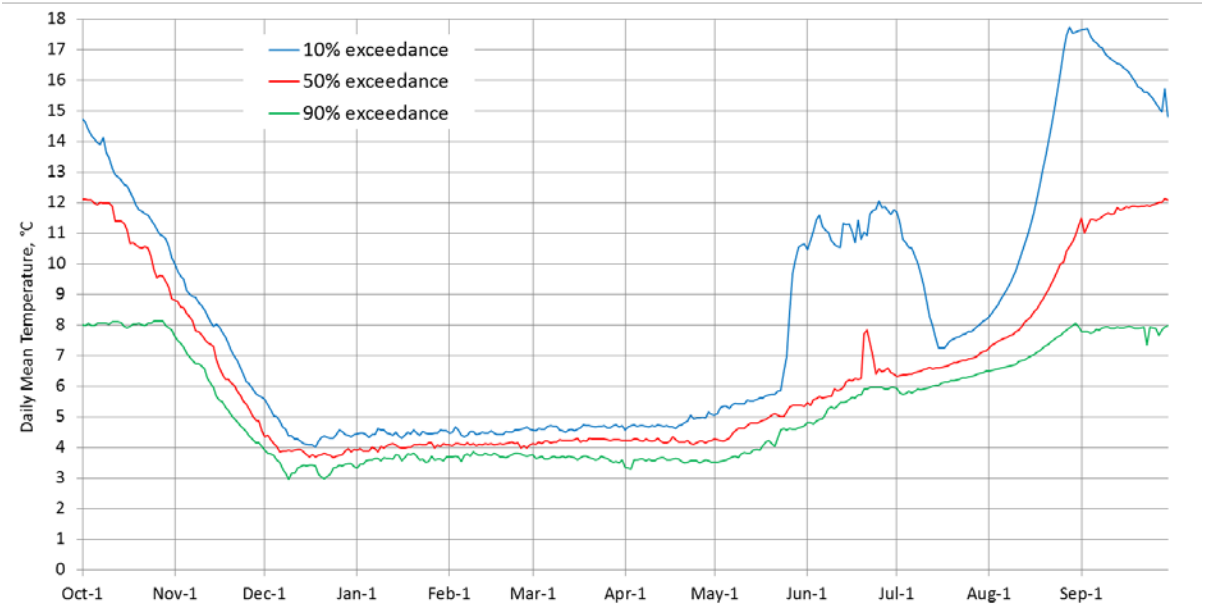


Figure 3-5. Summary thermograph of Deadwood Dam release from 1998–2012.

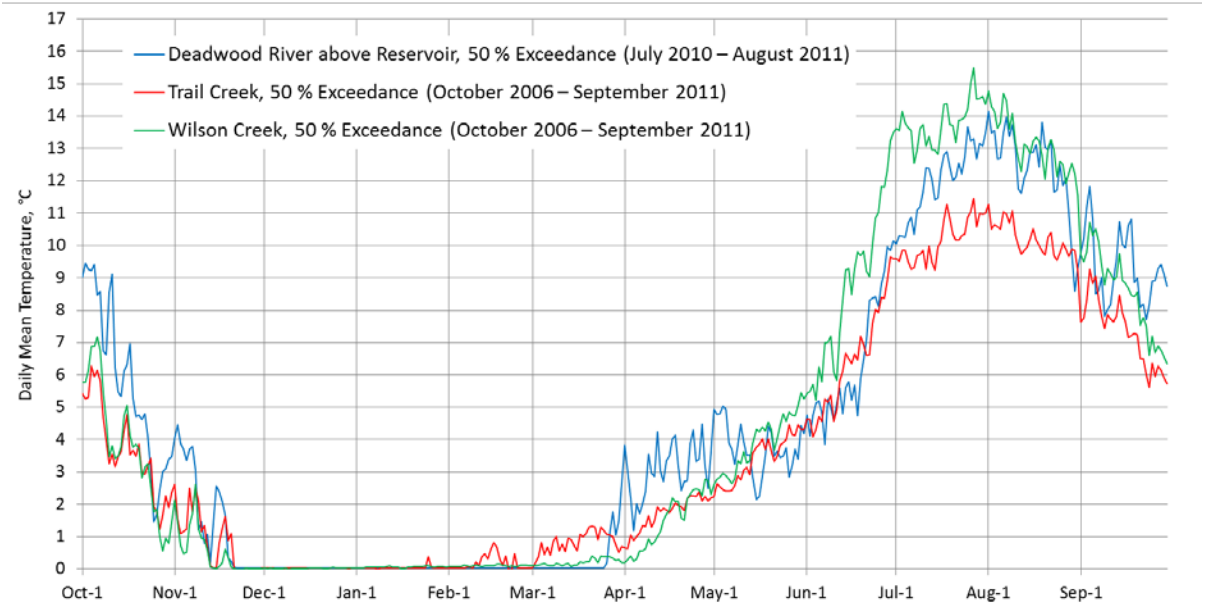


Figure 3-6. Summary thermograph depicting unregulated thermal regime.

The departure from the natural flow and thermal regime caused by Deadwood Dam can cause issues for aquatic habitat throughout the year, but in the winter there are important effects on ice formation. The warmer dam released water (approximately 4°C versus nearly zero in a natural condition) prevents surface ice and snow cover, as well as contributes to irregular and inconsistent formation of frazil and anchor ice, which tends to affect habitat negatively (Brown 1999; Brown et al. 2000; Brown et al. 1999; Brown et al. 2011; Brown and Mackay, 1995; Brown et al. 1993).

3.1.2 Methods

Field Data Collection Program

The lower Deadwood River area is remote, hazardous, and subject to severe weather conditions; therefore, field data collection required consideration of access, logistics, safety of field personnel, and selection of field sensors that are robust in severe conditions but able to provide the accuracy to address the scientific questions in the Biological Opinion (BiOp). The field program included the deployment of long-term automated sensors, manual measurements for verification, and synoptic survey events. This combination of approaches provided a check that the automated sensors were recording accurately, increased the density of measurements between the continuous recorders for higher longitudinal resolution and gave a means of providing potential backup data and surrogate information in the event of recorder malfunction.

Automated sensors relevant to measuring physical processes in the lower Deadwood River are listed in Table 3-1. The locations of the monitoring stations and instruments are shown in Figure 3-7 and Figure 3-8. Stage-discharge relations were created for a subset of tributaries indicated in Table 3-1 and results were extrapolated to other tributaries where synoptic measurements were made for verification. Stage recorders measured water surface elevations every 30 minutes (60 minute intervals during winter months when flow conditions vary more slowly and gage maintenance is more difficult or impossible). Temperature loggers were installed in pertinent tributaries and on either bank of the main river channel to evaluate the assumption of uniform mixing of tributary inputs. Temperature was intermittently measured at 60-minute intervals during the sampling years 2006 through 2012.

Table 3-1. List of all measurement locations on tributaries and main channel. (Locations are listed by descending distance from Deadwood Dam.)

Name	Distance from dam (m)	Stage/ discharge	Sampling Interval (min)	Temp	Sampling Interval (min)	Direct
Trail Creek (upstream of dam)	2690	X	30/60	X	60	X
Deadwood blw Deadwood Dam	90			X	60	
Deadwood blw Deadwood Dam	455	X	15			X
Wilson Creek	519	X	30/60	X	60	X
Deadwood blw Wilson Creek (L+R banks)	735			X	60	
Deadwood abv Warmsprings Creek (ID 1)	2518			X	60	
Warmsprings Creek	2535	X	30/60	X	60	X
Deadwood abv Warmsprings Creek (ID 3-7)	2553			X	60	
Deadwood abv Warmsprings Creek (ID 16)	2616			X	60	
Deadwood abv Warmsprings Creek (ID 13)	2673			X	60	
Deadwood abv Warmsprings Creek (ID 12)	2757			X	60	
Deadwood abv Warmsprings Creek (ID 7-11)	2844			X	60	
Whitehawk Creek	3337	X	30/60	X	60	X
Deadwood blw Whitehawk Creek (L+R banks)	3599			X	60	
No Man Creek	7367	X	30/60	X	60	X
Deadwood blw No Man Creek (L+R banks)	7500			X	60	
Ninemile Creek	10198					X
Scott Creek	11088			X	60	X
Deadwood blw Scott Creek (L+R banks)	11398			X	60	
Lorenzo Creek	15405			X	60	X
Deadwood blw Lorenzo Creek (L+R banks)	15485			X	60	
Sams Creek	21288					
Deadwood at Julie Creek Bridge	23931	X	30/60	X	60	X
Pine Creek	24061					X
Nellie's Basin Creek	24807					X
Josie Creek	25138					X
Stevens Creek	27676	X	30/60	X	60	X
Deadwood blw Stevens Creek (L+R banks)	28039			X	60	
Deadwood Jim Creek	30463					X
Slim Creek	34850					X
Slaughterhouse Creek	35210					X
Unnamed Creek	36690					X
Deadwood near South Fork Payette River	37946	X	30/60	X	60	X

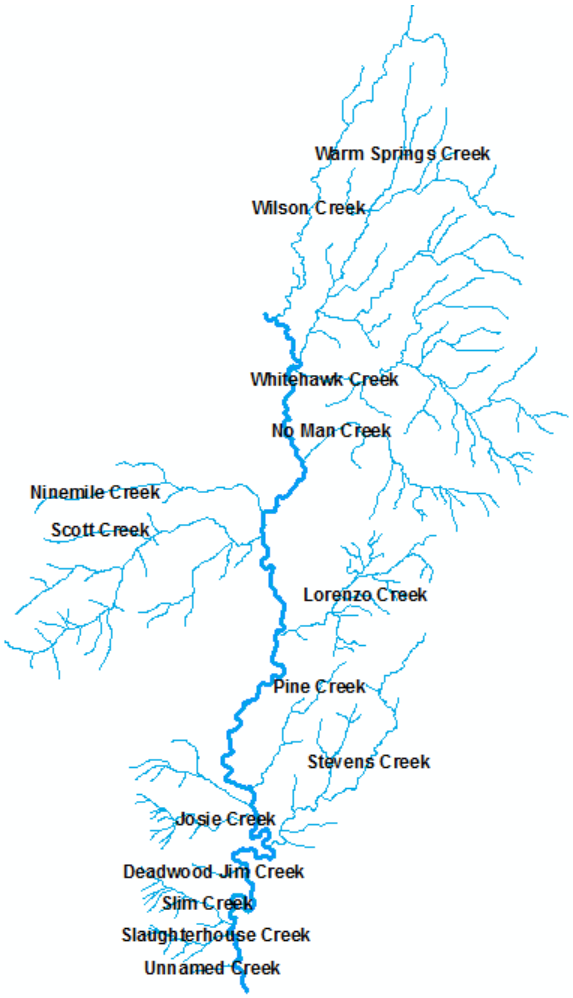


Figure 3-7. Measured tributaries and their flow networks in the Deadwood River watershed.

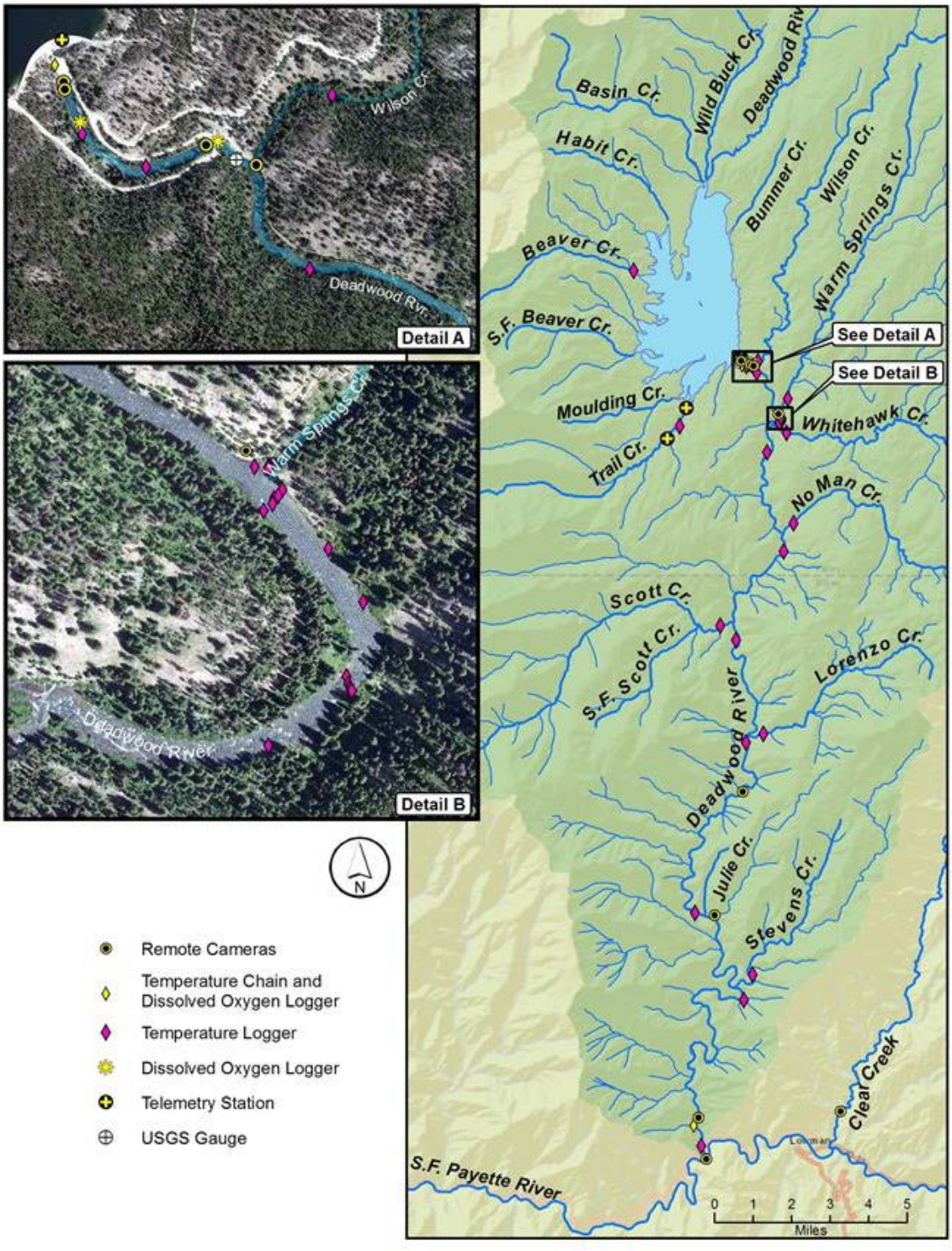


Figure 3-8. Deadwood River watershed sampling locations.

Hydraulic and temperature modeling

A set of numerical models[4] have been developed to study the effect of flow releases from the dam during the three BiOp years: dry, average, and wet. A one-dimensional (1D) hydraulic model coupled with a heat transport module was developed to investigate the effect of dam release water temperature on stream water temperature regime and available wetted usable areas. Modeled winter temperatures, coupled with measured temperatures, along the river were used to assess the impact of dam releases on surface ice formation. A two-dimensional (2D) hydraulic model was developed to study velocity distribution within the lower Deadwood River and investigate the role of discharge on eddy formation. A surface-subsurface model was developed to investigate the impact of winter and irrigation releases on the interaction between stream water and streambed sediment, which are used by benthic species, and salmonid embryos during incubations.

The following sections introduce each study, provide models and simulation details, and present and discuss the results.

3.1.3 One-dimensional Modeling of the lower Deadwood River for evaluation of the BiOp Scenarios

MIKE 11, developed by DHI, was selected to perform the simulations for the entire lower Deadwood River. MIKE 11 is a one-dimensional (1D), fully hydrodynamic modeling tool which utilizes the Saint Venant equations to simulate a wide range of river and channel systems, from simple to complex (DHI 2000). MIKE 11 was used to simulate the flow and thermal regimes for representative dry, average, and wet years within the Deadwood River watershed. These simulations were then repeated for a theoretical unregulated lower Deadwood River in order to quantify the effect Deadwood Dam has upon the lower Deadwood River system.

Construction of MIKE 11 Model

The bathymetry for the lower Deadwood River was acquired using the aquatic-terrestrial Experimental Advanced Airborne Research LiDAR (EAARL) system in 2007, which

[4] Interpretation of modeled thermal regimes below the dam is limited because water temperature in each scenario was modeled using empirical data sets collected within the study location in 2009 (Flex study 3-12 to 3-13). Calibrating the model demonstrated that modeled water temperatures accurately represent the empirical data (Flex study pages 3-15 to 3-17). It is significant to note that while 2009 offered the most robust data set for the purpose of modeling water temperatures, operations during 2009 did not include use of the spillway. During spillway use, water temperatures downstream of the dam are expected to increase (a result of warmer surface water from the reservoir being released) but this phenomena is not depicted in the modeled data. Spill, and the corresponding downstream temperature increase, would be expected for wet or average years.

provides spatial and elevation data accurate on the order of centimeters (McKean et al. 2009a; McKean et al. 2009). From the LiDAR point cloud, a 1-m digital elevation model (DEM) was constructed that formed the foundation of the MIKE 11 river topography and boundary conditions. Cross sections were extracted from the LiDAR derived DEM using the MIKE 11 GIS tool. Cross sections were defined every 30 meters (approximately corresponding to the average transverse flow width) longitudinally along the centerline/thalweg of the lower Deadwood River. This 30-m cross section spacing provides a greater density of topographic and bathymetric information than is typically implemented in such a model, but was selected to provide meaningful results for the study of the lower Deadwood River bed forms and the hyporheic exchange. With such high quality bathymetric information coupled with a high density of cross sections, it was possible to have an exceptional level of confidence in the river topography inputted into the 1D model, and the hydrodynamics derived therein.

To provide the required inflow boundary conditions input to the hydraulic model a host of gages were installed and/or utilized throughout the lower Deadwood River. The upstream boundary condition was provided by the discharge time-series data accessed via the USGS gage previously described (USGS gage no.13236500) and a temperature gage operated by the Reclamation and telemetered via the Hydromet network. The downstream boundary condition was defined by a stage-discharge rating curve developed for the gaging of lower Deadwood River outflows to the South Fork Payette River. Stage at the lower Deadwood River outlet is recorded by a SonTek Argonaut-SW® ADVM, and telemetered via Reclamation's Hydromet network. To track natural inflows below Deadwood Dam, significant tributaries that were most easily accessible were selected for gauging. Water levels were recorded in significant tributaries with AquaRod® instruments at Wilson, Warmsprings, Whitehawk, No Man, and Stevens Creeks. Time-series flow records for these tributaries were developed from stage-discharge relationships, established from independent flow measurements over the range of flow levels/conditions. To record temperature, Onset StowAway TidBiT temperature sensors (Manufacturer specification: measurement range -4°C to 38°C, resolution = 0.15°C, accuracy = 0.1°C.) were deployed in Wilson, Warmsprings, Whitehawk, No Man, Scott, Lorenzo, and Stevens Creeks. Further, to track temperature change longitudinally within the lower Deadwood River, pairs of TidBiT temperature loggers were deployed off the right and left banks, approximately 20 stream widths downstream from the confluence of the following creeks with the lower Deadwood River: Wilson, Whitehawk, No Man, Scott, Lorenzo, and Stevens. Figure 3-8 illustrates this and other instrumentation deployed throughout the Deadwood River watershed.

Calibration for 1-Dimensional Model

For all lower Deadwood River MIKE 11 simulations, the model time step was set at 4 seconds, with storage of data every 1 hour. Simulations were run for approximately 14 months, beginning in November of the previous year, through the entirety of the simulation year. In order to calibrate the river model the MIKE 11 model was initially set up to run for the 2009 calendar year, as 2009 was the most robust data set available. Due to the rough terrain, variable flow conditions, and propensity for localized extreme weather events, the Deadwood River basin is often very problematic to measure and monitor. As such, most years of the Deadwood River study contain noteworthy data gaps due to instrument loss or failure in at least one or more of the monitored sites within the basin. Thus, 2009 was selected for calibration of the river model as it represents the most complete flow and temperature data set. The calibration of flow resistance utilized a Manning's n value, which was set at 0.06. Due to the difficult nature of the terrain in the lower Deadwood River canyon, access is limited under all flow conditions and proved difficult to verify this calibration exclusively from water surface elevation (WSE) measurements. The steep canyon walls prevent a clear satellite signal to reach the canyon floor and precise GPS location and elevation measurements are problematic. Thus, flow resistance was initially calibrated to available approximate WSE measurements, and then verified by comparing and confirming agreement of the travel time of a flood wave within the model to observed travel time (approximately 6 hours). Further, a Manning's n value of 0.06 is consistent within the literature for streams classified similarly to the lower Deadwood River (Rosgen 1994; 1996).

To calibrate the MIKE 11 model for temperature, modeled temperatures were compared to the temperature time series observed from the in-stream temperature loggers in the lower Deadwood River, particularly those downstream from Whitehawk, Scott, and Stevens Creek confluences. Parameters of the temperature model were modified to match the diel temperature fluctuations observed in the lower Deadwood River. The amount of sunlight/solar radiation is of particular importance for temperature calibration (indeed more so than air temperature), which is consistent with the literature (Johnson 2003). The canyon-like nature of the lower Deadwood River prevents typical amounts of sunlight (for the geographic area) to reach the river and necessitated a shift in the timing and amount of incoming solar radiation.

In the morning hours, there is a significant delay in the time it takes for sunlight to first reach the bottom of the river canyon. Thus, to account for this, the modeled time zone was shifted back by 4 hours, which was found to accurately represent the hour at which sun first reaches the river. The lower Deadwood River canyon walls were found to be approximately 35 degrees from the center of the river, and thus solar calculations masked all sunlight until it has reached greater than 35 degrees from the horizon. For the Deadwood River basin, data obtained from a NOAA web product were used to build a relationship to calculate the total hours of sunlight theoretically available 35 degrees above the horizon line throughout the

year. It was found that at a minimum, sunlight hours do not affect the river system until April 1, and cease to influence the heat exchange after October 1; therefore solar radiation influence was limited and set to zero for this time frame in the model (Figure 3-9). Due to the lack of direct solar radiation measurements within the lower Deadwood River system, data from a nearby meteorological station were used as a surrogate. The daily maximum incident solar radiation (insolation) from the Bearskin Creek Weather Station was utilized and compared to the calculated number of theoretically available sunlight hours. A third degree polynomial relationship was then found to accurately represent sunlight hours per day given Bearskin Creek maximum daily insolation, with limits imposed based on the sunlight theoretically available 35 degrees above the horizon line (minimum of 2 sunlight hours per day, maximum of 9). With this methodology, a time series for lower Deadwood River sunlight hours per day was created for the MIKE 11 model.

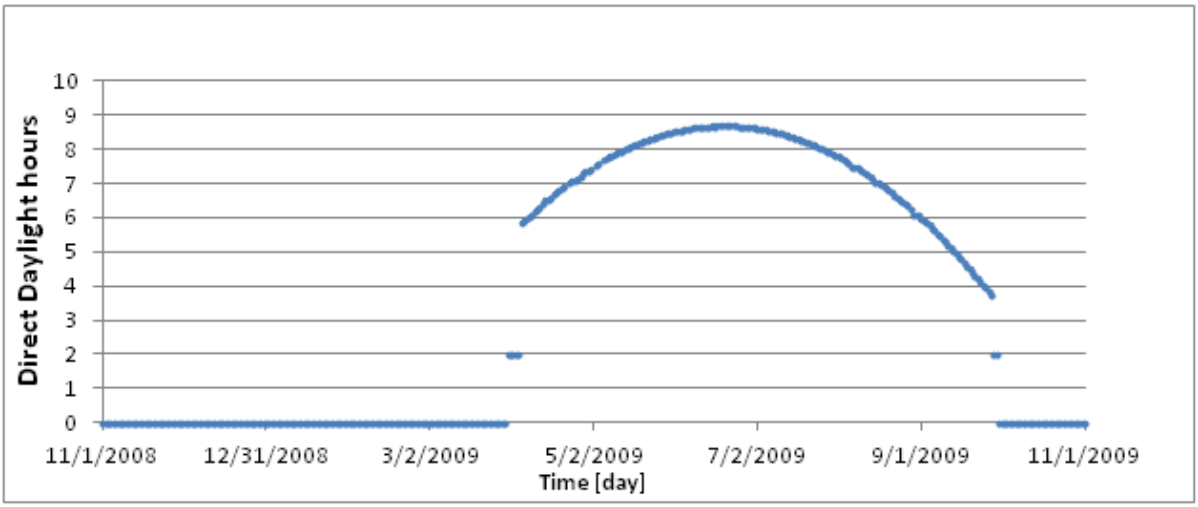


Figure 3-9. Direct daylight hours for within the lower Deadwood River canyon.

Further, it was observed that for river discharge below approximately 125 cfs, the flow is sufficiently shallow so that heat exchange within the river is dominated by interactions with river bed sediments rather than solar radiation. Thus, below 125 cfs the MIKE 11 model parameter for sunlight hours has been set to zero. These alterations to the typical heat exchange model have allowed for accurate representation of the lower Deadwood River temperatures (including the magnitude and timing of diel fluctuations). Exceptions do occur at certain locations during periods in the winter, as the model does not account for ice formation. Temperature throughout the winter months had a high probability of freezing along the margins of the river and proved inaccurate at freezing temperatures. Hence, the model was not able to be calibrated to actual instream temperatures during this period and reports temperature values higher than actually encountered in the river by up to 2^{o}C. Results from the 50 cfs dam release option show winter temperatures up to 2^{o}C greater than those measured in the field. This is due to the inability of the model to account for large

thermal losses via exposed cobbles and boulders within the channel. However, temperature sensors were located along the sides of the river and there is uncertainty as to whether they were frozen in the border ice or immersed in the flowing water. Results from the 2 and 0 cfs release options provide more realistic temperatures to those measured during the winter. Analysis of the 50 cfs release option is restricted during the winter months to measured values for the ice formation analysis.

To ensure accurate performance of the MIKE 11 temperature model, field data were compared to modeled data for April 1, 2009 to November 1, 2009. Figure 3-10, Figure 3-11, and Figure 3-12 show observed hourly temperatures regressed against modeled temperatures for the lower Deadwood River below Whitehawk, Scott, and Stevens Creeks with root mean square errors of 0.5, 1, and 1.6°C, respectively.

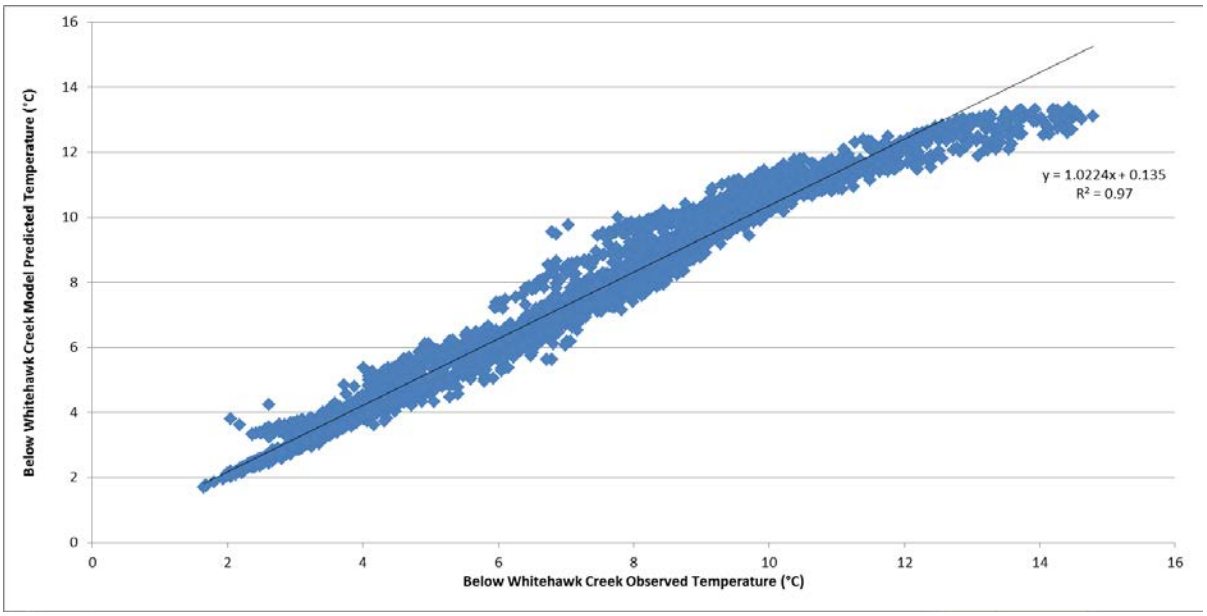


Figure 3-10. Predicted vs. observed hourly Deadwood River temperatures below Whitehawk Creek.

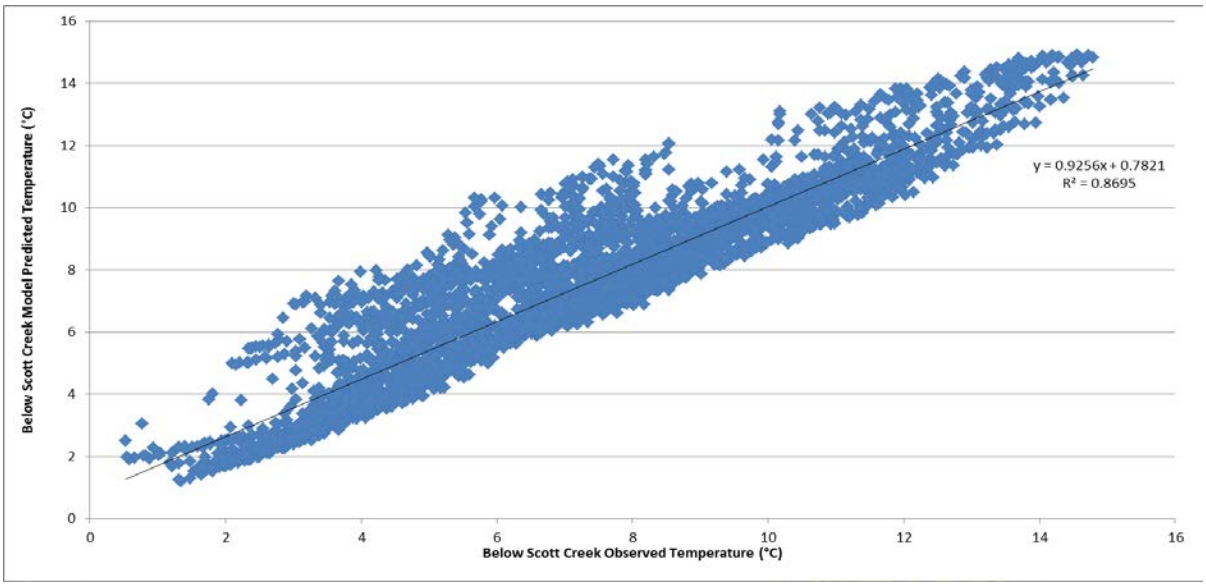


Figure 3-11. Predicted vs observed Deadwood River hourly temperatures below Scott Creek.

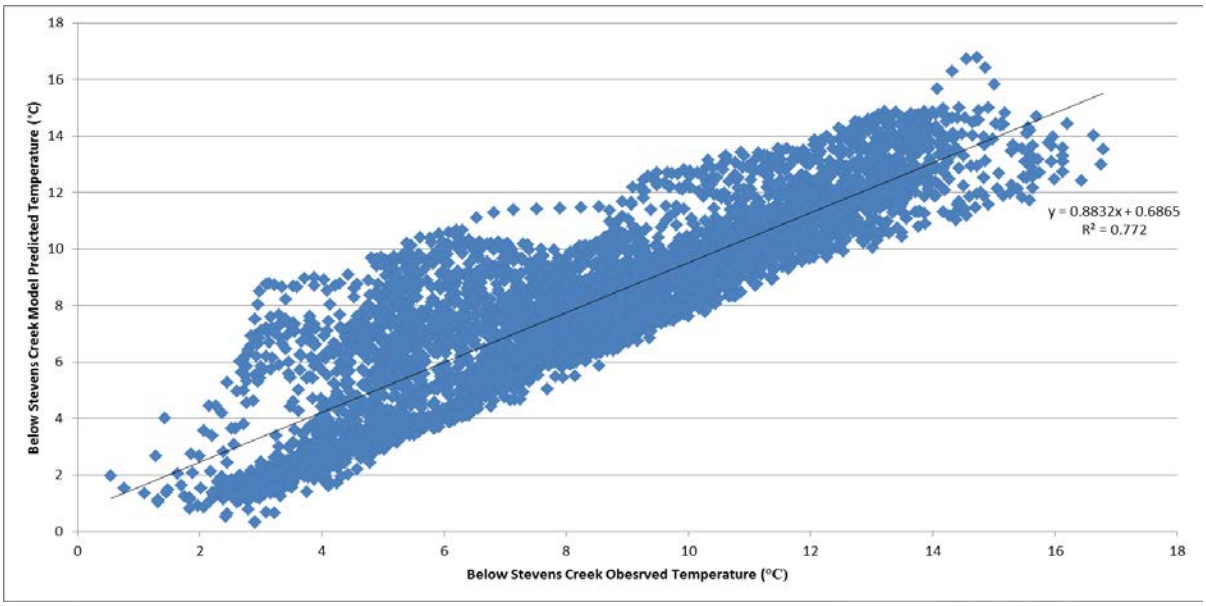


Figure 3-12. Predicted vs observed Deadwood River hours temperatures below Stevens Creek.

Figure 3-13, Figure 3-14, and Figure 3-15 plot the time series of observed temperatures overlaid with model predicted temperatures for the lower Deadwood River below Whitehawk, Scott, and Stevens creeks. It can be seen that modeled values track the natural changes in the thermographs quite well. There is a noticeable decrease in the accuracy of the model with distance from the dam due to the increasing influence of variable tributary inputs.

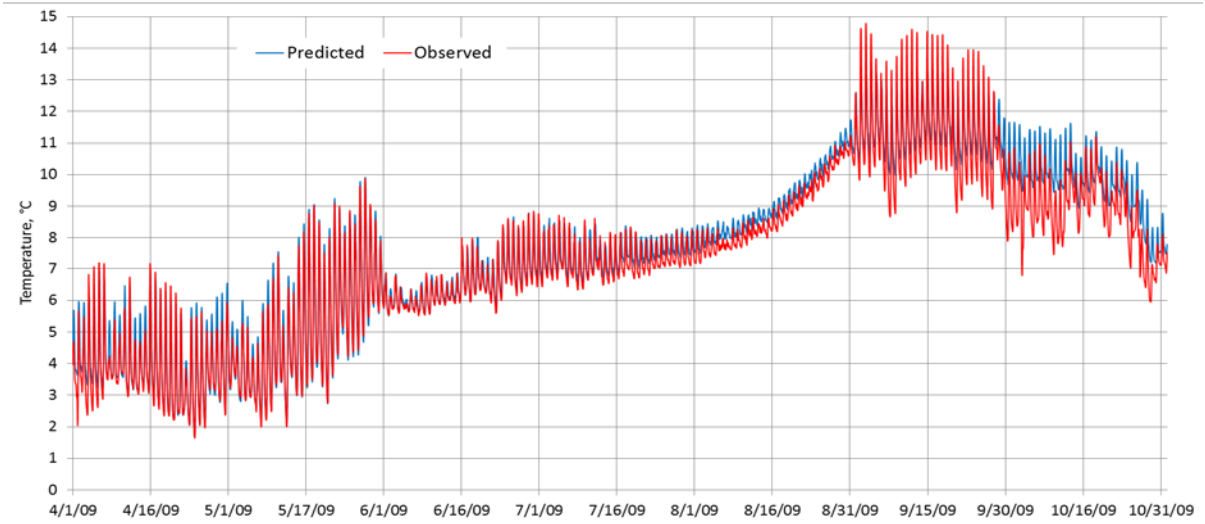


Figure 3-13. Observed temperatures compared to modeled temperatures for the Deadwood River below Whitehawk Creek.

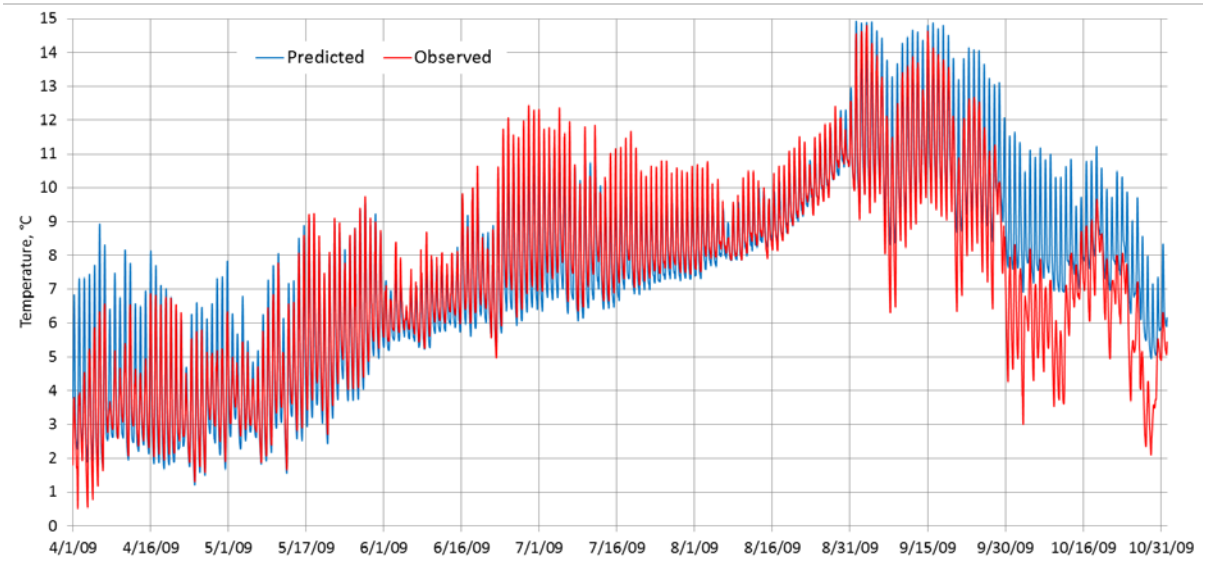


Figure 3-14. Observed temperatures compared to modeled temperatures for Deadwood River below Scott Creek.

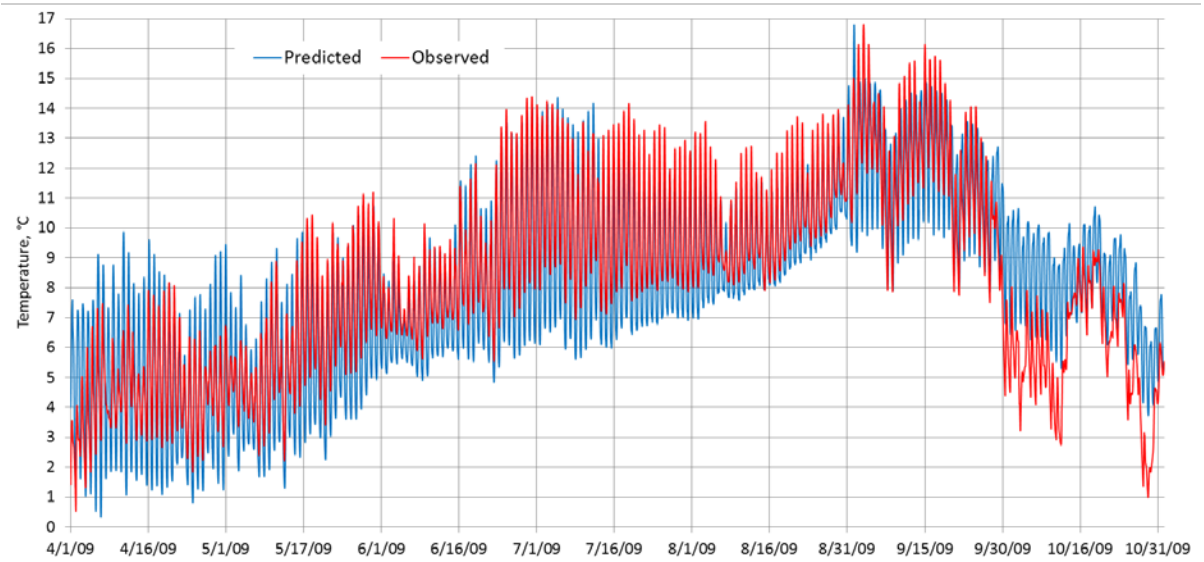


Figure 3-15. Observed temperatures compared to modeled temperatures for the Deadwood River below Stevens Creek.

Reclamation has identified recent years that are representative of dry, average, and wet climatic years for the Snake River basin above Brownlee Reservoir, which includes the greater Payette River basin and its subset Deadwood River basin. Based upon historical measured water balances at Brownlee Reservoir, a wet year is a year in which total annual inflow volume into Brownlee Reservoir is at a 10% exceedance level, a dry year is defined by the 90% exceedance level, and an average year is defined as years that fall within these limits (Reclamation 2004; 2007a). From this definition, 1997, 2001, and 2003 were selected as wet, dry, and average years, respectively (Reclamation 2004; 2007a). To confirm that these designations appropriately apply to the Deadwood River system, the total inflows to Deadwood Reservoir were examined (derived from the change in reservoir levels and the associated reservoir storage table). Figure 3-16 shows the annual inflows to Deadwood Reservoir from 1931–2011, and by this metric 1997, 2001, and 2003 are shown to be indicative of wet, dry and averages years.

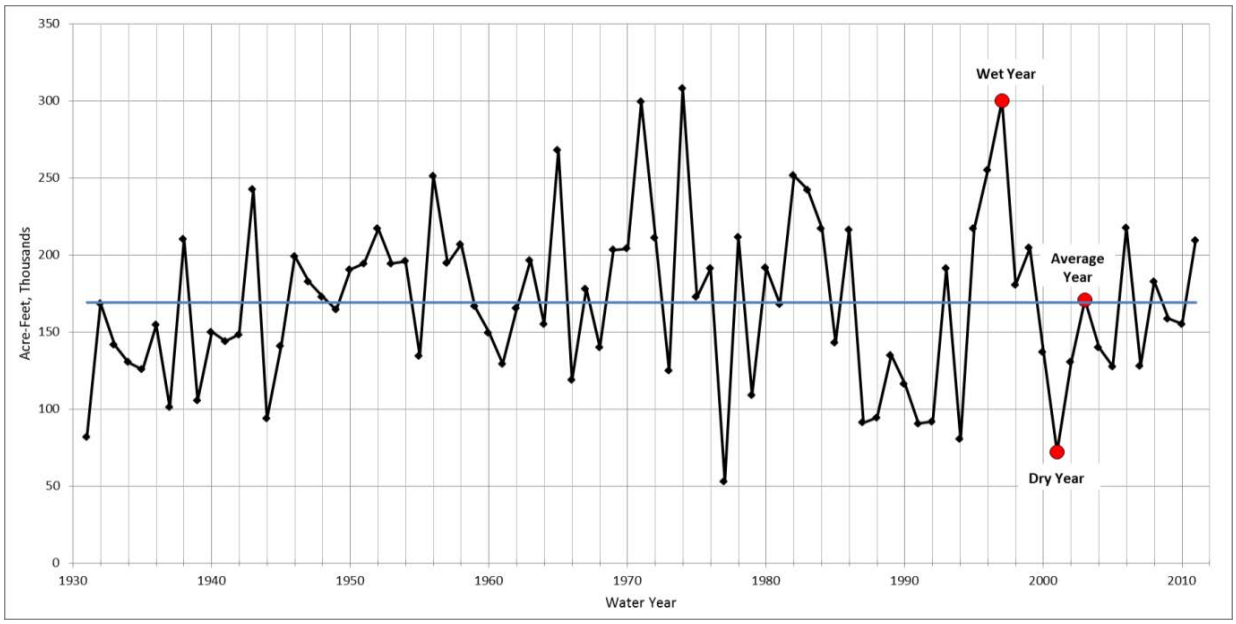


Figure 3-16. Total sum of annual inflows to Deadwood Reservoir, 1931–2011. Mean value for period of record (blue). Selected climatic years highlighted (red).

From this metric of total annual inflows to Deadwood Reservoir, compelling evidence exists that climatic conditions are indeed trending towards increased variability for the Deadwood River basin.

Table 3-2 demonstrates statistically that there is considerable change when using the year 1970 as a breakpoint. Note how minimum annual inflows decrease, while maximum values increase, and the standard deviation from 1931 to 1970 is markedly lower than that of 1971 to 2010. Interestingly, the mean total annual inflow from each period is not significantly different; indicating that average conditions remained unchanged, whilst variability has notably increased.

Both time periods are found to be normally distributed, which allows for a comparison of means with a t-test and a comparison of variances with an F-test. Both tests were run with a 5% confidence level. The t-test results show that the two periods have similar means (p-values 0.895). This provides statistical evidence that mean total annual inflows to Deadwood Reservoir have remained steady since 1931. The F-test results show that the two periods have statistically different variances (p-value of 0.006). This provides confidence that while climatically driven inflows to Deadwood Reservoir are on average the same, year-to-year they have become more variable, which is important to account for in future management and operations.

Table 3-2. Statistical breakdown of inflow conditions to Deadwood Reservoir before and after 1970. Values shown in thousands of acre-feet.

Time Period	Minimum	Maximum	Mean	Standard Deviation
1931-1970	81.7	268.1	167.7	42.4
1971-2010	52.9	307.8	169.4	64.2

With three BiOp years defined, the meteorological and hydrological inputs to the MIKE 11 river model needed to be defined for each of these years. Meteorological data (air temperature, relative humidity, and sunshine hours per day) and tributary temperature data from the proven 2009 calibration data set were utilized for all BiOp years. By holding these inputs constant across all BiOp years, we eliminate their influence as a source of difference between scenarios. Thus, observed differences in the model results can be attributed to the differences in the flow year experienced (average, dry, wet). However, it is important to adjust the tributary inflow data according to the type of flow year. Snow water equivalent and flow percentages of average for the Greater Payette River basin were used as metrics to compare the robust 2009 tributary flow data set to the BiOp years: 1997, 2001, and 2003. Figure 3-17 was obtained from the National Resources Conservation Service (NRCS). Note that 2009 is essentially average on this plot.

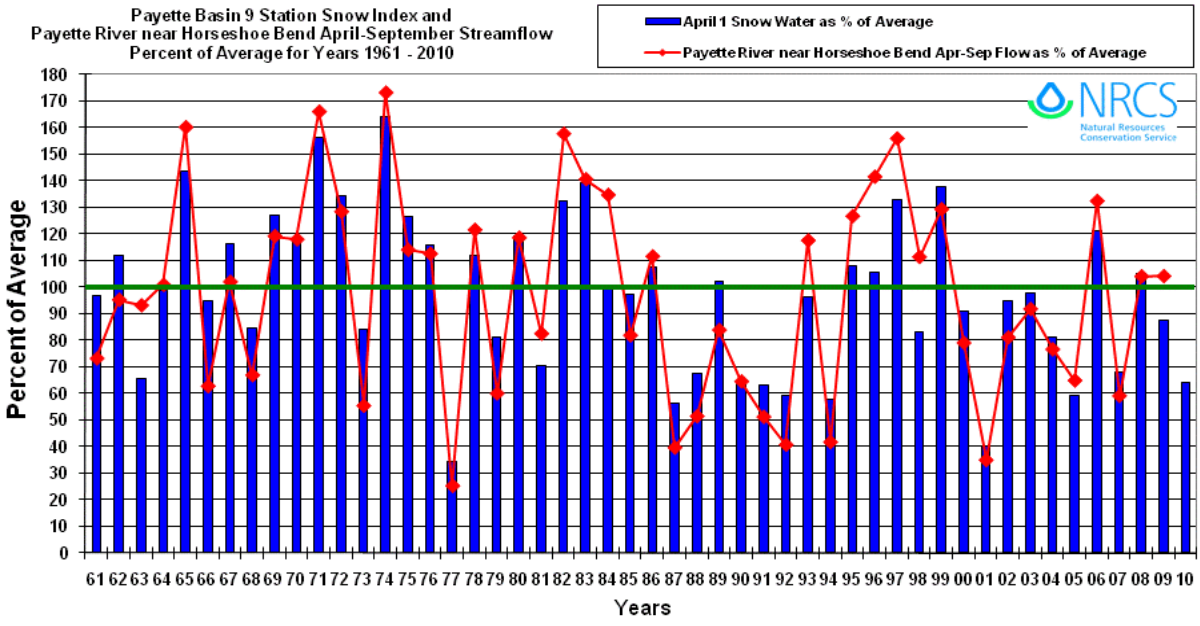


Figure 3-17. Snow and flow as percent of average for the Payette Basin.

Using these metrics to examine the BiOp years, it was decided to scale tributary flows for 1997 by 1.5 times the 2009 values, for 2001 by 0.4 times the 2009 values, and 2003 was left unscaled as it is approximately average.

Simulations were run for each of the representative climatic years using historically observed time-series for flow and temperature releases from Deadwood Dam (Simulation #1, 9, and 17 in Table 3-3). Unfortunately, temperature has only been officially recorded below Deadwood Dam beginning in late 1997. Therefore, modeled temperatures from Deadwood Reservoir for the 1997 wet climatic year were employed.

Table 3-3. Scenarios for the three hydrologic BiOp year conditions. Hydraulics and temperature were simulated in the Lower Deadwood River for each scenario.

Scenario Number	Background Conditions from BiOp[5]	T&C – 3a, 3b, 3e Winter Reservoir Release	River Modeling Timeframe	T&C – 3d, 3c Spring Ramp Up	T&C – 3c Fall Ramp Down
	Dry (2001)				
1	Historical	Historical	11/1/00-12/31/01	Historical Actual	Historical Actual
2	0 acre-feet carry over	50 cfs	11/1/00-12/31/01	Fast	Fast
3	0 acre-feet carry over	50 cfs	5/27/01-9/12/01	Slow	Slow
4	17,280 acre-feet carry over	2 cfs	11/1/00-12/31/01	Fast	Fast
5	17,280 acre-feet carry over	2 cfs	5/27/01-9/12/01	Slow	Slow
6	18,000 acre-feet carry over	0 cfs	11/1/00-12/31/01	Fast	Fast
7	18,000 acre-feet carry over	0 cfs	5/27/01-9/12/01	Slow	Slow
8	Unregulated Flows	Unregulated Flows	11/1/00-12/31/01	Natural Hydrograph	Natural Hydrograph
	Average (2003)				
9	Historical	Historical	11/1/02-12/31/03	Historical Actual	Historical Actual
10	0 acre-feet carry over	50 cfs	11/1/02-12/31/03	Fast	Fast
11	0 acre-feet carry over	50 cfs	5/27/02-9/12/03	Slow	Slow
12	17,280 acre-feet carry over	2 cfs	11/1/02-12/31/03	Fast	Fast

[5] Caution should be used when interpreting output from these models, which were allowed to self-calculate water carryovers. Additional water storage amounts presumed by the model are not necessarily represented in the actual data, as these additional acre-feet calculated do not uniformly translate into actual storage, but rather may become additional spill or flood control releases (additional reservoir water volumes cause flood control releases to begin earlier in the season, according to calculated flood control rule curves followed by dam operations). Model outputs should be compared with actual data for validation before being relied upon for broader extrapolation.

Scenario Number	Background Conditions from BiOp[5]	T&C – 3a, 3b, 3e Winter Reservoir Release	River Modeling Timeframe	T&C – 3d, 3c Spring Ramp Up	T&C – 3c Fall Ramp Down
13	17,280 acre-feet carry over	2 cfs	5/27/02-9/12/03	Slow	Slow
14	18,000 acre-feet carry over	0 cfs	11/1/02-12/31/03	Fast	Fast
15	18,000 acre-feet carry over	0 cfs	5/27/02-9/12/03	Slow	Slow
16	Unregulated Flows	Unregulated Flows	11/1/02-12/31/03	Natural Hydrograph	Natural Hydrograph
	Wet (1997)				
17	Historical	Historical	11/1/96-12/31/97	Historical Actual	Historical Actual
18	0 acre-feet carry over	50 cfs	11/1/96-12/31/97	Fast	Fast
19	0 acre-feet carry over	50 cfs	7/18/97-9/30/97	Slow	Slow
20	17,280 acre-feet carry over	2 cfs	11/1/96-12/31/97	Fast	Fast
21	17,280 acre-feet carry over	2 cfs	7/18/97-9/30/97	Slow	Slow
22	18,000 acre-feet carry over	0 cfs	11/1/96-12/31/97	Fast	Fast
23	18,000 acre-feet carry over	0 cfs	7/17/97-0/30/97	Slow	Slow
24	Unregulated Flows	Unregulated Flows	11/1/96-12/31/97	Natural Hydrograph	Natural Hydrograph

In order to model a theoretically unregulated river system for the 1997, 2001, and 2003 years (Simulation #8, 16, and 24 in Table 3-3), data output from the 3D reservoir model, ELCOM-CAEDYM, developed for Deadwood Reservoir by the Centre for Water Research at the University of Western Australia were utilized. A water balance was developed for each of the wet, average and dry years, which provide proper inputs to the reservoir model. Temperature time-series for inflow to Deadwood Reservoir were developed based upon comparison with available continuous data from selected inputs to Deadwood Reservoir, namely the upper Deadwood River and Trail Creek. In order to model an unregulated lower Deadwood River, these reservoir model inputs were employed as direct inputs to the MIKE 11 lower Deadwood River model.

Figure 3-18 and Figure 3-19 graphically show the collection of flow and temperature data used as inputs to the MIKE 11 model for the historical regulated and theoretical unregulated simulations (Table 3-3). As stated previously, this reservoir model was run for historical conditions in the 1997 climatic year, and the resulting modeled outflow thermal regime was used as an input for the historical 1997 simulation.

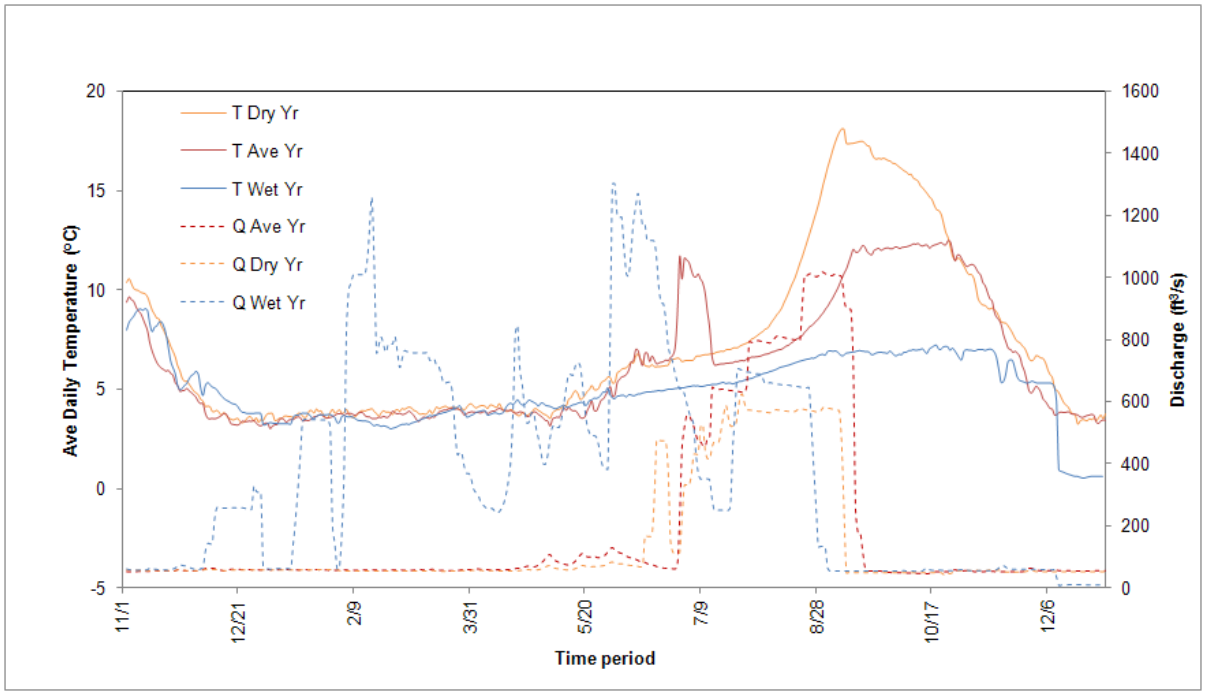


Figure 3-18. Historic flow regime at location 1 for dry, average, and wet BiOp years; a) dashed lines represent the hydrograph (right axis) and b) solid lines represent the thermograph (left axis).

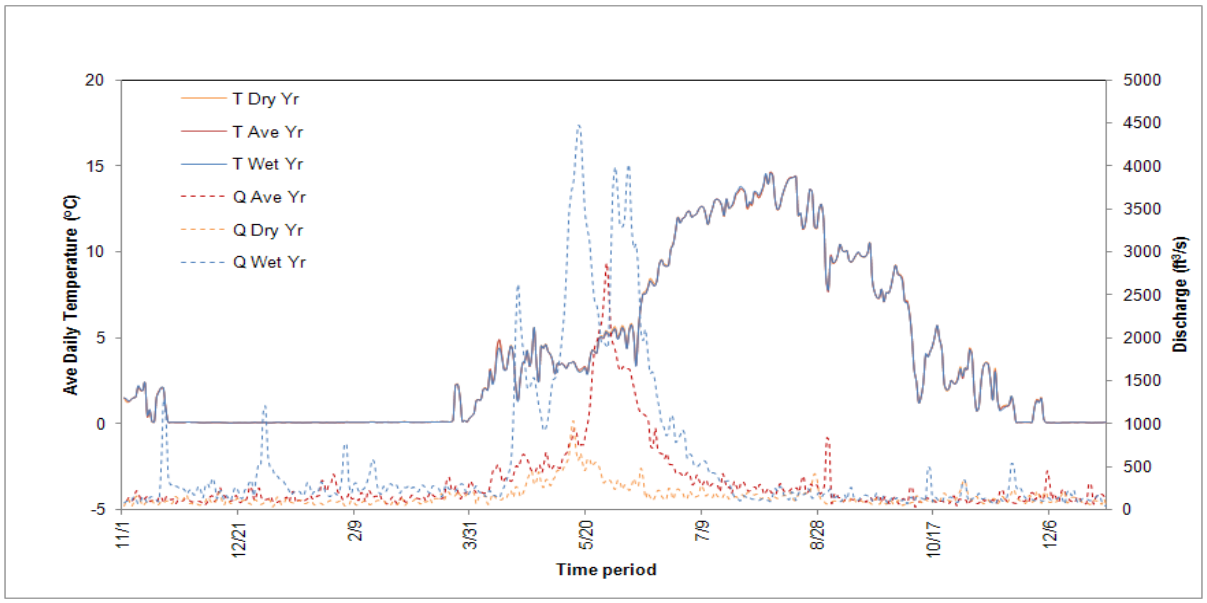


Figure 3-19. Unregulated flow regime at location 1 for dry, average, and wet BiOp years; a) dashed lines represent the hydrograph (right axis) and b) solid lines represent the thermograph (left axis).

The remaining simulations (Scenario numbers 2–7, 10–15, 18–23 in Table 3-3 above) were designed based on the historical conditions for each BiOp year. The historical hydrograph was modified to reflect the differences prescribed in winter discharge (50 vs 2 or 0 cfs) and up and down ramping rates (fast or slow) (Table 3-4). The modified hydrographs were placed as a forcing output flow for the Deadwood Reservoir model, which was then run to predict the temperature regime released with the aforementioned outflows.

Table 3-4. Definition of terms for investigated ramping methods. (See Appendix A for SOP documentation).

Method	Duration	Description
Slow ramp up	7 days	Approximation of the duration of the natural rising hydrograph
Fast ramp up	~2 days	Fastest possible defined by the standard operating procedures (2013)
Slow ramp down	10 days	Approximation of the duration of the natural falling hydrograph
Fast ramp down	2 days	Historical precedent

The modified hydrographs with lower winter discharges (2 and 0 cfs) retained an extra "carry-over" water volume in the reservoir due to less water released from the dam. This additional volume is not present in the historical reservoir levels or spillway flow records. New theoretical water balances for the additional volume were calculated along with the associated adjusted reservoir water levels. With additional water volume, the reservoir experiences full pool volume earlier than historically recorded, and thus spill begins earlier in the year. The hydrographs for these simulations were designed to begin spilling early enough such that the maximum historically experienced reservoir level (approximately 1,626 m in elevation) is never exceeded, and that spill ceases at the same time as historically recorded. This enables for consistency when comparing the spill period and magnitude throughout the range of simulations.

Under the climatic conditions of the three BiOp year alternatives, dry, average, and wet, the calculated "carry-over" water was allowed to spill over before the historic dam operations released any water. Under the dry BiOp year conditions, no water was available for spillway releases and hence all water, regardless of the winter release alternative, was stored in the reservoir for necessary irrigation requirements. During an average BiOp year, the 50 cfs winter release does not allow any "carry-over" water; therefore, no water was spilled over the dam.[6] When the 2 or 0 cfs options were modeled, available "carry-over" water was released

[6] This assumption is based on river modeling scenarios which used forced-output starting points, and it should be cautioned that these are not necessarily reliable when compared to actual carryover and water elevation data. For example, in actuality, reservoir elevations in 2003 (following 50 cfs winter discharges) exceeded 5,224 feet (spillway crest height) for 16 days. Model outputs should be compared with actual data for validation before being relied upon for broader extrapolation.

over the spillway prior to any pre-irrigation or irrigation release. The wet BiOp year provides ample opportunity to use the spillway and was modeled as historic conditions required reservoir evacuation due to excessive water.

Two locations were selected for analysis of the lower Deadwood River model to allow for direct comparison with the biological and chemical analyses (see other report sections). Location 1 is located 900 m below the dam and accounts for the dam releases and the influence of the tributary Wilson Creek. Location 2 is situated 37.9 km downstream of the dam, near the confluence with the South Fork Payette River, and represents the influence of the dam and all tributary inputs.

In total, 24 different dam operation scenarios were performed to represent the 3 BiOp year conditions (Table 3-3). Various hydrologic scenarios were presented in order to evaluate the impacts of dam operations on the thermal regime of the lower Deadwood River. Impact on the thermal regime in the river was broken into seasons (Table 3-5) in order to facilitate decision making at the operational level. Significant findings are those that exceed the 1^{o}C criterion, which is the estimated level of uncertainty in the model during unfrozen conditions. No significant differences in the thermal regime were apparent when the fast versus slow ramping up rates in the spring were analyzed (see Appendix B). Ramping down from irrigation flows to one of the alternative dam release options in a fast or slow manner can make a noteworthy difference and is discussed in the various scenarios below.

Table 3-5. Temporal definitions for seasonal analysis.

Season	Dates
Spring	03/21 - 06/20
Summer	06/21 - 09/20
Fall	09/21 - 12/20
Winter	12/21 - 03/20

The thermal regime of the lower Deadwood River is impacted by numerous drivers, the MIKE 11 model includes: incoming thermographs at each tributary and at the dam, solar radiation, ambient temperature, and relative humidity. Due to the canyon setting of the river, steep walls prevent much direct solar radiation from hitting the river surface during the late fall (November) through early spring (March). From April through September incoming radiation increases river temperatures dramatically through either direct sunlight or sunlight on tributary inputs (Figure 3-9). The high specific heat capacity of water moderates the diel and seasonal fluctuations within the river; however significant changes in temperature can occur when there is low discharge in the river. At flows below 125 cfs the thermal influence of the solar radiation is limited by the interaction of the flow and large substrate on the channel bed.

Figure 3-20 shows the historic hydrographs and thermographs at Location 2 for the 3 BiOp year conditions, dry, average, and wet. Although there are large differences in discharge between the 3 years, the thermographs display similar trends for most of the year. Temperature differences are evident during the summer and fall releases due to effects of the reservoir thermal structure and variable tributary inputs. Figure 3-21 shows the unregulated hydrographs and thermographs at Location 2 for the 3 BiOp year conditions. Given the large differences in peak spring runoff, the resultant modeled thermographs are remarkably stable. Small differences between the thermal regimes occur in the spring and summer, which are usually less than 2°C.

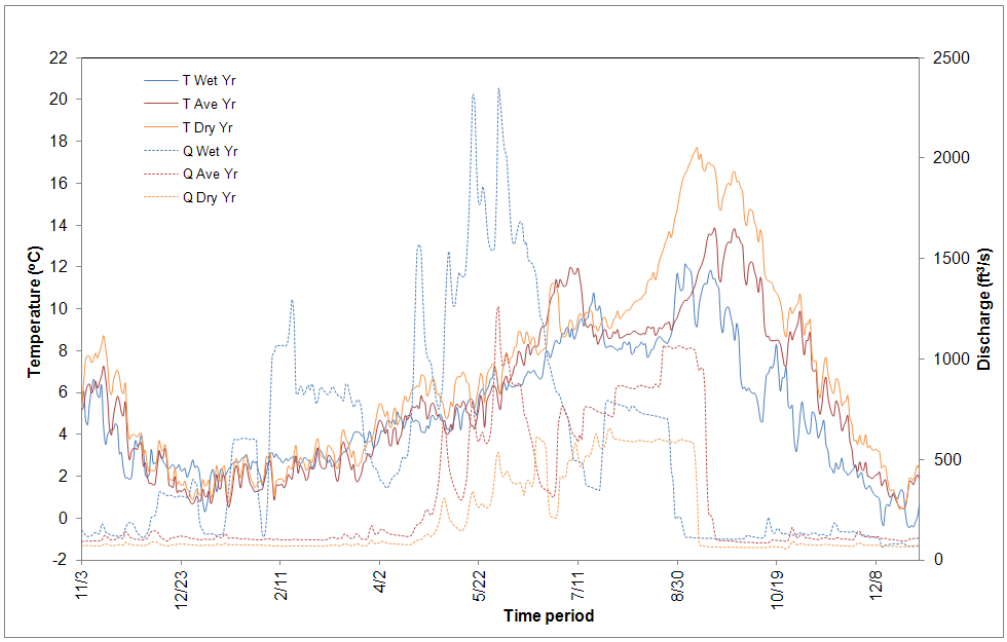


Figure 3-20. Historic flow regime at Location 2 for dry, average, and wet BiOp years; a) dashed lines represent the hydrograph (right axis) and b) solid lines represent the thermograph (left axis).

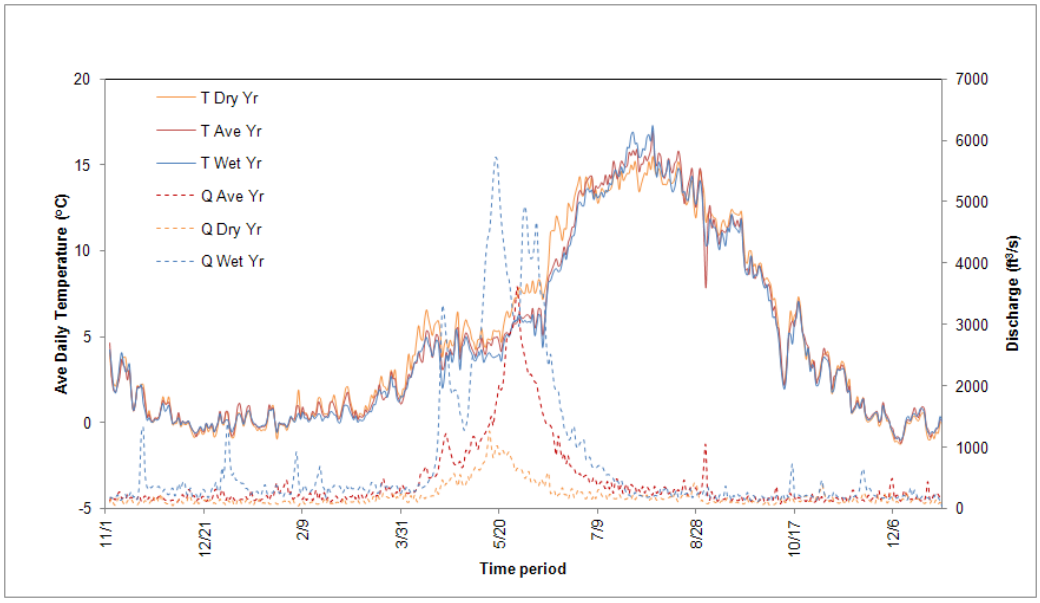
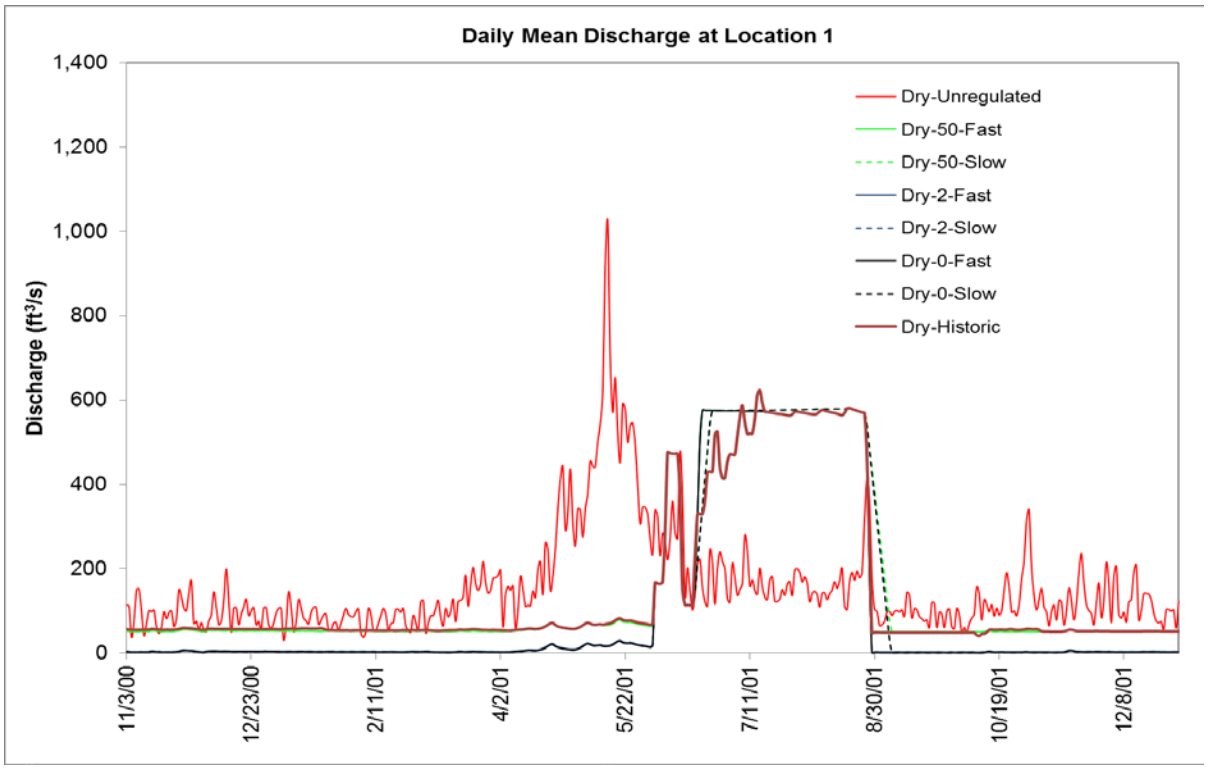


Figure 3-21. Unregulated flow regime at Location 2 for dry, average, and wet BiOp years; a) dashed lines represent the hydrograph (right axis) and b) solid lines represent the thermograph (left axis).

The most evident differences in Figure 3-21 occur in the spring, when limited solar radiation, variable air temperatures and cold tributary inputs affect the temperature regime of the lower Deadwood River to varying degrees. Differences occur between the three BiOp year conditions because the moderating effect of the spring flood hydrograph diminishes earlier in the dry years and remains later during the wet years. The small differences between thermographs that are evident throughout the rest of the year are due to the diel impact on the variable amount of water of the BiOp year conditions during low flow periods.

Dry Climatic Year

The period of November 2000 through December 2001 was used to represent an overall dry climatic year in the Deadwood River system. As previously presented, Figure 3-18 and Figure 3-19 show the hydrologic and thermal regimes as they enter the lower Deadwood River for both the historical and theoretical dam free scenarios. Figure 3-22 and Figure 3-23 show the hydrologic and thermal regimes of the lower Deadwood River 900 m below the dam (Location 1) and near the confluence with the South Fork Payette River (Location 2), as computed within MIKE 11.



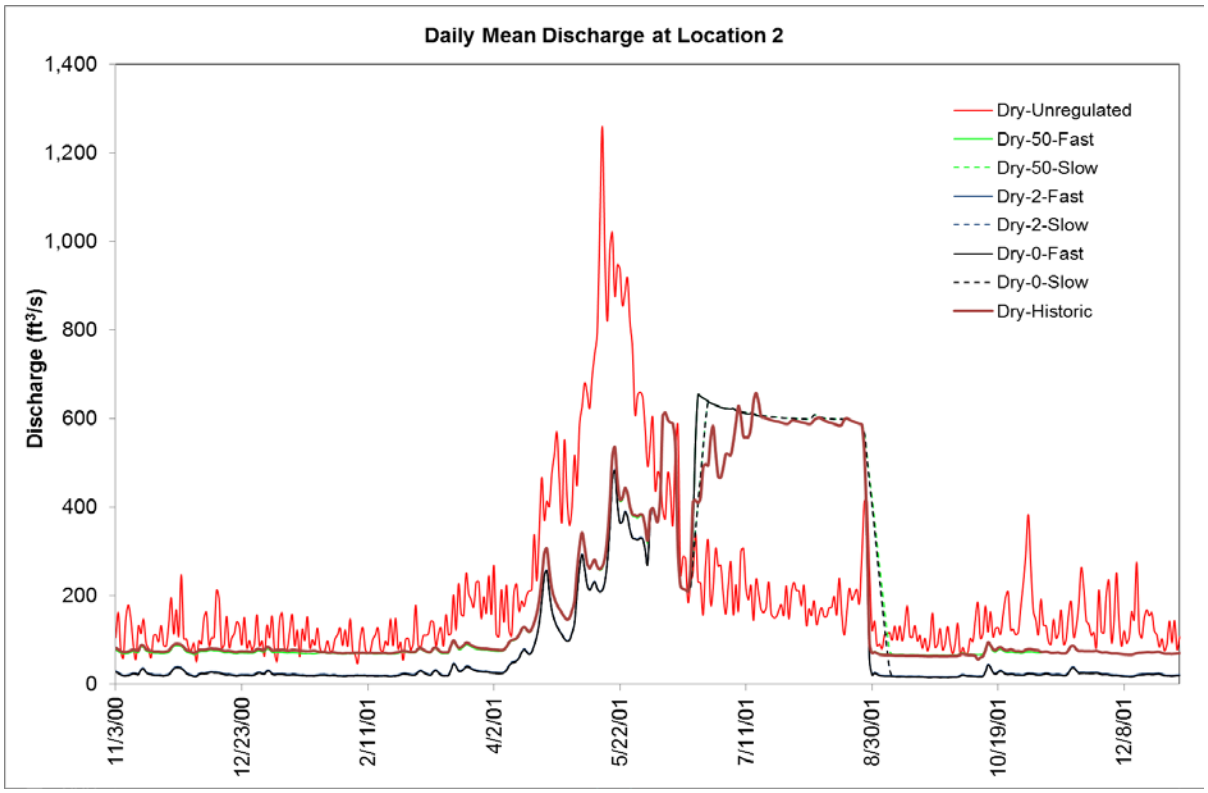


Figure 3-22. Daily mean discharge for Locations 1 and 2 on the lower Deadwood River.

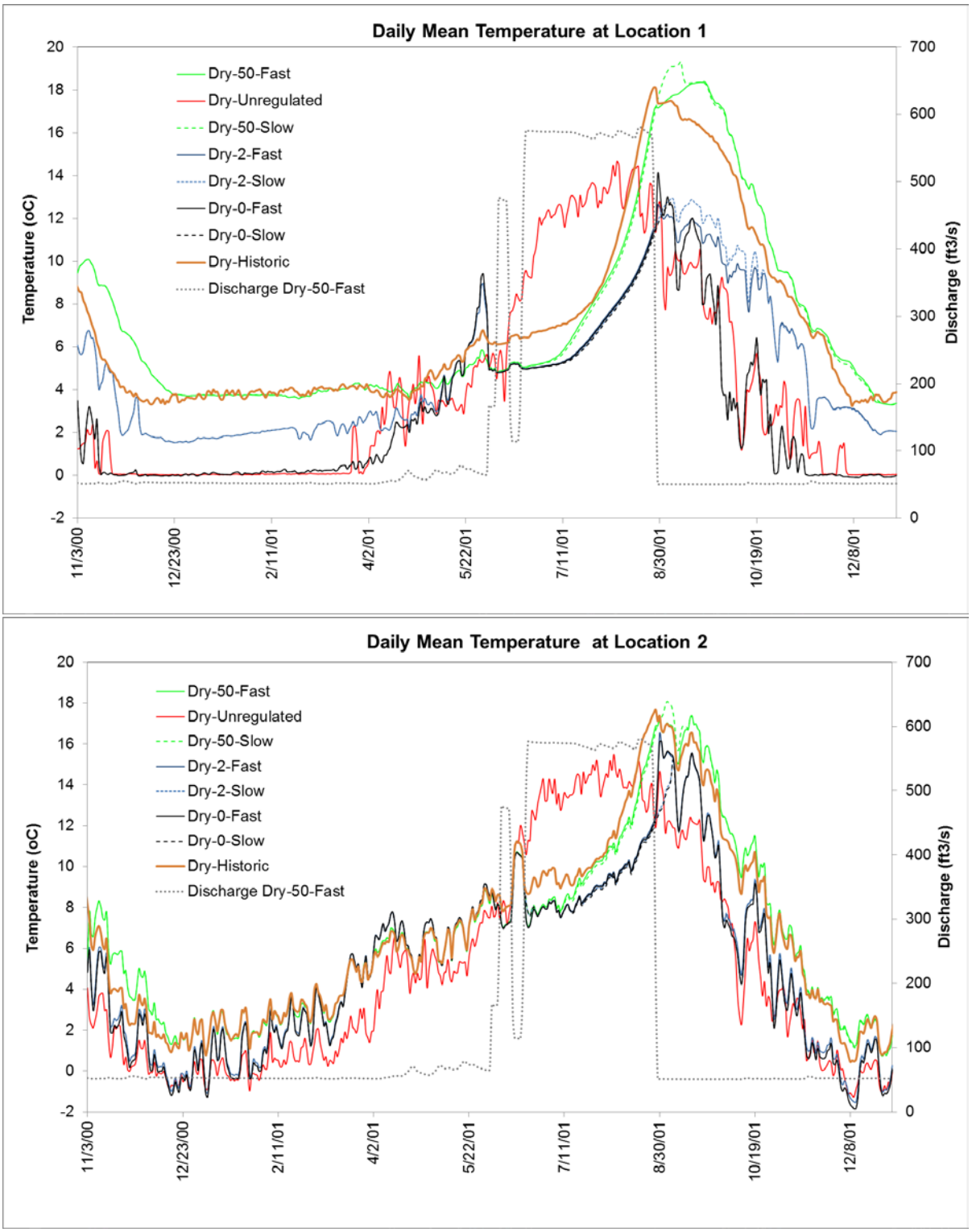
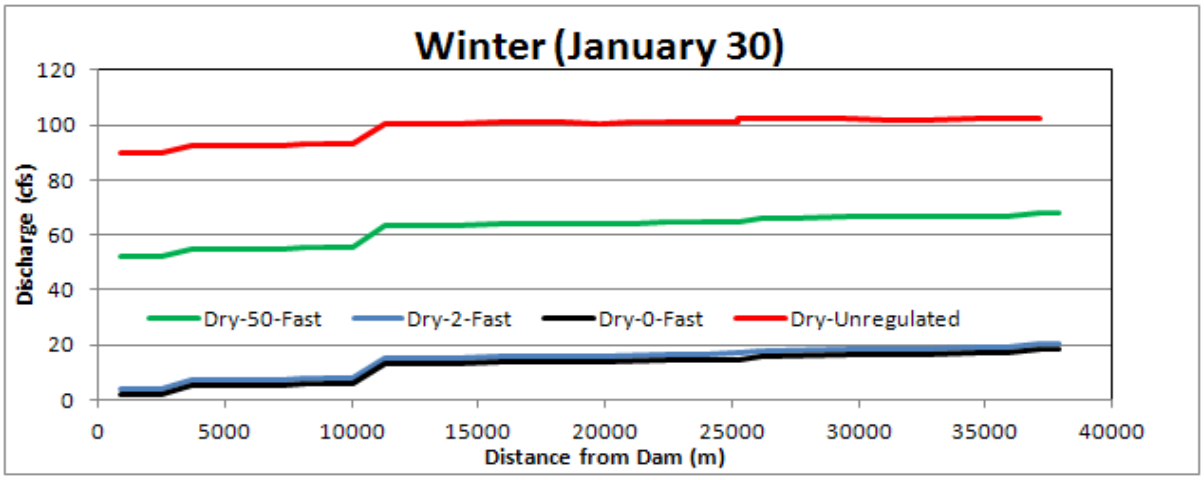


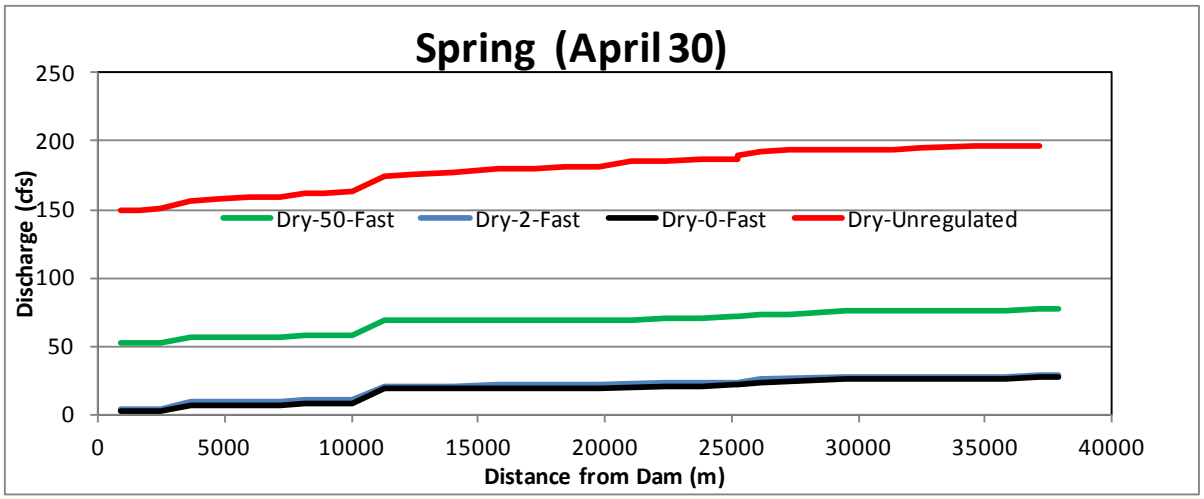
Figure 3-23. Daily mean temperature for Locations 1 and 2 on the lower Deadwood River.

Low flows characterize the winter period with dam-regulated releases generally 50% lower than the unregulated flows (Table 3-6). The effect of dam releases on stream discharge is attenuated by tributary inflows as shown in Table 3-6 and Figure 3-24.

Table 3-6. Regulated flows as a percent of unregulated flows for the different winter release options per season during the dry year.

	Winter Q=50 cfs		Winter Q=2 cfs		Winter Q=0 cfs	
	Location 1 Reg/Unreg	Location 2 Reg/Unreg	Location 1 Reg/Unreg	Location 2 Reg/Unreg	Location 1 Reg/Unreg	Location 2 Reg/Unreg
Winter	66%	73%	5%	24%	3%	22%
Spring	44%	61%	27%	49%	26%	48%
Summer	277%	249%	263%	237%	263%	237%
Fall	50%	57%	3%	18%	2%	17%





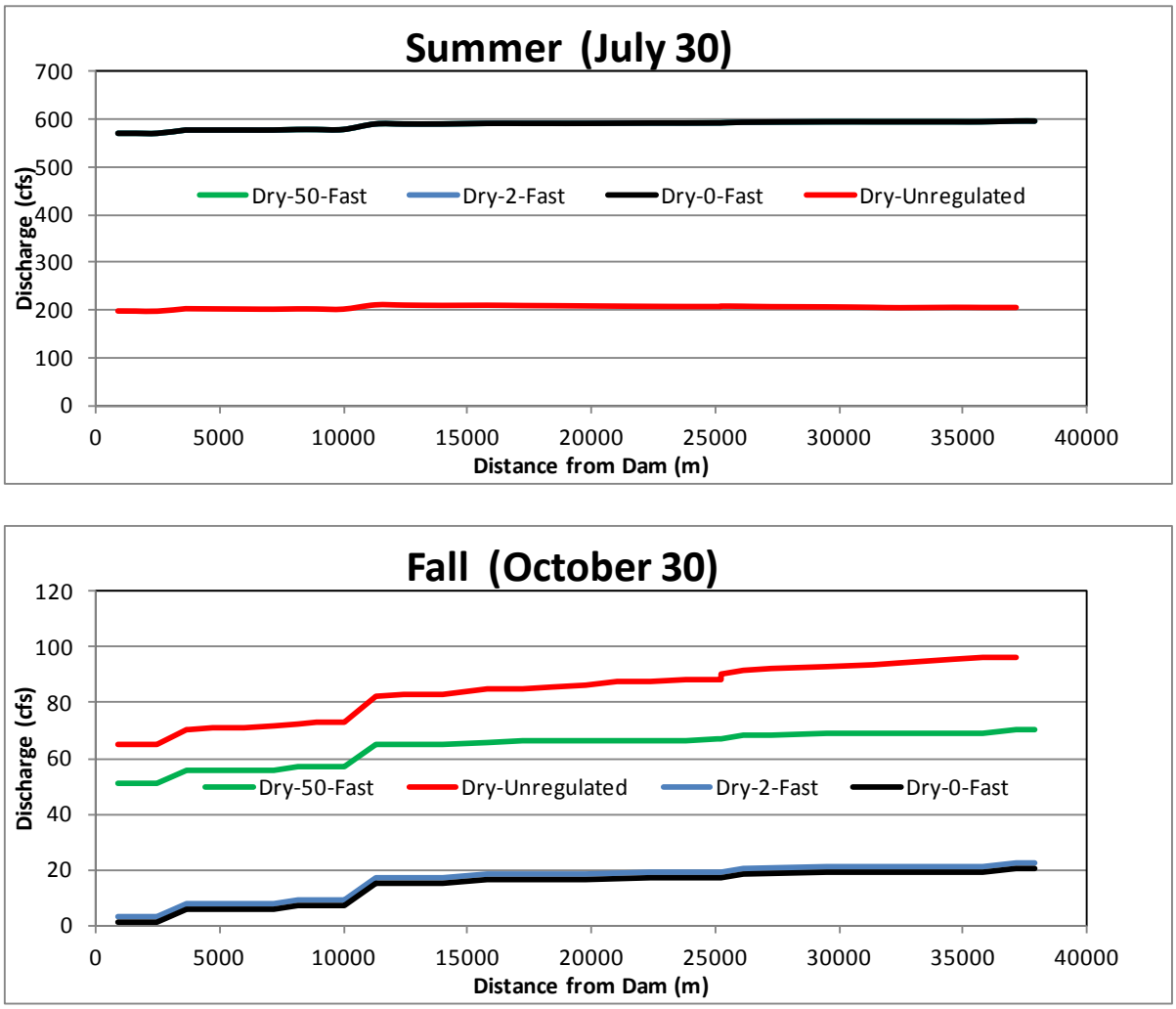


Figure 3-24. Changes in discharge (winter, spring, summer, and fall) along the lower Deadwood River.

Winter dam releases of 0, 2, and 50 cfs influence the available wetted areas with depths greater than 0.5 m (Figure 3-25). Differences between wetted areas for the 0 and 2 cfs options are negligible for most reaches except for reach 15 and 16, which are closest to the dam. The effect of 0 cfs release from the dam is attenuated by tributary inflows, whose cumulative effect starts influencing the wetted areas below reach 15 (Figure 3-24). Deep pools are available along the lower Deadwood River but they may become disconnected at low flows, as seen in Figure 3-26. At high flows, these deep areas may provide velocity refugia for fish and aquatic organ.

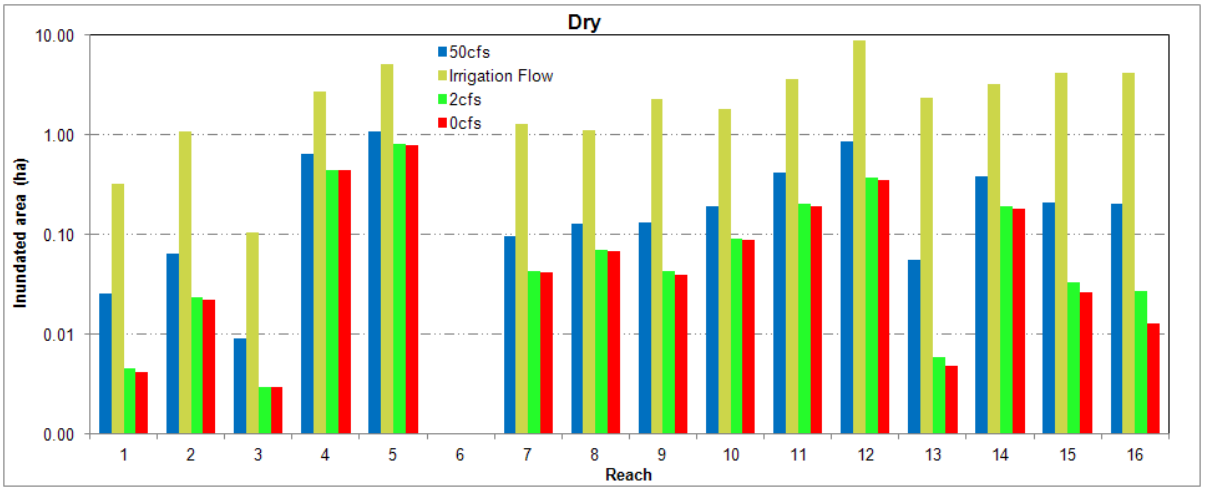


Figure 3-25. Dry year wetted areas (of 0.5 m depth and greater) for 0, 2, and 50 cfs winter releases (on October 11) and during the irrigation flow (August 15). Reach 1 corresponds to the confluence with the South Fork Payette; reach 16 corresponds to the furthest upstream reach.

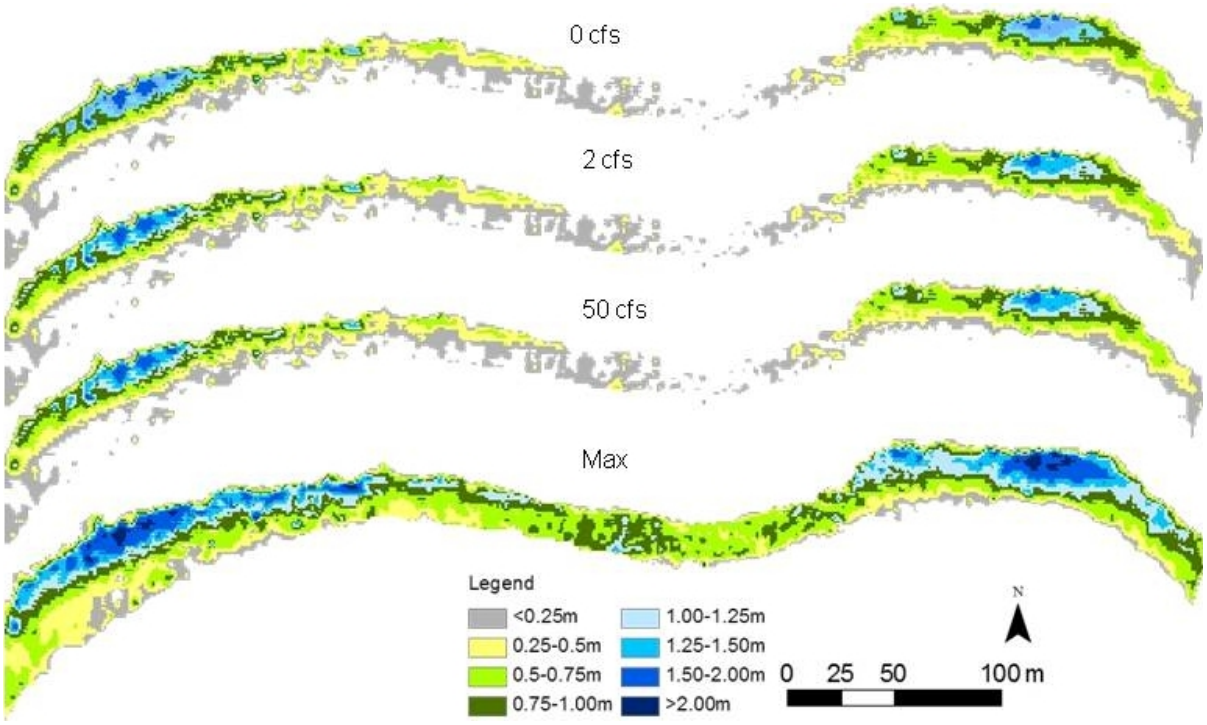


Figure 3-26. Example of wetted areas distribution for 0, 2, and 50 cfs winter releases for October 11 and during the irrigation flow August 15 for dry year. This is a section of reach 15.[7]

Winter season dam operations (Table 3-7) have historically released 50 cfs since 1993 with consistent temperatures of 4°C emerging from the bottom of the reservoir (Figure 3-22). The temperature of the water released (4°C) is greater than that of the natural hydrograph (0°C) and acts to prevent ice formation and snow cover that would form throughout the winter season. Winter videography from 2012 shows that these warmer dam releases of 50 cfs influence ice formation until approximately Lorenzo Creek, where colder tributary water and ambient temperatures act to cool the river water and allow for ice formation. The influence of these warmer dam releases carries downstream to the confluence with the South Fork Payette as seen in Figure 3-27. Temperature for the 50 cfs may overestimate the temperature by 2°C after Scott Creek.

[7] LiDAR data should be evaluated conservatively due to limitations in accuracy of the methods used, discovered during ground surveys to corroborate modeled data. For instance, this figure depicts areas of completely disconnected habitat to occur at 50 cfs; this was not found to be accurate following ground surveys. These issues with LiDAR are addressed more thoroughly in Chapter 4.2 of this document concerning LiDAR mapping of the physical elements of potential Bull Trout habitat.

Table 3-7. Regulated flows as a percent of unregulated flows for the different winter release options per season during the average year.

	Winter Q=50 cfs		Winter Q=2 cfs		Winter Q=0 cfs	
	Location 1	Location 2	Location 1	Location 2	Location 1	Location 2
	Reg/Unreg	Reg/Unreg	Reg/Unreg	Reg/Unreg	Reg/Unreg	Reg/Unreg
Winter	43%	58%	6%	31%	5%	30%
Spring	17%	43%	19%	45%	19%	46%
Summer	241%	216%	233%	210%	233%	210%
Fall	53%	66%	6%	35%	4%	34%

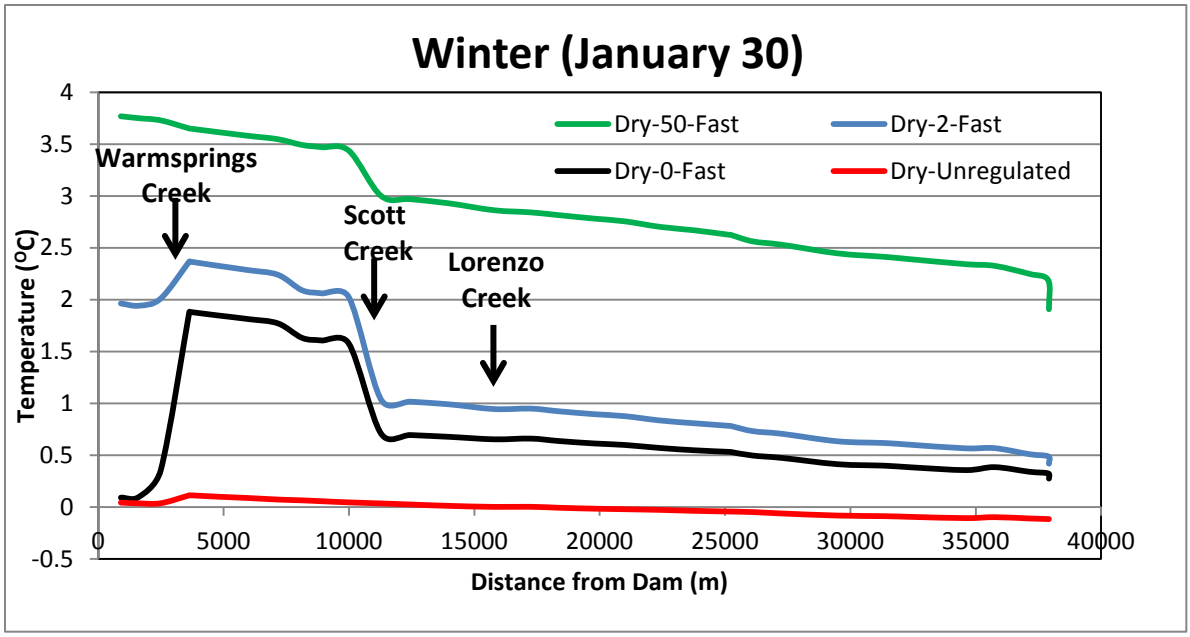


Figure 3-27. Downstream cooling of stream temperature during typical winter day on January 30, 2001. Unregulated hydrograph (red), 50 cfs (green), 2 cfs (blue), and 0 cfs (black). As noted previously in this chapter, these winter temperature models may vary from actual temperatures by up to 2°C.

Alternative winter release options include: 1) shutting off the dam completely to 0 cfs (Scenarios 6 and 7) and 2) shutting off the dam while allowing a 2 cfs discharge to be released from a small hydroelectric turbine (Scenarios 4 and 5). Model results show that a 0 cfs discharge would cutoff reservoir flow to the lower river and tributary inputs would provide 0°C to the system prior to Location 1,900 m below the dam. The second alternative of a 2 cfs discharge would still provide 4°C water from the dam, but with tributary input and ambient cooling the stream would cool sufficiently within 900 m to 1.5 to 2°C. Both

alternative flow options (2 and 0 cfs) provide comparable temperatures to the natural flow regime at the downstream Location 2 (Figure 3-23).

Under the dry BiOp year conditions, spring and summer flows in the lower Deadwood River have the most direct impact from dam operations, as the hydrograph undergoes a temporal shift from a brief spring flood peak to a sustained high summer discharge in order to satisfy irrigation demand. Low flows characterize the winter period with dam-regulated releases generally 50% lower than the unregulated flows (Table 3-6). The effect of dam releases on stream discharge is attenuated by tributary inflows as shown in Table 3-6 and Figure 3-24.

Spring flows (Table 3-5), under the natural hydrograph, peak in mid-May and return to base flow by the middle of June. The unregulated thermal regime in spring will begin under winter conditions near 0°C and steadily increase until it reaches warm summer temperatures of 12 to 13°C. Natural variability during this period can be significant due to cloud cover, localized high intensity precipitation events, and the presence of regional warm Pacific storms. Peak discharge during the spring runoff maintains cool temperatures in the river until base flow conditions return and solar radiation can influence the river's lower thermal mass later in the year.

Modeled scenarios for the dry BiOp year present a brief pre-irrigation spring release, followed by an irrigation-demand constant discharge (Scenarios 2 through 8). The pre-irrigation release acts in conjunction with tributary inflows to increase the magnitude of the spring peak flood at the downstream Location 2, which combined is less than the irrigation discharge later in the season (Figure 3-21). Timing of this pre-irrigation release in the spring acts to suppress the temperature downstream of the dam in various ways depending upon which release alternative is chosen (50, 2, or 0 cfs). As incoming solar radiation and ambient temperatures increase in the canyon, the river will respond differently to these drivers if significant thermal mass is present in the river or not. In a dry year any potentially available water in the reservoir would likely be used for irrigation by the end of the season regardless of the chosen release scenario, ultimately resulting in the same end-of-season water level. Therefore, the end result is that for all intents and purposes, no "carry-over" water is available during a dry BiOp year under any release alternative, due to limited inflows to the reservoir.

Employing the 50 cfs option in the winter season (Scenarios 2 and 3) provides 4°C water to the lower Deadwood River system until the pre-irrigation release occurs at the end of May. Increasing the discharge of 4°C water during the pre-irrigation release period acts to significantly increase the thermal mass of the river and offset the incoming solar radiation and low tributary input. Hence, the river remains at a near constant temperature (4 to 6°C) until irrigation flows are initiated in the summer and the warm pool in the reservoir is drawn down to the intake. This release option increases consistency in the thermal regime and

reduces daily variability during a time when the temperature of the natural hydrograph would be fluctuating significantly.

The alternative option of 2 cfs during this spring time period (Scenarios 4 and 5) has slightly greater variability in the daily temperatures at Location 1 than the 50 cfs option, due to its reduced thermal mass. It also increases stream temperature by 2.5ºC in the few days prior to the pre-irrigation release as the increasing solar gain and warmer tributaries begin to influence the reduced thermal mass of the main river. The 0 cfs option (Scenarios 6 and 7) responds similarly to the 2 cfs option with the exception of when it begins to warm up from its initial winter temperature (0ºC). Due to the low discharge of the 2 and 0 cfs release options in the spring, downstream temperatures at Location 2 are slightly higher (0.5 to 1.5ºC) than those modeled in the natural hydrograph. This is probably due to the fact that tributaries from higher elevations that would be providing colder water are being stored behind the dam while the lower tributaries are providing the majority of the warmer discharge. If suppression of the spring temperature is important for the ecological community in the river, in order for it to better fit the natural hydrograph temperature regime, alteration of the pre-irrigation release could be made to increase the thermal mass of the river. Instead of initiating a larger pre-irrigation release of short duration, the 50 cfs option could be exercised earlier in the season and extended until irrigation flows are ramped up in the early summer. This would effectively maintain constant temperature below the dam while not exerting any pressure on the irrigation flows during a dry climatic year.

Summer flows in the lower Deadwood River are mostly determined by irrigation demand, which are approximately 200% larger than the unregulated flows (Table 3-6) and have little room for alteration. Sustained irrigation flows during the summer period (Table 3-5) act to influence the downstream temperature in two distinct ways: 1) maintain cooler temperatures (approximately 4-6ºC) in the river than were present in the natural hydrograph during the first part of the summer, and 2) dramatically increase the temperatures, above those that were present in the natural hydrograph during the second part of the summer, as the warm pool in the reservoir is brought down to the dam intake.

If the 50 cfs option is selected for winter flows, lower pool level and reduced volume in the reservoir will be available in the spring and summer seasons. This reduced reservoir volume will warm faster during the summer months and reach the intake of the dam at an earlier date in the season than if one of the alternative options, 2 or 0 cfs, is selected. This can be seen as a steeper increase in temperature in the thermographs (Scenarios 2-7 in Figure 3-23). Evaluating the thermographs for average daily temperature under the 50 cfs regime, the early summer temperatures are approximately 6-7 ºC cooler than the natural hydrograph during the same period. In the second part of the summer, the modeled dam release peak occurs later in the year than the natural hydrograph by approximately 30 days and is approximately 5-6 ºC higher. This peak in temperature is closer in magnitude to that of maximum daily temperature than to that of the average. This difference in magnitude and timing of peak

temperatures persists throughout the length of the lower Deadwood River and can be clearly seen in thermographs from the downstream Location 2.

If the 2 cfs or 0 cfs option is selected for winter flow conditions, significant differences in the summer thermal regime are apparent. Due to irrigation demand, the first part of the summer will maintain cooler temperatures of approximately 6-7^{o}C (similar to that of the 50 cfs option) than would be present in the natural hydrograph. During the second part of the summer period the temperature would increase, but less dramatically than in the 50 cfs option. Peak temperatures would be similar in magnitude to those of the natural hydrograph (Scenarios 4 through 7). Peak temperatures would occur later in the year, but would persist for a shorter amount of time, 20 days longer with the 2 cfs flow and 7 days longer with the 0 cfs flow. The 2 cfs option, after irrigation demand ends, will maintain slightly higher temperatures in the lower river Location 2 of approximately 1-2^{o}C and lower daily variability due to continuing introduction of warm water from the dam release. If the 0 cfs option is selected after irrigation flows are over, temperatures and variability will be consistent with those of the natural hydrograph due to tributary input.

In evaluating the ramping down options for the dam, two forces are acting on the temperature regime in the lower river that must be accounted for: 1) the warm pool behind the reservoir is drawn down and entering the river at the dam, and 2) tributaries at higher elevations that would be adding cooler water at this time of year are trapped behind the dam and the lower tributaries provide warmer inputs. Examining the available ramping down options (fast vs. slow), with respect to the temperature regime, little difference is evident. At the 50 cfs flow release, the fast-ramping down option will reduce the peak temperature by 1^{o}C and show little difference at Location 2 downstream. Under the 2 and 0 cfs releases, tributaries dominate the heat balance in the main river and fast-ramping down will act to elevate the temperature in the main river up to 1^{o}C at Location 2 for approximately 9 days. This is due to the addition of warm tributaries to the already warm dam released water.

During the fall season, no irrigation demand is present and various options are available for reservoir operations. Using the 50 cfs option in the winter season will leave the reservoir warmer than the natural hydrograph would provide (maximum 19^{o}C). The 50 cfs option could be utilized after irrigation flows terminate to maintain warmer instream temperatures (by 7-9^{o}C) lasting into November if this may provide beneficial impact on aquatic organisms.

If the 2 cfs or 0 cfs option is exercised in the winter season, temperatures in the reservoir will remain elevated later in the season, but to a lesser degree than if the 50 cfs option was selected. If either alternative option (2 or 0 cfs) is employed after irrigation flows are over, temperatures will maintain 3^{o}C higher until mid-September, due to warm tributary input. As ambient temperatures cool, this difference will then decrease with time in a trend similar to that of the natural hydrograph.

In comparing the operational alternatives with the historical dam operations, slight modeling differences must be accounted for in order to clearly present the significant changes to the riverine temperature regime. Calculation of the historical dam releases use data from actual historical recorded environmental data from that period, whereas the alternative operational flows of 50, 2, and 0 cfs utilize the modeled ELCOM-CAEDYM reservoir outputs for the temperature at the dam. The environmental drivers for the alternative flows such as relative humidity, air temperature, and solar radiation were measured from 2009 and used as a consistent input for the modeled temperatures in the lower river. Finally, ramping rates and fluctuating dam release values for the historical operations provide another set of variables that introduce variation into the direct comparison of results. Accounting for all these sources of variation shows only minor differences between the historical dam operations and modeled alternative release of 50 cfs, implying the analysis of the alternative flows will accurately account for the magnitude of changes present in the different flow regimes.

The comparison of the alternative 50 cfs flow and historical releases should provide very similar conditions with small variations due to climatic drivers and varying releases during the historical operations. For example, it was common for the historical operations to fluctuate releases depending upon operational needs, so releases would be held at 48 cfs for a week and then increased to 55 cfs for the next week and then decreased to 51 cfs for the next two weeks. The modeled approach took a constant value during this period of 50 cfs and therefore should closely track the historical regime. This is in fact the case at both locations 1 and 2, with small differences up to 2^{o}C due to variable environmental conditions. These differences manifest during the spring and fall when local weather conditions are the most variable.

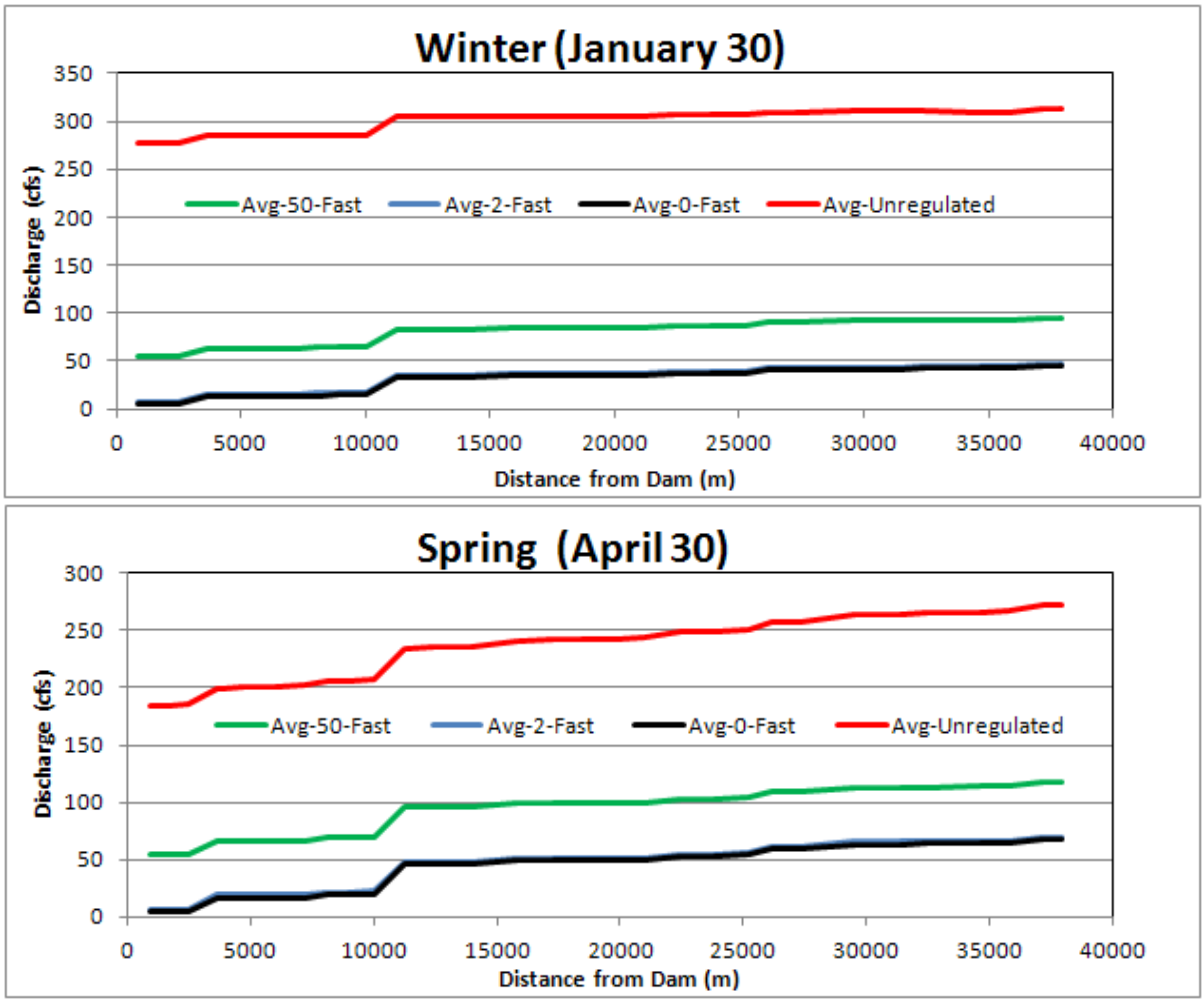
Examining the 2 and 0 cfs alternative release options during the dry years, model results show that operational differences due make a difference. The winter flows show the historical temperatures to be greater than the 2 and 0 cfs release options by 2-3^{o}C at both locations 1 and 2. During the spring, Location 1 shows a temperature spike of 2.5^{o}C in the modeled 2 and 0 cfs options whereas the historical release option shows a more stable and gradual increase in temperature before the irrigation releases are initiated. Large differences in temperature develop in the latter half of the summer and fall seasons under the historical option where the warm pool in the reservoir is drawn down and released into the river, therefore, increasing temperatures in the river by 5-7^{o}C (Location 1) and 3-5^{o}C (Location 2) above the 2 or 0 cfs options.

Average Climatic Year

The period of November 2002 through December 2003 was used to represent an overall average climatic year in the Deadwood River system. As previously presented, Figure 3-18 and Figure 3-19 show the hydrologic and thermal regimes as they enter the lower Deadwood River for both the historical and theoretical dam free scenarios. Figure 3-31 and Figure 3-32

show the associated hydrologic and thermal regimes of the lower Deadwood River 900 m below the dam (Location 1) and near the confluence with the South Fork Payette River (Location 2), as computed within MIKE 11.

As for the dry year, dam-regulated winter flows are lower than the unregulated flows and the reduction depends on flow release option (Table 3-7). However, the effect of dam releases on stream discharge is attenuated by tributary inflows as shown previously in Table 3-7 and below in Figure 3-28.



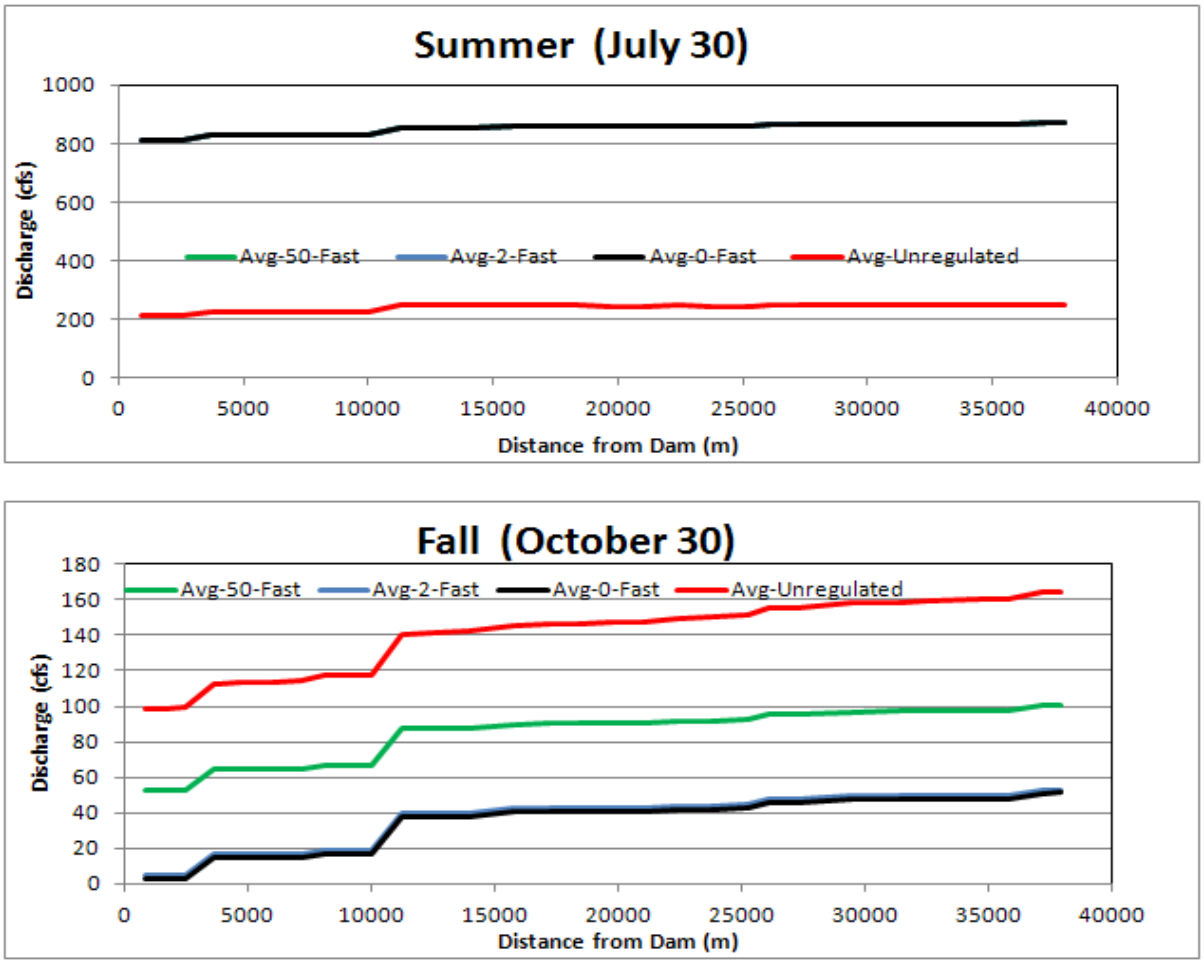


Figure 3-28. Change in discharge along the lower Deadwood River for winter, spring, summer, and fall.

As for the dry year, winter dam releases of 0, 2, and 50 cfs influence the available wetted areas with depth deeper than 0.5 m Figure 3-29. The average year presents more wetted areas deeper than 0.5 m than the dry year (Figure 3-25 and Figure 3-29). Differences between 0 and 2 cfs wetted areas are negligible for most reaches except still for reach 15 and 16. However, this difference is less than that observed in the dry year scenarios. Deep pools cover larger portion of the lower Deadwood River for the Average than dry year scenarios. During irrigation flows, deep pools extend more than in the dry year proving consistent areas of low flows Figure 3-30.

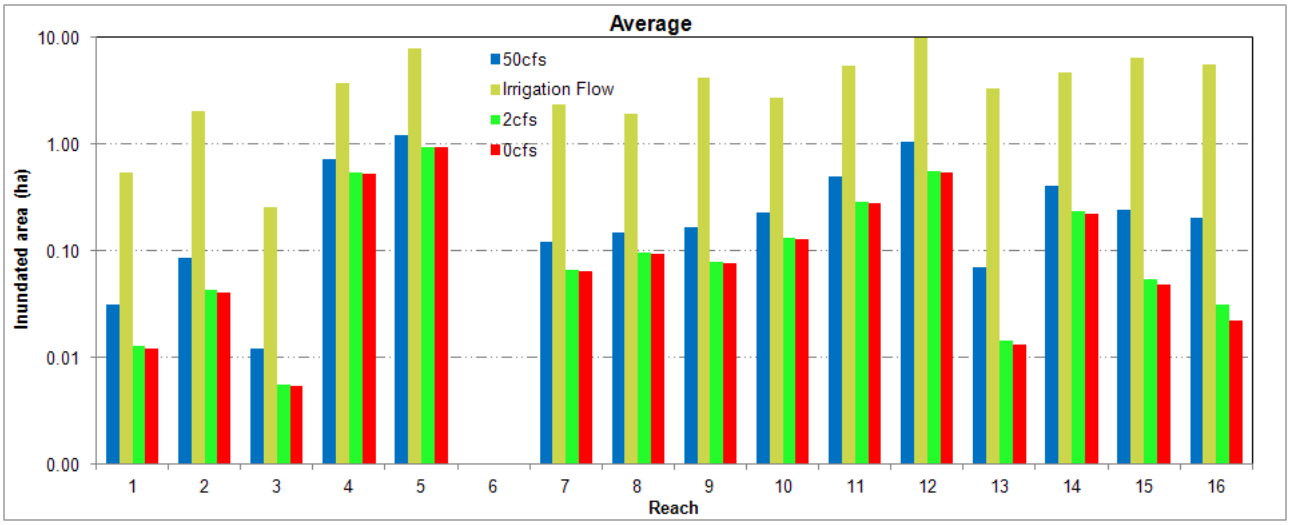


Figure 3-29. Average year wetted area (of 0.5 m depth and greater) for 0, 2, and 50 cfs winter releases (on October 11) and during irrigation flow (August 15).

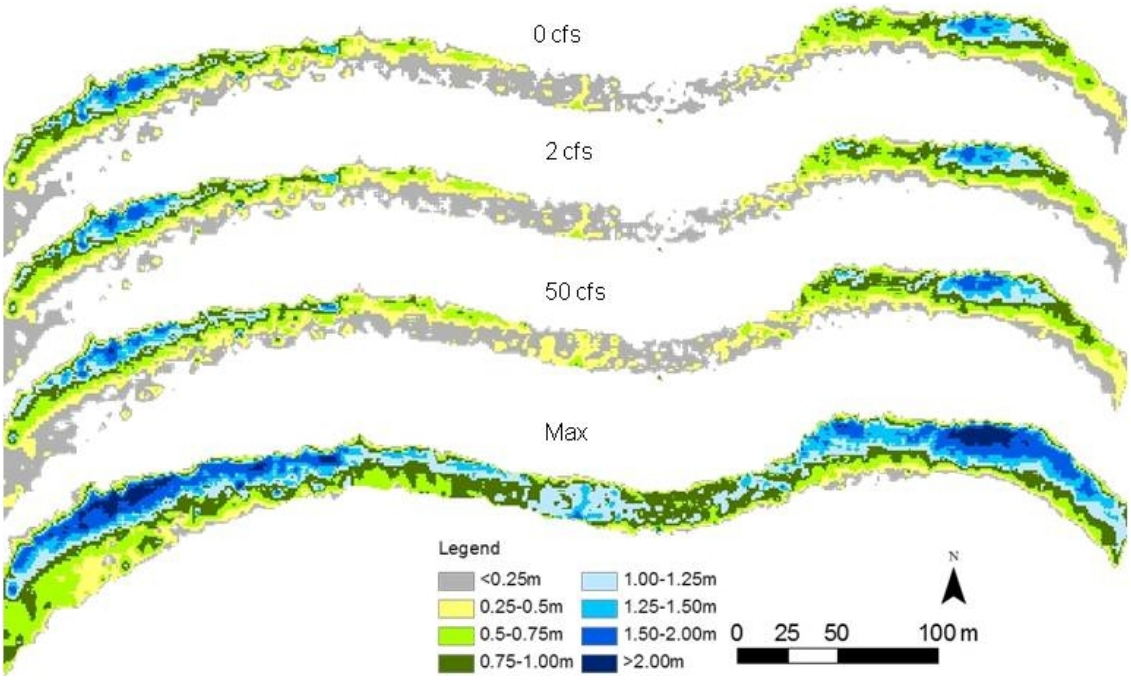


Figure 3-30. Example of wetted areas distribution for 0, 2, and 50 cfs winter releases for October 11 and during the irrigation flow August 15 for average year. This is a section of reach 15.

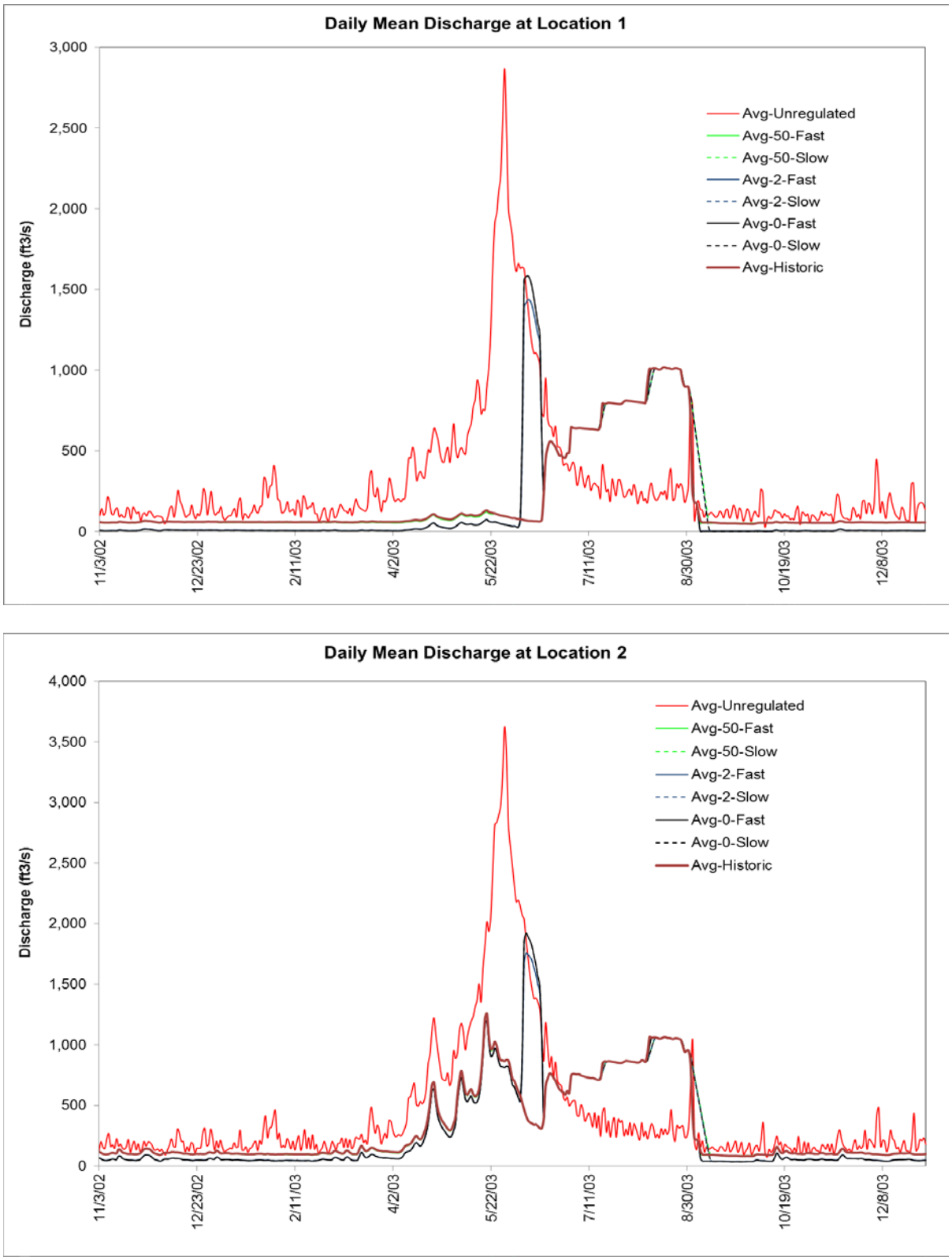


Figure 3-31. Daily mean discharge for Locations 1 and 2 on the lower Deadwood River.

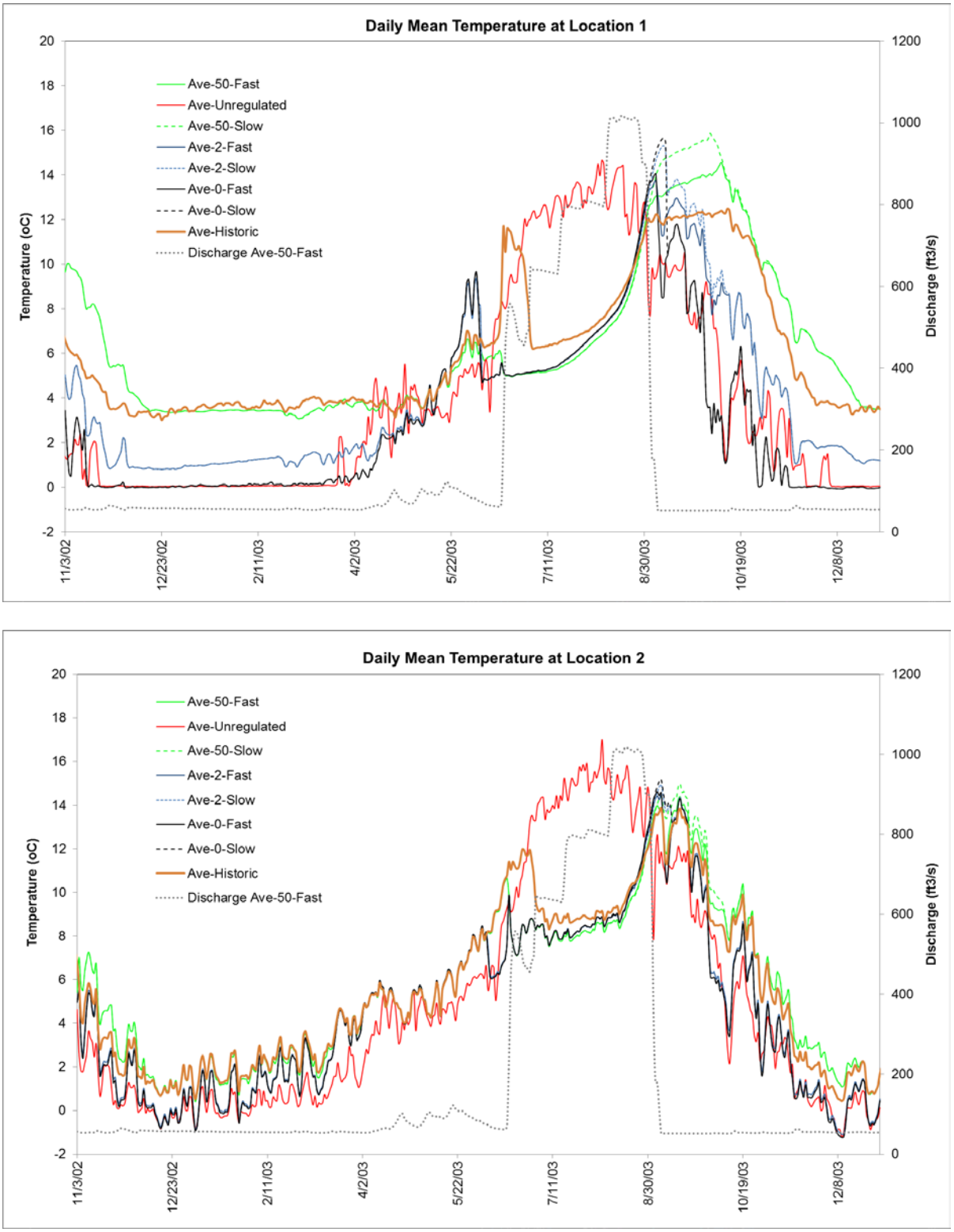


Figure 3-32. Daily mean temperature for Locations 1 and 2 on the lower Deadwood River.

Winter season flow conditions under the average BiOp climatic year respond very similarly to those in the dry BiOp year above (Table 3-8). Winter season dam releases provide water to the lower Deadwood River at 4°C that is warmer than the natural hydrograph would provide (0°C) (Figure 3-33). The 50 cfs winter release option would impact ice formation and snow cover in the upper reaches of the river below the dam, as seen in video from stationary winter cameras and aerial surveys. The increased thermal signature can be seen at the downstream Location 2 near the end of the lower Deadwood River, indicating that attenuation will occur over the course of the canyon on the order of 1-1.5°C. The alternative winter release options of 2 and 0 cfs have a reduced impact on the winter temperature regime in the river. The 2 cfs option does release elevated water temperatures into the upper end of the river as seen in the thermographs at Location 1 (Scenarios 12 and 13), however, attenuation of the thermal signal has occurred by the time it reaches the river's end at Location 2 and is virtually indistinguishable from the 0 cfs option (Figure 3-32).

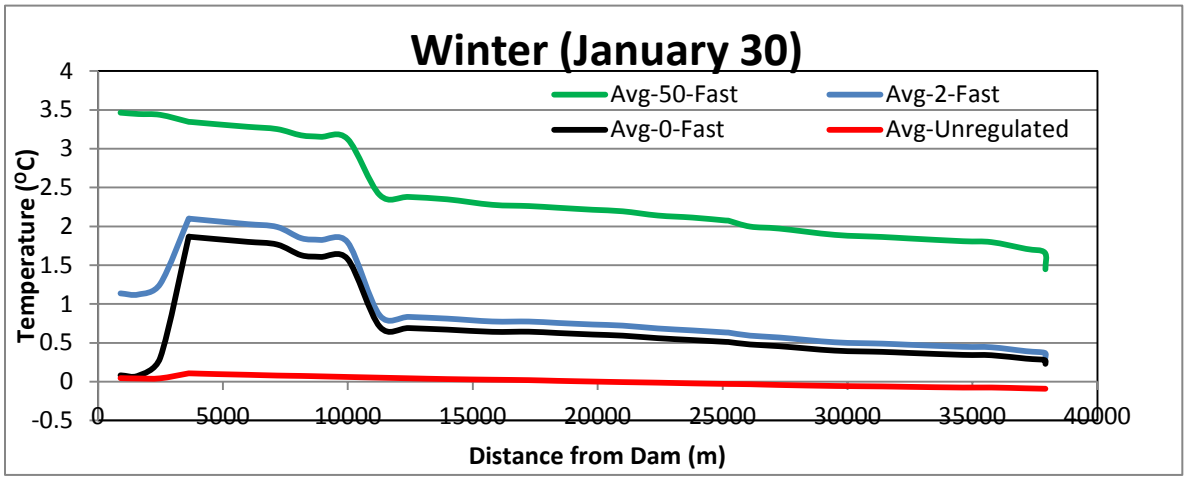


Figure 3-33. Downstream cooling of stream temperature during typical winter day 01/30/2003. Unregulated hydrograph (red), 50 cfs (green), 2 cfs (blue), 0 cfs (black).

Theoretical unregulated flows during the spring season begin to rise in mid April and extend through early July (Table 3-7). The associated thermal regime of the unregulated flow steadily increases during the spring season in a variable manner and then significantly increases around the end of June to its usual summer temperatures (12-14°C). Spring season options for dam operation prior to irrigation-demand releases have variable impacts during the average BiOp climatic year. The 50 cfs option in the winter season does not allow for any "carry-over" water for a pre-irrigation release in the spring. While this lack of spring flood may impact the seasonal cues of the resident ecological community, the temperature regime is more consistent under the 50 cfs release option (Northcote 1992). As solar radiation increases during the spring (Figure 3-9), greater thermal mass in the river from a higher discharge will maintain the thermal regime of the river at a more constant temperature (4-6°C). This greater discharge (50 cfs) acts to reduce the diel fluctuations in the daily

average, maximum and minimum temperatures. The thermal signature at the downstream Location 2 reflects the input of higher temperature water from the dam and reports consistently higher temperatures (approximately 1 to 2°C) for the daily average and daily maximum temperatures than those in the natural hydrograph. Daily minimum temperatures are similar to those seen in the theoretical natural hydrograph.

Alternative flow options of 2 and 0 cfs in the spring provide similar model results. If either lower flow option is selected for the winter season, "carry-over" water is available for a spring pre-irrigation release. Historically, the pre-irrigation release has chosen to maximize its discharge over a period of a few days to simulate a larger spring flood event than to lower the peak discharge and extend the duration of the release. In model Scenarios 12 through 15, the pre-irrigation release begins on June 6, 2003; however the thermographs show that the 11 days prior to that date the temperature increases above the theoretically natural hydrograph by 2.5°C and then drops back to approximately 5°C once the pre-irrigation release begins. This spike in temperature does get attenuated by approximately 1°C in the downstream direction as it reaches Location 2, but is still clearly evident. If the pre-irrigation release were to be precluded by a 50 cfs release or reduced in magnitude and begin earlier in the season for a longer duration, this spike in temperature could be avoided entirely.

Summer flows are dominated by irrigation-demand discharge and act similarly to those described above in the dry BiOp year (Table 3-7). Slightly different model results emerge as greater hydrologic inputs 1) lessen the impact of dam releases on the drawdown of the warm pool in the reservoir, and 2) tributary inputs below the dam are more effective over the length of the river at attenuating the hydrologic and thermal signal of the dam releases. Summer dam releases have two distinct and contrasting effects on downstream river temperature over the course of the season. Initially, cold hypolimnetic water is released into the river maintaining a temperature below that of the natural hydrograph by approximately 6-7°C. In the latter part of the summer season, the warm pool in the reservoir is drawn down to the dam intake and temperature in the river increases precipitously. Peak temperatures in this second part of the summer season are similar in magnitude to the daily average temperature, however are less than the daily maximum and greater than the daily minimum; in essence, minimizing the summer variability of the system.

During an average year the greater quantity of water in the system, than that of the dry BiOp year, means that greater operational flexibility is possible. The timing of the warm pool draw down during the irrigation season is similar; however, after irrigation deliveries are completed, dam release options, 50, 2, or 0 cfs will extend the influence of the warm water in the lower Deadwood River to varying degrees. Selecting the fast ramping down method to 50 cfs (2-day reduction) provides water 1.5°C less than the slow ramping down method (10 day reduction). Downstream at Location 2 the temperature is attenuated slightly by tributary contributions, and ramping effects are reduced to less than 1°C. In order to evaluate how far

the ramping influence extends downstream until the 1°C criterion is reached, an arbitrary day in the fall (September 16, 2003) is selected and modeled temperatures are examined in the longitudinal direction (Figure 3-34). Initially at Location 1, the temperature differential is 1.5°C. Moving downstream the various tributary inputs act to cool the instream temperature, until Scott Creek comes in and the difference between ramping rates falls below the 1°C significance threshold. Due to the influence of the ambient environment, the temperature differential continues to diminish with the distance downstream.

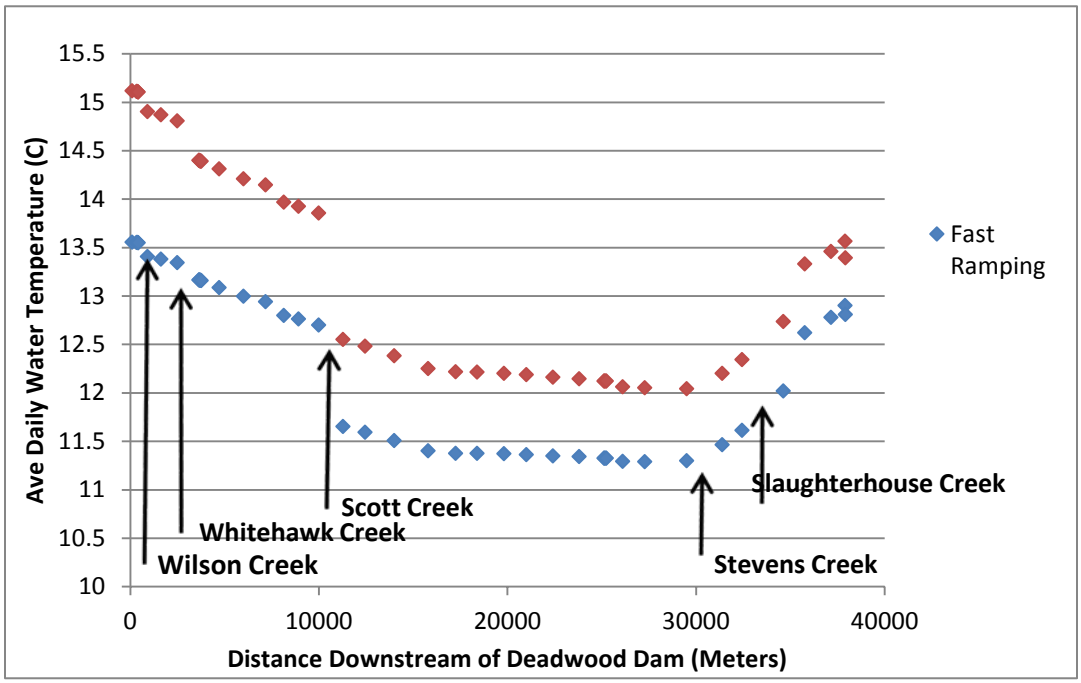


Figure 3-34. Downstream effect of ramping to 50 cfs on temperature for September 16, 2003. After Scott Creek the difference between the ramping rates falls below the 1 C criterion for significance.

After irrigation flows terminate, alternative 2 and 0 cfs options provide a means to minimize the influence of the warm water in the reservoir on the downstream system. The different ramping rates during this time of year can make a difference due to the variable ambient temperatures and cloud cover. Slow ramping down (10-day reduction) to the 2 or 0 cfs releases will provide a more consistent temperature during this period (approximately 20 days) than the fast ramping down rate (2-day reduction). Differences between the two ramping rates can be as high as 3°C at Location 2 (Scenarios 12 through 15 in Figure 3-32).

The fall season release options provide the most flexibility with regard to ecological management options (Table 3-7). Given the warm water in the reservoir, the temperature in the downstream river can be significantly manipulated depending upon ramping down method and which flow scenario is selected. As tributary and ambient air temperatures cool

and incoming solar radiation diminishes stream temperature is expected to drop (Figure 3-9. Exercising the 50 cfs dam release would extend the warm temperatures later into the fall by 40 days and maintain water temperatures 6-10°C higher than the natural hydrograph at Location 1. Downstream attenuation would occur due to tributary influence, but would remain 3-5°C higher than the natural hydrograph at Location 2. The 50 cfs option would reduce daily temperature variability due to the greater thermal mass in the river.

Employing either the 2 or 0 cfs approach in the fall would minimize the persistence of dam released warm water in the river system. The 2 or 0 cfs release will extend warm temperatures (1 to 3°C above the natural hydrograph) at Location 2 by approximately 20 days after the thermal regime of the natural hydrograph would have subsided. This is due to warm tributary inputs (simulations 12 through 15). Diel fluctuations are similar to the natural hydrograph in both alternative flow situations.

In comparison with the historical flow option, the 50 cfs modeled release during average years shows very similar trends with exceptions occurring in the spring and fall. The spring historical flows were operated to release 50 cfs continuously until irrigation season. During historic spill, as in modeled scenarios, temperature in the river increased by 6.5°C introducing water to the system that reached 11°C at both Locations 1 and 2. During the fall season, an opposite trend occurs with the 50 cfs option maintaining temperatures 1.5°C higher for fast down-ramping rates and 3°C higher for slow down-ramping rates at Location 1. Location 2 shows little difference between the two due to downstream attenuation.

The 2 and 0 cfs options show some similarities with the historical releases due to the operational regime at the dam. During the winter period, temperatures in the historical releases are higher than the 2 and 0 cfs alternatives by 3 to 4°C at Location 1 and 1.5°C at Location 2. The spring shows a spike in temperature of similar magnitude in the release options prior to initiation of irrigation flows. The historical spike persists for a longer duration than the 2 or 0 cfs options and this may be due to the dam operator trying to maximize reservoir storage by reducing flows for a longer period prior to irrigation demand. After irrigation flows end, the fall season shows a reduction in stream temperatures under the 2 and 0 cfs release options, whereas the historical releases maintain higher temperatures at Location 1 by 3.5°C and Location 2 by 1.5°C. Slow ramping rates maintain higher temperatures in the fall by up to 1°C that diminish within approximately 45 days.

Wet Climatic Year

The period of November 1996 through December 1997 was used to represent an overall wet climatic year in the Deadwood River system. As previously presented, Figure 3-18 and Figure 3-19 show the hydrologic and thermal regimes as they enter the lower Deadwood River for both the historical and theoretical dam free scenarios. Figure 3-35 and Figure 3-36

show the modeled hydrologic and thermal regimes of the lower Deadwood River 900 m below the dam (Location 1) and near the confluence with the South Fork Payette River (Location 2).

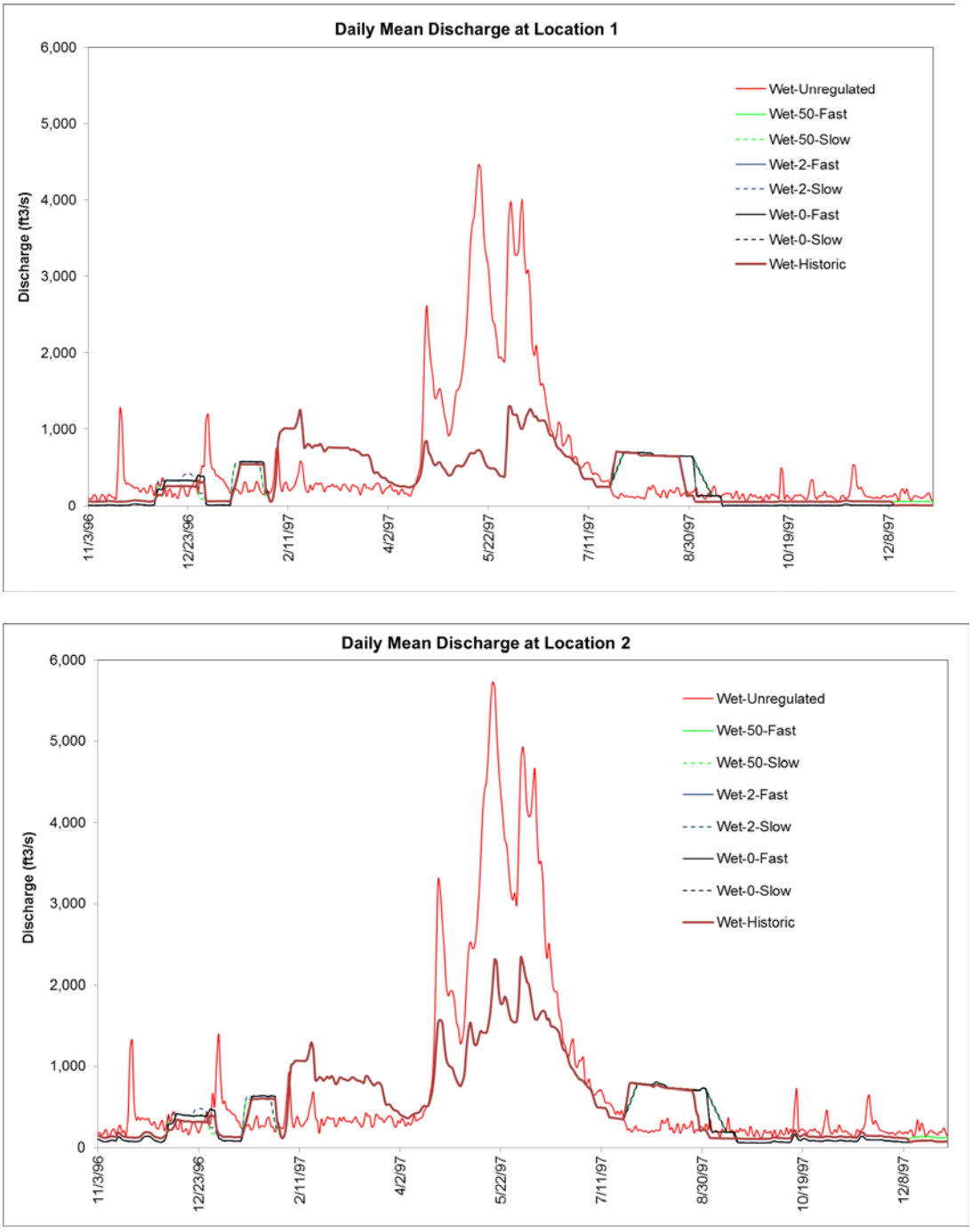


Figure 3-35. Daily mean discharge for Locations 1 and 2 on the lower Deadwood River.

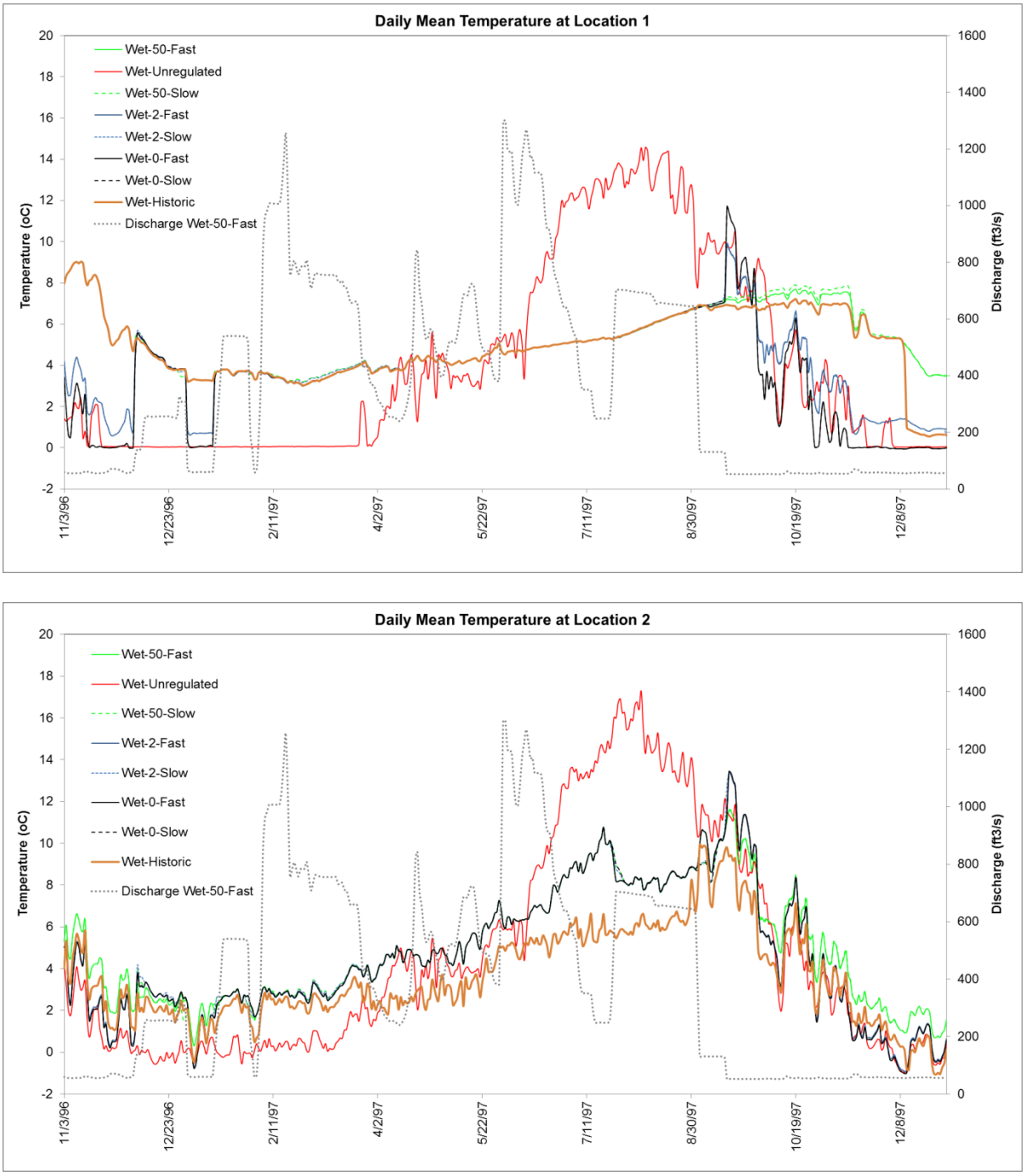


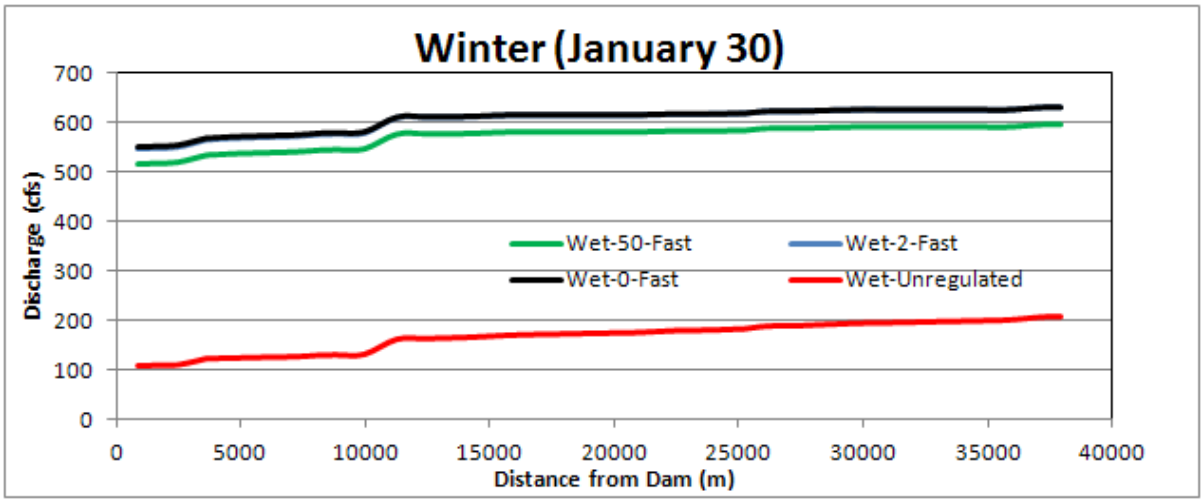
Figure 3-36. Daily mean temperature for Locations 1 and 2 on the lower Deadwood River.

Conversely, from the previous two BiOp years, winter regulated flows are much larger than the unregulated system (Table 3-8). The change in percentage is comparable to the summer changes of approximately 200%. Sustained dam releases during the winter are due because the reservoir is already full and water needs to be evacuated to provide volume for the spring

run-off. The effect of tributary inflows to the stream is almost entirely overwhelmed by the dam releases as shown in Table 3-8 and Figure 3-37. The extra flow for the 0 and 2 cfs for the winter day is due to the "carry-over" volume.

Table 3-8. Regulated flows as a percent of unregulated flows for the different winter release options per season during the wet year.

	Winter Q=50 cfs		Winter Q=2 cfs		Winter Q=0 cfs	
	Location 1 Reg/Unreg	Location 2 Reg/Unreg	Location 1 Reg/Unreg	Location 2 Reg/Unreg	Location 1 Reg/Unreg	Location 2 Reg/Unreg
Winter	219%	190%	225%	194%	225%	195%
Spring	73%	78%	73%	78%	73%	78%
Summer	249%	192%	247%	191%	247%	191%
Fall	46%	64%	6%	40%	5%	39%



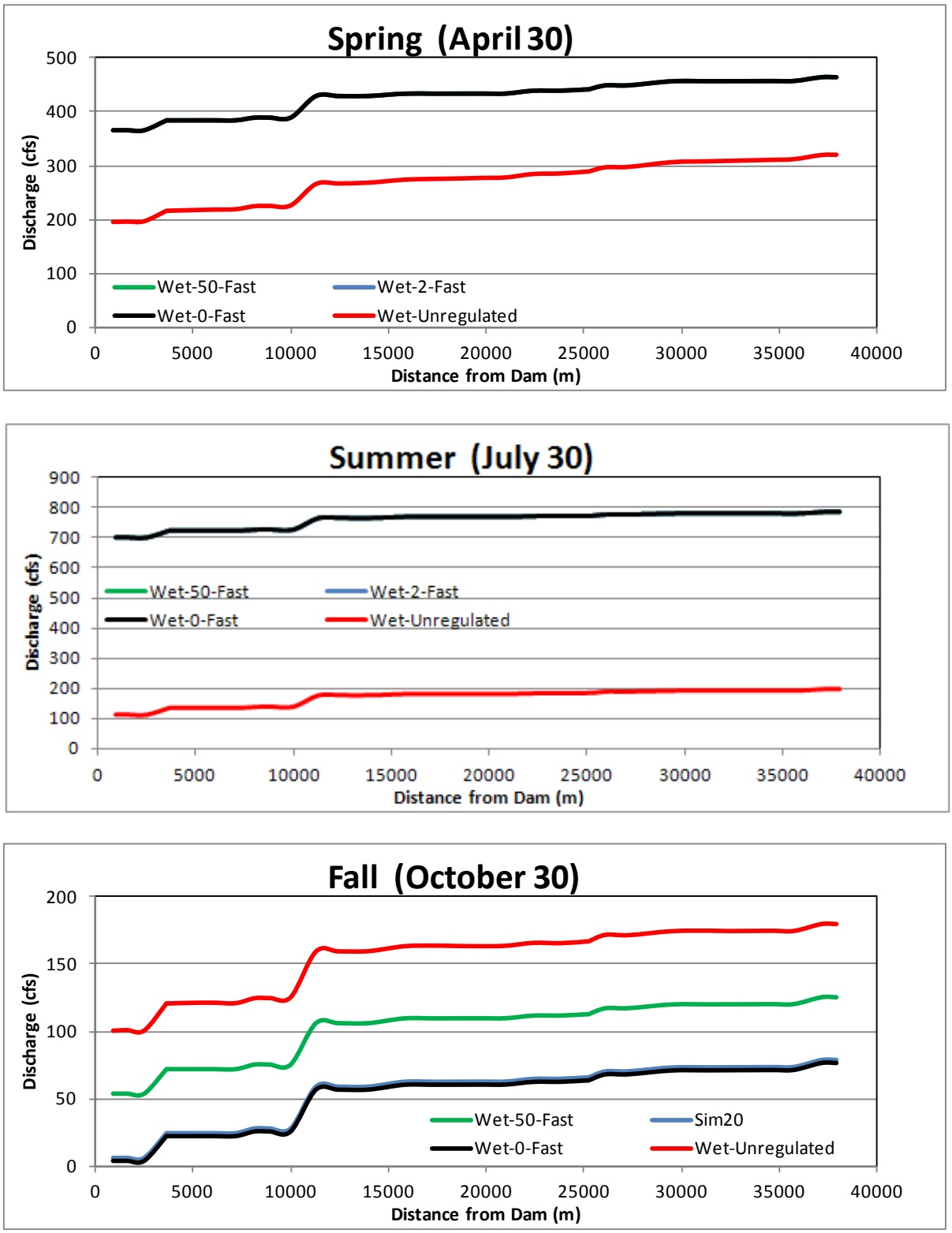


Figure 3-37. Change in discharge along lower Deadwood River for winter, spring, summer, and fall.

To study the wetted areas during winter dam releases of 0, 2, and 50 cfs a period when these controlled flows occurred was selected. The dam releases influence the available wetted areas with depth deeper than 0.5 m (Figure 3-38). The extend of wetted areas deeper than 0.5m increases in the wet year respect to both dry and average years (Figure 3-39 to Figure 3-25 and Figure 3-29). As observed for the previous 2-year scenarios, differences between 0 and 2 cfs wetted areas are negligible for any reaches except for reach 15 and 16. Connectivity between pools is more consistent in the wet year than for the dry and average years. Irrigation flows present comparable wetted extend areas to the dry and average year (Figure 3-38).

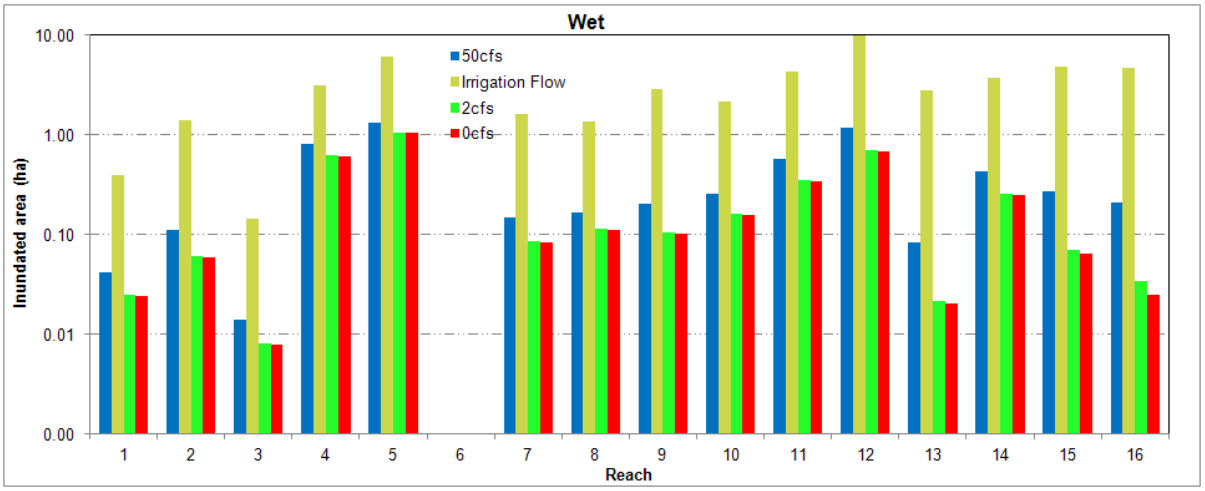


Figure 3-38. Wet year wetted area (of 0.5 m depth and greater) for 0, 2, and 50 cfs winter releases (on October 11) and during the irrigation flow (August 15).

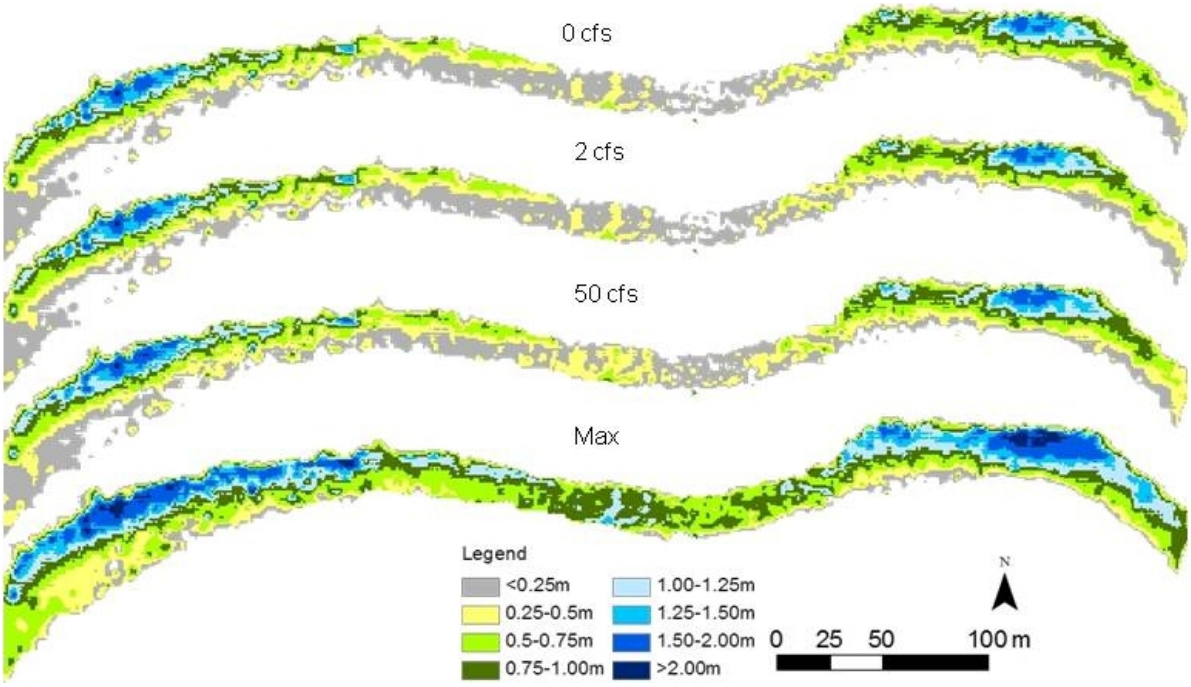


Figure 3-39. Example of wetted areas distribution for 0, 2 and 50 cfs winter releases for October 11 and during the irrigation flow August 15 for average year. This is a section of reach 15.

The wet BiOp climatic year acts differently than both the dry and average years, due to an overabundance of water in the reservoir that must be evacuated periodically throughout the winter and spring seasons. Dam releases have been historically limited to approximately 1,200 cfs; however, the outlet works are capable of releasing 2,600 cfs and the spillway has a discharge capacity of up to 11,000 cfs. Tributary influence is also more significant over the course of the river, with greater precipitation increasing the impact of each individual tributary's thermal regime on the main river.

Winter season flow conditions during a wet BiOp year are not as consistent as those in the dry and average years (Table 3-8). Irregular dam releases for long periods of time can be an order of magnitude larger than expected winter flows. The theoretical temperature regime of the unregulated hydrograph, as predicted by the model, displays consistent winter temperatures at 0°C; however, during a wet year this may or may not be the case, given the influence of large Pacific storms passing through the region. As the reservoir pool fills and large dam releases become necessary for water evacuation, the winter 50 cfs release option takes on less operational significance. Winter water temperature emerging from the dam is a consistent 4°C and would likely impact any ice formation or snow cover over the length of the system, given the large discharges that occur for extended durations. Location 2 at the downstream end of the river reports a consistent 2.5 to 3°C higher temperature throughout the season than that of the natural hydrograph, which fluctuates around 0°C (Figure 3-36). If

either of the alternative flow options 2 and 0 cfs are evaluated during the winter season, they show little difference from the 50 cfs option. This is due to the necessary dam releases of extended duration. Due to operational safety issues created by freezing winter temperatures, winter valve adjustment, including shutoff or reduction of flows followed by a return to higher flows, is not possible.

The theoretical unregulated hydrograph during a wet year begins to rise in mid-April and returns to near base flow conditions around mid-July. Spring flow conditions during the wet BiOp year allow for maximum pre-irrigation releases to occur for simulating spring floods with the limitation of the maximum safe output at the dam. Maximum dam releases combined with modeled tributary inputs provide peak discharges that approach one third of the natural hydrograph peak downstream at Location 2 (Figure 3-40). Due to the necessity to evacuate water from the reservoir, none of the three operational alternatives are possible to exercise during the spring season for long periods of time. Water temperatures during this season fluctuate very little from the 4°C water output from the reservoir at Location 1. Model results at Location 2, near the confluence with the South Fork Payette River, show that the temperature stays fairly consistent throughout the early spring and increases only during the last month by approximately 1°C. These results track the thermal regime of the natural hydrograph quite closely throughout the spring season.

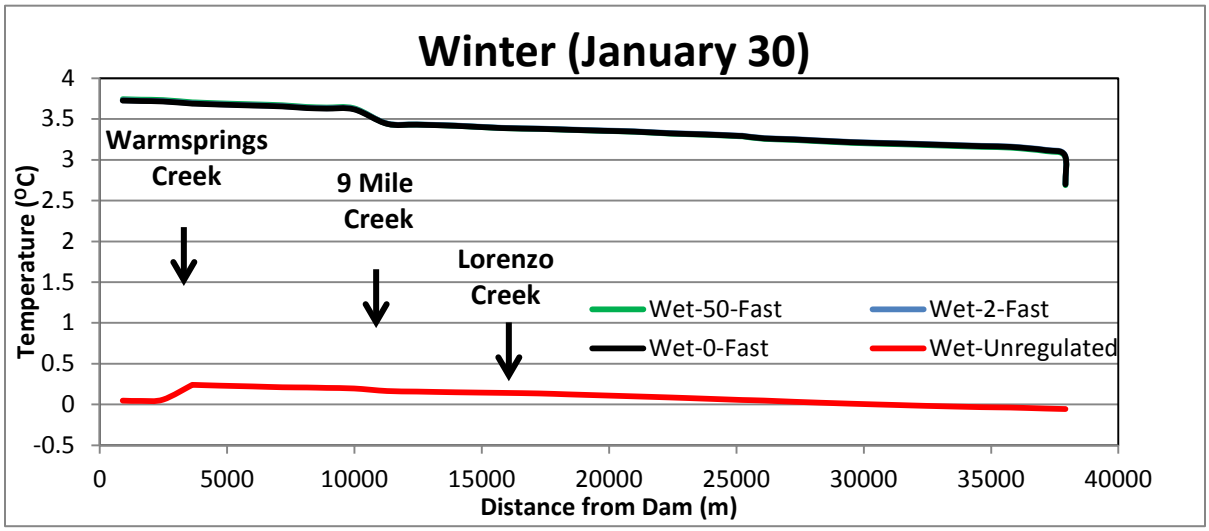


Figure 3-40. Downstream cooling of stream temperature during typical winter day January 30, 1997. Unregulated hydrograph (red), 50 cfs (green), 2 cfs (blue), 0 cfs (black).

The summer irrigation demand during a wet year is significantly abbreviated, beginning near the end of June and ending at the end of August (Table 3-8). This reduced demand does not draw down the warm pool in the reservoir as dramatically and cold, bottom-release water is provided throughout the irrigation period. This cold water is approximately 6 to 8°C cooler than the natural hydrograph during this period. After the irrigation demand ends in August

the alternative release options can determine how the system equilibrates towards the unregulated thermal regime. The 50 cfs option will continue to pull cold water from the reservoir providing a maximum temperature at Location 1 of approximately 7°C. Location 2 at the downstream end of the river shows solar radiation and tributary influence slightly buffering this temperature and raising it to approximately 11°C. The 2 and 0 cfs alternative options show very little difference between their responses. Selecting either low flow option, the model results show an increase in temperature to that of the natural hydrograph and track the trend throughout the rest of the season at both Locations 1 and 2. Ramping down options (fast vs. slow) show little difference between the three options (50, 2, or 0 cfs). Fast ramping down shows no significant difference from slow-ramping down at Location 1; however, a slight increase of 1°C at the downstream Location 2 occurs due to warm tributary inputs and persists for approximately 8 days during the ramping down.

The fall flow regime during a wet year tracks the natural regime at Location 2 downstream regardless of which flow option is selected due to the large influence of tributary inputs late in the season (Table 3-8). The 50 cfs dam release option will deliver 7°C water to the river at the upper end (Location 1), but will be overwhelmed by the natural thermal signal of the tributaries and be less than 1°C cooler than the natural hydrograph at Location 2. Selecting either the 2 or 0 cfs option will track the thermal regime of the natural hydrograph at both upstream and downstream locations (Figure 3-36).

Historical operations show virtually no differences with the modeled 50 cfs release option under the wet year conditions. The 2 and 0 cfs options provide some differences in the winter season when no spill is occurring at the dam for requisite water releases. The instream temperatures during these short time periods are reduced to those of tributary inputs near 0°C. After irrigation demand is over in the fall and the 2 and 0 cfs options can be employed, temperatures depart from the historical scenario by 3-5°C and may persist for up to 38 days at Location 1. Location 2 shows differences between the historical and modeled flows beginning in the spring and persisting through the fall. This is due to varying climatic drivers in the system and different release rates from the dam and spillway. All modeled flows show similar trends to the historical operations in the fall season once high flows diminish.

3.1.4 Two-dimensional Modeling of the lower Deadwood River for evaluation of the BiOp Scenarios

A 2D steady-state hydraulic model, by DHI, was developed for a 1 km reach of the lower Deadwood River near the confluence with the South Fork Payette River. MIKE 21 is a 2D, fully hydrodynamic modeling tool which utilizes the Saint Venant equations to simulate a wide range of river and channel systems, from simple to complex (DHI 2000). This model

was used to further the understanding of riverine hydraulics under the various BiOp scenarios presented.

Construction of MIKE 21 Model

The MIKE 21 model utilized the LiDAR topography to create a structured 0.5 m bathymetric grid, with each cell representing 0.25 square meters ($m^{2)}$. The total model river length is approximately 1 km, extending upstream from the Reclamation gage at the lower end to below the confluence of Slaughterhouse Creek (Figure 3-41). Selection of the study reach was based on finding a reach with maximum habitat diversity that may be representative of habitats throughout the lower Deadwood River, maximum availability of data for calibration, and access for direct measurements.

Boundary conditions for the model were collected from the gage at the downstream end and the cumulative discharge of the dam release and estimated tributary inputs. The downstream boundary condition was imposed as an elevation corresponding to the stage-discharge relationship at the gage. The upstream boundary condition was introduced as the sum of the dam release discharge of interest and the inflows of all the discharges scaled to the specific BiOp year conditions.

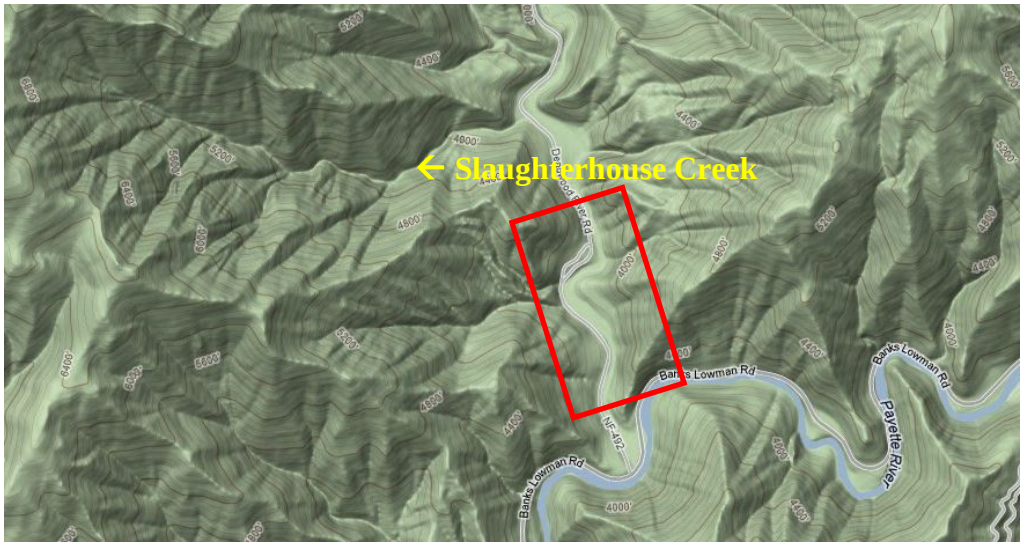


Figure 3-41. Extent of 2D model reach in lower Deadwood River.

The 2D model results do not account for velocity and depth alterations induced by winter conditions. Physical reduction in the cross sectional area of flow may occur due to border or anchor ice formation and ice jams inducing local changes in the velocity field. Additionally, surface ice and snow cover can alter the free surface pressure condition at the water surface, in turn, affecting the vertically averaged model results reported herein. Hence, model results

during winter conditions should be reviewed critically and used only as a general guide for the hydraulics.

Calibration of the 2D model

The model was run as a steady-state scenario until the hydraulics equilibrated towards a constant value at each node. A sensitivity analysis was performed to see how long each model run was required to remove any perturbation in the system. Approximate model time for perturbations to equilibrate was 25 minutes (Figure 3-42). Hence, each run was performed for 2 hours of model time in order to ensure all parameters had converged within the model domain.

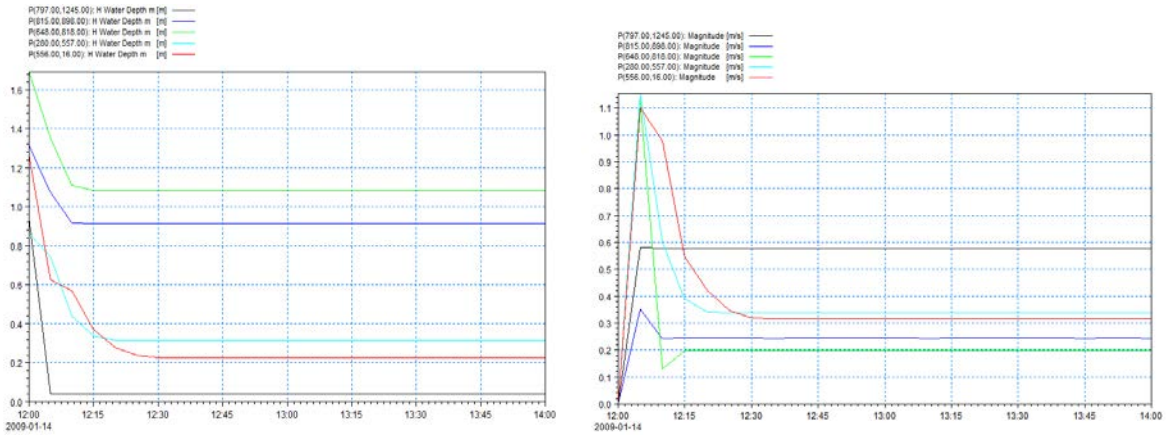
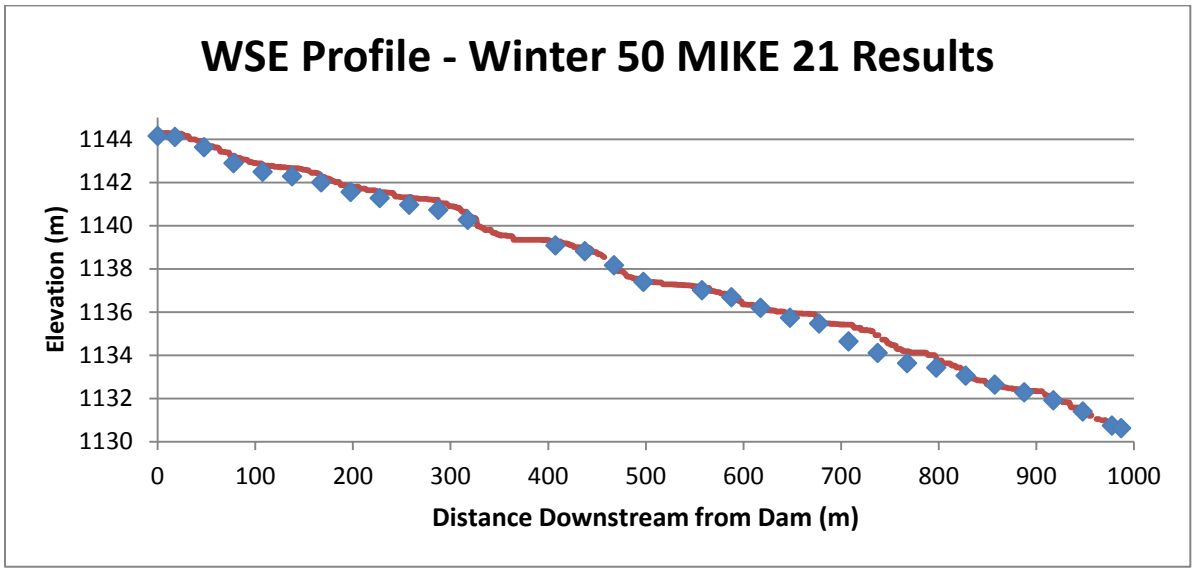


Figure 3-42. Time series at 5 points within the model domain for the winter 50 run. Depth (left) and velocity magnitude (right) over the duration of the 2-hour model run.

Given the field difficulties in calibrating the 1D model in the canyon environment, the 2D model was calibrated to all available data. Within the 1 km study reach, data were available for the downstream boundary condition from the Reclamation gage and were accurate to within 3 centimeters. Water surface elevations were compared with the 1D model at equivalent discharges for the four model runs (examples of the low (Q=50 cfs) and high (Q=950 cfs) discharges are shown in Figure 3-43.



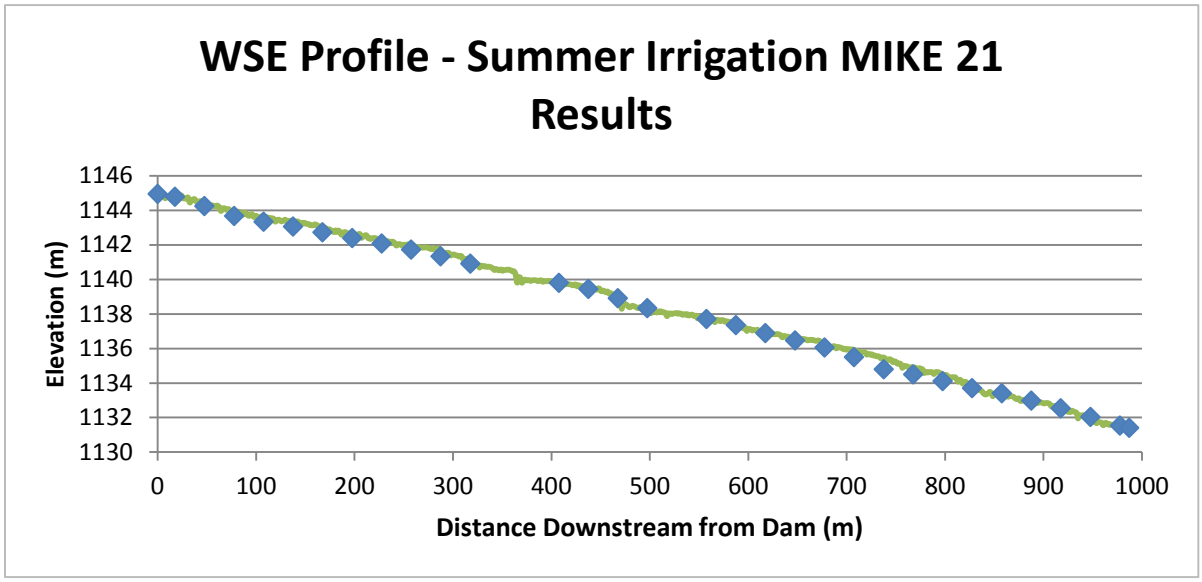


Figure 3-43. Comparative water surface elevations between MIKE 11 and MIKE 21 results for the winter low flow (red, Q=50 cfs) and the summer high flow (green, Q=950 cfs).

Initial model roughness estimates were based on the Manning's n value used in the 1D model (n=0.06). Given the solution scheme to satisfy 2D closure of the continuity and momentum equations, roughness of a 2D model is not equivalent to that of a 1D model (Tonina and Jorde in-press). Hence, iterative execution of the model was performed with decreasing roughness values until good agreement with the water surface elevations from the 1D model were possible (Figure 3-43). Roughness and model values are reported in Table 3-9. Differences between the two models can be seen from 700-800 m in both flow conditions

above. This is due to an island located near the end of the modeled reach that splits the channel in two and proves difficult to match up with the centerline of the stream.

Table 3-9. Two-dimensional model values for various runs. Column 5 reports dam release values and the contributing tributary inputs (Q tributary = approximately 50 cfs).

Name	Discharge (cfs)	Manning's n	Eddy Viscosity (m^2/s)	Wetted Area (m^2)	Dam Release (cfs)
Irrigation	950	0.04	0.01	27720.75	900 + Q tributary
Pre-irrigation	431	0.045	0.01	25507	381 + Q tributary
Winter 100	100	0.045	0.01	21620	50 + Q tributary
Winter 50	50	0.05	0.01	19747.25	2 (or 0) + Q tributary

Effect of discharge on flow velocity distribution

Four MIKE 21 model simulations were developed to enhance understanding of the hydraulics in the lower Deadwood River. Model scenarios in Table 3-9 show what discharge scenarios were run at the study reach and their respective equivalent dam release discharge values. Tributary inputs were considered to be 50 cfs throughout the year for the purpose of the 2D model development. Results of the model analysis in the study reach indicate that the wetted area during the winter low flow of 50 cfs (Winter 50) is 29% less than the highest discharge modeled during irrigation season (Irrigation) and 9% less than the alternative winter flow of 100 cfs (Winter 100).

Hydraulic conditions were examined for available Bull Trout habitat by examining pools greater than 1 m deep and concurrent hydraulic flow separation or eddy development that would allow for passive fish presence. No criterion was developed for the minimum areal extent of the pool. Table 3-10 enumerates the number of pools at each modeled flow with and without the availability of an adjacent eddy feature. At higher flows the hydrodynamic field increases in complexity and opens up a greater amount of pool habitat as seen in the irrigation and pre-irrigation flows listed below. The pre-irrigation flow has a larger number of unique pool habitats, as at the higher irrigation flow some of those pools merge to form one continuous deep water habitat.

Table 3-10. Modeled discharges and the respective number of pools greater than 1 meter with and without an adjacent eddy.

Name	No. Pools > 1 m	No. Pools > 1 m and adjacent eddy
Irrigation	458	104
Pre-irrigation	465	91
Winter 100	31	18
Winter 50	16	10

In addition to the overall size of eddies, the eddy location and dimensions will fluctuate with flow depth. As flows increase, features near the middle of the channel that induce flow separation and cause eddies tend to be submerged and cause the center of rotation of the eddy to migrate towards the channel margins. This migration towards the channel banks can alter the orientation of the depth-dependent turbulent eddies within the flow and in turn, the magnitude of momentum exchange. Along the margins of the channel, eddies will increase their streamwise dimension proportional to their transverse dimension (Table 3-11). With greater streamwise length, eddies increase their ability to exchange momentum and material with the main body of flow. This increase in suspended material exchange from the streamwise flow into the recirculating low velocity zones (lateral eddies) can trap material for extended periods of time. Previous investigations have found that suspended food tends to collect at higher densities in these recirculation zones, increasing their relative habitat value (Parkinson 2007).

Table 3-11. Location and dimensions of specific persistent eddies at various modeled discharges. Note that distances are in meters as transverse length (half eddy)/streamwise length (full eddy).

Eddy no.	j model node	k model node	Winter 50	Winter 100	Pre-Irrigation	Irrigation
1	649	814	2.5/7.5	2.5/7.5	2.5/7	2.5/7.5
2	351	434	2.5/3.5	2/2.5	0/0	0/0
3	362	373	2/3.5	2/4	2.5/4.5	3/5.5
4	417	477	3.5/4.5	4/5	3/4.5	3/4.5
5	476	437	0/0	1/2	1.5/3	2.5/4
6	461	420	3/6.5	3.5/7.5	3.5/8.5	4/8.5

Figure 3-44 shows the location of two large eddies present in the study site. Figure 3-45 through Figure 3-48 and Figure 3-49 through Figure 3-52 show the physical structure of eddies 1 and 6 in Table 3-11, respectively. Eddy 1 is the deepest pool in the model domain and shows remarkable stability across all four modeled flow regimes. This coherent flow structure is formed from a vertical bedrock intrusion and therefore remains stable even under

significant changes in flow depth. Eddy 6, on the other hand, is formed as flow passes an acute bend in the river and is highly dependent upon the flow depth. The center of the circulation zone during the Winter 50 low flow is located at the deepest part of the pool and steadily migrates towards the left bank as discharge increases. The streamwise boundary at the irrigation discharge has a length of 15 m and steadily diminishes with discharge to 12.5 m, 11.5 m, and 9.5 m at the respective modeled flows.

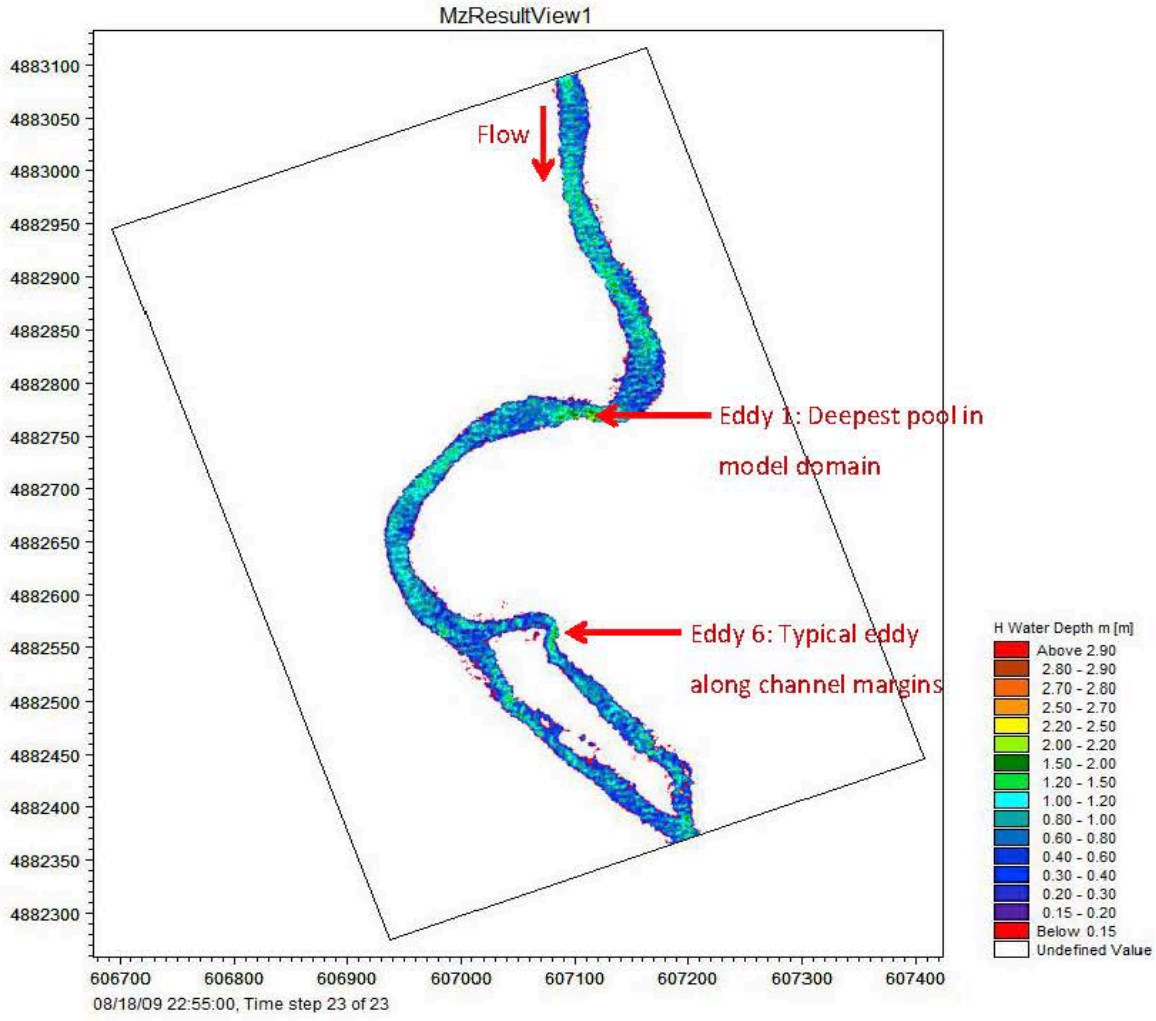


Figure 3-44. Overview of model domain and areas of interest specified in the text

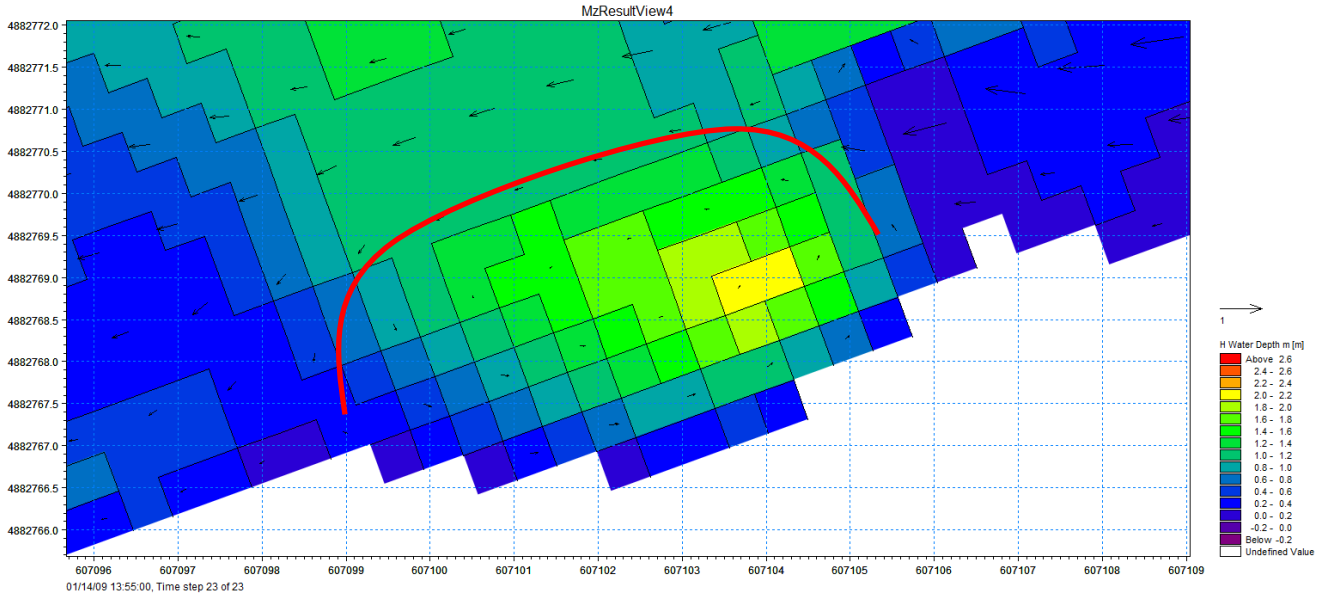


Figure 3-45. Eddy 1 size and strength for winter 50 flow, 50 cfs.

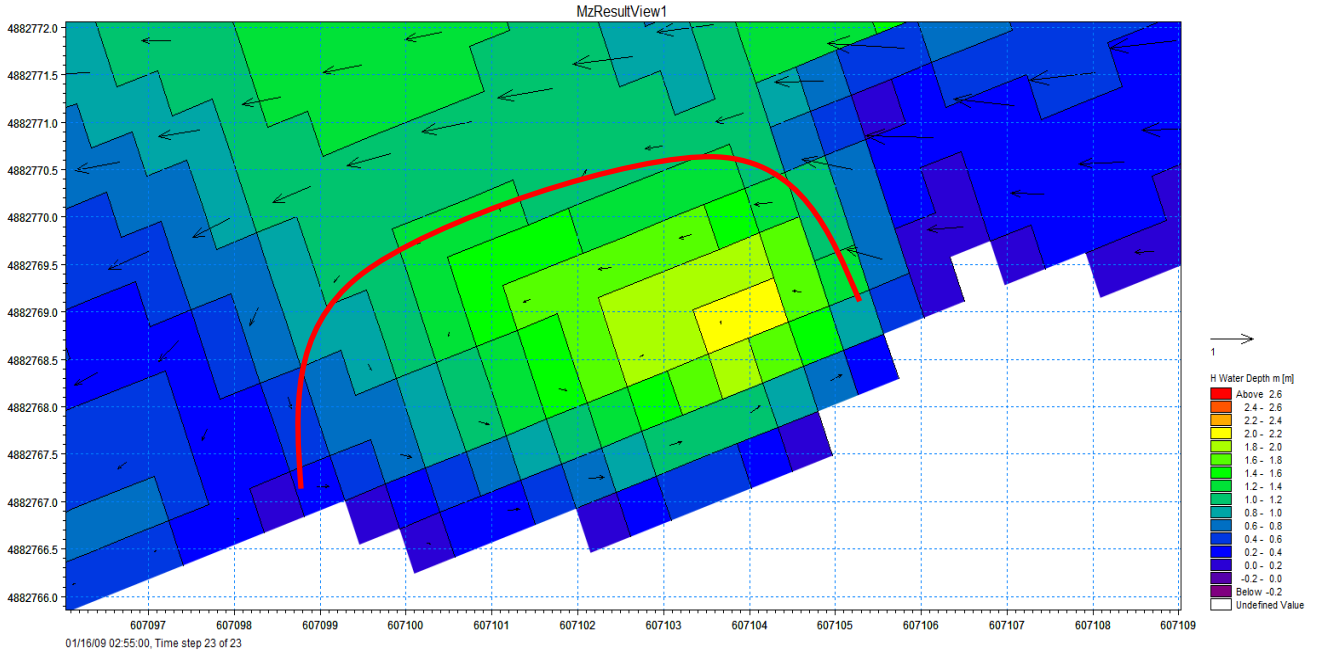


Figure 3-46. Eddy 1 size and strength for winter 100 flow, 100 cfs.

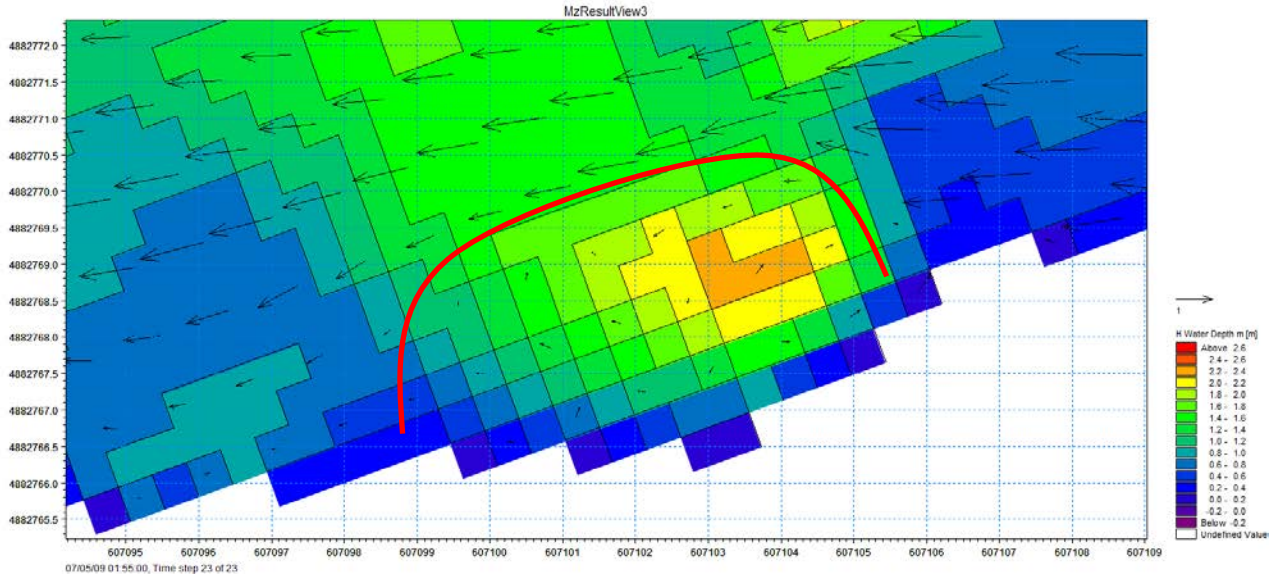


Figure 3-47. Eddy 1 size and strength for pre-irrigation flow, 431 cfs.

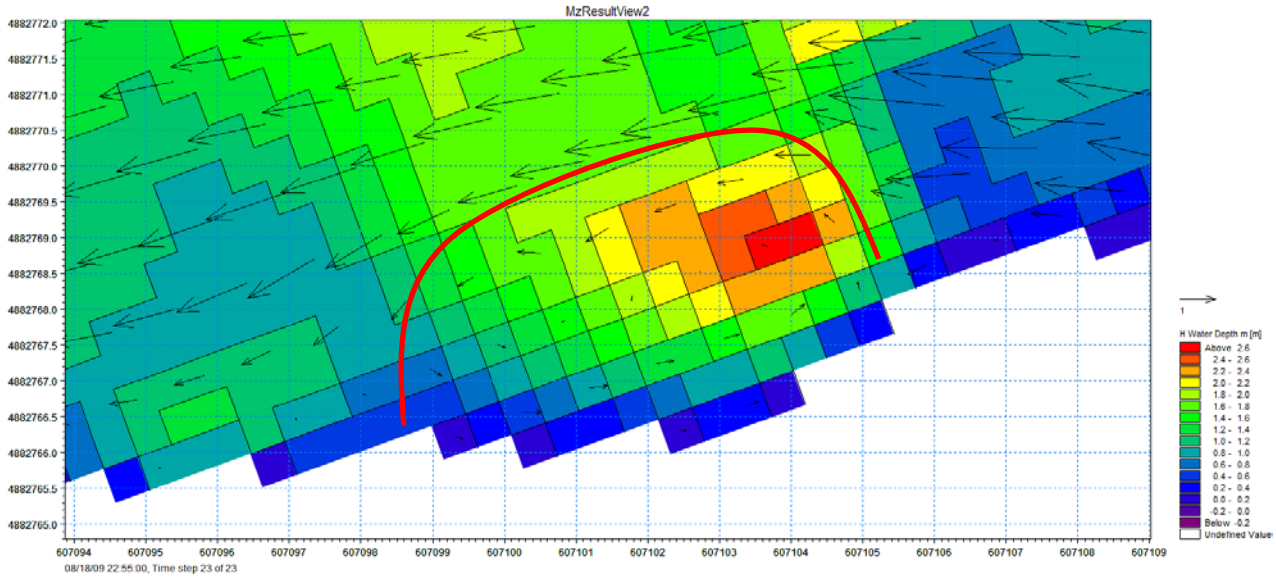


Figure 3-48. Eddy 1 size and strength for irrigation flow, 950 cfs.

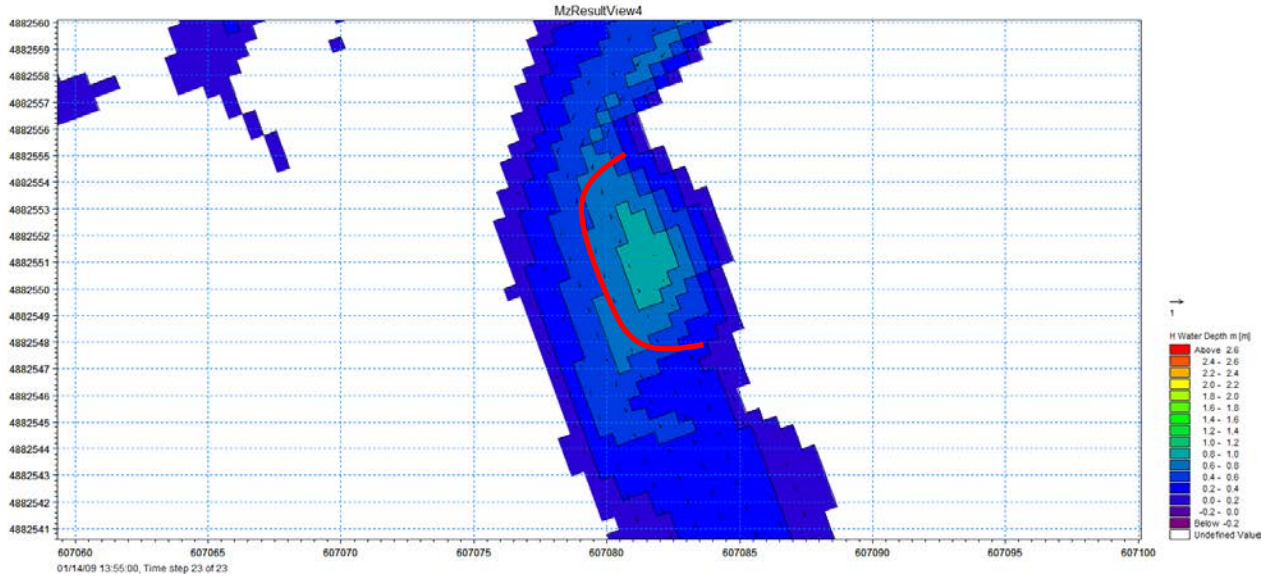


Figure 3-49. Eddy size and strength for winter 50 flow, 50 cfs.

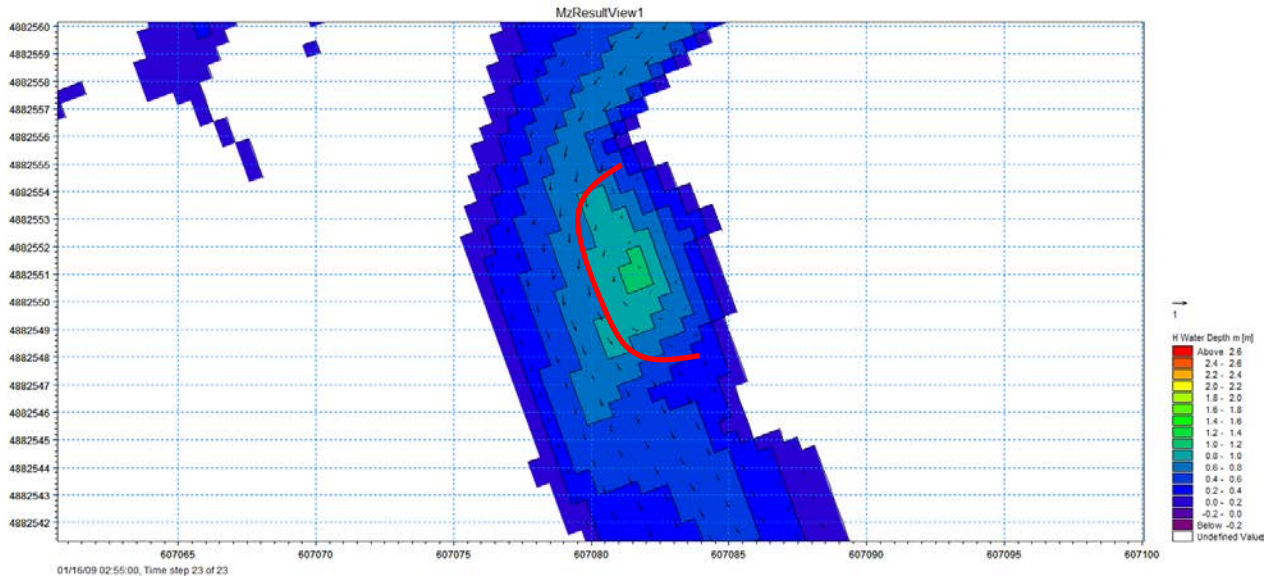


Figure 3-50. Eddy size and strength for winter 100 flow, 100 cfs.

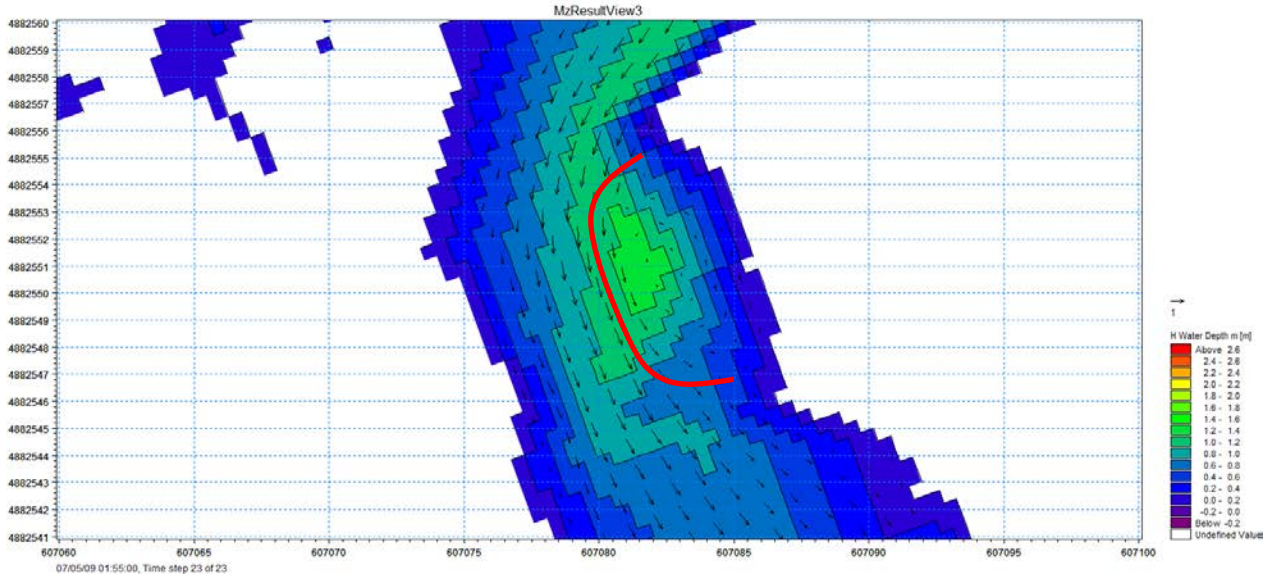


Figure 3-51. Eddy size and strength for pre-irrigation flow, 431 cfs.

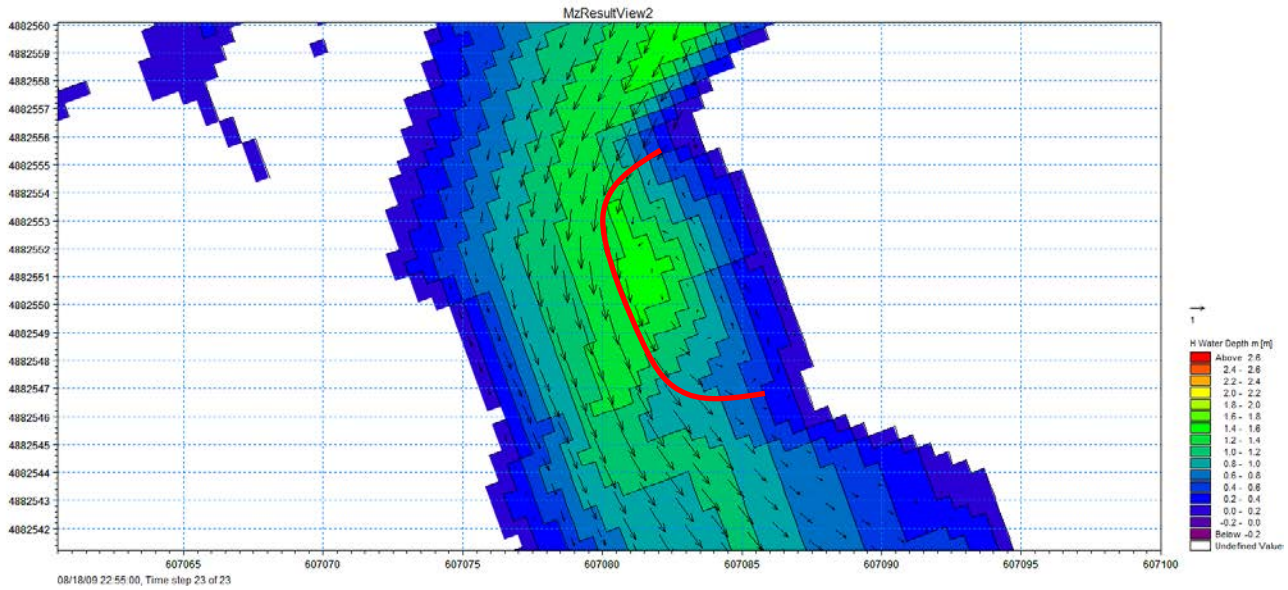


Figure 3-52. Eddy size and strength for irrigation flow, 950 cfs.

Flow strength within eddies also changes with the flow regime. Examining eddy 6, located in the lower portion of Figure 3-44, over the four modeled discharge scenarios a progression of recirculation strength is illustrated. Examining the Winter 50 model run of 50 cfs, initial flow separation occurs and circulates over the shallow margins. High roughness elements compared with flow depth keep velocities low, providing a low velocity, shallow water (<1 m) environment. Model cells in purple (0.25 m^2) are depth values less than 0.20 m and may be inaccessible to aquatic species if significant border ice formation and snow encroachment

occurs. At 100 cfs new marginal habitat opens up with low velocities around the recirculation zone. Slightly greater depths may allow predatory fish to access a larger area within the eddy. It remains a very low velocity environment that does not foster significant material exchange with the main body of the flow. A significant increase in discharge at the pre-irrigation flow (431 cfs) shows that much higher depths and velocities exist in the eddy that persist and level off even at the higher irrigation flow (950 cfs). A greater diversity of habitat exists at these higher discharges with greater depths and access to extended marginal areas.

The lower Deadwood River is dominated by cobble and boulder substrate, which during winter low flows will protrude through the surface of the water. These obstacles create local perturbations to the cross-sectional flow field that significantly depart from the reach average velocity. The results of the 2D model make it apparent that at all modeled discharges the instream local velocities available to fish extend from those well below the average cross sectional velocity, as seen along the stream margins and within deep pools, to those far greater than the average velocity such as in riffles and in convergence zones. To extend a greater understanding of the hydraulics within the lower Deadwood River, a statistical approach was developed to use the results from the 1 km long reach in the 2D model and extrapolate the velocity distribution to each reach in the river.

Assuming that the features within the 2D model are representative of those seen in the other reaches of the river, a probability function can be derived from the 2D model results that can be extrapolated over the extent of the lower river. To accomplish this, point velocities within the 2D model domain were normalized by the average velocity in the reach and fit by a probability distribution function. Pertinent variables in the distribution function were the Froude Number and relative depth (D50/Depth), both of which can be calculated from field measurements and the results of the 1D MIKE 11 model (Lamouroux et al. 1995). Velocities were lumped into representative bins for each operational dam release as slow, medium, and fast currents reported from the ecological literature (Beecher et al. 2002; Beecher et al. 1995; Mesa et al. 2008; Muhlfeld et al. 2011). Results are presented in Table 3-12 for each modeled BiOp year.

Table 3-12. Percentage of wetted area reporting velocities, in m/s, as slow, medium or fast within each of the 16 reaches in the lower Deadwood River. Reach 1 begins near the confluence with the South Fork Payette River and progresses upstream towards Deadwood Dam at reach 16. a) dry BiOp year, b) average BiOp year, and c) wet BiOp year

a) Dry BiOp Year

Reach	578 cfs			50 cfs			2 cfs			0 cfs		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3
1	7.6	31.3	61.1	18.2	51.9	29.9	24.5	52.1	23.4	24.7	51.9	23.4
2	7.8	31.2	61.0	30.1	51.3	18.7	53.3	41.1	5.7	53.4	46.6	0.0
3	3.3	28.9	67.8	17.5	52.5	29.9	35.1	49.9	15.0	35.2	51.2	13.6
4	19.3	50.8	29.9	57.5	39.2	3.3	66.3	32.8	0.9	66.3	32.8	0.9
5	8.4	36.8	54.8	24.4	52.1	23.4	37.3	48.8	14.0	37.5	49.7	12.7
6	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
7	8.4	30.9	60.7	34.8	51.7	13.5	57.2	38.2	4.6	57.2	38.9	3.9
8	9.1	36.4	54.5	30.7	48.4	21.0	43.8	46.6	9.5	49.1	42.3	8.6
9	3.7	22.8	73.5	19.6	54.0	26.4	38.6	48.5	12.9	44.0	44.2	11.8
10	4.2	28.6	67.2	13.2	38.0	48.8	17.2	45.0	37.8	17.9	39.8	42.2
11	13.7	37.7	48.6	47.7	44.1	8.3	73.4	26.6	0.0	76.1	23.9	0.0
12	8.3	31.0	60.7	24.2	49.4	26.4	37.1	50.3	12.6	42.7	45.8	11.5
13	20.6	49.6	29.9	76.1	23.9	0.0	100.0	0.0	0.0	100.0	0.0	0.0
14	3.8	22.8	73.4	18.6	51.5	29.9	57.9	38.8	3.3	66.6	32.5	0.9
15	8.9	36.6	54.6	31.0	52.1	16.9	54.6	38.6	6.8	59.3	36.4	4.3
16	8.4	25.0	66.6	25.1	54.0	20.9	67.2	32.8	0.0	100.0	0.0	0.0

b) Average BiOp Year

Reach	1005 cfs			50 cfs			2 cfs			0 cfs		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3
1	3.9	22.8	73.3	17.8	48.2	34.0	18.4	51.7	29.9	18.4	51.7	29.9
2	4.2	22.7	73.1	24.2	52.3	23.4	36.3	51.3	12.5	36.4	51.2	12.5
3	2.9	17.3	79.8	17.2	48.8	34.0	23.1	53.5	23.3	23.2	53.5	23.3
4	13.4	48.1	38.4	57.6	38.4	4.0	57.3	40.1	2.6	57.3	40.1	2.6
5	4.7	28.5	66.8	24.2	52.3	23.4	24.8	48.7	26.4	25.0	51.6	23.5
6	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
7	4.3	22.7	72.9	29.0	54.4	16.6	40.8	49.3	10.0	40.8	50.3	8.9
8	5.1	28.3	66.5	25.1	51.4	23.5	36.9	47.7	15.4	37.0	49.0	13.9
9	3.0	17.3	79.8	19.0	51.1	29.9	31.0	48.0	21.0	31.2	49.9	18.8
10	4.0	17.2	78.9	12.7	38.3	49.0	15.2	46.7	38.2	15.4	46.4	38.1

a) Dry BiOp Year												
	578 cfs			50 cfs			2 cfs			0 cfs		
Reach	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
11	8.7	24.9	66.3	21.5	67.1	11.3	62.5	34.8	2.7	62.6	35.4	2.0
12	4.7	28.5	66.8	23.9	46.2	29.9	25.1	54.0	20.9	25.2	53.9	20.9
13	15.0	42.0	43.0	73.4	26.6	0.0	95.5	4.5	0.0	97.0	3.0	0.0
14	1.0	14.3	84.7	18.4	47.7	33.9	41.9	47.9	10.2	47.5	44.3	8.2
15	4.9	28.4	66.7	30.8	52.4	16.9	49.1	42.4	8.6	49.3	42.1	8.6
16	4.6	22.7	72.8	25.1	51.4	23.5	67.1	31.9	1.0	73.1	26.9	0.0
c) Wet BiOp Year												
	1005 cfs			50 cfs			2 cfs			0 cfs		
Reach	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3	< 0.5	0.5 - 1.3	> 1.3
1	8.2	31.0	60.8	13.1	48.4	38.5	18.3	51.8	29.9	18.3	51.7	29.9
2	5.0	34.3	60.7	18.9	51.2	29.9	25.0	56.4	18.7	25.0	56.3	18.7
3	3.7	28.8	67.5	12.4	49.0	38.6	17.7	52.4	29.9	17.7	55.9	26.4
4	19.4	50.7	29.9	52.7	41.8	5.5	57.5	39.3	3.2	57.5	39.3	3.2
5	8.9	36.5	54.6	19.1	51.0	29.9	19.6	54.0	26.4	19.6	54.0	26.4
6	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
7	8.8	30.8	60.5	23.7	57.8	18.5	35.1	51.4	13.5	35.1	51.4	13.5
8	9.4	36.2	54.3	19.9	53.6	26.4	25.9	55.3	18.8	25.9	55.2	18.8
9	3.9	22.8	73.3	14.0	47.6	38.3	20.0	53.6	26.4	20.1	53.4	26.4
10	4.7	22.7	72.7	8.4	36.8	54.8	9.9	41.6	48.6	14.0	42.8	43.2
11	9.9	41.6	48.6	36.4	49.9	13.8	48.0	45.6	6.5	53.1	41.3	5.6
12	8.7	30.8	60.5	18.8	47.4	33.9	19.7	53.9	26.4	19.7	53.8	26.4
13	20.5	45.8	33.7	70.3	29.7	0.0	89.8	10.2	0.0	90.9	9.1	0.0
14	1.5	19.6	78.9	13.7	52.4	33.9	20.6	52.9	26.5	36.1	50.1	13.8
15	5.5	34.1	60.4	25.5	55.8	18.8	43.5	46.0	10.5	43.7	46.8	9.5
16	5.0	22.6	72.4	25.1	51.4	23.5	63.5	34.4	2.2	60.5	35.7	3.7

It can be seen in Table 3-12 above that the distribution of velocities stays relatively stable across all three modeled winter flow options (50, 2, and 0 cfs). As flow increases, probabilities tend to shift towards the higher velocity bins, however there is very little difference between the distribution of velocities in the 2 and 0 cfs options. Close to the dam, in reaches 14, 15, and 16, there are slight differences from the effect of no water coming from the dam, but tributary inputs make them virtually identical by reach 13 (about 3 km downstream from the dam). Differences are usually less than 5%, with the exception of reach 16 in the dry BiOp year and reach 14 in the wet BiOp year where individual bins increased by more than 10%. These differences account for the cross-sectional geometry within the reach and the contribution of tributary input with respect to the climatic year. As flows increase to the 50 cfs dam release option velocities tend to increase in each of the

reaches, in turn, increasing the percentage in the high velocity bin. The biggest impact of these changes occur upstream of reach 10 where the tributary input is not substantial enough in the 2 and 0 cfs options to provide very high velocities. Below reach 10, the differences are reduced and similar velocity distributions can be seen between the flows. It is interesting to note that reach 13, in all climatic years, shows no velocities greater than 1.3 m/s in any of the three winter flow options, likely due to increased channel width and large instream roughness elements.

3.1.5 Ice Formation

Three types of ice may occur in rivers when the water is cold enough to freeze but too turbulent for a surface layer of ice to form. Border ice forms at the edges of the river, frazil ice is comprised of small, suspended ice crystals that form in super-cooled (< 0°C) water, and anchor ice is a layer of ice that forms on the river bottom (Ettema and Kempema 2012). In this study, we evaluate the potential for subsurface ice (i.e., frazil and anchor ice) formation in the regulated Deadwood River and describe potential adverse effects on salmonid fishes.

Frazil ice forms when there is no surface ice, water super-cools to less than 0°C by sub-freezing air temperatures, and flow turbulence prevents stratification. Frazil ice is a soft, grey ice composed of fine spicules, which may appear feathery in the current, clumpy at the water surface, or as a slush throughout the water column (Maciolek and Needham 1952). Small (0.1–1 mm) discoid or spicule shaped ice crystals form from seed crystals that are introduced at the surface, from water vapor that sublimates above the water surface and falls back into the water column or snowflakes blown into the water from the nearby banks, to expand in the super-cooled water (Figure 3-53) (Brown et al. 2011). Frazil ice crystals grow continuously via flocculation and adhere to surfaces including rocks, woody debris, and vegetation. Frazil ice may also occur in water column as slush. Once open water conditions freeze over with stable ice cover, heat transfer to the atmosphere is greatly reduced and frazil ice formation can no longer occur (USACE 2006).



Figure 3-53. Frazil ice crystals are small (0.1 – 1 mm) discoid or spicule shaped ice crystals that are formed from seed crystals that are introduced at the surface and continue to grow in size in supercooled water (accessed online: http://summitcountyvoice.com/2010/05/10/the-daily-photo-frazil-ice-on-dillon-reservoir/#jp-carousel-7114R).

Anchor ice is an agglomerate crystalline structure that adheres to the channel bed when super-cooled water and frazil ice are advected into the flow column and reach the bottom of the river. Anchor ice appears as a grey, translucent coat over the streambed. Anchor ice crystals are larger more granular than those of frazil ice, which makes it more rigid (Maciolek and Needham 1952). Frazil ice on the river bed may form a sheet of ice composed of small ice crystals that then seed larger ice crystals in situ (Figure 3-54) (Kempema and Ettema 2009). Anchor ice can also appear as scales or balls on gravel and cobble (Kempema and Ettema 2009). Under winter low flow conditions, steep, shallow rivers with exposed riffles are particularly susceptible to the formation of anchor ice (Ettema 2002). Riffles can potentially freeze from the bottom up to create an anchor ice dam that backs up the flow upstream of that section. Once anchor ice becomes thick enough to float or when temperatures increase, sufficient buoyancy occurs to float the channel sediments (of potentially large diameter) that the ice is connected to downstream.



Figure 3-54. Photo left shows anchor ice that is formed when ice deposits on the bottom of the river channel and forms a sheet of ice composed of many small ice crystals that continue to grow larger into ice scales or balls. Photo right shows three types of subsurface ice: bottom: anchor ice; mid-column: frazil slush; top: hanging dam. (Photograph R.S. Brown)

This phenomenon is known as ice-rafting and can influence geomorphic features such as pool expansion, as sediment is exported from the area, and downstream riffle accumulation when the ice raft gets caught on a downstream riffle. In small systems anchor ice can act as a significant geomorphic driver, locally influencing stream stability and modifying winter habitat, as sediment transport of bed material occurs either directly via anchor ice rafting or indirectly with increased local flow velocities (Ettema and Kempema 2012). Anchor ice rafting occurs when ice crystals adhere to the rocky substrate overnight when temperatures are the coldest and then releases the next day as temperatures rise. As the anchor ice releases, it takes part of the streambed with it, including fine sediment, gravel and macroinvertebrates (Martin et al. 2001) found almost 30 times more aquatic insects in the drift on days after anchor ice had formed than on days when it was not present. Anchor ice also changes the nature of the streambed by infiltrating the cobble and gravel substrate, which can eliminate the interstitial spaces that some juvenile fish use for cover (Brown et al. 2011).

Ice break-up can happen when a warm perturbation occurs in the stable winter atmospheric conditions, usually in the late fall and early spring. Conditions that facilitate break-up are warm ambient air temperatures, precipitation as rain, and incoming solar radiation (insolation). If a partial break-up occurs in the system, especially upstream, floating ice floes can accumulate at the front edge of stable ice cover and induce an ice jam. This partial blockage of the cross section can increase local velocities via convective acceleration and induce bed and bank scour. Geomorphic effects resulting from ice jams include thalweg shifting, meander cutoff, scour hole formation and abandonment of split channels (Ettema and Kempema 2012). Predication of where ice jams will occur is still an elusive research topic in engineering and is largely based on observational data at a site (USACE 2006). Maciolek and Needham (1952) found 63 dead trout lying in a dewatered pool after an anchor ice dam had blocked the flow of the creek completely. Brown et al. (2000) found that hanging dams could occupy up to 80% of pool volume which resulted in reduced physical space and increased flow velocities. Mean bottom water velocities increased from 6 to 27 cm/s due to the formation of hanging dams while water depth decreased from 2.25 m to 0.45 m (Brown et al. 2000).

Significant snow and ice accumulation occurs intermittently within the lower Deadwood River canyon during winter months. The formation of surface ice on the river, when thermal conditions allow, provides a platform for accumulation from snowfall events and avalanche materials from the steep canyon walls. Winter base flow conditions from the upper basin, under unregulated conditions, would provide a substantial thermal mass in the river to maintain a near 0°C temperature throughout the length of the canyon. Spatially, local tributary inputs may increase the temperature (i.e., Warmsprings Creek) for a short distance downstream until ambient weather conditions can act to cool the main body of flow to near 0°C once again. Additionally, in a temporal sense, the late fall and early spring can supply

warm Pacific storms that pass through the region reducing snow cover accumulation and providing bursts of warm precipitation to the entire basin that increase the overall temperature of the system. These small spatial and temporal perturbations can temporarily increase the temperature of the river water and cause open water conditions to allow for the formation of anchor and frazil ice in the lower Deadwood River. The larger question of the impact that winter dam operations has on the formation of frazil and anchor ice in the river is addressed herein.

Reservoir operations create altered temperature regimes with warmer than normal winter water temperatures. This eliminates stationary ice cover and increases the likelihood of super-cooling and resultant subsurface ice formation (Brown 1999; Brown et al. 2011; Simpkins et al. 2000). Frazil ice was observed eight times on the regulated Big Horn River (Wyoming) on mornings when the air temperature had dipped below -24°C (Simpkins et al. 2000). The lower Deadwood River canyon experiences variable winter air temperatures that periodically reach -24°C or lower.

The regulated lower Deadwood River appears to be susceptible to subsurface ice formation based on the limited information available. On January 17, 2007 photos were taken from a helicopter documenting the presence of anchor ice on the Deadwood River from above Scott Creek to the mouth of the Deadwood River (Figure 3-55a and 3-55b). On December 18, 2006, pictures were taken one mile upstream from the mouth showing a mixture of surface ice and frazil ice (Figure 3-56). A picture taken near Scott Creek on February 08, 2009 shows evidence of previous subsurface ice (Figure 3-57). Shelf ice had formed well above winter water levels, perhaps due to an anchor ice dam that temporarily created a deeper pool. These pictures indicate that winter conditions are favorable for subsurface ice formation. The frequency and extent of frazil and anchor ice occurrence under current dam operations is not known.



Figure 3-55. Anchor ice seen from helicopter in the Deadwood River. Photo left (a) taken above Scott Creek tributary; photo right (b) taken near Scott Creek tributary. (Reclamation photograph, A. Prisciandaro – January 17, 2007).



Figure 3-56. A mixture of surface ice and frazil ice on the Deadwood River (1 mile upstream from the mouth). (Reclamation photograph, A. Prisciandaro – December 18, 2006).



Figure 3-57. Evidence of previous subsurface ice formation on Deadwood River (near Scott Creek). The shelf ice was formed above the winter water level, perhaps caused by an anchor ice dam that temporarily created a deeper pool. (Reclamation photograph, A. Prisciandaro – February 8, 2009).

Current ice cover-breakup models are under development and limited in their application given the empirical requirements necessary for calibration (USACE 2006). Given the variability in local climatic conditions and constant influx of water greater than 0°C at the dam, an ice cover-breakup model within the lower Deadwood River would require access and resources that were not possible given the physical constraints of the canyon during winter conditions. Hence, the free surface open channel model was selected for analysis and used as a guide to illustrate general temperature changes. Results of the 1D MIKE 11 temperature model were initially examined to determine if specific locations could be identified that facilitated the formation of stable ice cover. Model results during this time do not account for surface ice formation or heat loss through exposed substrate, therefore, calibration proved difficult during this time period. This problem was exacerbated by the temperature loggers freezing within the ice cover that formed along the river margins, therefore only open water conditions can be modeled (see calibration of 1D model section for details). Winter flow conditions of 50 cfs dam release were modeled along with the 2 and 0 cfs options. The 50 cfs flow option was not able to be cooled sufficiently within the model domain, due to intermittent ice cover that substantially reduces atmospheric heat flux and provides a continuous 0°C boundary condition and unaccounted heat loss through large river substrate, therefore, over predicts stream temperatures by up to 3º in places. The 2 and 0 cfs release options are dominated by tributary inputs near 0°C and provide more reliable results within the model.

To evaluate the winter flow conditions, measured data from water years 2007 through 2012 were analyzed to find locations of possible ice cover. Jakober et al. (1998) examined ice formation in small streams in Montana and conjectured that frazil ice induced a negative response in Bull Trout, causing them to migrate downstream towards more stable conditions. In their surveys, ice formation began when water temperatures reached 1°C. Although ice formation is a process that occurs over numerous days and is highly dependent upon diel extremes, this 1°C criterion will be used as the metric for stable ice cover in the lower Deadwood River. While available data cover water years 2007 through 2012, similar results are expected for the modeled BiOp years.

During the period of winter data collection, 2007 through 2012, 50 cfs dam releases were consistently employed. Water temperature released from the dam is approximately 4°C whereas tributary inputs were found to be close to 0°C, with the exception of Warmsprings Creek that reported winter temperatures around 6 to 7°C (Figure 3-58). Water temperature decreases significantly with distance from the dam, however, the amount of cooling depends upon ambient air temperatures in the river canyon and the presence or absence of ice cover. For example, Figure 3-58 (a) and (b) show available water temperatures for two dates in the winter, December 9 and February 16, during water years 2009 through 2012.

Field personnel performed aerial surveys during these two dates in 2012 to inspect the extent of ice cover under the 50 cfs dam release option. On December 9, 2011, stable ice cover was established near the confluence with Lorenzo Creek tributary whereas on February 16, 2012 ice cover was very limited and open water conditions extended over the majority of the river. Examining the instream temperatures for these two days, similar longitudinal distributions of temperatures exist; however, stable ice cover occurred in December whereas February had little ice cover. This can be seen in Figure 3-58 (a) and (b) (orange lines for water year 2012), where both temperature distributions drop below the 1°C criterion for stable ice cover by the time Scott Creek tributary is reached. To better understand this, the average travel time for the 50 cfs option was calculated from the 1D model as 15.5 hours; therefore, a water particle will have this amount of exposure time to the ambient air temperature for cooling before reaching the South Fork Payette River. If an ice cover occurs at some point in the river, atmospheric heat loss will drop to near zero and air temperature will cease to directly influence the water temperature until open water conditions are returned. The average air temperature was calculated for the 15.5 hours prior to the dates of the surveys (T50, black vertical line in Figure 3-58) and reported in Table 3-13. The mean air temperatures are very similar during this exposure time and would act to cool the instream temperatures to a similar degree. If the mean air temperatures are examined from the 5 days prior to the aerial surveys, it is apparent that the December survey had temperatures substantially lower than in February to facilitate the formation of a stable ice cover.

Table 3-13. Reported mean values for air temperature at Deadwood Dam 15.5 hours and 5 days before the aerial snow survey, degrees Celsuis.

Survey Date	Air Temperature 15.5 hours prior (C)	Air Temperature 5 days prior (C)
December 9, 2011	-4.6	-7.9
February 16, 2012	-3.2	-1.9

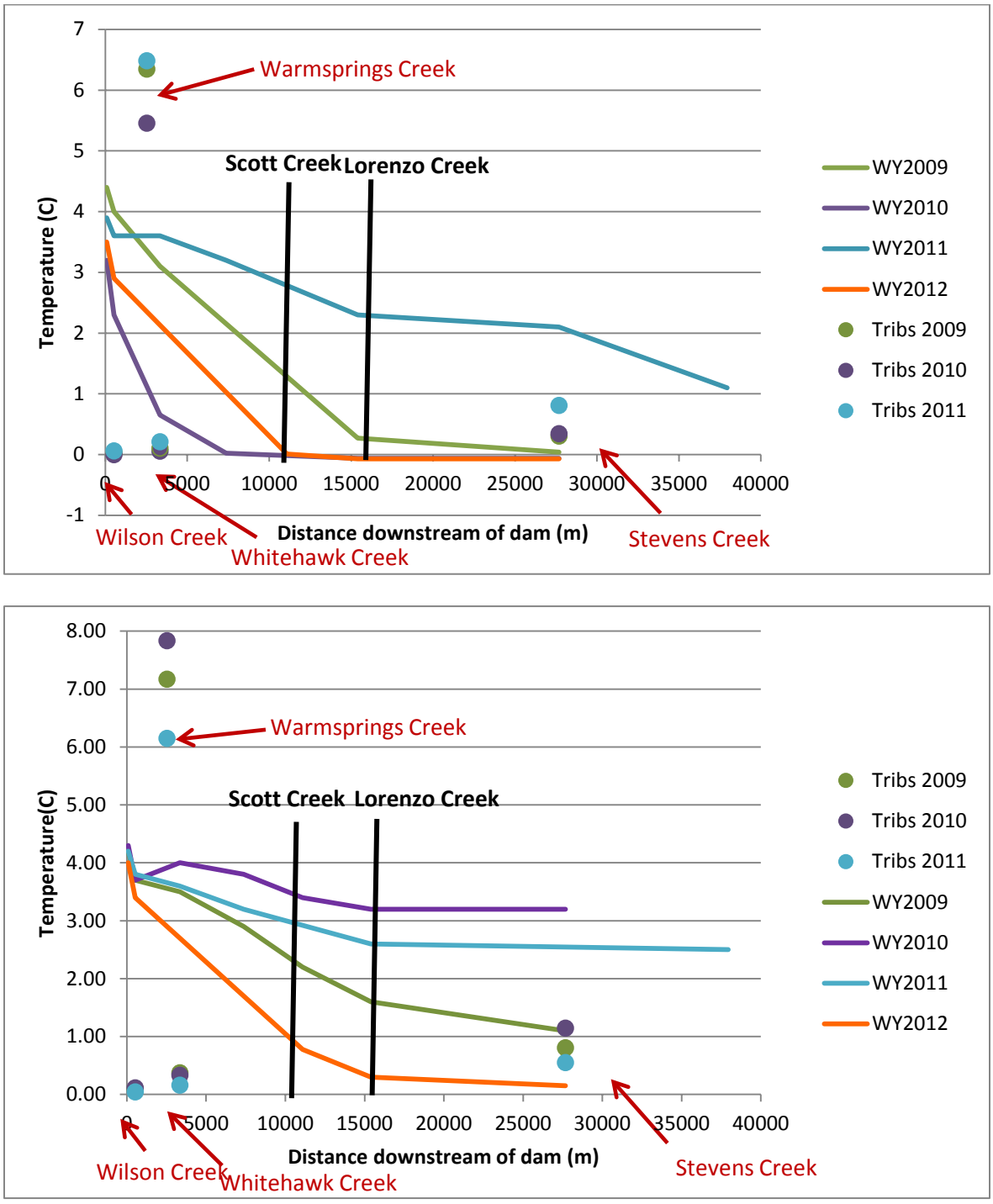


Figure 3-58. Longitudinal temperature distribution of lower Deadwood River on a) December 09, 2009 – 2012 and b) February 16, 2009 – 2012. Lines are measured instream daily average temperatures (C) and points are monthly average measured tributary temperatures (C).

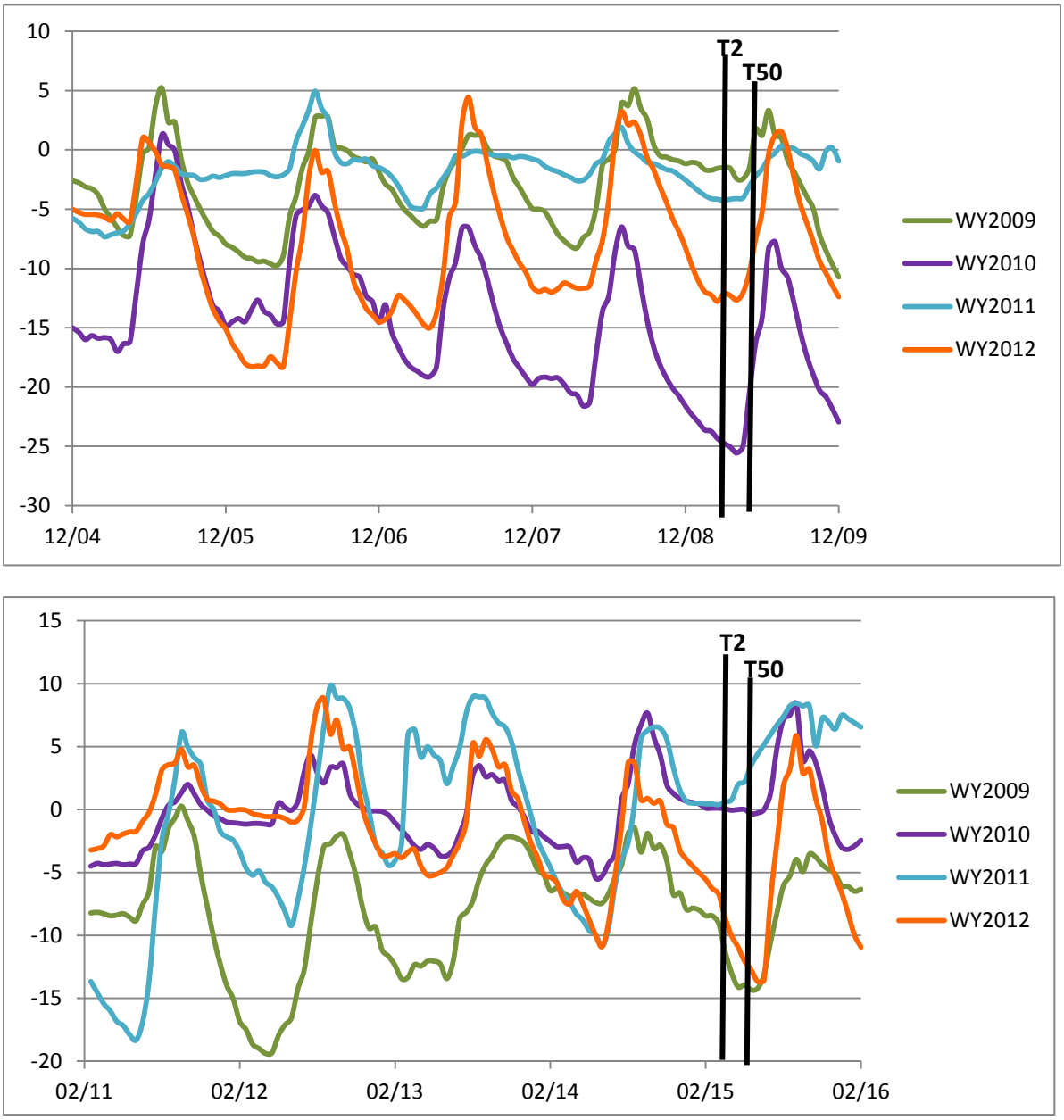


Figure 3-59. Air temperature (C) at Deadwood Dam 5 days prior to a) December 09, 2009 – 2011, and b) February 16, 2009 – 2011. Vertical black lines represent the average residence time of water in the lower river prior to the aerial ice surveys for the 50 and 2 cfs discharge options.

Figure 3-58 and Figure 3-59 make it apparent that air temperature drives heat loss during the winter more than tributary input under the 50 cfs release option. Under cold ambient temperature conditions, a stable ice cover could form in the lower Deadwood River (when stream temperature drops below 1°C) approximately 10,000 m below the dam near the confluence with Scott Creek; however, under warmer conditions a stable ice cover would not

occur anywhere along the profile. Figure 3-58 (a) and (b) show that large variations in water temperature can occur throughout the year and between years, implying that stable cold ambient temperatures are not maintained within the canyon all season long. This variability in ambient air temperature is a function of the diel fluctuation throughout the winter, where 30 degree shifts (-25 to 5°C) in air temperature can occur within 12 hours of each other. These ambient temperature fluctuations, in addition to the introduction of warm water (4°C) at the dam, make the 50 cfs dam release very unstable for seasonal ice cover in the lower Deadwood River. Diel fluctuations in ambient air temperatures may become even more significant in future decades if the Central Idaho batholith proves to be sensitive to changing global climatic conditions.

If the 2 or 0 cfs dam releases were utilized during the winter, lower initial temperatures below the dam and far less thermal mass in the river would make ice formation more responsive to ambient temperatures and conducive for formation of ice cover (see Figure 3-27). Under the alternative 2 or 0 cfs release options, cold tributary input from Whitehawk Creek (3,337 m below the dam) may provide sufficiently cool temperatures to offset the warmer influence of Warmsprings Creek (2,535 m below the dam) and allow ice cover to form within the main channel.

Less discharge under the 2 or 0 cfs options would reduce the overall wetted area and allow for border ice to encroach into the channel. This may change the channel hydraulics in two main ways: 1) allow border ice to narrow the channel and increase flow depth over a reduced cross-sectional area, and 2) facilitate the formation of anchor ice where flow is very shallow (i.e., riffles). Examination of resultant depths from the wetted area calculations (Figure 3-26, Figure 3-29, and Figure 3-38) and the 2D model under winter low flow conditions, if ice builds up along the shallow riffles and marginal areas this could act to isolate pools, induce convective scour holes and prevent fish passage. An example of this can be seen in Figure 3-60, downstream of Lorenzo Creek tributary, where anchor ice had adhered to the streambed and backed up flow a significant distance upstream. As flow pours over the top, the seasonal feature acts as a low head dam increasing pool depth upstream of the riffle and blocking the channel to any upstream movement. This occurred at the 50 cfs dam release option and may be increased under the low flow conditions.



Figure 3-60. Water pouring over an anchor ice dam in the lower Deadwood River upstream of Lorenzo Creek tributary.

3.1.6 Hyporheic Modeling

In this section, we investigated the role of flow discharges on hyporheic exchange along the lower section of the Deadwood River. Interaction between streamflow and its surrounding streambed sediment is commonly referred to as hyporheic exchange (Tonina and Buffington 2009a) and it has ecological and biogeochemical importance (Baxter and Hauer 2000; Edwards 1998; Findlay et al. 1993; Geist et al. 2002; Stanford and Ward 1988, 1993; Stanford et al. 1994). Hyporheic exchange mixes stream and pore waters and affects benthic, hyporheic organisms, and salmonid embryos, which are buried in the streambed sediment during incubation (DeVries 1997; Tonina and Buffington 2009a; 2009b). It also regulates pore water temperature (Cardenas and Wilson 2007a; Marzadri et al. 2012). Streamflow interaction with both small and large topographical features of the streambed induces hyporheic flow. Small topographical features, such as dunes and submerged cobles generate pressure head distributions in the flow due to dynamic head variations at the surface (Figure 3-61) (Cardenas and Wilson 2007b; Cardenas and Zlotnik 2003; Elliott and Brooks 1997a, 1997b).

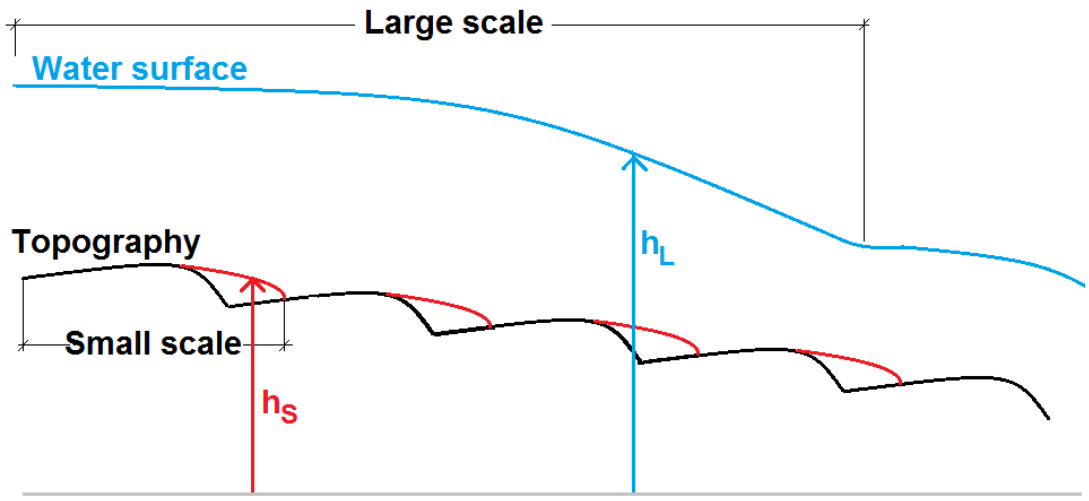


Figure 3-61. Sketch of small (h_s) and large (h_L) scale head variation generated by small and large topographical variations and discharge variations.

Large topography such as bars and riffles cause head variations due to water surface elevation changes (Tonina and Buffington 2007; 2009a). The lower Deadwood River presents longitudinal variations of both small and large-scale topographical features. The former include large particles or clusters of particles and the latter longitudinal variations of channel width and depth. Additionally, tributary inputs increases stream discharge. Therefore, to account for these changes, we coupled the hyporheic flow with surface hydraulics. We used the results of the MIKE 11 simulations for the year 2009. MIKE 11 predicted surface flow data at each cross section. Cross sections were extracted every 30 m from the DEM of the stream. This cross-section spacing provided detailed streamflow depths, water surface elevations and velocities, which were used in the hyporheic model. Six flow scenarios were selected to test the effect of winter flow releases (0, 2, and 50 cfs) and spring and summer high flows (400, 580, and 960 cfs) (Table 3-14).

Table 3-14. Main characteristics of stream water discharge scenarios.

Scenario Name	Water Discharge cfs	Date Range
1. Winter	0	5-1-2009 --> 24-2-2009
2. Winter	2	5-1-2009 --> 24-2-2009
3. Winter	50	5-1-2009 --> 24-2-2009
4. Spring: pre ramping	400	20-6-2009--> 5-7-2009
5. Spring: ramping	580	15-7-2009--> 20-7-2009
6. Summer: high flow	960	4-8-2009 --> 27-8-2009

Wavelet analysis was used to subdivide the entire river into 15 homogenous reaches, with each reach having uniform wavelet power and mean streambed slopes (Table 3-15).

Table 3-15. Main features of the 15 reaches of the Deadwood River.

Reach	Chainage from Dam (m)	Reach L (m)	Reach bed slope (-)
1	0-2472	2472	0.014
2	2475-5244	2769	0.010
3	5247-8544	3297	0.017
4	8547-11433	2886	0.008
5	11436-13755	2319	0.008
6	13758-17379	3621	0.007
7	17382-18576	1194	0.024
8	18579-19617	1038	0.009
9	19620-21486	1866	0.009
10	21489-22962	1473	0.017
11	22965-25449	2484	0.009
12	25452-28314	2862	0.019
13	28317-32736	4419	0.011
14	33315-35646	2331	0.006
15	35649-37938	2289	0.018

Deployment of Field Sensors

A tail-pool tail-riffle sequence was selected in the lower Deadwood River, near the confluence with South Fork of the Payette River, to measure hyporheic temperatures for comparison with model predictions. The site was chosen because it was representative of a typical pool-riffle-run sequence of the Deadwood system and it offers access for sensor deployment, maintenance, and retrieval. It was instrumented with 16 temperature sensors (Onset StowAway TidBiT) located at 4 different cross sections along the centerline, 4 pressure transducer sensors (HOBO water level 13 feet) located in 2 different cross sections along the centerline (Figure 3-62), and 1 pressure transducer sensor left in the open air to measure barometric pressure. Both temperature and pressure sensors were protected with a PVC pipe (Figure 3-63).



Figure 3-62. Overview of the study site sections along the Deadwood River. The positions of temperature sensors, and pressure transducers are shown with red and blue lines, respectively.

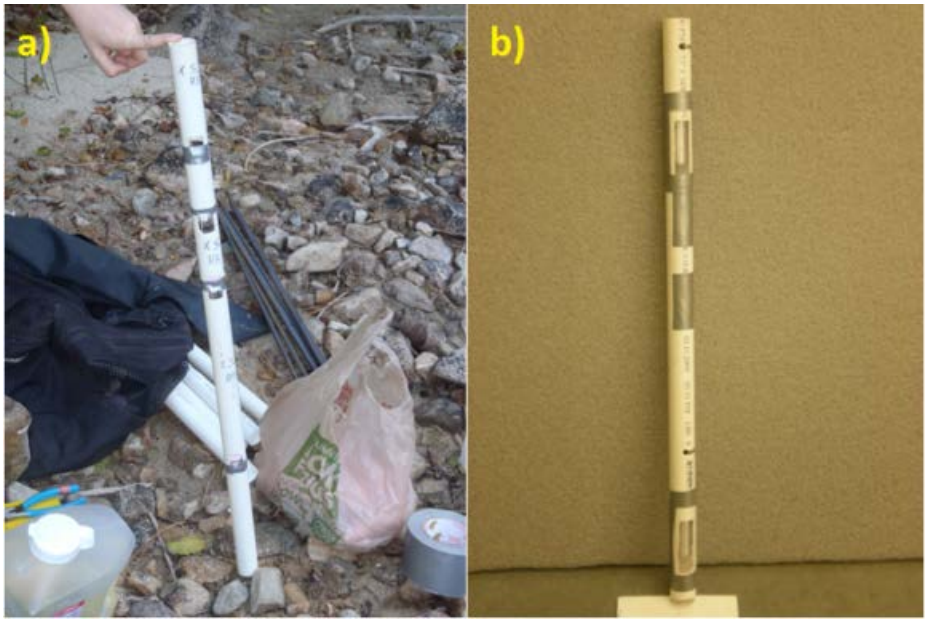


Figure 3-63. Particular of the PVC pipe for (a) temperature sensors, and (b) pressure transducer.

At each location, temperatures were recorded every 15 minutes by nesting four TidBiT sensors in a PVC pipe (Figure 3-63a). The upper end of the vertical array was located at the streambed to provide data within the hyporheic sediment at 0, 10, 20, and 50 cm below the streambed, respectively. Near the temperature probes, two pressure transducer sensors were installed that recorded both pressure and temperature every 15 minutes. This was accomplished by nesting two Onset HOBO U20 Water Level Logger in a PVC pipe (see Figure 3-63b). As for the TidBit sensors, the topmost of them were located at the streambed-water interface while the other was located within the hyporheic sediments at 50 cm below the streambed. The measurement range, the resolution and the accuracy specified by the manufacturer for both Onset HOBO pressure sensors and Onset HOBO temperature sensors are reported in Table 3-16.

Table 3-16. Main characteristics of onset HOBO pressure and temperature sensors.

Sensor Type	Measurements Range	Resolution	Accuracy
Onset HOBO pressure	0-145 kPa	0.02 kPa	±0.14 kPa
Onset HOBO temperature	-20 - 50°C	0.1 °C	0.1 °C

The PVC pipe was perforated at each sensor location to allow direct contact with streambed sediments and seepage water. In order to prevent vertically preferential flow paths within the PVC pipe, disks of styrofoam material and streambed sediments were inserted in between sensors (see Figure 3-63). Both pressure and temperature sensors were checked prior to and following deployment for temporal or thermal drift by testing their measurements in a temperature-controlled water bath. Data collection began on October 2, 2011 and ended on September 28, 2012 for the TidBit temperature sensors; while for Onset HOBO U20 Water Level Logger data collection began on October 2, 2011 and ended on May 15, 2012.

Description of the Hyporheic Flow model

The lower Deadwood River flows in a narrow canyon with limited depositional material and bedrock walls shaping the plan form of the streams. Consequently, the system can be schematized with non-erodible banks, without any hyporheic exchange between meanders and a thin alluvium layer. We accounted for both small and large topographical variations by superposing the effects of small and large topography features. We used the 2D hyporheic model developed by Stonedahl et al. (2010) and Elliott and Brooks (1997b). This model was coupled with a temperature model, which accounts for conduction, advection, and longitudinal diffusion (Marzadri et al. 2012). The details of both model developments are reported in the Appendix C. The hyporheic hydraulic model assumes constant and isotropic hydraulic conductivity, which was set equal to 0.005m/s and was verified with the temperature probes.

Model Validation

The PVC pipe with the TidBit sensors in Section 1, the uppermost TidBit in Section 3 and Section 4, and the TidBit at -20 cm in Section 4 were not found at the end of the irrigation season (see Figure 3-62). High flows probably removed or buried the probes at Section 1 and 3. The probe at Section 4 was found with the upper part of the PVC pipe broken, which could have been due by sediment transport. The sensors left in the stream were found buried at the time of retrieval. We assumed that sediment transport deposited sediment on top of the sensors during high flows, thus we used only the data before high flows.

The 3-day period of April 13 to April 15, 2012 was selected to compare the predicted and measured data because the hyporheic mean daily temperatures did not differ from that of the surface water and therefore it was suitable for interpretation within the model. We used MIKE 11 hydraulic predictions for 50 cfs dam releases. The mean measured temperature at 50 cm below the sediment was used as groundwater temperature and the temperature at the water-surface interface (0 cm) as stream water temperature. The thermodynamic parameters used in the simulations are reported in Table 3-17. According to the data reported by Niswonger et al. (2003) and considering that the Deadwood River sediments are characterized mainly as surface cobbles with gravel and sand beneath, it was assumed that the heat capacity of the soil was CS= 1.6x106 J/(m3°C); therefore:

$$C = \phi C_w + (1 - \phi)C_s \qquad (1)$$

Table 3-17. Values of thermodynamic parameters used in the simulation for modeling temperature measurements along the Deadwood River, Idaho. Cw is the heat capacity of the water, C is the effective volumetric heat capacity of the sediment-water matrix, Ke is the average bulk thermal diffusivity, KT is the effective thermal conductivity, ϕ is the porosity of the sediment and αL is the longitudinal component of the dispersivity.

Cw **(J m^{-3} ^{o}C^{-1})**	C **(J m^{-3} ^{o}C^{-1})**	Ke **(m^{2} d^{-1})**	K_T **(W m^{-1} ^{o}C^{-1})**	**Φ** **(-)**	**α_L** **(m)**
4.2x106	2.6X106	0.060	1.8	0.38	0.01

Comparison between the temperature predicted by the temperature model and those measured in the hyporheic zone of the lower Deadwood River, provided good agreement (Figure 3-64 and Figure 3-65). Measured and modeled signals are in phase and present comparable maximum and minimum values. The disagreement between the modeled and the measured values are probably due to the model neglects lateral diffusion and mixing with the groundwater.

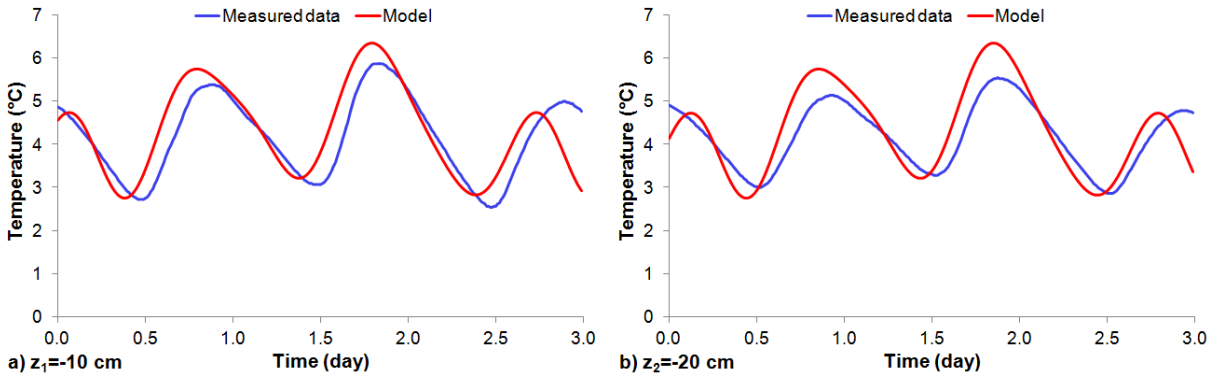


Figure 3-64. Comparison between our model-predicted and the field-measured temperatures across the Section 2 of the study site during April 13–15, 2012. The signals are compared at two depth positions: at (a) z1=-10 cm and (b) z2=-20 cm.

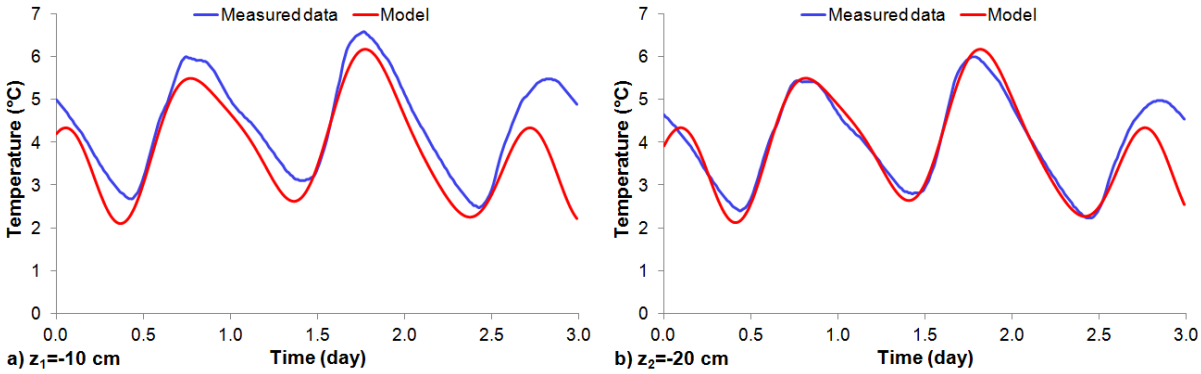


Figure 3-65. Comparison between our model-predicted and the field-measured temperatures across the Section 3 of the study site during April 13–15, 2012. The signals are compared at two depth positions: at (a) z1=-10 cm and (b) z2=-20 cm.

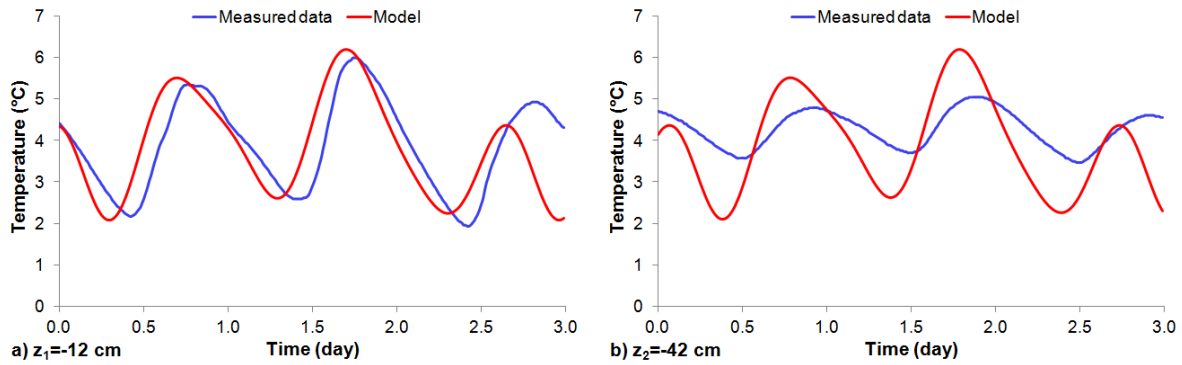


Figure 3-66. Comparison between our model-predicted and the field-measured temperatures across the Section 4 of the study site during April 13–15, 2012. The signals are compared at two depth positions: at (a) z1=-12 cm and (b) z2=-42 cm.

Effects of Dam Releases on Hyporheic Flow

Figure 3-67 shows the distribution of the mean upwelling flux for the 6 different scenarios along the 15 reaches, which are arranged by progressive distance from Deadwood Reservoir. The mean upwelling flux averaged over each reach is plotted. The downwelling flux presents similar values but with a negative sign. For each scenario, the distribution of the mean upwelling flux changes from upstream to downstream reaching the maximum value near reach 7. Figure 3-67 shows that discharge has limited effects on hyporheic fluxes. Consequently, winter releases of 0, 2, or 50 cfs may have similar effects on hyporheic flows.

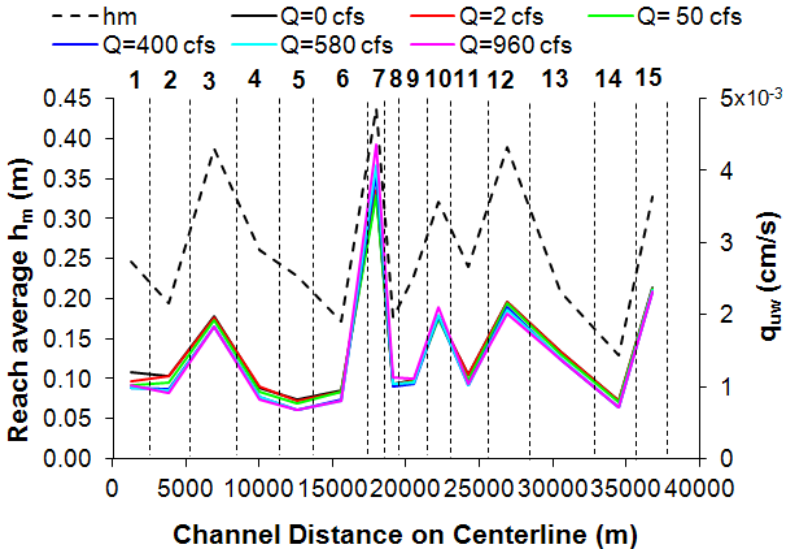


Figure 3-67. Comparison between the distribution of mean hyporheic upwelling flux (q_{uw}) and the reach average dynamic head fluctuation (h_m) along the Deadwood River for six different scenarios.

Figure 3-68 shows the distribution of the median hyporheic residence time ($\tau 50$) averaged over each reach of the lower Deadwood River for the six different scenarios. The median hyporheic residence time represents the time at which 50% of the downwelled particles left the hyporheic zone. The time that water spends within the sediment decreases with increasing discharge. The distribution of $\tau 50$ varies with reach and presents its minimum value in reach 7.

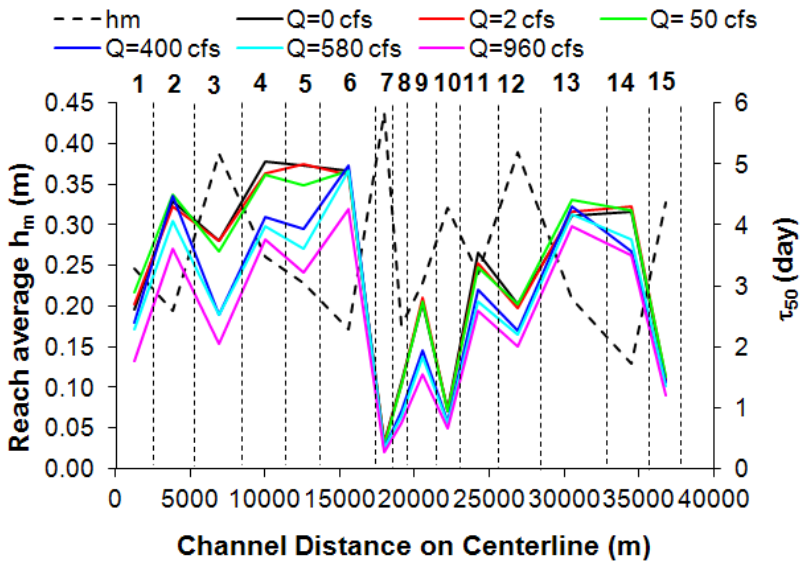


Figure 3-68. Comparison between the distribution of median hyporheic residence time (τ_{50}) and the reach average dynamic head fluctuation (h_m) for the 6 different scenarios.

Direct comparison of the three winter dam releases shows limited effects on both hyporheic residence time and fluxes (Figure 3-69).

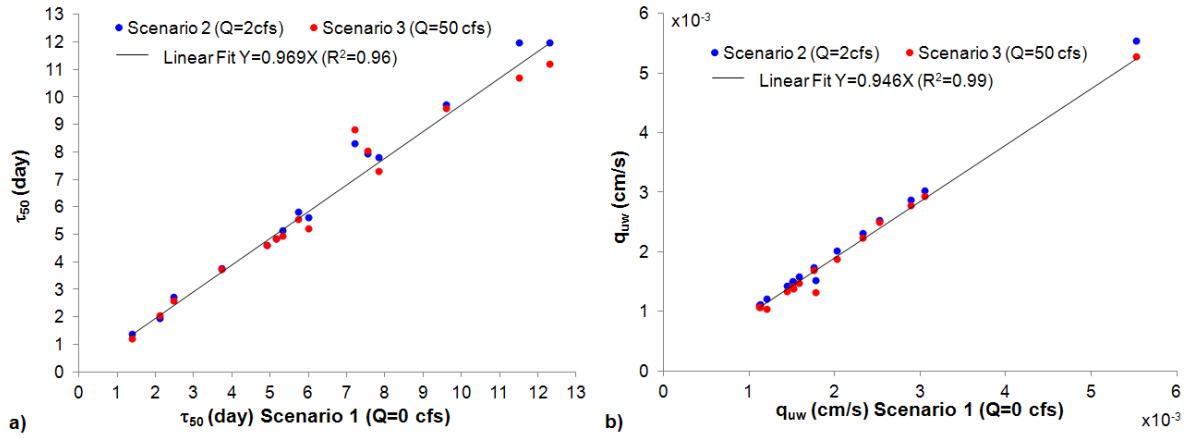


Figure 3-69. Comparison between hyporheic (a) reach median residence time, and (b) reach mean upwelling flux among the three winter scenarios, Scenario 1 Q=0 cfs, Scenario 2 Q=2 cfs, and Scenario 3 Q=50 cfs.

To consider how the small and the large scale head variations may influence the distribution of the hyporheic zone pathlines, a set of simulations were performed changing the depth of the alluvium layer (zd). As observed by Zijl (1999), the flow field generated by the small scale head variations has larger intensity at shallow depths; while the deep streamlines are almost entirely governed by the large-scale head variations. Figure 3-70 illustrates how the hyporheic zone depth responds to the superposition effects on small and large-scale head variations in terms of mean upwelling flux, while Figure 3-71 shows the same behavior but in terms of the median hyporheic residence time.

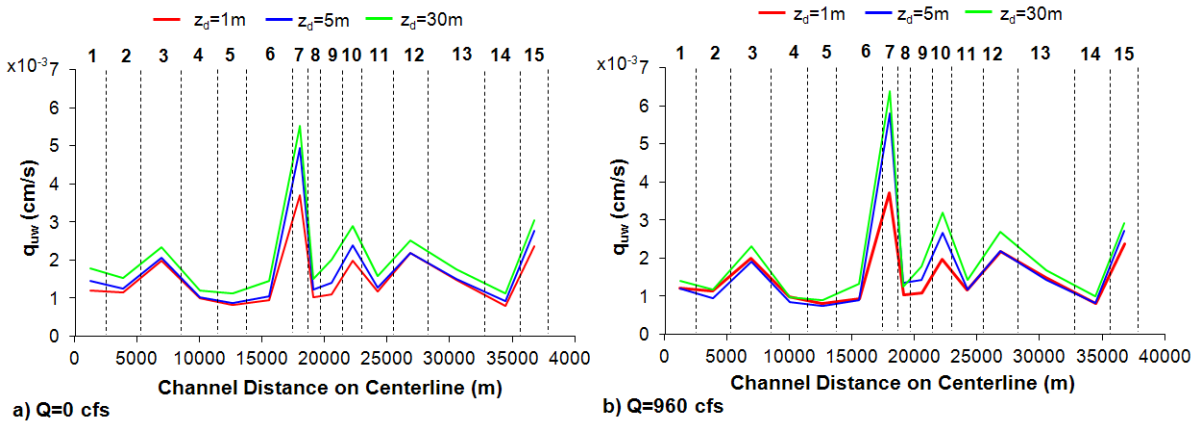


Figure 3-70. Effects of alluvium depth on the mean upwelling flux for the two extreme water discharge scenarios: (a) Scenario 1 Q = 0 cfs, (b) Scenario 6 Q = 960 cfs.

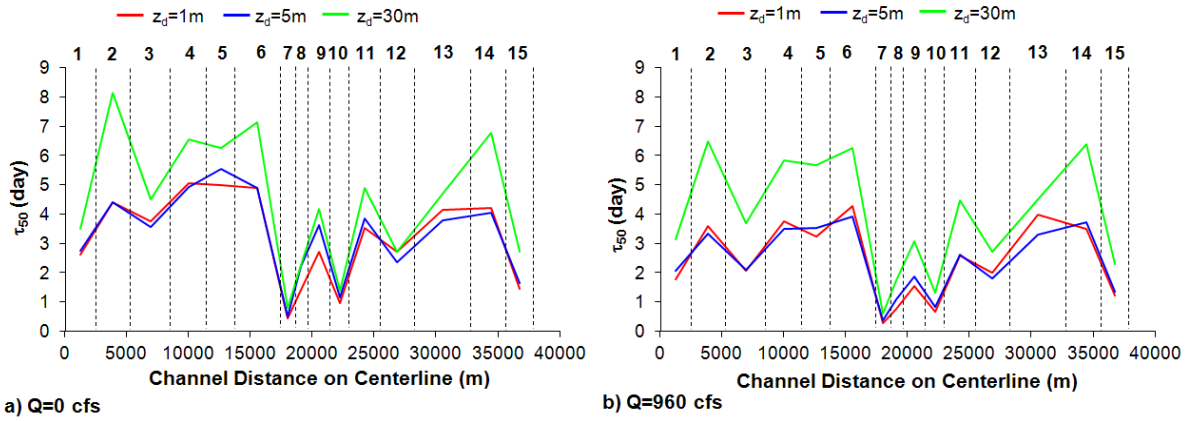


Figure 3-71. Effects of alluvium depth on the median hyporheic residence time for the two extreme water discharge scenarios: (a) Scenario 1 Q = 0 cfs, (b) Scenario 6 Q = 960 cfs.

As the depth of the hyporheic zone increases, the mean upwelling flux is nearly the same, while the median hyporheic residence time presents a strong variation between 5 and 30 m. From these results and considering that this portion of the Deadwood River flows is in a narrow and deep canyon with limited alluvium depth, errors on its mean depth between 1 or 5 m will have limited effects on the results.

The results presented above consider the mean behavior along each reach and provides the global response of the hyporheic zone at each reach scale along the lower Deadwood River. Figure 3-72 shows the hyporheic upwelling flux every 300 m for the two extreme flow scenarios and the trend of wavelet power. The latter is an index of streambed variations at the small scale. Fluxes vary within each reach depending on the local morphological and hydrodynamic characteristics of the river. As observed in the previous graphs, the mean upwelling flux presents its maximum values in reach 7 and shows small dependence on stream discharge.

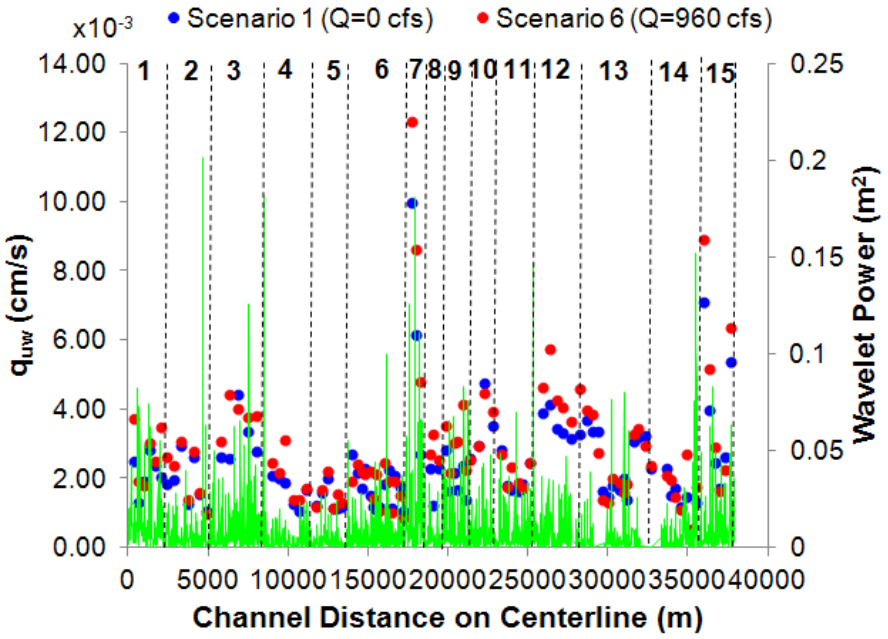


Figure 3-72. Distribution of average hyporheic upwelling flux (q_{uw}) over a 300 m area for the two extreme scenarios and comparison with the trend of wavelet power.

Figure 3-73 shows the behavior of the hyporheic median residence time every 300 m. The high discharge shows larger median residence time than the low discharge, as observed at the reach scale. Comparison of median residence time and hyporheic flux at 300 m scale among winter flow scenarios shows small variations as predicted by the reach averaged values (Figure 3-74).

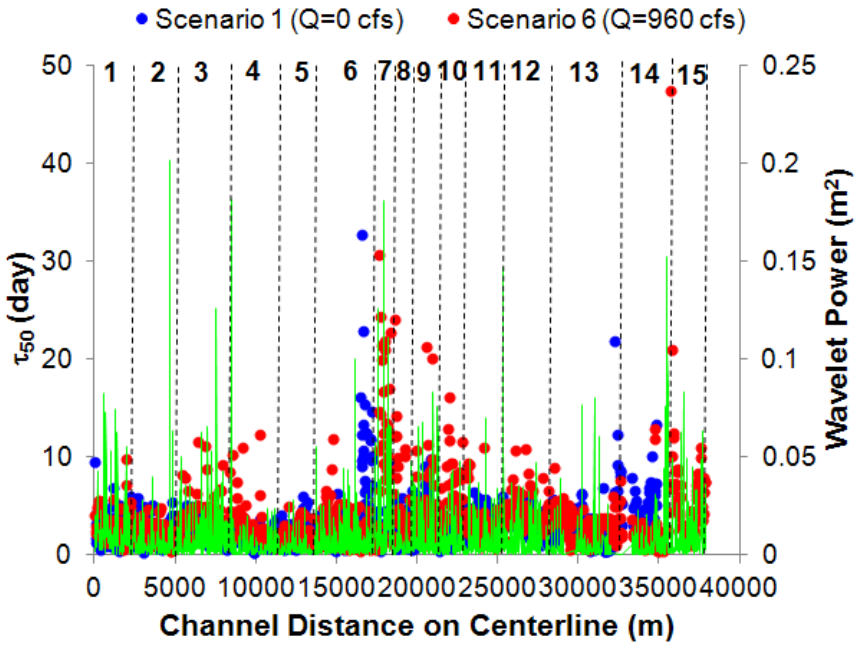


Figure 3-73. Distribution of median hyporheic residence time over a 300 m area for the two extreme scenarios and trend of wavelet power (green lines).

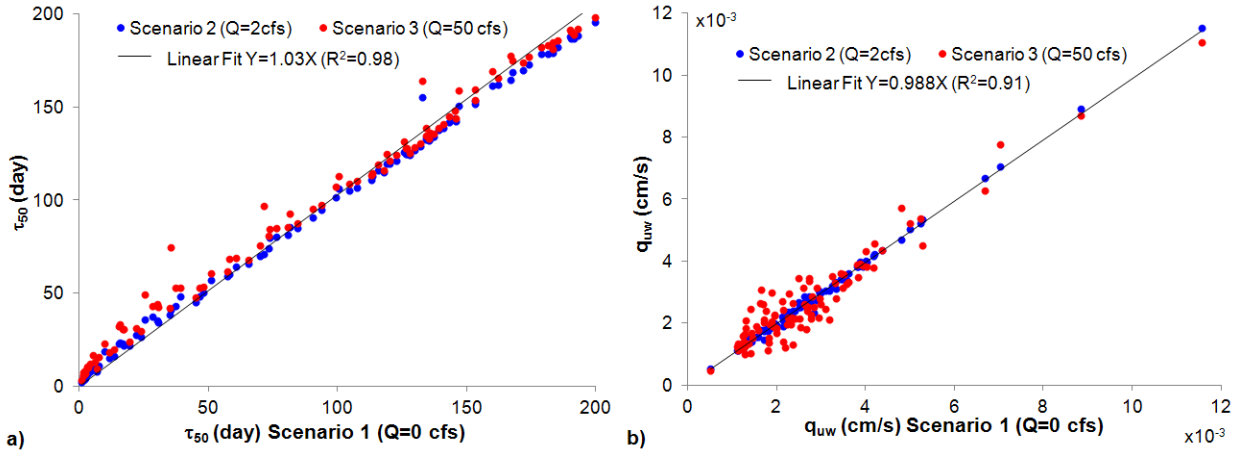


Figure 3-74. Comparison between hyporheic a) median residence time and b) mean upwelling flux averaged over 300 m among the three winter scenarios, Scenario 1 Q=0 cfs, Scenario 2 Q=2 cfs and Scenario 3 Q=50 cfs.

Effects of Dam Releases on Hyporheic Temperature Regime

In this analysis it is assumed that the stream temperature can be represented as a sum of a constant component and a diel sinusoidal component (Equation (1–23), which leads the hyporheic thermal response in the same form as in Equation (1–31) considering the main parameters reported herein (Table 3-18).

Table 3-18. Parameters used in the simulations for modeling temperature pattern along the Deadwood River, Idaho. T_0 is the mean in-stream water temperature, T_{GW} is the ground water temperature, T_A is the amplitude of the sinusoidal variation of the in-stream temperature, C_W is the heat capacity of the water, C is the effective volumetric heat capacity of the sediment-water matrix, K_e is the average bulk thermal diffusivity, K_T is the effective thermal conductivity, ϕ is the porosity of the sediment and α_L is the longitudinal component of the dispersivity.

T_0 (°C)	T_{GW} (°C)	T_A (°C)	C_W ($Jm^{-3}°C^{-1}$)	C ($Jm^{-3}°C^{-1}$)	C_T (-)	K_T (-)	t_d (day)	α_L (m)
12	6	4	$4.2x10^6$	$2.6 x10^6$	1.62	1.8	1	0.010

At the global scale, temperature attenuation, (Δamp in Equation[0–32]), is desynchronized with respect to the median residence time. Figure 3-75 (a) and (b) show this behavior for the two extreme discharge scenarios (Scenario 1 and Scenario 6). As the water discharge increases, the median hyporheic residence time decreases and therefore the attenuation signal increases. The less time water spends within the hyporheic zone, the closer are the hyporheic upwelling and instream temperatures.

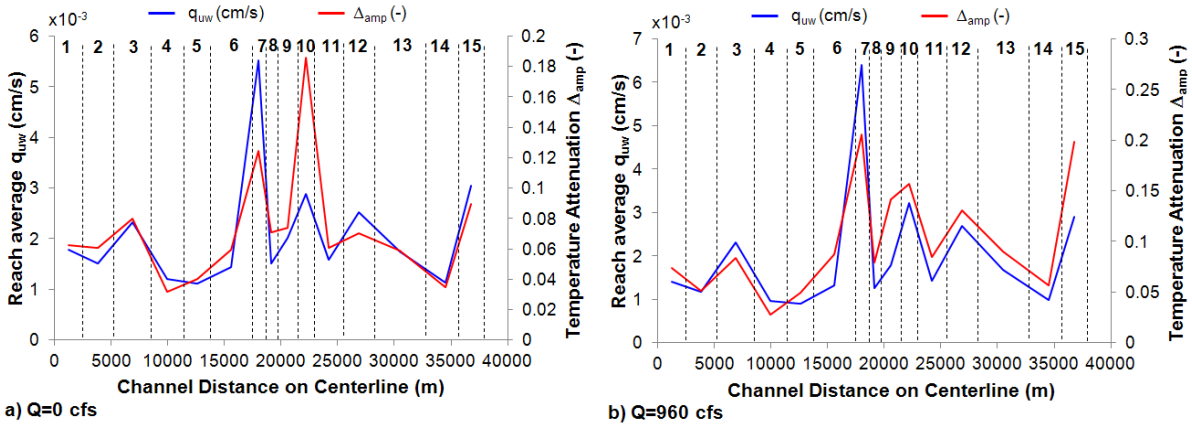


Figure 3-75. Comparison between the distribution of the median hyporheic residence time (τ_{50}) and the temperature attenuation signal (Δ_{amp}) along the Deadwood river for the two extreme water discharge scenarios: a) Scenario 1 Q=0 cfs and b) Scenario 6 Q=960 csf.

Figure 3-76 (a) and (b) shows the comparison between the distribution of the mean upwelling flux (q_{uw}) and the temperature attenuation signal (Δ_{amp}) for the same two extreme water discharge scenarios. The distributions of mean upwelling flux and temperature attenuation are perfectly in phase. Zones with high upwelling flux (small residence time) present small temperature attenuations and the mean amplitude of upwelling temperature differ only slightly from the instream water temperature. Conversely, zones with low upwelling flux (long residence time) are characterized by a mean amplitude of upwelling temperature signal much lower than the amplitude of the instream water temperature.

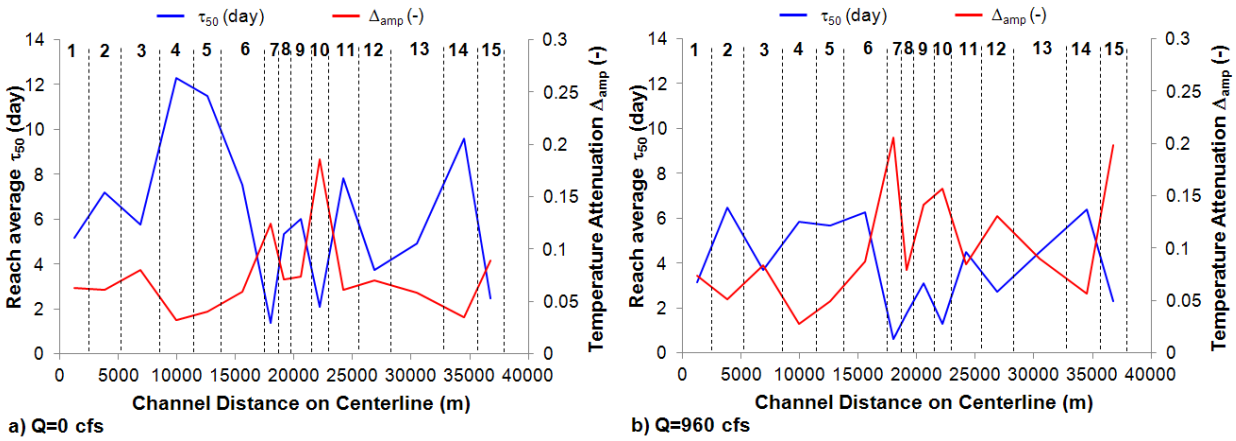


Figure 3-76. Comparison between the distribution of the mean upwelling flow (q_{uw}) and the temperature attenuation signal (Δ_{amp}) along the Deadwood River for the two extreme water discharge scenarios: a) Scenario 1 Q=0 cfs and b) Scenario 6 Q=960 cfs.

Because of the limited changes in residence time and fluxes among the three winter scenarios, it is also expected that stream water temperature fluctuations on the hyporheic thermal regime will be limited (Figure 3-77). This result is shown in Figure 3-77, which compares the results for Scenario 2 and 3 against Scenario 1.

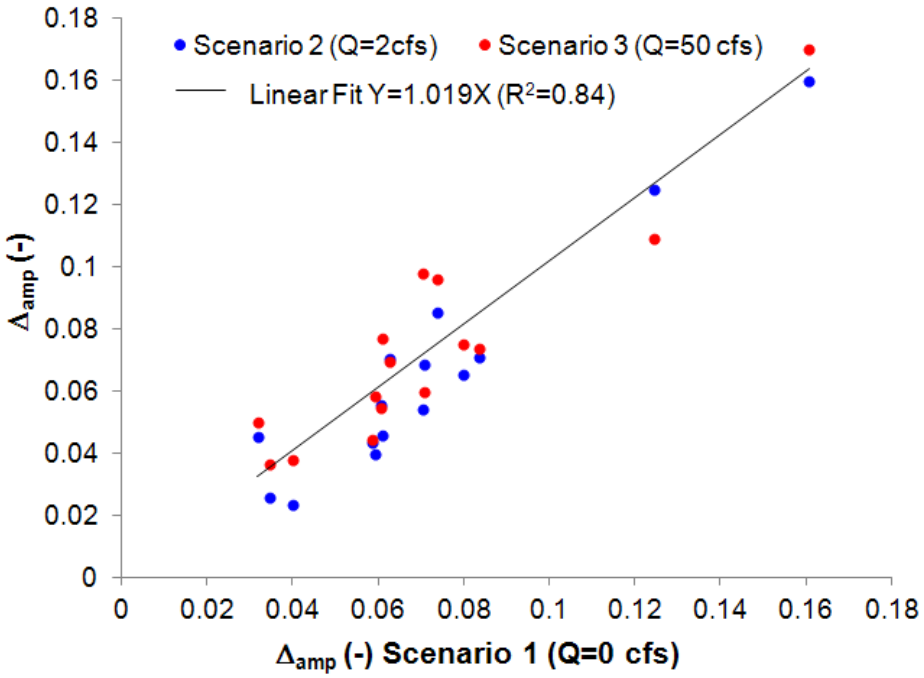


Figure 3-77. Comparison of amplitude ratio between stream and hyporheic mean response for Scenario 1 Q=0 cfs, Scenario 2 Q=2 cfs and Scenario 3 Q=50 cfs.

3.1.7 Conclusions

Major seasonal changes have occurred to the hydrologic and thermal regime below Deadwood Reservoir due to historic dam operations. Alteration to those operations may improve habitat quality below the dam for the resident ecological community, with respect to the hydrologic and thermal regimes. This study has focused on potential effects of manipulating the current dam operations for Bull Trout habitat. Operational changes that are currently available to the dam operators include altering the quantity of water released in the winter, variable operational schemes in the spring and fall seasons, and ramping alternatives at the beginning and end of the irrigation season.

The winter dam releases output water from the bottom of the reservoir (4°C) that is higher than the unregulated hydrograph would provide (0°C). This affects ice formation and snow cover for a substantial distance downstream of the dam until tributary inputs and ambient cooling can reduce the stream temperature to 1°C. This effective distance is governed by the climatic year of interest, the selected dam release option, and local ambient weather conditions. Modeled and measured thermographs along the main channel show that this distance can extend from 3.5 km below the dam during a dry or average hydrologic year to the entire river during a wet year. The 50 cfs release option will maintain warmer temperatures throughout a greater length of the river, whereas either lower flow option (2 or 0 cfs) will provide instream temperatures similar to that of the tributaries.

Spring releases from the reservoir maintain consistently cool temperatures (4-6^{o}C) in the river during a time when the stream temperature should be steadily increasing towards its peak summer temperature of 12 to 14^{o}C. Variability during this time is greatly reduced depending upon which release option (50, 2, or 0 cfs) is selected. The lower flow options will respond more quickly to the varying thermal inputs of the tributaries below the dam. If one of the lower alternative winter release options (2 or 0 cfs) is selected, "carry-over" water would be available during average climatic years for beneficial instream habitat modulation through an extended period of spill. Ramping up rates (fast vs. slow) during this season make very little difference with respect to the thermal regime of the stream due to the consistent 4^{o}C temperature water from the reservoir.

The summer irrigation season requires certain contractual discharge quantities to be met, which limits the flexibility of the dam operator during this season. Summer irrigation releases are significantly higher than the unregulated hydrograph would provide during this season. This acts to maintain cool temperatures (4 to 6^{o}C) during the first part of the summer when cold hypolimnetic water is available in the reservoir. As the warm pool in the reservoir is drawn down to the intake, temperatures in the lower river increase precipitously to summer high temperatures, depending on the climatic year (dry year 18^{o}C, average year 13^{o}C, and wet year 7^{o}C). Depending upon which ramping down method and release option is selected the influence of the warm water can be extended much later into the fall season.

Variable ramping rates can be employed at the end of irrigation season to manipulate the temperature regime of the river below the dam. Due to the combined effect of 1) the warm water pool behind the dam lowering to the intake, and 2) higher elevation tributaries that would be providing cooler water to the lower river being trapped in the reservoir, fall water temperature can be augmented through ramping the flow down in either a fast or slow manner. Depending upon the hydrologic year and the alternative release option (50, 2, or 0 cfs) significant changes can be made that would extend warmer temperatures up to a maximum of 69 days after the end of irrigation. Table 3-19 below summarizes the effects of ramping down the discharge assuming the fast option is selected. The number of days shows the time interval for which the two ramping modes provide different temperatures in lower Deadwood River. For instance in the dry year, a 2 cfs release from the dam requires 55 days for the two ramping modes to reach the same temperature in the river near the dam (Location 1) and 10 days near the confluence with the Payette River (Location 2). During those periods, the stream water is 1.5^{o}C colder for the fast than slow ramping near the dam and 2 to 3^{o}C warmer near the confluence.

Interpretation of modeled thermal regimes below the dam is limited because water temperature in each scenario was modeled using empirical data sets collected within the study location in 2009 (Flex study 3-12 to 3-13). Calibrating the model demonstrated that modeled water temperatures accurately represent the empirical data (Flex study pages 3-15 to 3-17). It is significant to note that while 2009 offered the most robust data set for the

purpose of modeling water temperatures, operations during 2009 did not include use of the spillway. During spillway use, water temperatures downstream of the dam are expected to increase (a result of warmer surface water from the reservoir being released) but this phenomena is not depicted in the modeled data. Spill, and the corresponding downstream temperature increase, would be expected for wet or average years.

Table 3-19. Comparison of temperature regime below Deadwood Dam, assuming fast ramping down.

	Flow	No. Days	Location 1	No. Days	Location 2
Dry	50 cfs	16	1ºC less than slow	16	1ºC less than slow
	2 cfs	55	1.5ºC less than slow	10	2-3ºC greater than slow
	0 cfs	8	2ºC +/- than slow	10	2-3ºC greater than slow
Average	50 cfs	39	1.5ºC less than slow	36	<1ºC less than slow
	2 cfs	42	1-2ºC less than slow	9	<1ºC less than slow
	0 cfs	10	3ºC less than slow	9	<1ºC less than slow
Wet	50 cfs	69	<0.5ºC less than slow	10	1ºC greater than slow
	2 cfs	9	<0.5ºC greater than slow	10	1ºC greater than slow
	0 cfs	9	<0.5ºC greater than slow	10	1ºC greater than slow

Fall discharge in the unregulated lower Deadwood River is dominated by low base flow conditions with localized high intensity precipitation events providing short duration floods. Base flow during this season allows very little thermal buffering capacity to occur in the stream and quick responses to changes in ambient weather conditions will occur. If the 50 cfs release option is exercised after irrigation demand ceases, significantly warmer temperatures will persist well into November. If either lower flow option (2 or 0 cfs) is chosen, the river will respond similarly to that of the unregulated temperature regime.

A 2D model was developed for a 1-km reach near the lower end of the river to assess the spatial variability of instream velocities and extent of possible hydrodynamic refugia for Bull Trout. The results showed that due to the large size of substrate on the channel bed, significant deviations from the reach average velocity can occur over a range of flows. The size, shape, and location of coherent recirculation zones are dependent upon the flow depth and will change with the dam release option. In order to better understand the hydraulics of the entire river, a statistical method was employed to extrapolate the velocity results from the 2D model to the rest of the lower river. Probability distribution functions were developed from the Froude number and relative roughness (D50/depth) from each reach to examine the percent of wetted area exhibiting specific velocities. These velocity distributions can then be utilized for evaluating potential habitat within each specific reach.

Ice cover can occur in winter months on the lower river; however, the process is highly dependent upon ambient air temperatures and the amount of water in the river. Most tributaries provide water near 0°C during the winter with the exception of Warmsprings Creek (6 to 7°C) that acts to locally increase water temperatures in the main channel of the river. Also, given the canyon walls and northern latitude, very little direct sunlight reaches the river surface during the winter, so air temperatures are the biggest driver for ice formation. If air temperatures remain cold enough to create ice cover the river will respond differently depending upon which flow option is selected. Under the 50 cfs discharge option a significant amount of 4°C water is present in the river and tributary inputs have less impact on modifying the river's water temperature. Hence, significant expanses of open water can form at the upper end of the river periodically when near 0°C air temperatures cannot sufficiently cool the continuous release of 4°C water from the dam. If either the 2 or 0 cfs release options are selected, tributary input plays a more significant role in modifying the stream temperature and the water temperature in the main channel will be more responsive to ambient air temperatures in creating a stable ice cover.

Hyporheic modeling showed negligible effects of 0, 2, and 50 cfs dam releases during low flows period on surface-subsurface water interaction. Consequently, during fall, winter and spring times the three alternative dam release options would provide similar hyporheic exchange and maintain comparable pore-water habitats. Discharge affects hyporheic exchange when dam releases are larger than 400 cfs.

3.2 Nutrient and Chlorophyll Transport in the lower Deadwood River

The fate and transport of water and associated constituents following their delivery into Deadwood Reservoir are determined by the interactions of a myriad of physical, chemical, and biological processes operating within the reservoir over a wide range of spatial and temporal scales. The outcome of these interactions determines the reservoir's water-quality characteristics, as well as the quantity and nature of constituents discharged through Deadwood Dam. Once introduced into the lower Deadwood River, riverine processes and watershed-based influxes of water and constituents modify those initial water-quality characteristics as they are transported downstream.

This section discusses the approach, results, and interpretation of water-quality sampling conducted in the lower Deadwood River during water years 2007 through 2011. This section focuses on nutrients and chlorophyll *a* at tributary stations DEA101, immediately downstream of Deadwood Dam, and DEA108, upstream of the confluence with the South Fork Payette River (Figure 3-78).

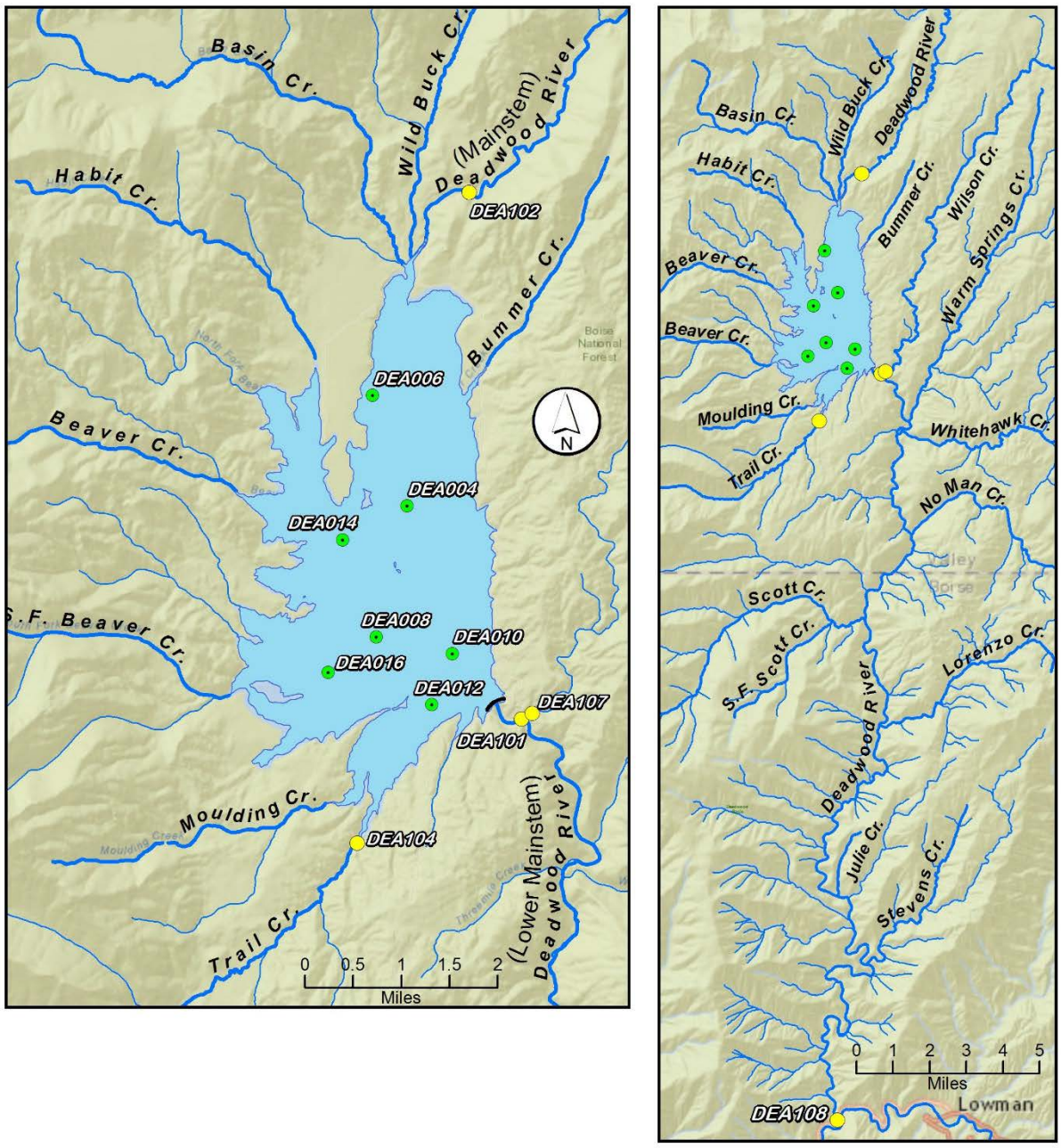


Figure 3-78. Water chemistry and reservoir profile locations (water chemistry also sampled at reservoir profile locations for surface, mid, and bottom water column conditions).

3.2.1 Methods

Water-quality sampling at the two lower Deadwood River stations, DEA101 and DEA108, consisted of Hydrolab measurements of water temperature, dissolved oxygen (DO) concentration, pH, specific conductance, turbidity, and fluorescence and collection of water-

quality samples for later analysis. Water-quality samples were analyzed by Reclamation's Pacific Northwest Regional Water Quality Laboratory in Boise using analytical procedures and quality assurance practices (Reclamation 2007b; 2011).

Nutrient samples collected from DEA101 and DEA108 were analyzed for total concentrations of phosphorus and Kjeldahl nitrogen (organic plus ammonia nitrogen) and dissolved concentrations of orthophosphate, nitrite plus nitrate, and ammonia. Analytical detection limits, in ug/L, for 2007 samples were as follows: 100 for Kjeldahl nitrogen; 10 for total phosphorus, dissolved nitrite plus nitrate, and ammonia; and 3 for dissolved orthophosphate. Nutrient analyses were revised in 2008 because the 2007 samples had a preponderance of below-detection limit concentrations for dissolved nitrite plus nitrate and orthophosphate. The revised analytical detection limits, in ug/L, were as follows: three for dissolved nitrite plus nitrate and one for orthophosphate. The other three nutrient analyses remained at their 2007 analytical detection limits.

Beginning in 2008, chlorophyll *a* sampling of the riverine water-column, not periphytic algae, was initiated at DEA101 and DEA108. Reclamation's Water Quality Laboratory in Boise performed the analyses using an acid-corrected spectrophotometric method, one that yields values for both chlorophyll *a* and pheophytin *a*.

The nutrient-concentration data and streamflow data obtained from DEA101 and DEA108 were used to compute nutrient loads transported between the two riverine stations. Load is defined as the quantity of a constituent passing a riverine cross section per unit of time and is calculated as the product of constituent concentration, streamflow, and appropriate conversion factors for measurement units. The computer program FLUX (Walker 1996) employs a variety of multiple-regression models to compute loads using stratified data sets based on relationships between either streamflow and nutrient concentration or time and nutrient concentrations. The model and data-stratification scheme that yields the smallest coefficient of variation, r2, is considered the best estimate of load. Nutrient-load computations were restricted to 2009 and 2010 because of inadequate streamflow data for DEA108 in the other years.

3.2.2 Nutrient Transport

Reservoir Effects on Nutrients

The interactions of physical, chemical, and biological processes in Deadwood Reservoir produced the water-quality characteristics of discharges through Deadwood Dam into the lower Deadwood River. The magnitude and timing of discharges through the dam, in concert with spatial and temporal variations in reservoir water quality, had important influences on the quantity of constituents, such as nutrients and chlorophyll, introduced into the lower Deadwood River. The more substantial downstream effects were generated during reservoir

drawdown that began near the peak of summer reservoir productivity. The combination of robust phytoplankonic primary productivity and well-developed thermal stratification lead to degradation of hypolimnetic water-quality during late summer and early autumn. During the early stage of reservoir drawdown, only cold hypolimnetic water was discharged through the dam's deep outlet. If reservoir water levels were reduced enough near the end of drawdown to induce early convective circulation of the reservoir, then the outlets could draft warmer metalimnetic and, on occasion, epilimnetic water. That situation occurred in 2007 when reservoir water levels were about 5 m lower than in 2008 to 2011; discharged peak-water temperatures in 2007 were between 4°C and 6°C warmer than in the other 4 years (Figure 3-79).

Depletion of DO concentrations within the reservoir's hypolimnion is well-illustrated in Figure 3-79. The early onset of convective circulation in 2007 maintained hypolimnetic DO concentrations above 4 mg/L and facilitated reaeration of the hypolimnion during September. In each of the other 4 years hypolimnetic DO concentrations declined below 3 mg/L; in 2010 they declined to about 0.5 mg/L. In contrast to 2007, minimum hypolimnetic DO concentrations occurred later by about 4 to 8 weeks. The extended periods of hypolimnetic deoxygenation allowed for additional recycling of nutrients within the hypolimnion and bed sediments; nutrients that would become available for distribution throughout the water column once full-depth convective mixing commenced.

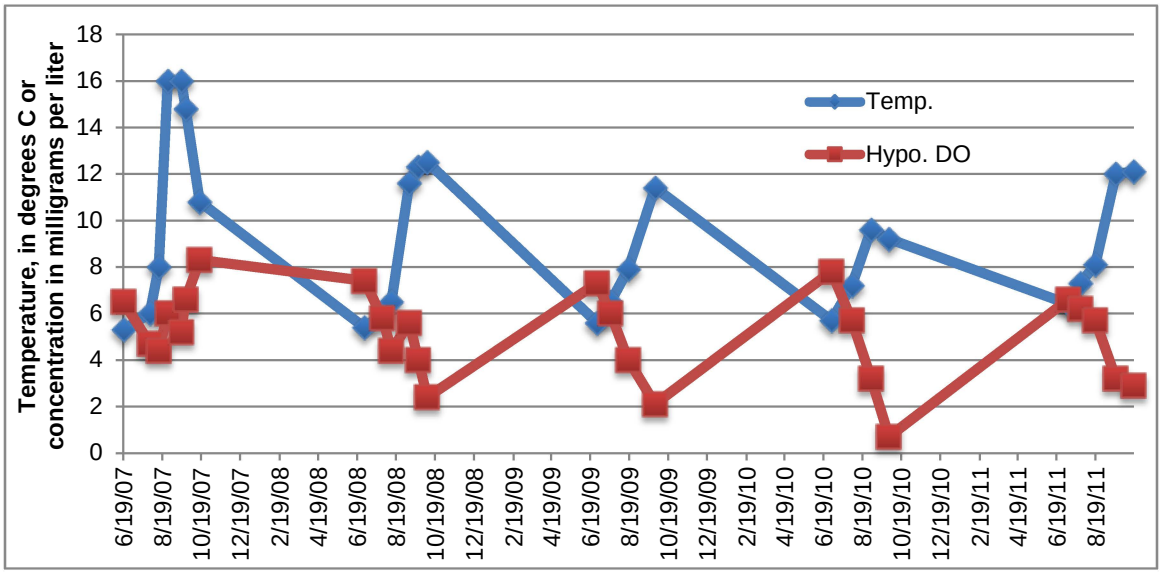


Figure 3-79. Temporal variation in hypolimnetic water temperatures, in degrees Celsius, and DO concentrations, in milligrams per liter, from mid-June 2007 to late September 2011 at reservoir station DEA010, Deadwood Reservoir.

The water-quality effects on the lower Deadwood River of reservoir processes are apparent in the following four time-series plots of nutrient concentrations at station DEA101, just

downstream of Deadwood Dam (Figure 3-80 to Figure 3-83). The four nutrients often increased sharply in concentration during mid-September to mid-October, the time period following the end of reservoir drawdown but prior to full-depth convective circulation. For example, in early October of 2011 minimum and maximum concentrations of total phosphorus, dissolved orthophosphate, total organic nitrogen, and dissolved inorganic nitrogen ranged, respectively, by factors of 6, 14, 2, and 12. Note that the two dissolved nutrients varied over a wider range, reflective of robust hypolimnetic recycling of particulate nutrients into dissolved nutrients.

With the exception of total organic nitrogen, the highest concentrations of the four nutrients were measured in October 2006. Although not illustrated in Figure 3-79, hypolimnetic DO concentrations during October 2006 were less than 2 mg/L. In addition to increased recycling of nutrients in the DO deficient hypolimnion during the first half of October 2006, the Rattlesnake Fire had been burning since mid-August 2006 and may have added ash-borne nutrients to Deadwood Reservoir and the lower Deadwood River.

The downstream effects of winter-time, hypolimnetic deoxygenation, and nutrient recycling are also depicted in Figure 3-80 to Figure 3-83. During March 2007, March 2008, and April 2010, concentrations of total phosphorus, dissolved orthophosphate, and dissolved inorganic nitrogen from DEA101 were elevated with respect to summer concentrations. The opposite was observed for total organic nitrogen; its concentrations on those three dates were some of the lowest measured at DEA101. The likely explanation is that winter decomposition of organic matter within the reservoir had converted total organic nitrogen into dissolved inorganic nitrogen.

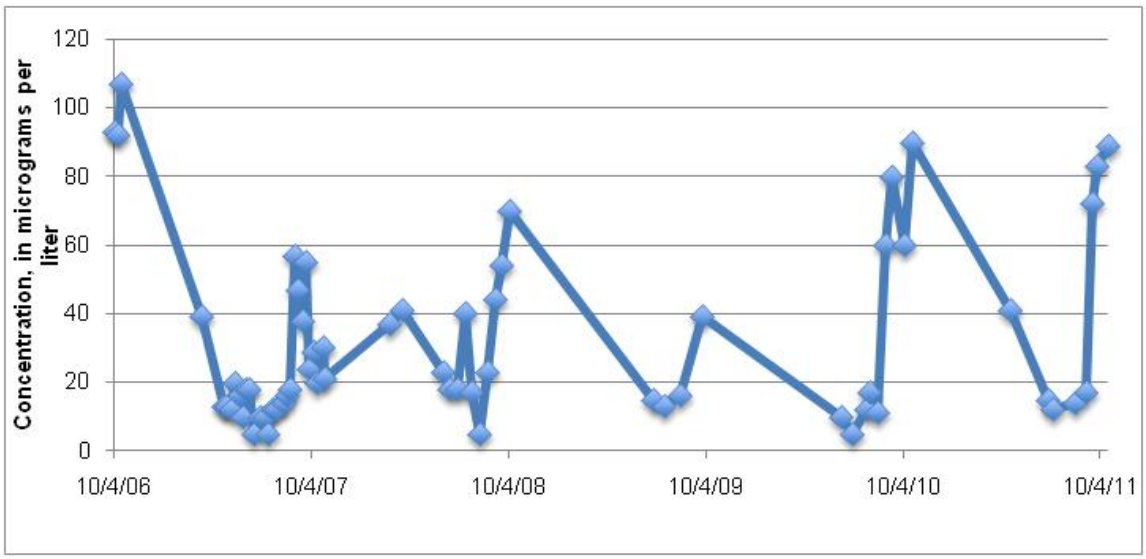


Figure 3-80. Concentrations for total phosphorus (TP), in micrograms per liter, at tributary station DEA101 for water years 2007–2011, lower Deadwood River.

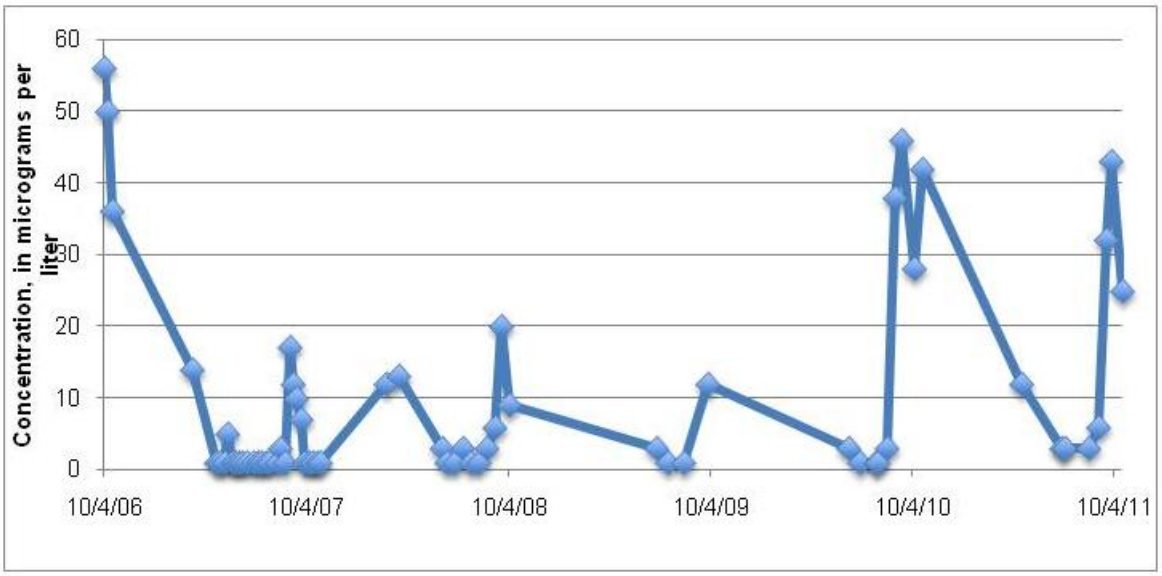


Figure 3-81. Concentrations for dissolved orthophosphate (DOP), in micrograms per liter, at tributary station DEA101 for water years 2007–2011, lower Deadwood River.

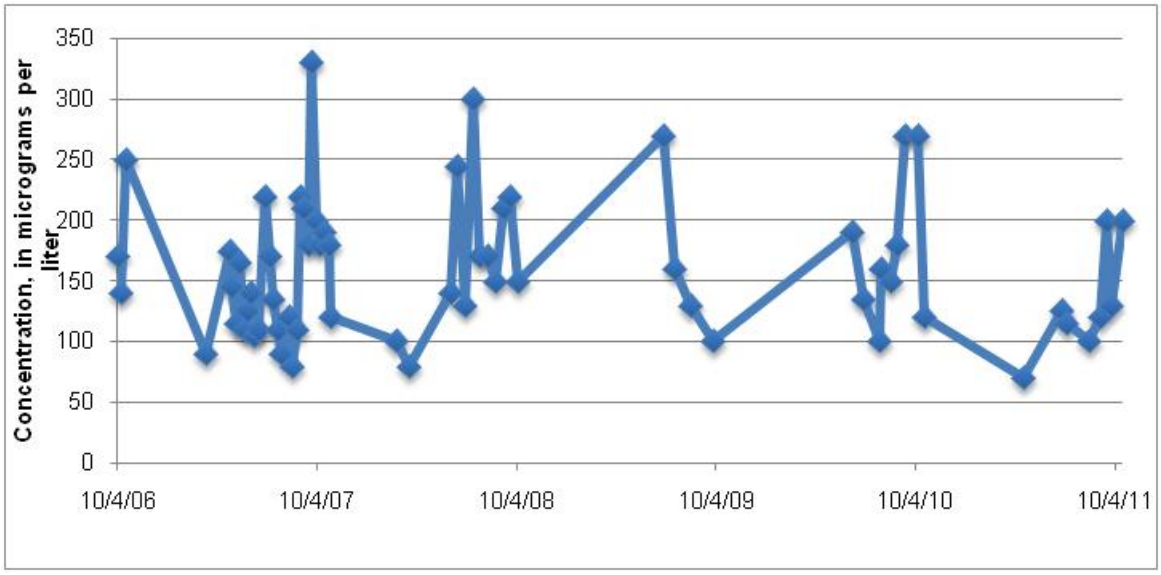


Figure 3-82. Concentrations for total organic nitrogen (TON), in micrograms per liter, at tributary station DEA101 for water years 2007–2011, lower Deadwood River.

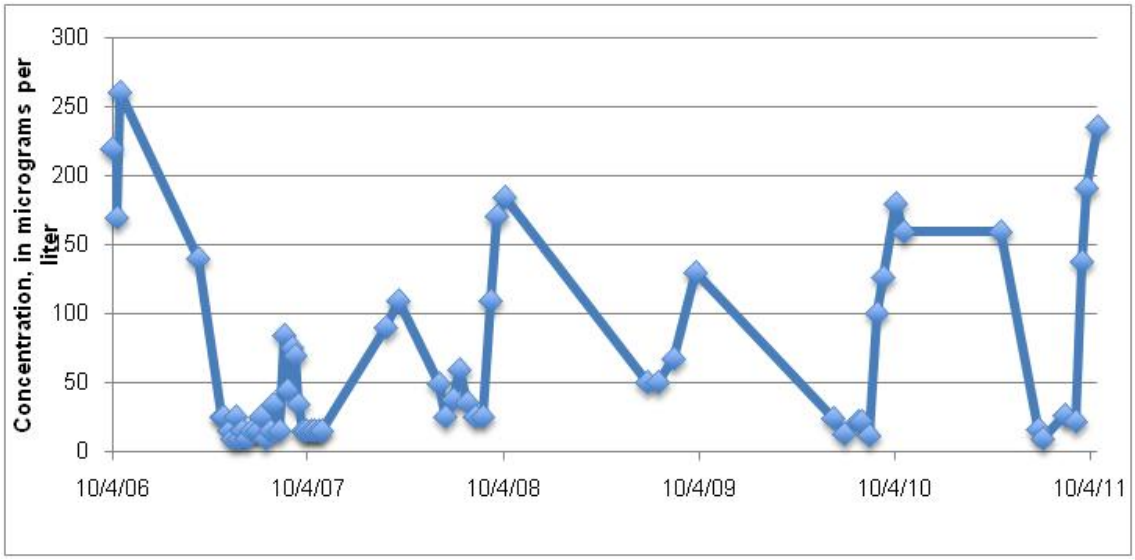


Figure 3-83. Concentrations for dissolved inorganic nitrogen (DIN), in micrograms per liter, at tributary station DEA101 for water years 2007–2011, lower Deadwood River.

Temporal Aspects of Nutrient Transport

The combined influences of riverine processes and watershed-based influxes of water and nutrients during nutrient transport from DEA101 to DEA108 are apparent in Figure 3-84 to Figure 3-87. The four nutrients tended to have higher concentrations at DEA101, especially in the autumn following reservoir drawdown. The lessening of nutrient concentrations at DEA108 was largely due to dilution by increased streamflow between DEA101 and DEA108. For the years 2009 and 2010, with complete streamflow data for both stations, streamflow at DEA108 was about 175% of that at DEA101. Only during snowmelt runoff were nutrient concentrations at DEA108 often higher than those at DEA101, with the exception of dissolved inorganic nitrogen. Those increases during snowmelt runoff indicate increased delivery of nutrients from the watershed as well as scour and transport within the lower Deadwood River.

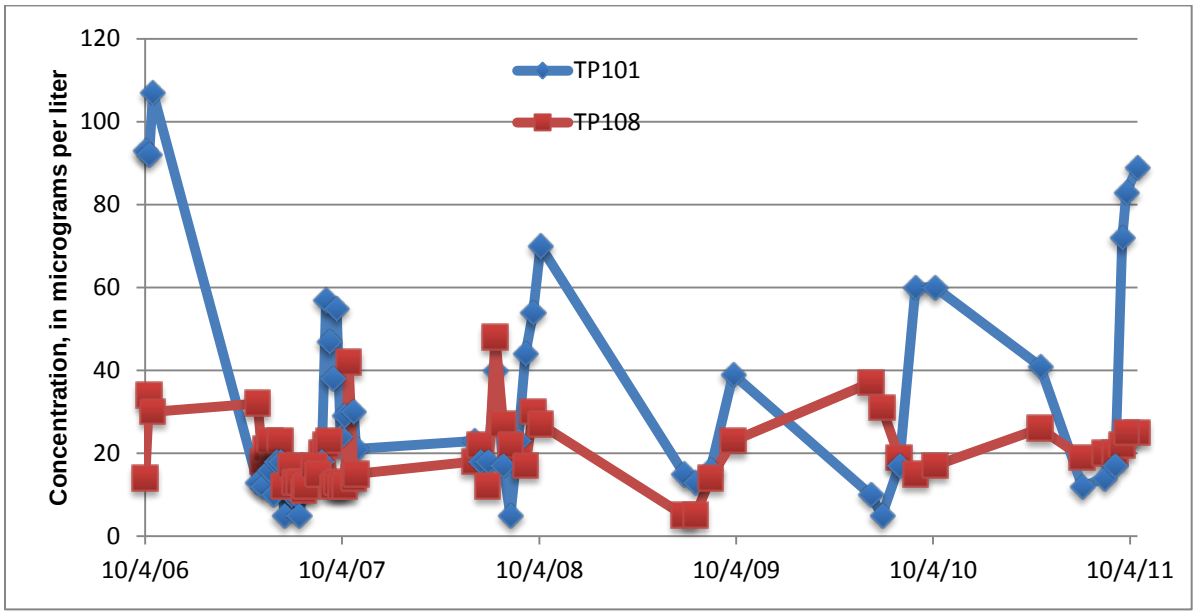


Figure 3-84. Concentrations for total phosphorus (TP), in micrograms per liter, at tributary stations DEA101 and DEA108 for water years 2007–2011, lower Deadwood River.

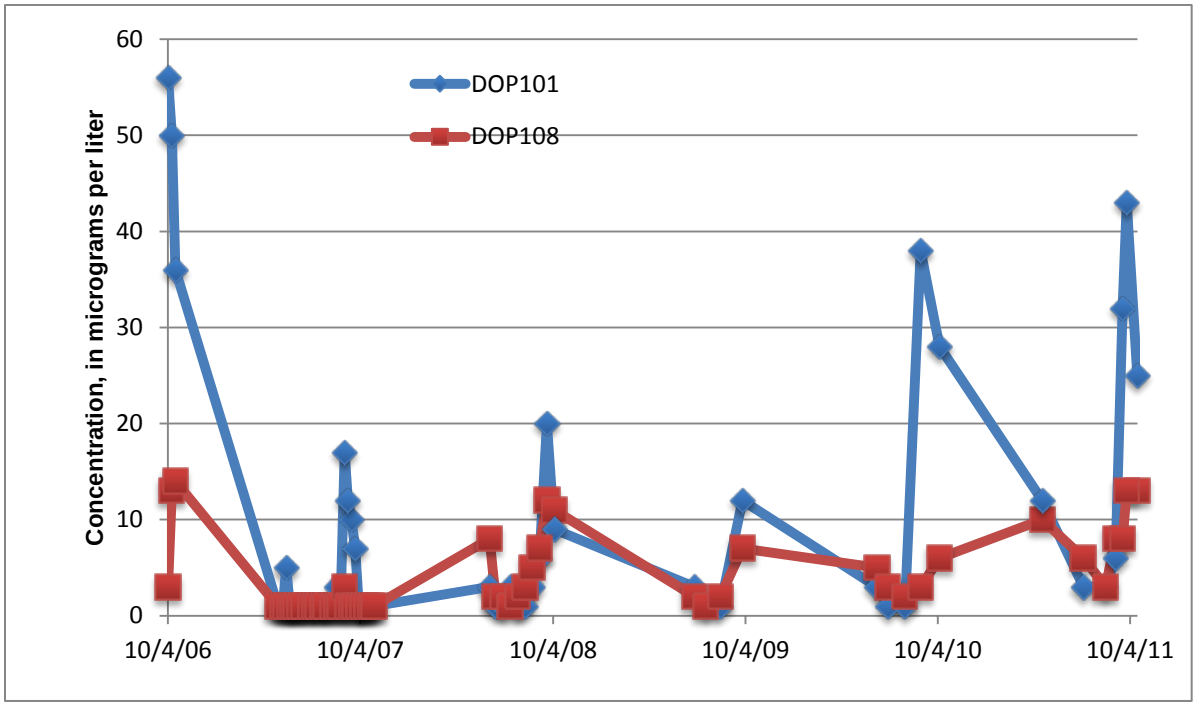


Figure 3-85. Concentrations for dissolved orthophosphate (DOP), in micrograms per liter, at tributary stations DEA101 and DEA108 for water years 2007–2011, lower Deadwood River.

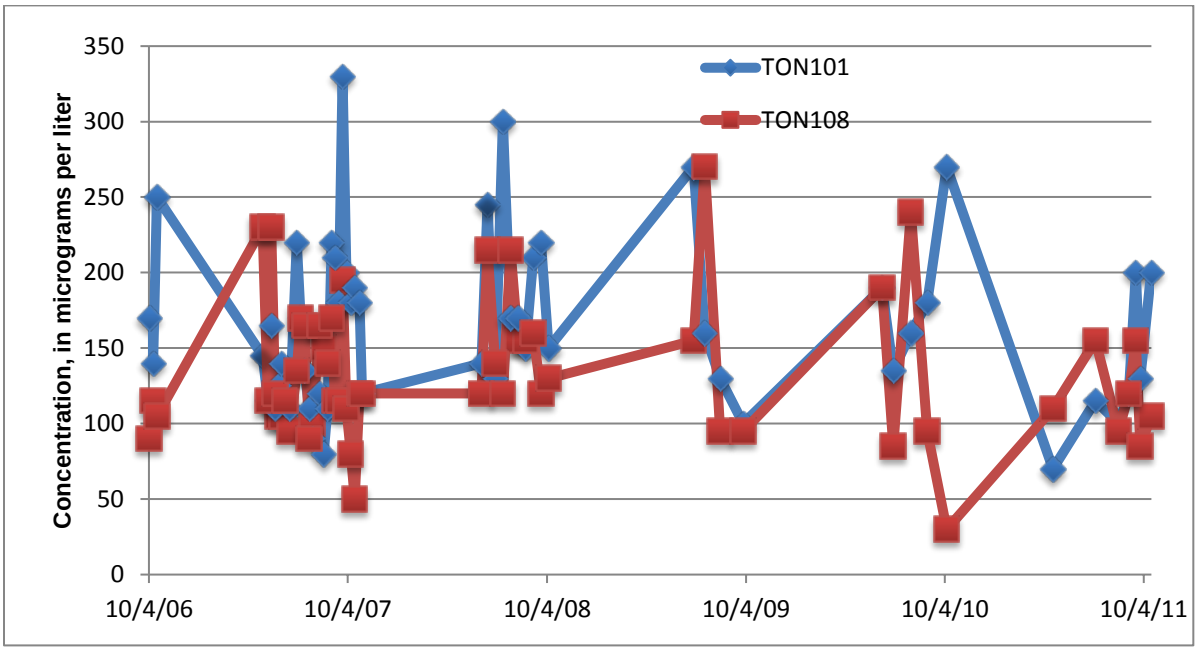


Figure 3-86. Concentrations for total organic nitrogen (TON), in micrograms per liter, at tributary stations DEA101 and DEA108 for water years 2007–2011, lower Deadwood River.

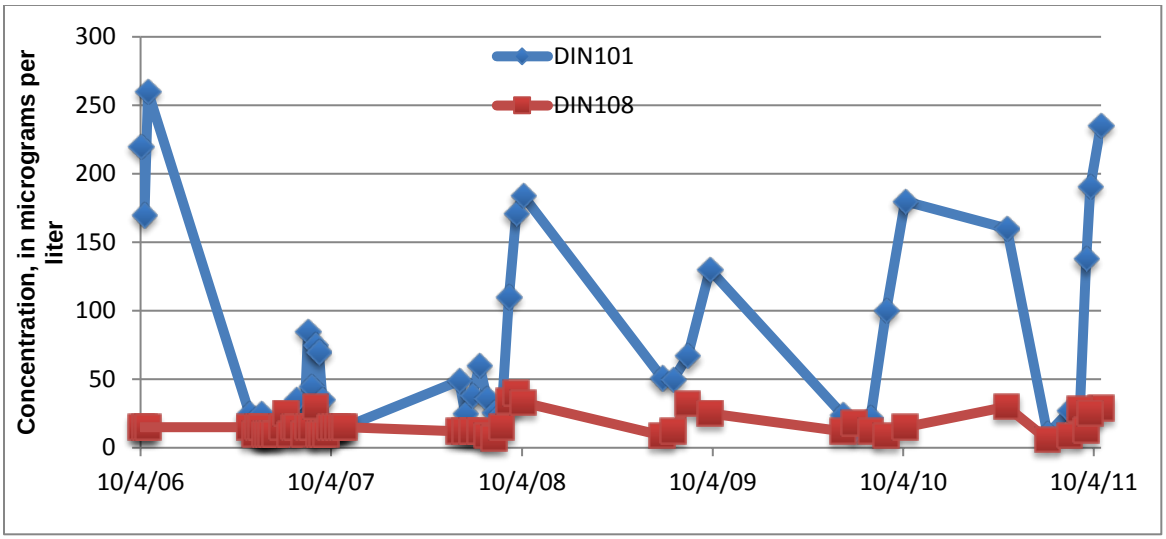


Figure 3-87. Concentrations for dissolved inorganic nitrogen (DIN), in micrograms per liter, at tributary stations DEA101 and DEA108 for water years 2007–2011, lower Deadwood River.

Nutrient Mass Balance, 2009 to 2010

The fate and transport of nutrient loads downstream of Deadwood Dam were evaluated with load computations for stations DEA101 and DEA108 (Table 3-20). During 2009 and 2010, loads of total phosphorus, dissolved orthophosphate, and total organic nitrogen increased

downstream, with increases of 1.7 to 2.7 times the loads that originated at DEA101. The increases in those loads were largely due to the near-doubling in streamflow from DEA101 to DEA108. In contrast, loads of dissolved inorganic nitrogen between the two stations decreased, rather substantially in 2009. A likely explanation for the decreases was assimilation of dissolved inorganic nitrogen by periphyton, with subsequent conversion into total organic nitrogen. A portion of the increased loads of total organic nitrogen at DEA108 were due to senescence, scouring, and transport of periphyton between the two stations.

Table 3-20. Comparisons of phosphorus and nitrogen loads, in kilograms, gained or lost between DEA101 (reservoir outlet) and DEA108 (confluence with South Fork Payette River) for water years 2009 and 2010, lower Deadwood River.

Nutrient, Station, Gain or Loss	Water Year 2009	Water Year 2010
Total phosphorus mass (kg)		
DEA101	3,650	2,660
DEA108	6,300	7,180
Gain (Loss)	2,650	4,520
Dissolved orthophosphate mass (kg)		
DEA101	750	620
DEA108	1,400	1,480
Gain (Loss)	650	860
Total organic nitrogen mass (kg)		
DEA101	29,000	26,100
DEA108	49,000	49,400
Gain (Loss)	20,000	23,300
Dissolved inorganic nitrogen mass (kg)		
DEA101	12,600	5,760
DEA108	4,760	4,990
Gain (Loss)	-7,840	-770

3.2.3 Chlorophyll *a* and Pheophytin a

Chlorophyll *a* and pheophytin a loads were to have been computed from water-column samples; however, more than half of their analyses were reported at less than analytical detection limits. For the 10 sampled dates with usable data at both DEA101 and DEA108, there was a slight decrease in median chlorophyll *a* concentrations downstream (1.55 to 1.15 ug/L) whereas median pheophytin a concentrations were both 1.7 ug/L (Table 3-21).

Table 3-21. Comparisons of chlorophyll *a* and phenphytin*a* concentrations, in micrograms per liter, measured at tributary stations DEA101 and DEA108 on selected dates over water years 2008-2011, lower Deadwood River.

Date	DEA101	DEA101	DEA108	DEA108
	Chlorophyll *a*	Pheophytin *a*	Chlorophyll *a*	Pheophytin *a*
6/3/08	2.4	1.9	2.1	0.6
6/30/08	1.4	1.5	1	0.9
7/14/08	1.9	1.8	1.5	1.9
8/25/08	3	1.3	2.1	2
9/8/08	1.5	1.8	0.6	2.3
9/22/08	1.6	2	1.2	2
10/6/08	1.6	2.8	1.2	3.2
6/29/09	1.2	0.4	0.8	0.4
9/28/09	1.2	0.4	0.8	1.2
10/17/11	1.5	2.2	1.1	1.5

The 2008 water year was the only one in which the variations in chlorophyll *a* and pheophytin *a* concentrations from DEA101 to DEA108 could be followed over several months (Figure 3-88). At DEA101, chlorophyll *a* concentrations exceeded or nearly equaled pheophytin *a* concentrations from June through August. The opposite was true during September and October when these increases in pheophytin *a* concentrations were attributable to hypolimnetic discharges from the reservoir. At DEA108, chlorophyll *a* concentrations were less than those measured at DEA101 by about 0.5 ug/L. Similar to DEA101, pheophytin *a* concentrations at DEA108 were at their highest in September and October. The downstream increase in pheophytin *a* concentrations was likely due to senescence, scouring and transport of periphyton.

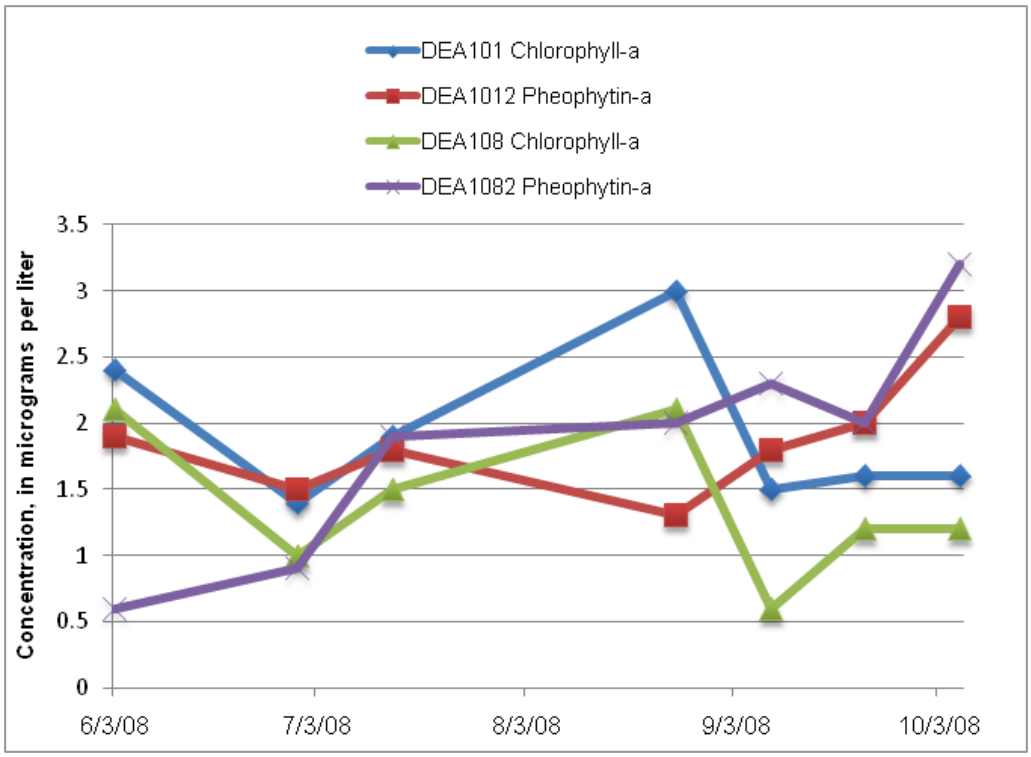


Figure 3-88 Variation of chlorophyll *a* and pheophytin *a* concentrations, in micrograms per liter, between DEA101 and DEA108 during June to early October 2008, lower Deadwood River.

3.2.4 Conclusions

Water-quality characteristics in the lower Deadwood River between DEA101 and DEA108 were generated in a similar manner via the interplay of numerous physical, chemical, and biological processes. Both riverine sampling stations also received watershed-based influxes of water and associated constituents; however, reservoir processes dramatically modified those influxes prior to discharging them into the lower Deadwood River at DEA101. Once in the lower Deadwood River, the nutrients and chlorophyll from the reservoir became important components of riverine productivity, which shifted from a phytoplankton-dominated basis to a periphyton-dominated one.

3.3 Influence of Reservoir Operations on Macroinvertebrate Production in the Deadwood River

3.3.1 Introduction

Water temperature in the regulated lower Deadwood River is colder in the summer, warmer in the winter, and displays less diurnal variability than unregulated streams nearby (see Section 3.1). Such alteration in temperature regime is common below bottom-release reservoirs (Lehmkuhl 1974; Munn and Brusven 1991). Alteration of temperature and other factors influence benthic macroinvertebrate communities; for example, abundance of mayflies, stoneflies, and caddisflies often decreases below dams, while abundance of chironomids commonly increases (Johnson and Harp 2005; Lehmkuhl 1974; Morley et al. 2008; Munn and Brusven 1991; Munn et al. 1996; Pardo et al. 1998; Stevens et al. 1997). Such effects on macroinvertebrate communities can affect higher levels in the aquatic foodweb that rely directly or indirectly on macroinvertebrates as a food source.

Bull Trout are rare in the lower Deadwood River, but occur in unregulated rivers nearby as well as in the upper Deadwood River. The *Biological Opinion for Bureau of Reclamation Operations and Maintenance in the Snake River Basin above Brownlee Reservo*ir describes factors that potentially limit Bull Trout in the lower Deadwood River (USFWS 2005). One factor identified is that low water temperature may limit macroinvertebrate populations, which serve as the prey base for Bull Trout and their forage fish. In past studies, abundance and diversity of macroinvertebrates and fish has been reported to be low in the lower Deadwood River, and researchers attributed these findings to altered temperature and flow regimes (Allen 1998; Salow 2004).

Direct measurement of Bull Trout growth in the Deadwood River is challenging because Bull Trout occur at very low densities and capturing fish is difficult because wading or boating is hazardous in many stretches of this whitewater river. Benthic invertebrates in low gradient riffles can be sampled more reliably. The present study was predicated on the assumption that if secondary production of benthic invertebrates is high enough to provide an adequate prey base for Bull Trout and their forage fish, then food is not likely to limit Bull Trout in the Deadwood River.

This study has three major objectives: 1) to report rates of secondary production in the lower Deadwood River and compare these to rates measured in unregulated streams nearby and to rates reported in the scientific literature; 2) to develop a temperature-dependent model of macroinvertebrate production for the lower Deadwood River, and 3) to use the macroinvertebrate production model to predict effects of alternative reservoir operations on

macroinvertebrate production. In addition to these major goals, we describe site characteristics using measurements of flow, temperature, water quality, physical habitat, periphyton abundance, and drift, and community-level attributes of the macroinvertebrates community.

3.3.2 Methods

Study Sites

A combined spatial comparison approach (Braatne et al. 2008) was used to evaluate conditions in the regulated portion of the Deadwood River. There were a total of ten study sites including four located in the regulated lower Deadwood River and six in unregulated reference rivers (two sites each on the upper Deadwood River, upper South Fork Payette River, and Clear Creek; Figure 3-89). Bull Trout occur in all sites, although density of Bull Trout in the lower Deadwood River appears to be much lower than in the other sites (Reclamation and USFS, unpublished data).

Cobble-dominate riffles are the stream habitat type that supports the highest densities of macroinvertebrates in rivers (Buffagni and Comin 2000; Moulton et al. 2002) and so this was the target habitat for sampling. High geomorphic and habitat variability (Chapter 4) and poor access to the river prohibited sampling in the middle reaches of the lower Deadwood River so sites were located in the top and bottom reaches of the lower Deadwood River. Reference sites in upper Deadwood River, Clear Creek, and South Fork Payette River were selected to provide physical habitat similar to that sampled in the lower Deadwood River (Table 3-22).

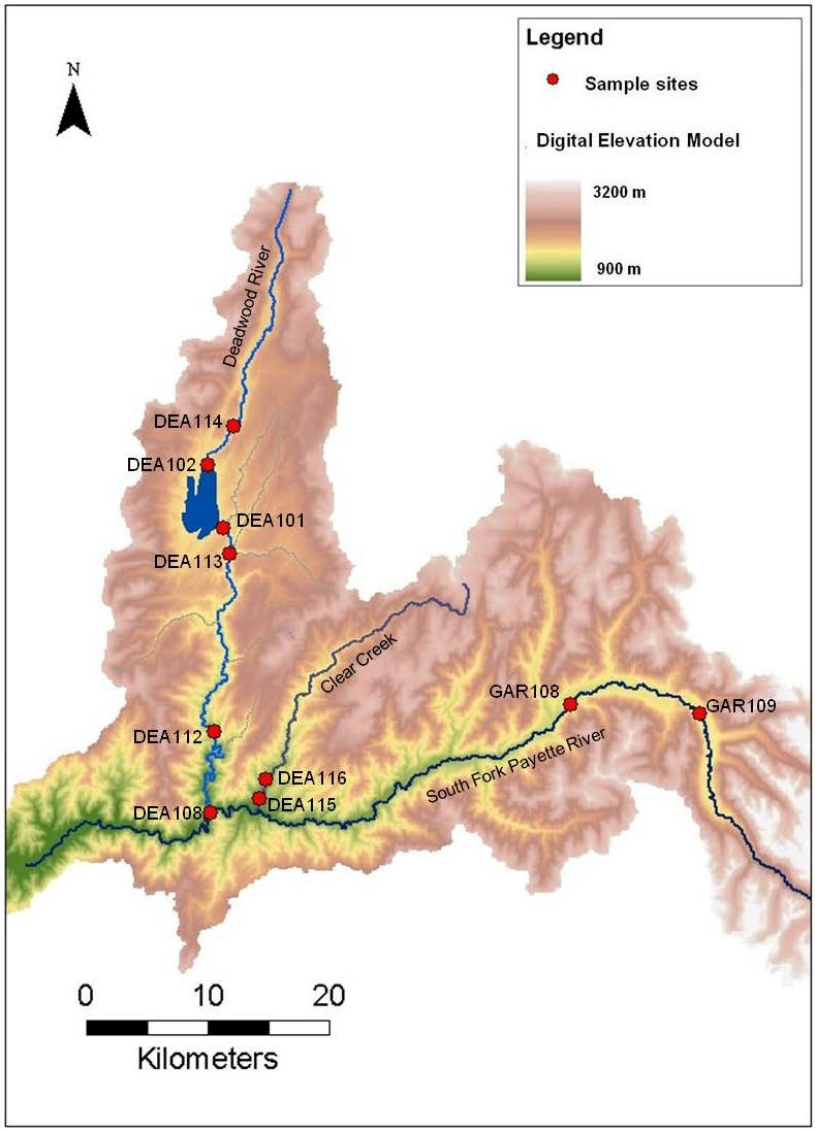


Figure 3-89. Map of the sample site locations on the upper and lower Deadwood River, South Fork Payette River and Clear Creek.

Table 3-22. Characteristics of sampling sites on lower Deadwood River, upper Deadwood River, South Fork Payette River, and Clear Creek.

River	Status	Stream Order	Length (km)	Slope (%)	Site Name	Drainage Area (HA)	Elevation (m)	Site Description
upper Deadwood R.	Unregulated	5	28[1]	1.8	DEA114	16,000	1642	4.8 rkm above reservoir
					DEA102	17,000	1629	1.2 rkm above reservoir
lower Deadwood R.	Regulated	5	38[2]	2.4	DEA101	28,000	1592	0.4 rkm below Deadwood Dam (above Wilson confluence)
					DEA113	40,000	1540	3.7 rkm below dam (below Whitehawk confluence)
					DEA112	50,000	1317	24.8 rkm below dam (below Julie Creek bridge).
					DEA108	61,000	1131	38.3 rkm below dam (above mouth)
Clear Creek	Unregulated	4	31	2.6	DEA115	14,000	1149	~1 km upstream from confluence with South Fork Payette River
					DEA116	13,000	1262	~3 km upstream from confluence with South Fork Payette River
SF Payette R.	Unregulated	6[3]	100	0.3	GAR108	61,000	1432	South Fork Payette River at mile marker 93 off of highway 21
					GAR109	28,000	1557	South Fork Payette River downstream from Grandjean campground

[1]Source to dam
[2]Dam to confluence
[3]Sample sites were located in the upper, 5th order reach

Field Sampling Protocol

Field sampling occurred from June through October 2010, and July through October 2011. Snow, ice, and high flows prohibited sampling during other seasons. Sites were sampled approximately monthly, which provides an ideal interval for measuring macroinvertebrate growth (McCutchan 2010). On each sampling date, three transects were selected randomly within an established 100-m-long sample site. Transects were not resampled during the 2-year study. Data were collected at spatial scales including river segment, sample site, transect within site, or point within transect. Water quality, periphyton, macroinvertebrate, and some physical habitat data were collected monthly; other habitat data were collected once during the study.

Discharge and Water Temperature

Average daily discharge was recorded at gaging stations for the lower Deadwood River below Deadwood Dam and the South Fork Payette River at Lowman. Daily discharge for the upper Deadwood River (DEA102) was obtained from a new stage-discharge relationship established by Matt Tiedemann (Tiedemann, unpublished data, 2011a). Clear Creek discharge was measured biweekly with a Marsh-McBirney flow meter by the USFS Lowman Ranger Station (Grover-Weir 2010). Clear Creek discharge could not be measured in early June, 2010, due to high flow so discharge was estimated using a polynomial regression fit to data from 2007–2010 (Table 3-23).

Table 3-23. Sources of discharge data.

Location	Period of Data	Data Source
upper Deadwood R.	10/1/09 – 10/11/11	USBR hydromet DRII. (Data provided by M. Tiedemann, U. of Idaho)[2,3]
lower Deadwood R.	10/1/09 – 10/2/11	USBR/USGS hydromet DEDI station #13236500.
	10/1/09 – 12/1/11	USBR hydromet DRMI (data provided M, Tiedemann, U. of Idaho, on 1/4/12)[2, 3]
Clear Creek	04/2010 – 09/2010, 02/2011 – 08/2011	Data provided by K. Grover-Wier, Lowman Station USFS[4]
SF Payette	10/1/09 – 10/2/11	USBR/USGS PRLI station #13235000, South Fork Payette River near Lowman.

[1] Raw data (< 1-hour interval records) were converted to hourly data by selecting the value closest to 00:00 (min:sec) for each hour.

[2] (a) The instrument is prone to icing in winter so winter data should be considered with this limitation, (b) Due to instrumentation difficulties there are data gaps which cannot be filled (c) Flow over 1150 cfs is an extrapolation outside of the rating and should be considered unverified (Tiedemann 2011b).

[3] Flow above 2000 cfs has higher associated error (Tiedemann 2011b).

[5] Data were collected approximately every 2 weeks using a March-McBirney flow meter (Grover-Wier 2010).

Water temperature was recorded hourly using Tidbit temperature loggers or Reclamation Hydromet stations (Table 3-24). The upper Clear Creek (DEA116) logger malfunctioned from July 7 – September 20, 2010, and so lower Clear Creek (DEA115) data were used to represent both Clear Creek sites because available data between the two sites were nearly identical (Figure 3-90).

Table 3-24. Sources and locations for water temperature data.

Location	Site Name	Latitude		Longitude		Data Source
upper Deadwood	DEA114	44	22.017	115	37.755	RMRS Tidbit
	DEA102	44	20.937	115	39.060	USBR Tidbit
lower Deadwood	DEA101	44	17.312	115	38.311	USBR hydromet DEDI[1]
	DEA113	44	16.335	115	38.112	USBR Tidbit[2]
	DEA112	44	8.447	115	39.229	USBR Tidbit
	DEA108	44	4.887	115	39.603	USBR hydromet DRMI[3]
Clear Creek	DEA115	44	5.432	115	36.557	RMRS Tidbit
	DEA116	44	6.295	115	36.083	RMRS Tidbit
SF Payette	GAR108	44	9.389	115	17.232	RMRS Tidbit
	GAR109	44	8.910	115	9.314	RMRS Tidbit

[1] Data were deleted for the period 9/13/2010-10/7/2010 when reservoir discharge was < 5 cfs and considered to be in error due to the sensor being exposed to air. Values of 0 from 22:45, 4/15/2011 through 02:30, 4/16/2011 were deleted.
[2] Deleted values of -5.9 at 06:00, 07:00, and 08:00, 1/23/2011
[3] Deleted values of 0 from 09:00 through 11:15, 6/12/2010, and a value of 64 at 11:30, 6/12/2010.

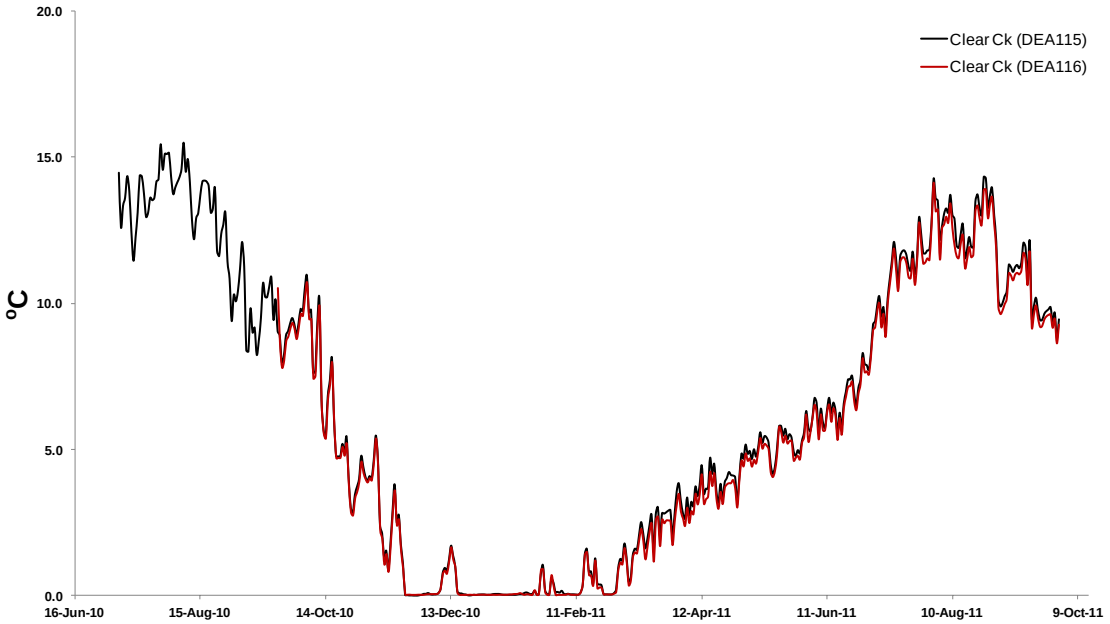


Figure 3-90. Water temperatures of the two Clear Creek sites sampled. DEA116 is located ~2 km upstream of DEA115.

Water Quality and Periphyton

At the upstream boundary of each sample site, temperature, DO, pH, and conductivity were measured using an YSI Professional Plus meter. Water samples were collected for laboratory analysis of total Kjeldhal nitrogen, nitrate + nitrite nitrogen, ammonia, total phosphorus, dissolved phosphorus (orthophosphate), silicon dioxide, turbidity, total organic carbon, and dissolved organic carbon at the Reclamation's Pacific Northwest Regional Water Quality Laboratory. At each transect, depending on the amount of periphyton present, three or four cobble-sized rocks were collected and periphyton was scraped within a 58.1 cm2 quadrat. All samples for a site were pooled and analyzed within 48 hours for chlorophyll *a*, pheophytin a, and ash-free dry mass (AFDM).

Physical Habitat

On each sampling date, wetted width for each transect was measured using a laser rangefinder. Substrate composition (Table 3-25), embeddedness (Table 3-26), and looseness (Table 3-27) were estimated visually within 10 m of each transect and at each Hess sample location (Cummins 1962; Sylte and Fischenich 2002). Between September to October 2010, bankfull width, substrate composition (Wolman 1954) and canopy cover (measured with a spherical densiometer at 25, 50, and 75 m along the sample site length) were measured once at each site

Table 3-25. Substrate size classes

Substrate Class	Size (mm)	Guide for Visual Approximation
Sand & Silt	< 2	Gritty between fingers.
Gravel	2 – 64	Ladybug to tennis ball.
Cobble	65 - 250	Tennis ball to basketball.
Boulder	251 - 4000	Basketball to car.
Bedrock	> 4000	Greater than a car.

Table 3-26. Embeddedness ratings modified from (Sylte and Fischenich 2002).

Rating	Description
5	Less than 5% of surface covered by fine sediment.
4	5- 25% of surface covered by fine sediment
3	25 – 50% of surface covered by fine sediment
2	50 – 75% of surface covered by fine sediment
1	Greater than 75% of surface covered by fine sediment.

Table 3-27. Looseness ratings of river substrate.

Rating	Description
Loose	Greater than 50% of cobble in sample can be easily lifted from substrate on which it sits.
Tight	Less than 50% of cobble in sample can be easily lifted from substrate on which it sits.
Both	Sample is a mixture of "Tight" and "Loose" cobble.

Drift

Drift samples were taken as close to the thalweg as possible, but access was sometimes limited due to swiftwater conditions. Three 10-minute drift samples were collected at each site during early summer (June 23 through July 8), late summer (August 14 through September 2), and fall (October 4 through October 17) in 2010. Samples were collected in a 363 µm, 12 x 18 in rectangular frame, floating drift net (Rickly Hydrological Company). Mean flow velocity for each drift sample was calculated from six velocity measurements taken at the center of the drift net during each 10-minute sample. Drift material was preserved in 70% ethanol.

At the laboratory, samples were sieved into fine particulate organic matter (FPOM, 0.25 – 1 mm) and coarse particulate organic matter (CPOM, > 1 mm) size fractions. Macroinvertebrates and zooplankton were sorted from both fractions and identified. Zooplankton, aquatic invertebrates, FPOM, and CPOM were dried at 600C for 24 hours and ashed at 5500C for 4 hours to determine dry mass and AFDM. Mean flow measurements were used to calculate drift rate for FPOM, CPOM, macroinvertebrates, and zooplankton.

Benthic Macroinvertebrates

Six benthic macroinvertebrate samples were collected at each site using a Hess sampler. At each transect, samples were taken at 0.3 and 0.5 m depth and composited, generating three samples for each site on each date. Samples were preserved in 70% ethanol and sent to EcoAnalysts Inc. (Moscow, Idaho) for identification. Each sample was subsampled randomly using a Caton box, counting a minimum of three Caton squares and 300 individuals. Macroinvertebrates were identified typically to species or genus, and sometimes to higher levels of taxonomic resolution due to complexity or condition of identifying characteristics. Functional feeding group was assigned to each taxon (Table 3-28).

Table 3-28. Functional feeding groups assigned to identified macroinvertebrate taxa (Merritt et al. 2008).

Functional Group	Sub-Group	Dominant Food	Description
Collectors	Filterers Gatherers	Fine particulate organic matter (FPOM)	Use nets or body parts to filter FPOM Move around to gather FPOM
Shredders	Shredders	Coarse particulate organic matter (CPOM)	Chew up living or dead plant tissue
Macrophyte Piercers	Piercers-Herbivores	Plant cells	Living vascular hydrophyte cell and tissue fluids or filamentous algal cell fluids
Scrapers	Scrapers Scrapers/Predators	Attached algae (periphyton).	Scrape periphyton from rocks and other surfaces.
Predators	Predators/Gatherers Predators	Living animal tissue Living animal tissue	Attack prey and ingest whole animals or parts.

Body measurements (head capsule width for Tipulidae, body width for Oligochaeta, or body length for all other taxa) were taken for the first ten individuals of each taxon encountered; care was used to avoid size bias in selection of individuals for measurement. For each individual with a body measurement, dry mass was estimated using relationships developed from large numbers of invertebrates collected in montane streams in Colorado (McCutchan, unpublished data; Equation 1):

$$ln\ (mass) = ln\ (a) + b\ (length\ or\ width) \qquad (1)$$

Population and Community Analyses

Population density (#/m2 and g/m2) was calculated for each taxon on each sample date using taxon-specific length-mass relationships (Equation 1; Table 3-29). Taxonomic Richness (S), Shannon Diversity Index (H'), and Simpson Index (λ) were calculated (Table 3-30) and density (#/m2) by functional feeding group was reported.

Table 3-29. Benthic macroinvertebrate orders found in river samples. All orders were included in analysis, unless noted. "Excluded" taxa were typically non-insects that were low in abundance, and were not included in biomass or production analyses.

Category	Order	Common Name	# Sites Found	Mean % abundance
Included	Coleoptera	Aquatic beetles	10	6
	Diptera	Flies	10	5
	Diptera-Chironomidae	Flies	10	30
	Ephemeroptera	Mayflies	10	30
	Oligochaeta (class)	Worms	10	11
	Plecoptera	Stoneflies	10	6
	Trichoptera	Caddisflies	10	6
Excluded	Amphipods	Scuds	2	<0.1
	Arachnida (class)	Spiders	8	0.1
	Arhynchobdellida	Proboscisless leeches	1	<0.1
	Hydroidea	Hydras	2	<0.1
	Nematoda (phylum)	Nematodes	10	1.2
	Nemertea (phylum)	Ribbon or proboscis worms	1	<0.1
	Odonata	Dragonflies & damselflies	1	<0.1
	Ostracoda (class)	Seed shrimp	8	0.2
	Rhynchobdellida	Jawless leeches	1	<0.1
	Sarcoptiformes	Mites and ticks	5	1.2
	Tricladida	Flatworms, Class Turbellaria	9	0.1
	Trombidiformes	Water mites, Class Arachnida	10	3.1
	Turbellaria (class)	Flatworms	10	0.4
	Veneroida	Bivalve mollusks	8	0.1

Table 3-30. Benthic macroinvertebrate diversity indices

Index Name	Equation	Description
Species Richness (S)	S = total # species	Count of the number of unique taxa in a given sample. Dependent on sample size.
Shannon Diversity Index (H')	$H' = -\sum_i p_i \ln(p_i)$	Where p_i is the proportion of total count arising from the *i*th species. Takes into account both the number of species present and the dominance or evenness of species in relation to one another.
Simpson Index (λ)	$\lambda = \sum p_i^2$	Dominance index. Probability that two individuals are the same species ($\lambda \leq 1$).

Population and community-level analyses were done using the PRIMER statistical package (PRIMER v6; Clarke and Gorely 2006). Prior to analysis, data were square-root transformed to reduce effects of right-skewedness and matrix wide non-detections and to reduce the influence of highly abundant taxa. A Bray-Curtis similarity matrix was constructed to examine differences in macroinvertebrate abundance and biomass between samples (Clarke and Warwick 2001).

Differences in macroinvertebrate community composition were examined using nonmetric multidimensional scaling, an iterative optimization method that attempts to find the configuration of points that minimizes stress between similarity rankings and corresponding distance rankings in a plot (MDS; Clarke and Warwick 2001; McCune and Grace 2002). Kruskal's stress was reported; a value less than 0.1 indicates good representation without a large chance of misinterpretation, while a value less than 0.2 gives a potentially useful 2D ordination but should not be relied on alone for interpretation of results.

Differences among sample sites were tested using analysis of similarities (ANOSIM), a non-parametric analog to analysis of variance that tests for differences in community composition by comparing rank similarities in a resemblance matrix. One-way ANOSIM and pairwise comparisons were used to test the null hypothesis that there was no difference in abundance of benthic macroinvertebrates between sample sites. For each pairwise comparison an R value was calculated (close to zero = no difference, close to 1 = large difference) and a resemblance matrix was plotted using MDS to display relationships between sites.

Similarity percentage (SIMPER) was used to examine which macroinvertebrate orders drove differences in community composition between sites. SIMPER describes the contribution of an individual taxon to similarities and differences within and between groups by decomposing average Bray-Curtis dissimilarities between all pairs of samples into a percent contribution for each species. Sites were grouped according to differences determined a priori in the ANOSIM pair-wise analysis and discriminating taxa were determined as those that contributed most to differences between groups.

Macroinvertebrate Production

For each site, macroinvertebrate production was estimated over intervals between sampling dates. For taxa that could be identified to species and followed as a cohort through time, the instantaneous exponential form of the increment-summation method was used to calculate interval production (Gillespie and Benke 1979; McCutchan and Lewis 2002):

$$P_{ism} = \frac{(g)}{(g-m)} * (B_t - B_{t-1}) \qquad (2)$$

where *g* is the average growth for an individual over the interval, *m* is mortality, *B* is biomass, and *t* is the number of days in the interval between sampling dates, defined in Equations 3-5:

$$g = \frac{ln(mean\ Wt_t) - \ln(mean\ Wt_{t-1})}{t} \quad (3)$$

$$m = \frac{ln(density_t) - \ln(density_{t-1})}{t} \quad (4)$$

$$B = mean\ individual\ mass * density \quad (5)$$

For taxa that could not be identified to species or followed over time as distinct cohorts (e.g., Chironomidae), production was estimated using the instantaneous growth rate method (Gillepsie and Benke 1979; McCutchan and Lewis 2002; Equation 5).

$$P_{igr} = g * \bar{B} * t \quad (6)$$

where *g* is the growth rate calculated for each taxon (see below), $\bar{B}$ is the mean biomass for the taxon over the interval, and *t* is the number of days in the interval between sampling dates.

Growth rates of non-cohort taxa were estimated with a multiple regression equation developed from growth rates of species from all sites in this study that could be followed as cohorts (McCutchan and Lewis 2002; Equation 7):

$$ln(g) = -4.86 \pm 0.23 + 0.155 \pm 0.019\,\overline{T} - 0.53 \pm 036\ ln(W) \quad R^2 = 0.35 \quad (7)$$

where g is the instantaneous rate of growth, $\overline{T}$ is mean water temperature (ºC) over the interval, and W is mean individual mass (mg) at the start of an interval. The relationship between g and T was significant ($p < 0.001$) but the relationship between g and $ln(W)$ was not significant ($p = 0.147$; Figure 3-91). Significant differences in growth rate were tested among orders and families.

Production for each taxon (excluding taxa noted in Table 3-29) equaled Pism + Pigr for each interval between sampling dates. Total macroinvertebrate community production for each sampling interval equaled the sum of production for all taxa. Using these estimates, community productivity per date (mg/m2/d) and annual production (g/m2/yr) were calculated for each site.

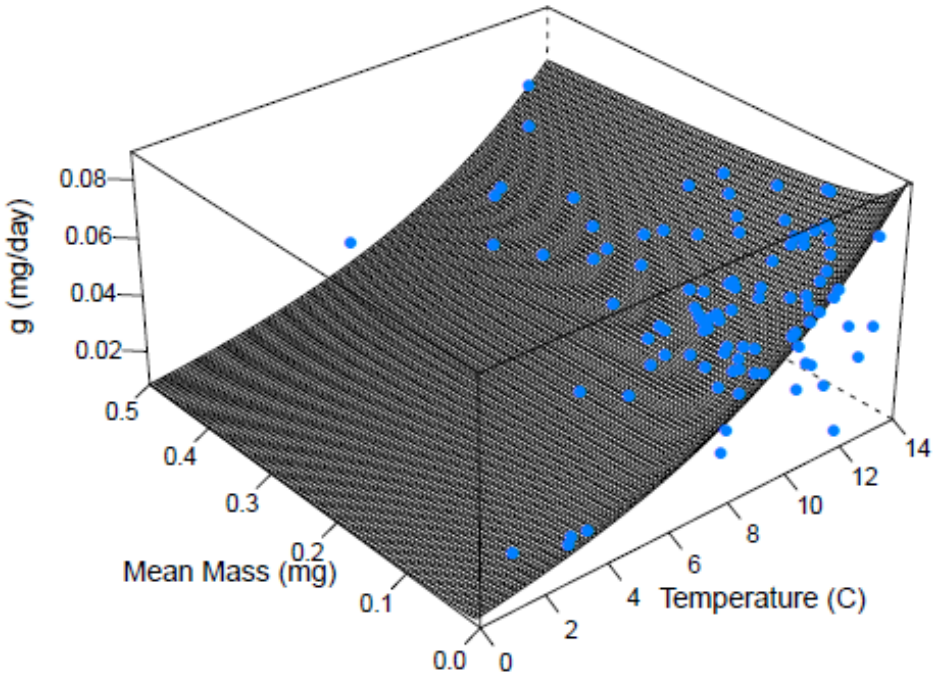


Figure 3-91. Wireframe representation of the relationship between instantaneous growth, mean interval temperature, and mean mass for benthic macroinvertebrates species that could be followed as cohorts. Each point represents a species measured for one interval at any of the ten study sites.

Macroinvertebrate Production Simulations for Alternative Scenarios of Reservoir Operations

The temperature-dependent growth model (Equation 7), developed using data from all study sites, was used to estimate macroinvertebrate production at the four regulated lower Deadwood River sites, for 24 scenarios of reservoir operations (Chapter 1). Mean daily temperature at each site was simulated for each operational scenario using the ELCOM-CAEDYM reservoir model (Chapter 2) and MIKE-11 river model (Chapter 3). Scenarios varied by hydrologic conditions, ramping rates, and winter release schedules. Hydrologic conditions varied to represent dry (2001), average (2003), and wet (1997) water years. Ramping rates in simulations included "fast" or "slow" up- and down-ramping rates. Winter release schedules included historical (historical reservoir operations, which generally were near 50 cfs), unregulated (natural tributary inflows with dam effect removed), 50 cfs, 2 cfs, or 0 cfs (Table 3-31).

Table 3-31. Reservoir operations scenarios (scenario numbers in parentheses). Mean daily temperature at each site was predicted for 24 scenarios of reservoir operations, using the ELCOM/CAEDYM reservoir model and MIKE-11 river model. Simulated temperature for each scenario was used to drive a macroinvertebrate growth model and simulate macroinvertebrate production for each regulated site in the lower Deadwood River.

Operations	Water Year and Ramping Rate		
Winter Release	**Dry**	**Average**	**Wet**
Historical	Historical (1)	Historical (9)	Historical (17)
50 cfs	Fast (2), Slow (3)	Fast (10), Slow (11)	Fast (18), Slow (19)
2 cfs	Fast (4), Slow (5)	Fast (12), Slow (13)	Fast (20), Slow (21)
0 cfs	Fast (6), Slow (7)	Fast (14), Slow (15)	Fast (22), Slow (23)
Unregulated	Unregulated (8)	Unregulated (16)	Unregulated (24)

ELCOM/CAEDYM and MIKE 11 simulations were used to predict hourly water temperature at each regulated river site from November 1 through December 31 of the following year. For simulation of macroinvertebrate production, water temperature data for the latter January 1 – December 31 were used to parameterize mean interval temperature in Equation 7. To simulate macroinvertebrate production for each scenario, the mean modeled water temperature ($\bar{T}$) for each interval between sampling dates was used with measured mean individual mass (W) in Equation 7 to estimate growth rates for both cohort and non-cohort taxa. Interval production for each taxon was estimated using Equation 6. Total macroinvertebrate community production for each sampling interval, community productivity per date (mg/m2/d), and annual production (g/m2/yr) were calculated as described above.

3.3.3 Results and Discussion

Water Quality and Aquatic Habitat Characteristics

In recent years, Deadwood Reservoir has been operated to release water at a rate of 50 cfs during periods of post-irrigation release, spill if needed during early summer (e.g., 2010), and then maintain high flows for delivery of irrigation water through summer until Labor Day (Figure 3-92 and Figure 3-93). Due to tributary inputs below Deadwood Dam, flows in the lower Deadwood River near the confluence with the South Fork Payette River resemble a more natural hydrograph. During this study, annual peak flows occurred later and high flows persisted longer in 2011 than in 2010 at all sites, due to heavy snowpack. In 2010, reservoir releases were reduced to ~ 0 cfs for bridge abutment repairs below the dam from August 23 through October 8, and seepage was less than 5 cfs.

Water temperature in the lower Deadwood River was colder in the summer and warmer in the winter than in the unregulated rivers within the basin (Figure 3-93and Figure 3-94). At unregulated sites, annual maximum water temperature was 12 to 15^0C in 2010 and 2011, and the maximum temperature occurred in August. Just below the Deadwood Reservoir (DEA101), annual maximum water temperature was 11 to 12^0C and occurred late in August in 2010 and in October in 2011. Elevated temperatures persisted in the lower Deadwood River later in the fall, compared to unregulated rivers. During winter, water temperature at DEA101 remained above 3^0C while unregulated rivers were close to 0^0C. The influence of river regulation diminished with distance from the dam due to tributary inflows (Figure 3-94). DEA113, located 3.7 km downstream of the dam, showed a strong dam influence but by 24.8 km downstream the dam influence was minimal and the shape of the thermograph resembled that of unregulated sites nearby.

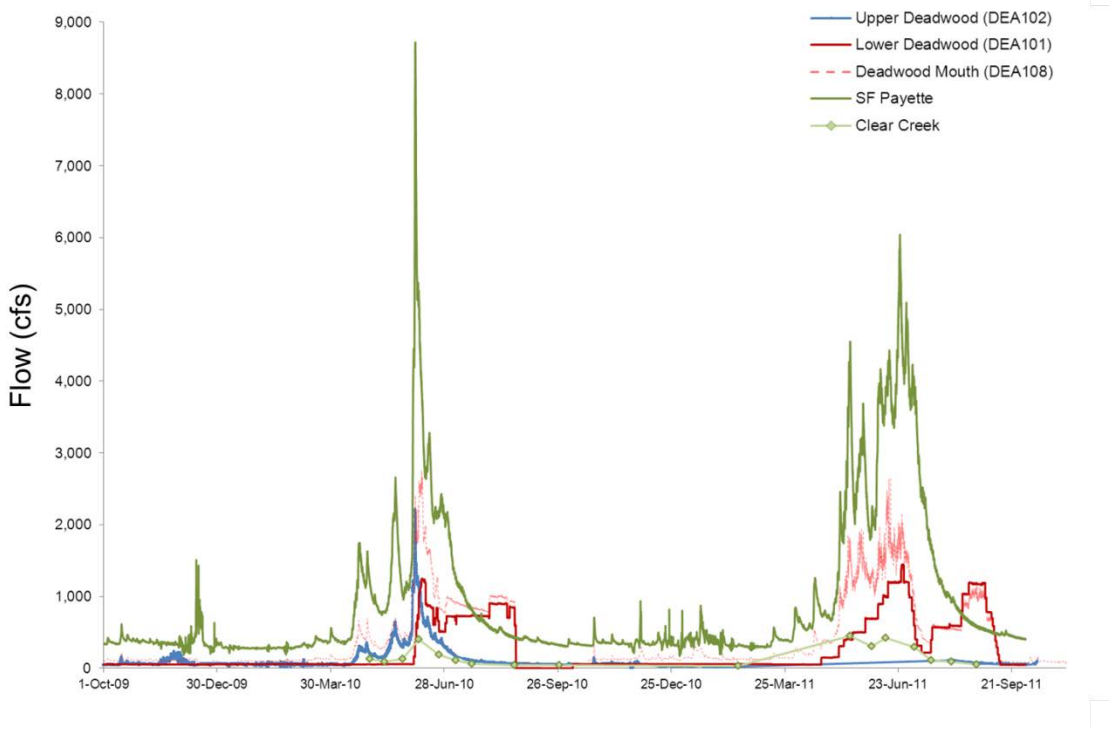


Figure 3-92. Discharge at regulated (lower Deadwood River, DEA101 and DEA108) and unregulated (upper Deadwood River, South Fork Payette River, and Clear Creek) sites.

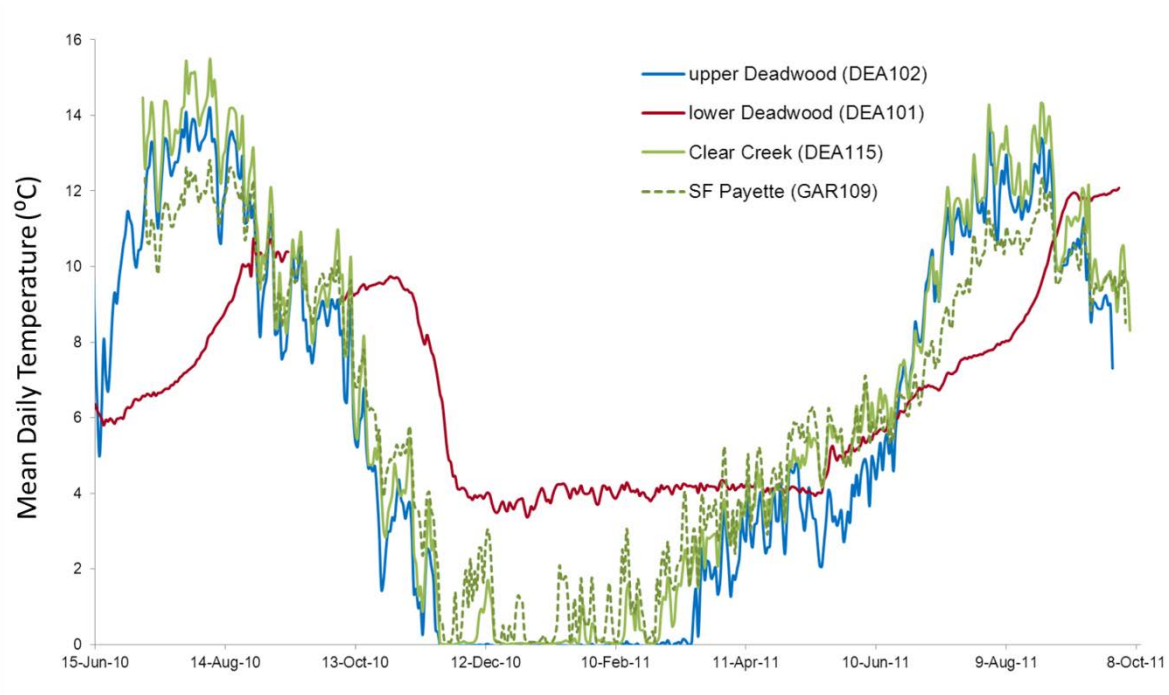


Figure 3-93. Mean daily water temperature at regulated (lower Deadwood River) and unregulated (upper Deadwood River, Clear Creek, and South Fork Payette River) sites.

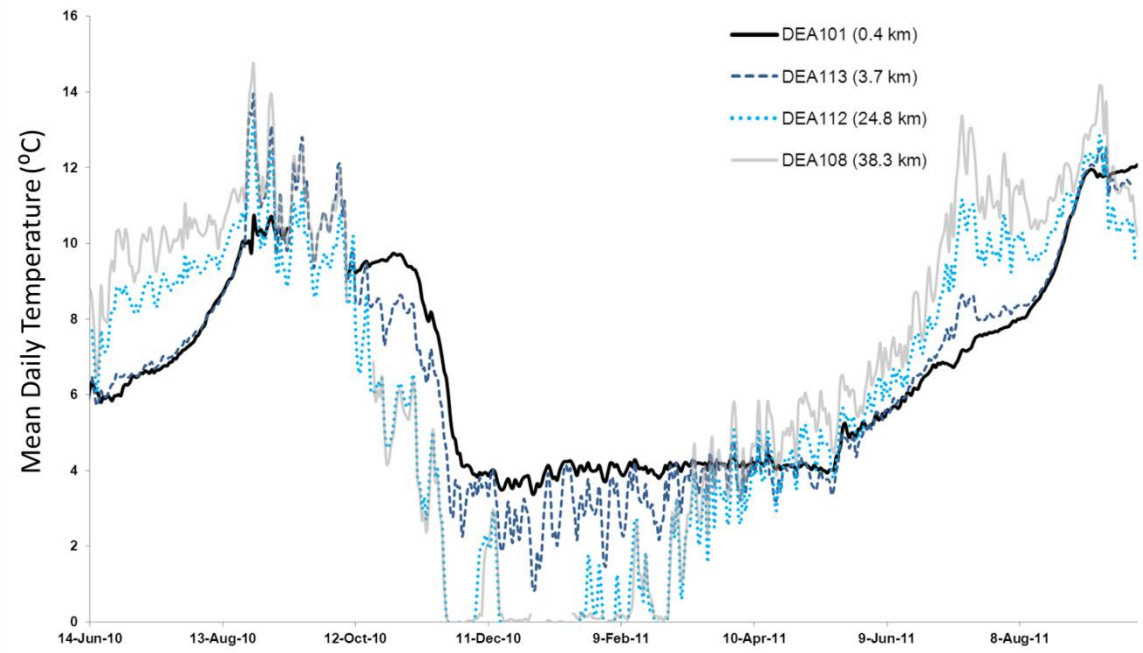


Figure 3-94. Mean daily water temperature at sample sites in the regulated lower Deadwood River. Distance from reservoir outflow in river kilometers is noted.

Water quality was generally similar in regulated and unregulated sites except in the regulated lower Deadwood River (DEA101) during fall, when discharge was low and temperature was high (Figure 3-95 through Figure 3-106). Total Kjeldahl nitrogen (TKN) and total phosphorous (TP) are integrative measures that include both inorganic (nitrate, nitrite, ammonia, orthophosphate) and organic forms of these nutrients. TKN was similar at regulated (0.04 – 0.31 mg/L) and unregulated (0, i.e., below detection limits – 0.28 mg/L) sites. These values are close to those reported as typical for western forested mountain rivers (0.12 – 0.20 mg/L; Smith et al. 2003; Figure 3-95). TP was similar at regulated (0 – 0.09 mg/L) and unregulated (0 – 0.04 mg/L) sites for most sample dates (Figure 3-98). During the fall low flow period, TP tended to increase at regulated sites; however, increased TP during the fall also was observed in Clear Creek in 2011. Except for the fall low flow period, TP was within the range reported as typical (0.015 – 0.022 mg/L) for western forested mountain rivers (Smith et al. 2003). Silica is used by diatoms and can influence algal production (Wetzel 1983). Values for silicon dioxide generally met or exceeded the average value of 7.2 mg/L reported for North American rivers (Figure 3-100) (Allan 1995). Total organic carbon (TOC; range 0.5-3.7 mg/L; Figure 3-101) and dissolved organic carbon (DOC; range 0.4 – 3.3 mg/L; Figure 3-102) were low; average values reported for TOC are 2-10 mg/L for rivers and 1-4 mg /L for streams in the U.S. (Allan 1995). Turbidity (typically < 1 NTU; Figure 3-103) was very low. Conductivity (22 – 55 µs/cm; Figure 3-104) fell within the 6 to 100 uS/cm range that is reported as typical for undisturbed rivers in western forests (Mulvey and Borisenko 2008). DO was 7.4 – 11.8 mg/L at unregulated sites and 8.4 – 13.5 mg/L at

regulated sites (Figure 3-105), and pH also was similar at unregulated and regulated sites (range 7.6 – 8.9; Figure 3-106). In sum, water quality parameters were similar between unregulated and regulated sites, with two general exceptions: 1) DOC and TOC (and rarely, TKN) tended to be elevated at regulated sites, and 2) N and P were elevated below Deadwood Reservoir during fall low flow periods.

Physical habitat was similar among all sample sites. As intended in the study design, cobble was the dominant substrate (Figure 3-107 to Figure 3-108). Sites just below Deadwood Dam tended to have more (5-25%) surface fines than unregulated sites, but differences among regulated and unregulated sites were not significant due to high variability. Sites typically had < 5% fines and contained a mixture of loose and tight substrates (Figure 3-109 and Figure 3-110). Other sections of the Deadwood River near the mouth have high percent fines but these areas were not target habitat (low-gradient riffles) and were not sampled in this study. Canopy cover was similar among all sites (range 18 – 60 %), with a high intra-site variability due to specific location of an individual transect (Figure 3-111).

Periphyton was scraped from randomly-selected cobbles to provide a rough comparison of algal productivity among sites. Chlorophyll *a*, which serves as a proxy for living periphyton productivity, ranged from <1 – 72 mg/m^2 at unregulated sites and from 1 – 809 mg/m^2 at regulated sites. The highest values in chlorophyll *a* were found closest to the reservoir outflow (DEA101), with values exceeding 800 mg/m^2 in 2010 when the flow was reduced to 0 cfs (Figure 3-112). More typical values ranged from 100-500 mg/m^2. The next site downstream from the reservoir (DEA113) had the next highest chlorophyll *a* values (27- 200 mg/m2). Sites closer to the mouth of the lower Deadwood River (DEA112, DEA108) had chlorophyll *a* values similar to those at unregulated sites. Pheophytin a is a degradation product from aging periphyton cells that provides a measure of plant-based detritus. Pheophytin a followed a similar pattern to chlorophyll *a*, being low at all unregulated sites and high at sites closest to the reservoir outflow (Figure 3-113). Ash-free dry mass measures the total amount of all organic material (including autotrophs, heterotrophs and detritus). Again, the site immediately below the reservoir (DEA101) had the highest AFDM followed by the next site downstream (DEA113; Figure 3-114).

High abundance of periphyton below the reservoir may be due to factors such as less mobile substrate, increased temperatures, and higher nutrients flowing from the reservoir (Morley et al. 2008; Munn and Brusven 1991). Large mats of filamentous green algae occur below the dam. Filamentous algae, while increasing habitat for chironomids, is detrimental to mayflies that prefer bare rocks and diatomaceous algae as a food source (Morley et al. 2008; Munn and Brusven 1991). As the summer progressed, the base layer of filamentous algae appeared to die off while the top layer kept growing, which explains the large values of decaying plant matter (pheophytin a) and organic material (AFDM) in the sites closest to the dam.

Taken together, measurements of discharge, temperature, water quality, physical habitat, and periphyton suggest that the unregulated sites should serve as reliable indicators of reference conditions. Effects of Deadwood Reservoir on flow, temperature, nutrients, and periphyton are apparent at the site closest to the dam (DEA101). These effects are partially attenuated by 3.7 km downstream (DEA113). The sites farther downstream (DEA112 and DEA108) show almost complete attenuation of dam effects due to the influence of tributary inflows and likely to a lesser degree, nutrient spiraling. Lack of sampling in the river between 3.7 km and 24.8 km downstream prevents a more detailed description of how quickly the dam effect attenuates; data and modeling in Section 3.1 and 3.2 help inform this question. Notably, Idaho Department of Environmental Quality surface water quality criteria for general aquatic life and for Bull Trout juveniles were never exceeded during this study (Table 3-32). The temperature criterion for Bull Trout spawning was exceeded but the lower Deadwood River mainstem is not classified as spawning or rearing habitat (75 FR 63898).

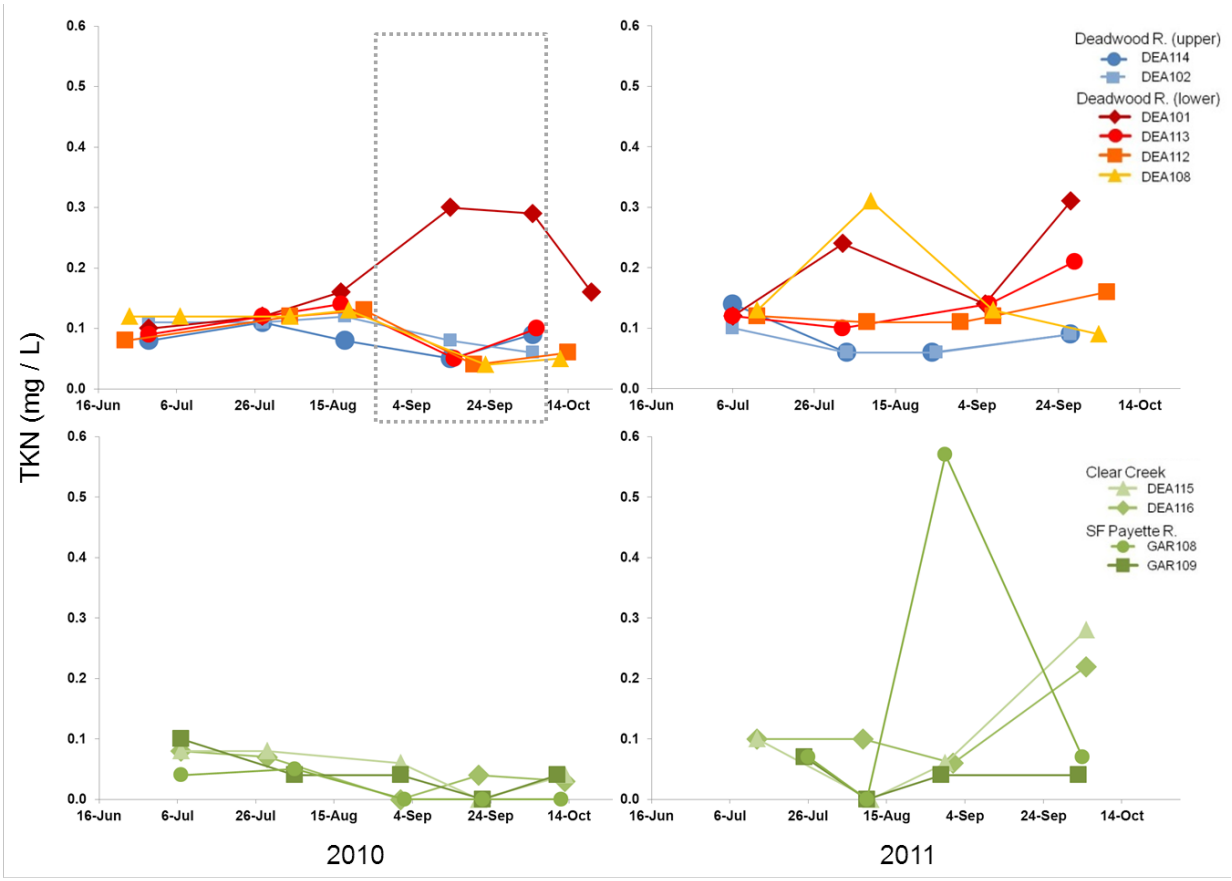


Figure 3-95. Total Kjeldahl nitrogen (TKN) at sample sites. The dashed box delineates when reservoir discharge plus seepage was < 5 cfs.

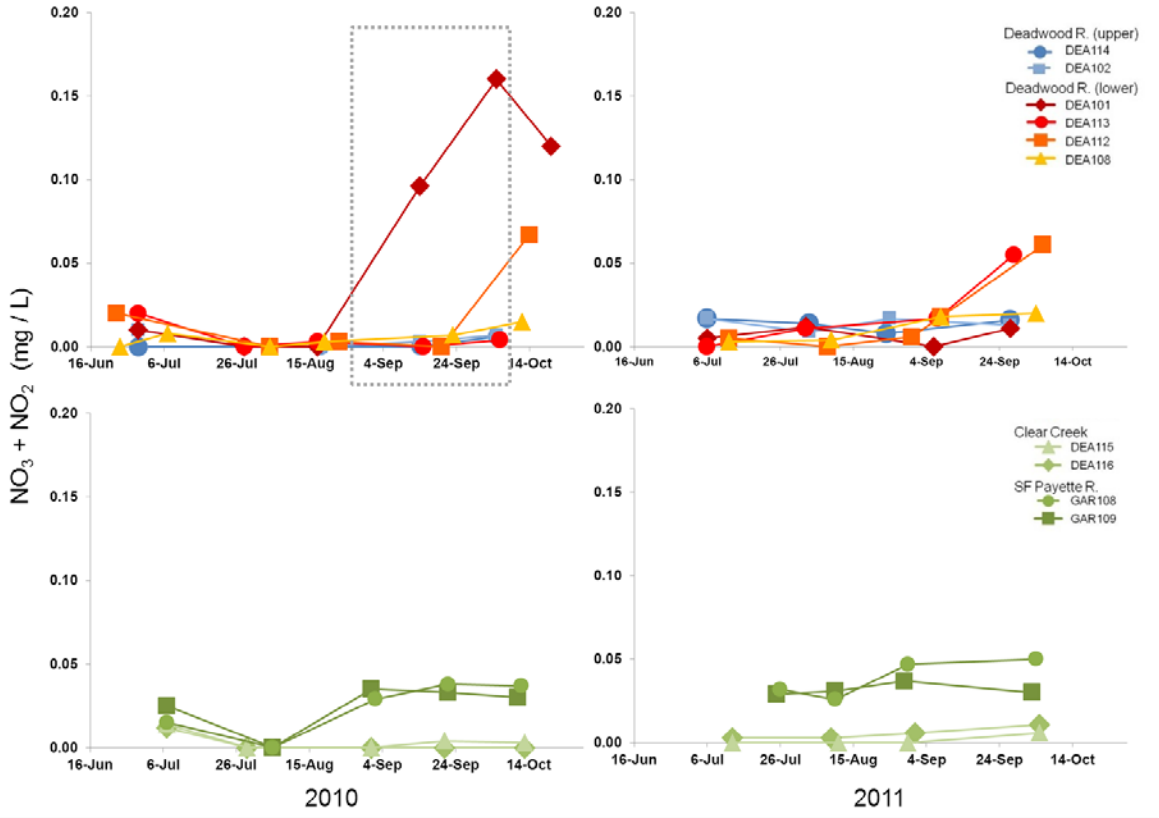


Figure 3-96. Nitrate (NO_3) + nitrite (NO_2) at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

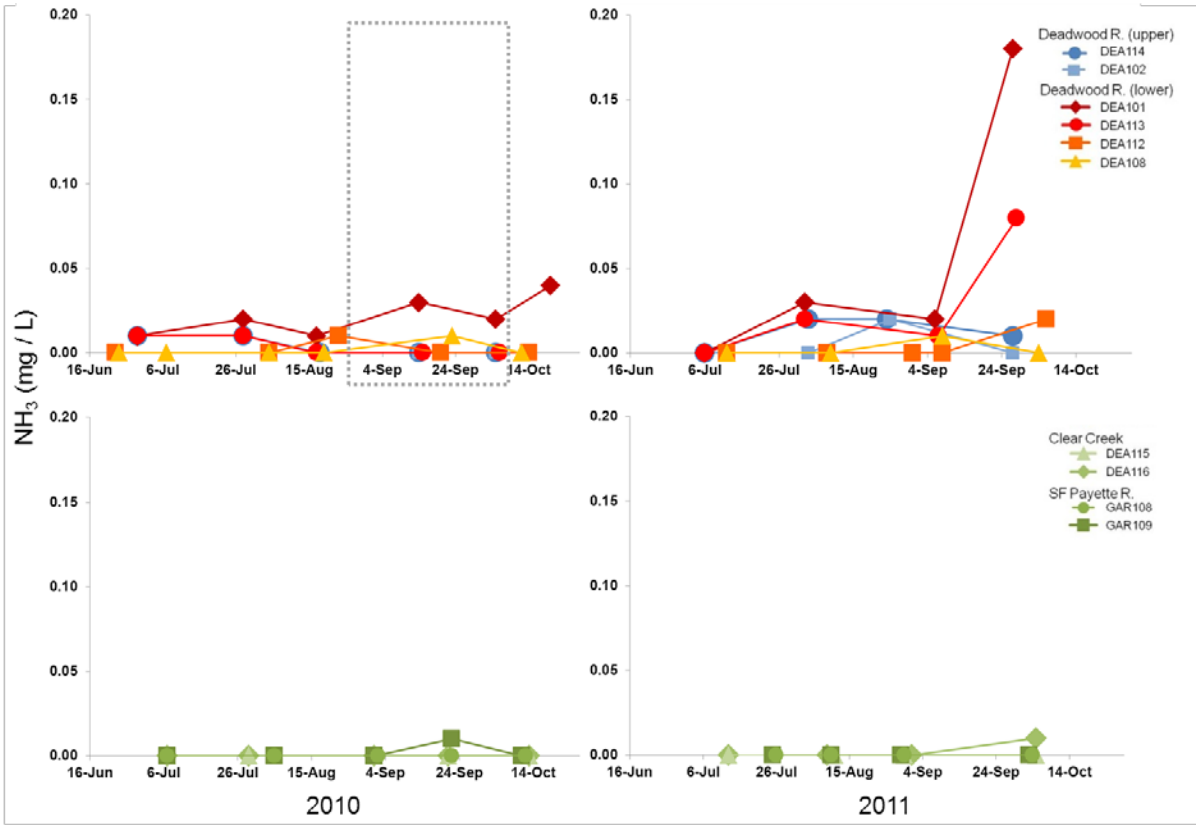


Figure 3-97. Ammonia (NH_3) at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

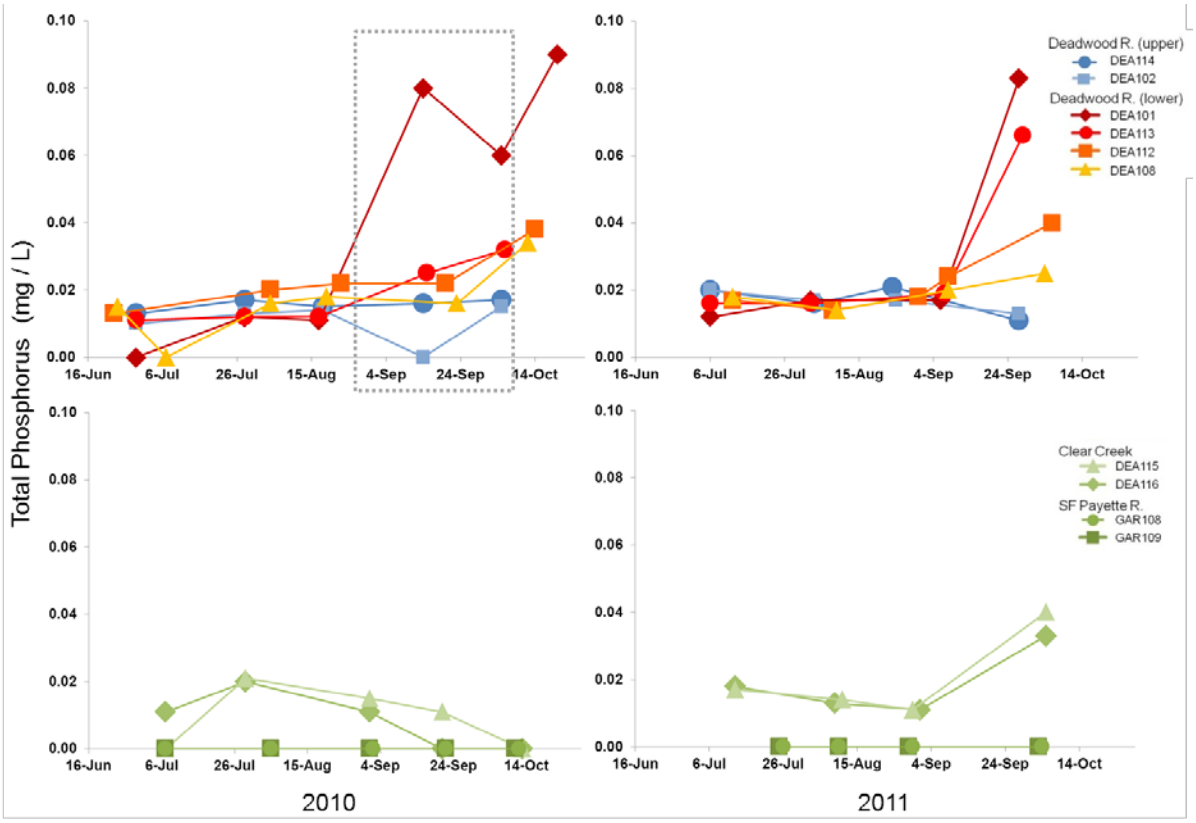


Figure 3-98. Total phosphorus at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

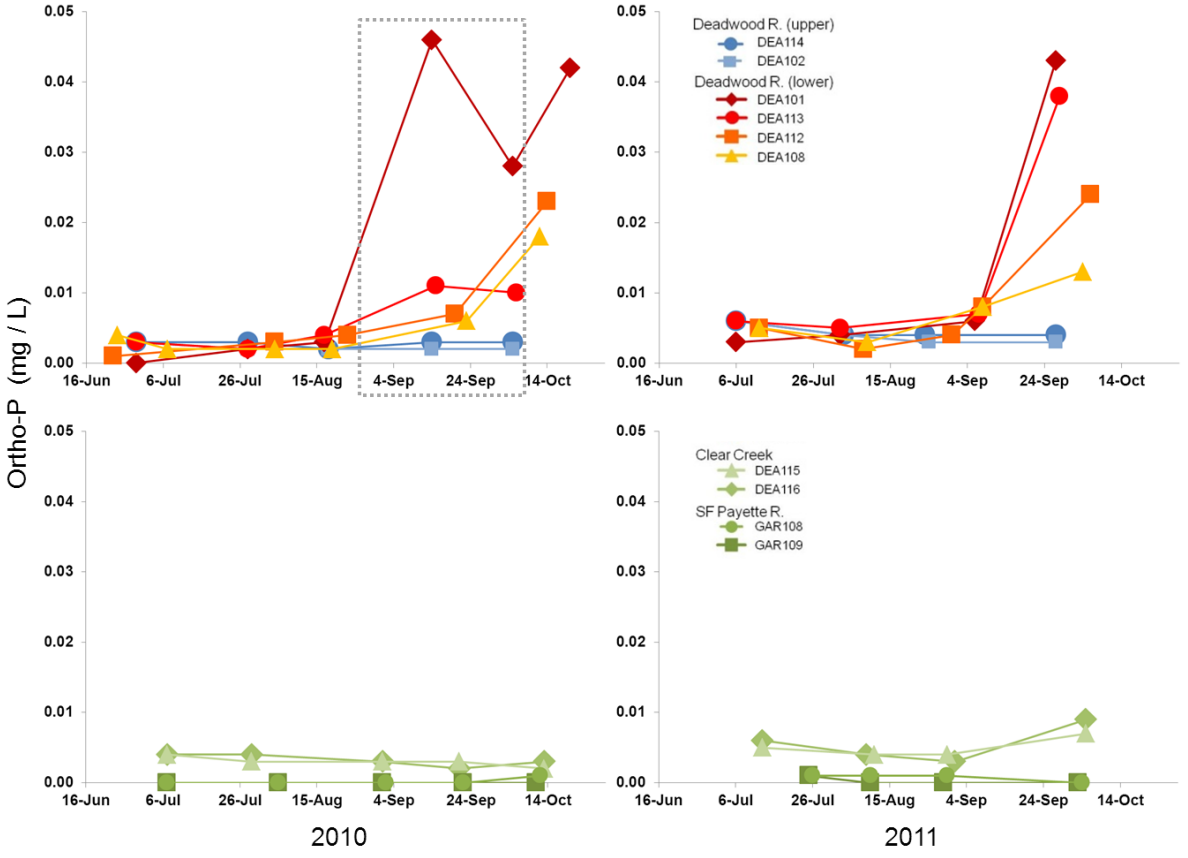


Figure 3-99. Dissolved phosphorous (orthophosphate) at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

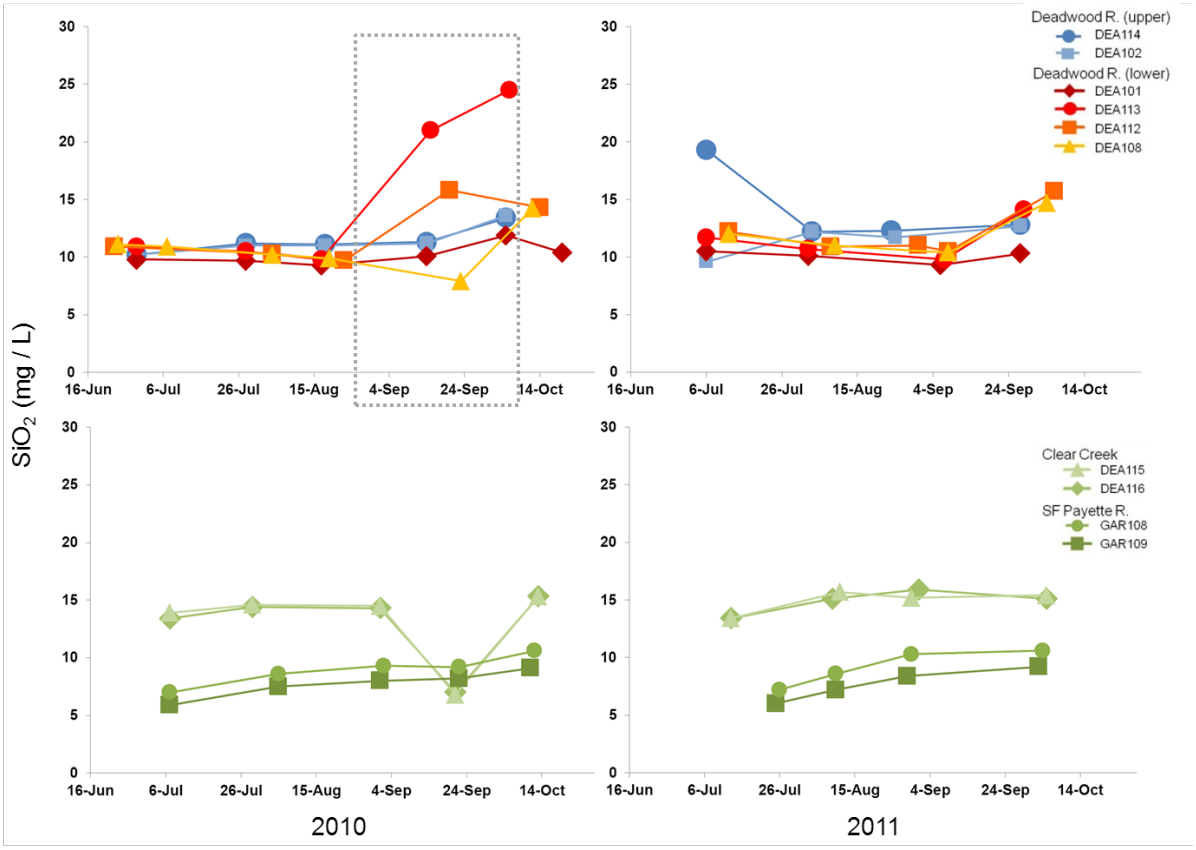


Figure 3-100. Silicon dioxide (SiO_2) at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

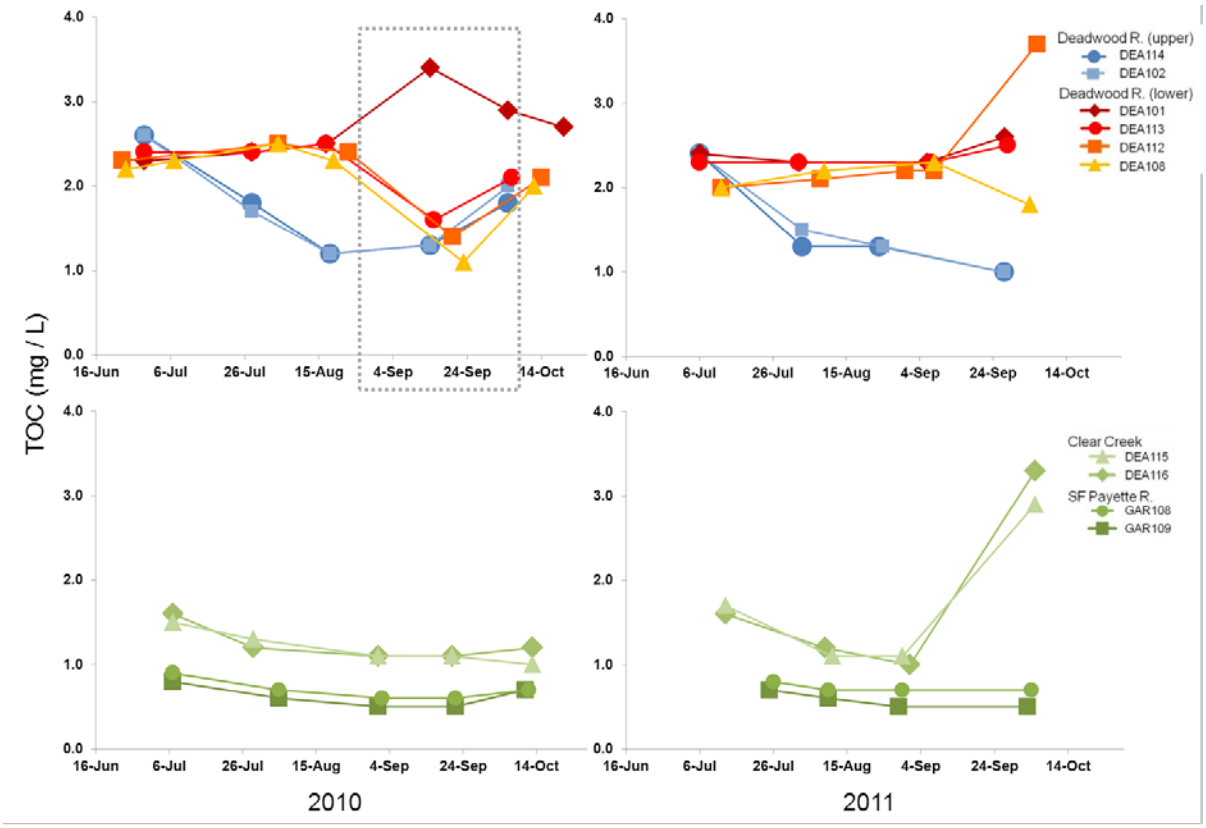


Figure 3-101. Total organic carbon at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

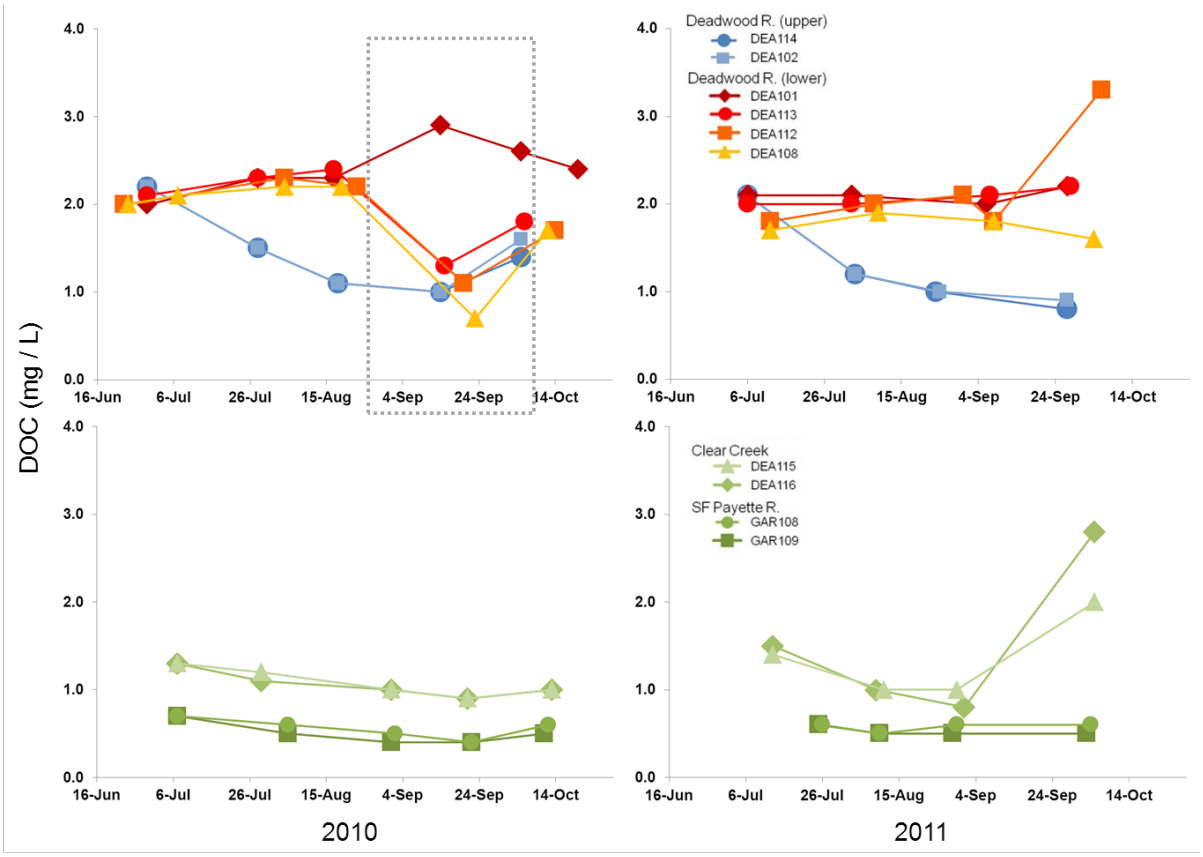


Figure 3-102. Dissolved organic carbon at sample sites. The dashed box delineates when reservoir discharge plus seepage <5 cfs.

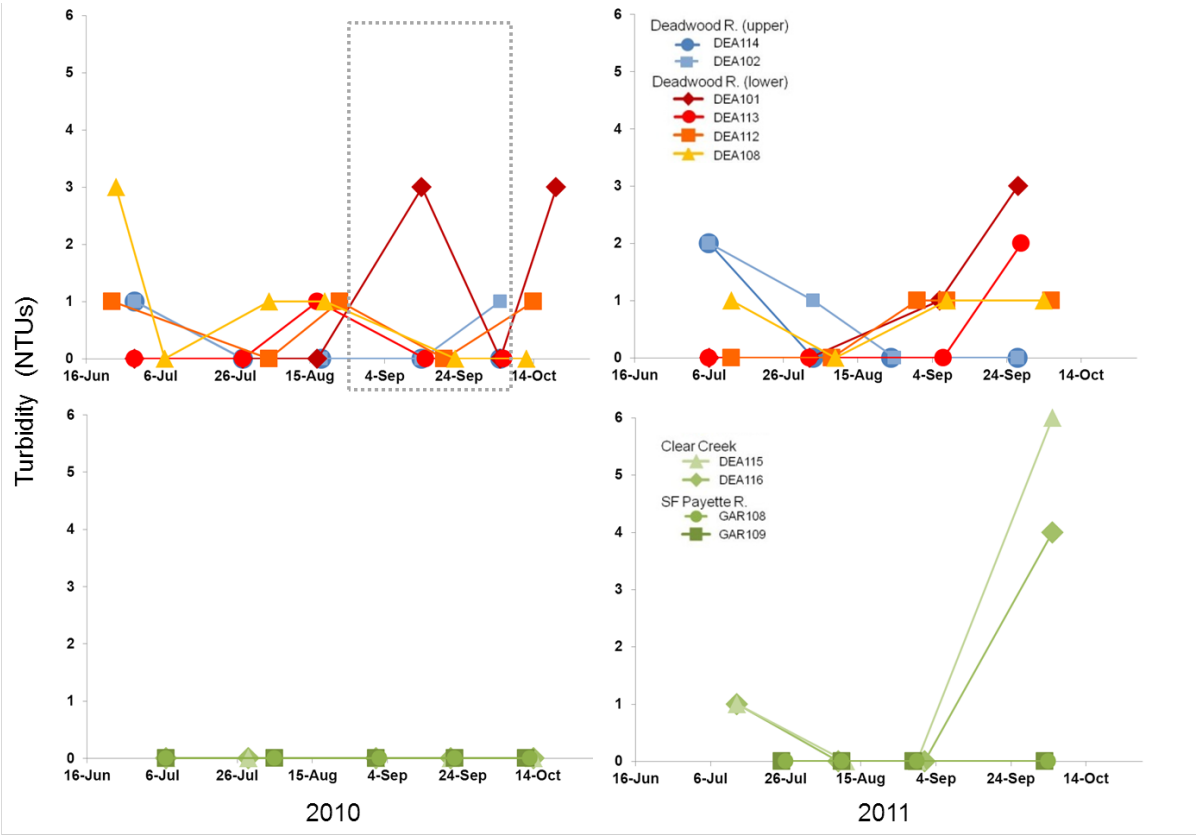


Figure 3-103. Turbidity at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

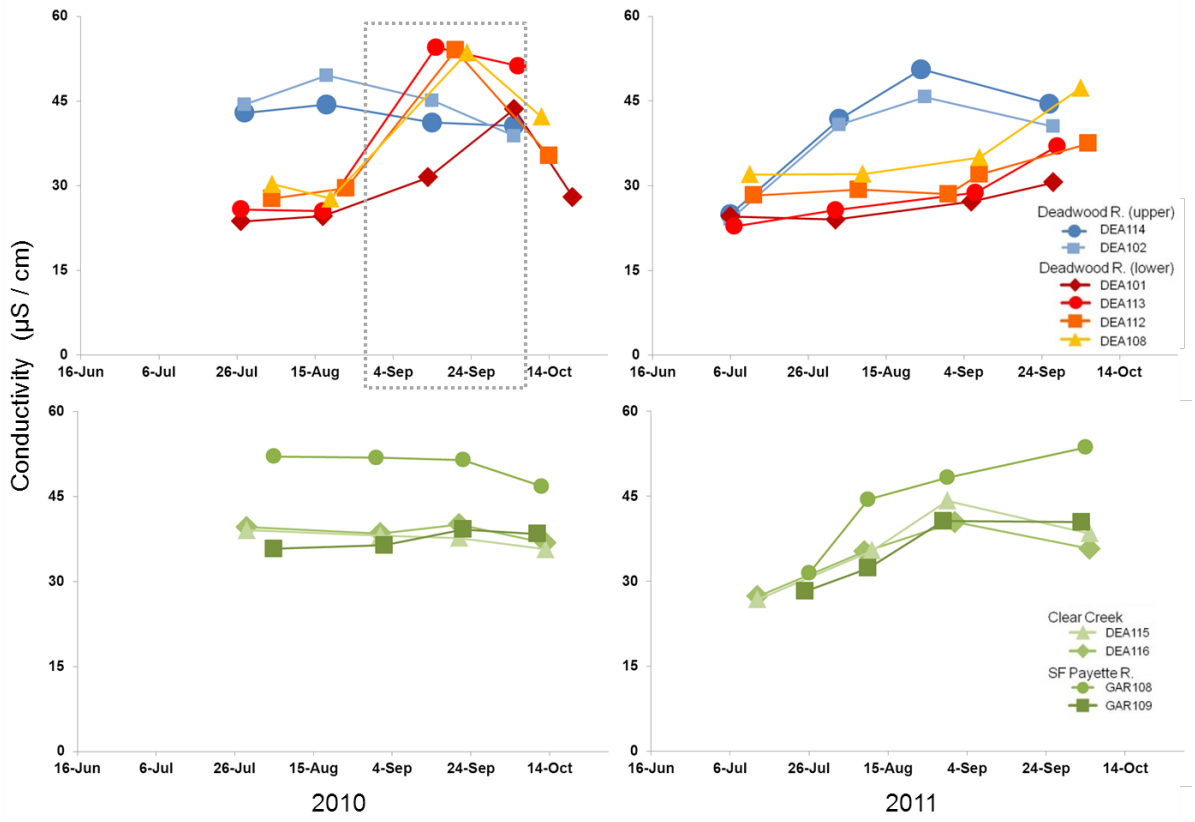


Figure 3-104. Conductivity at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

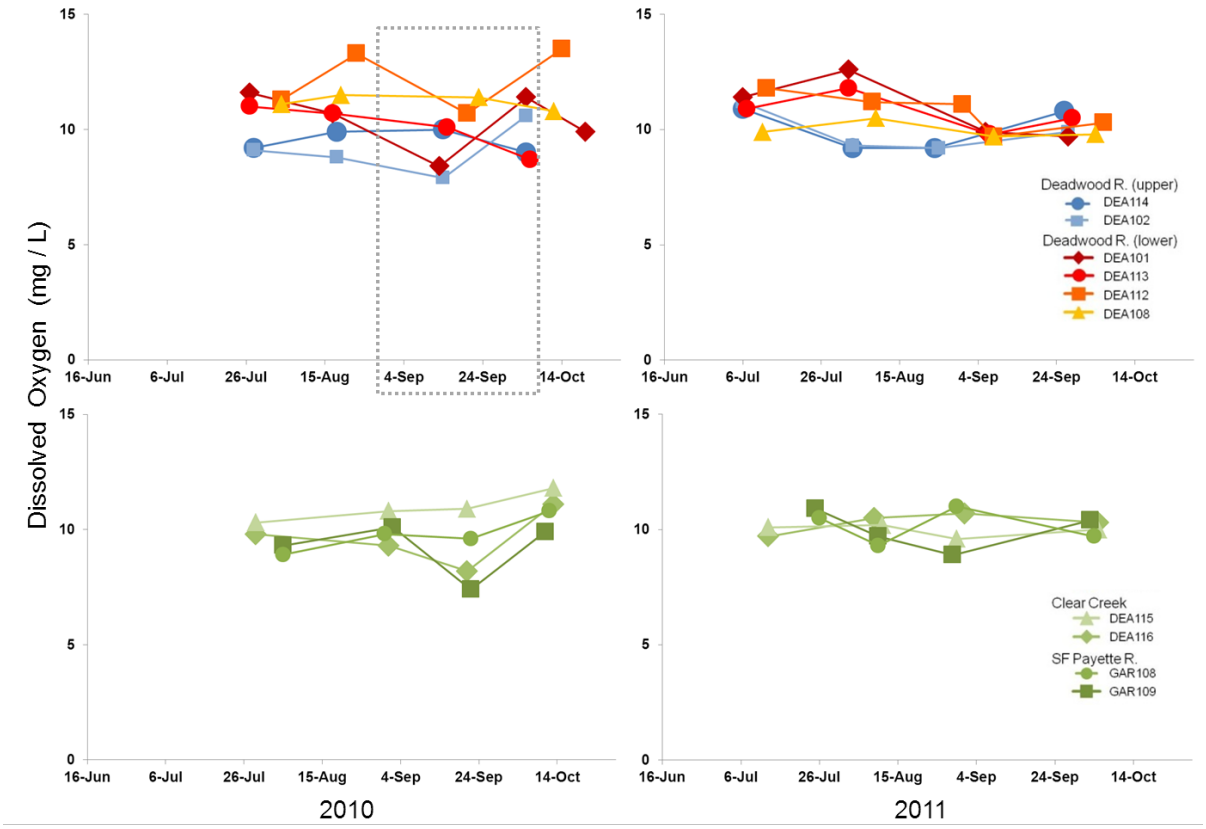


Figure 3-105. DO at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

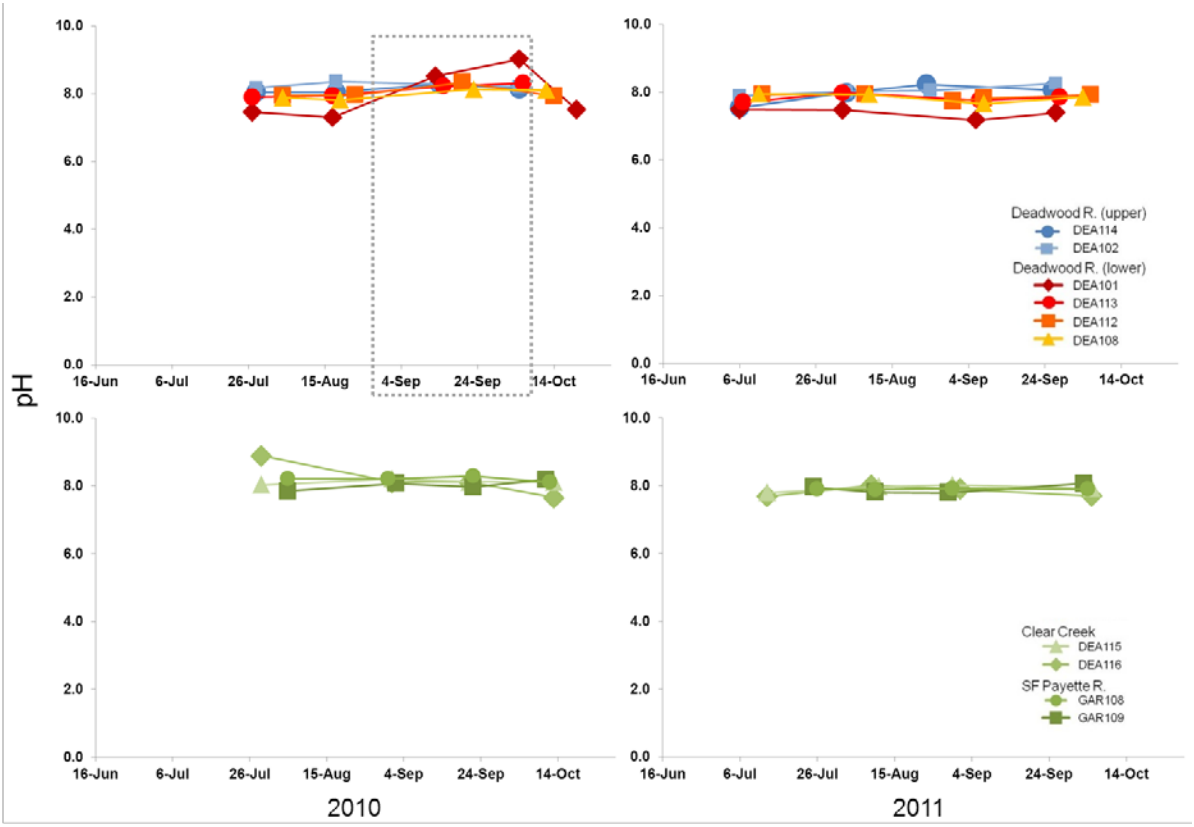


Figure 3-106. pH at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

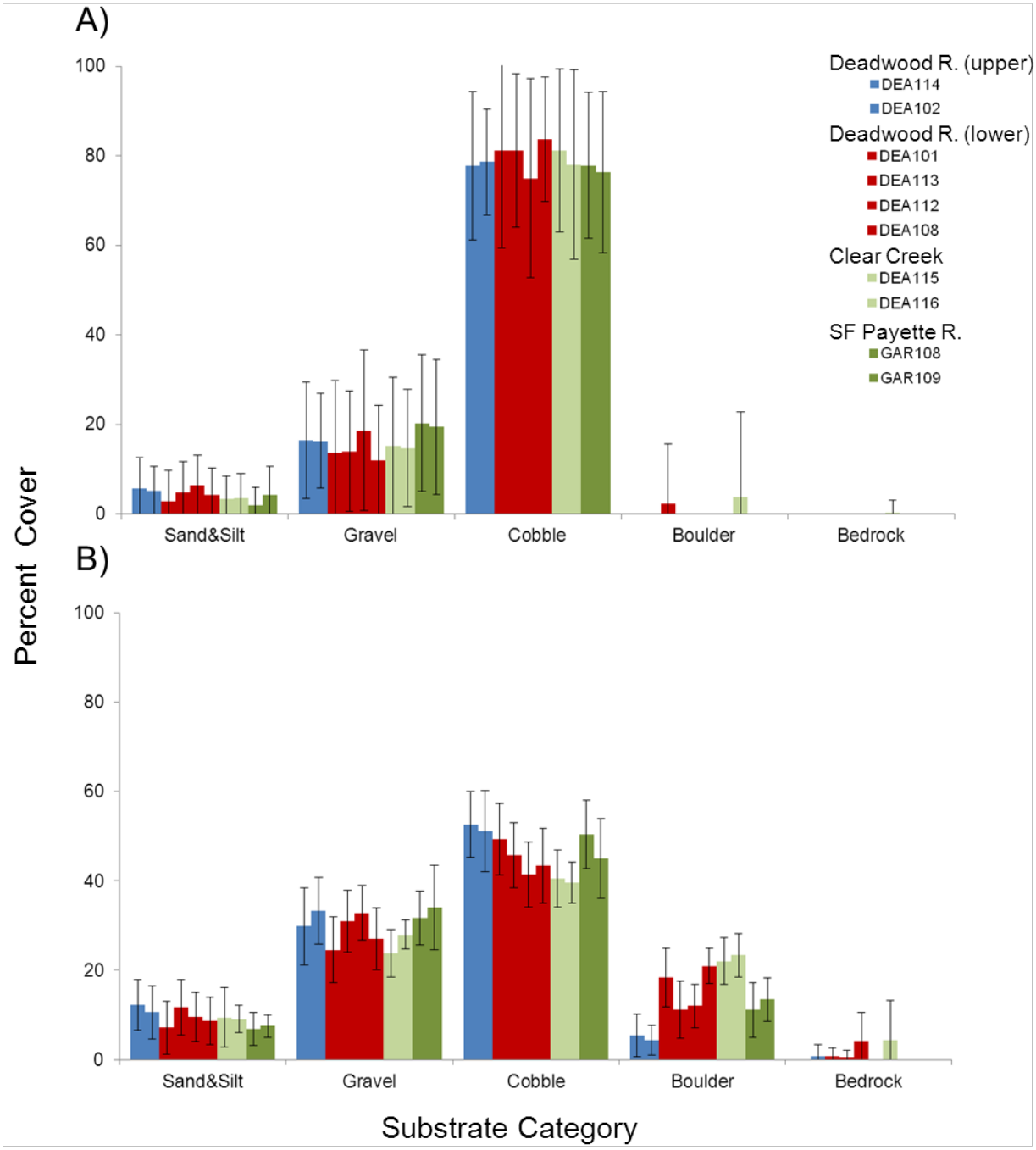


Figure 3-107. Mean (± standard deviation) percent substrate composition in A) Hess sample locations and B) within 10 meters of each transect.

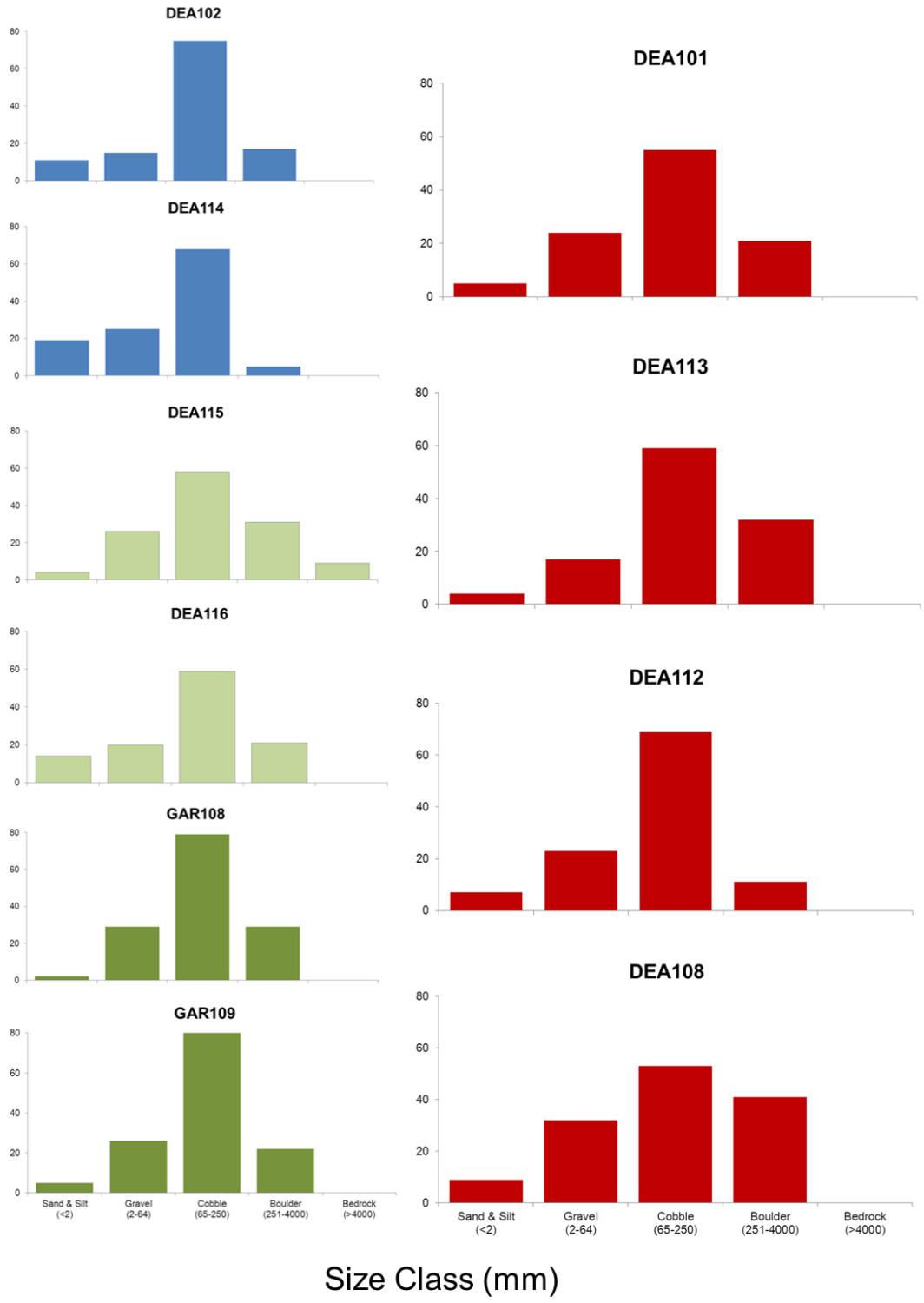


Figure 3-108. Substrate size distribution for sample sites in the upper Deadwood River (blue), lower Deadwood River (red), Clear Creek (light green) and South Fork Payette River (dark green). Data reflect one Wolman pebble count done at each site in fall 2010.

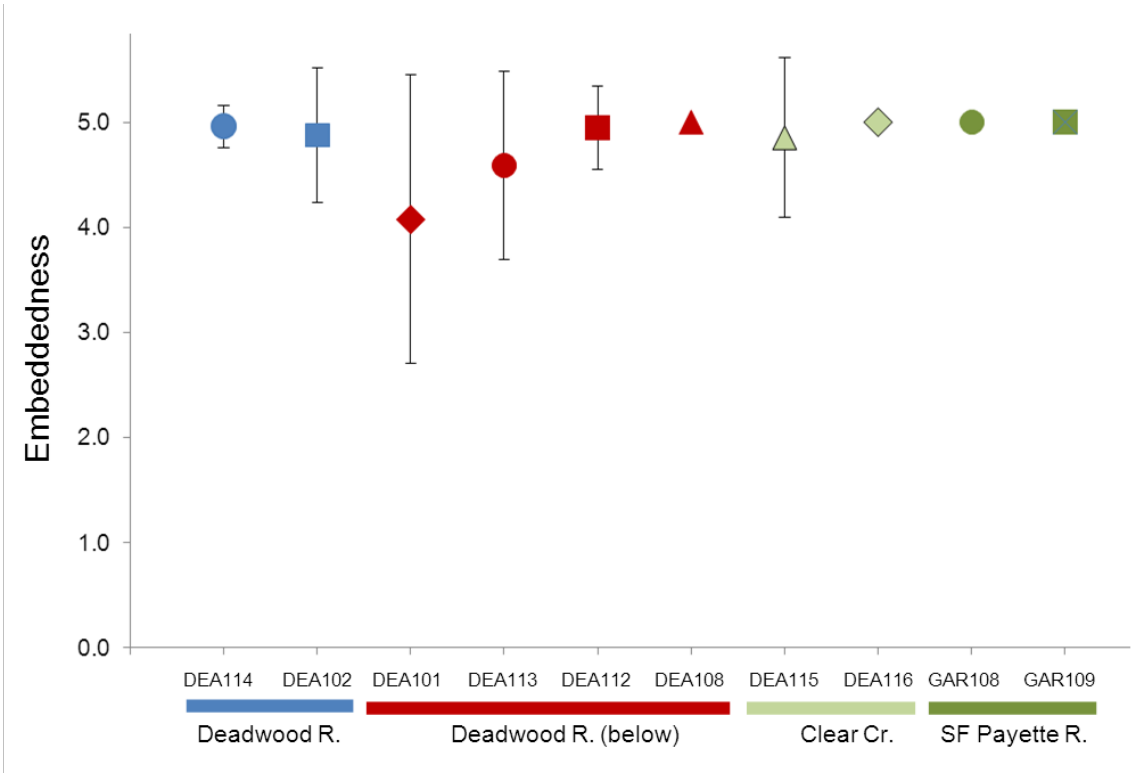


Figure 3-109. Mean (± standard deviation) embeddedness rating at Hess sample locations. See Table 5 for definition of ratings.

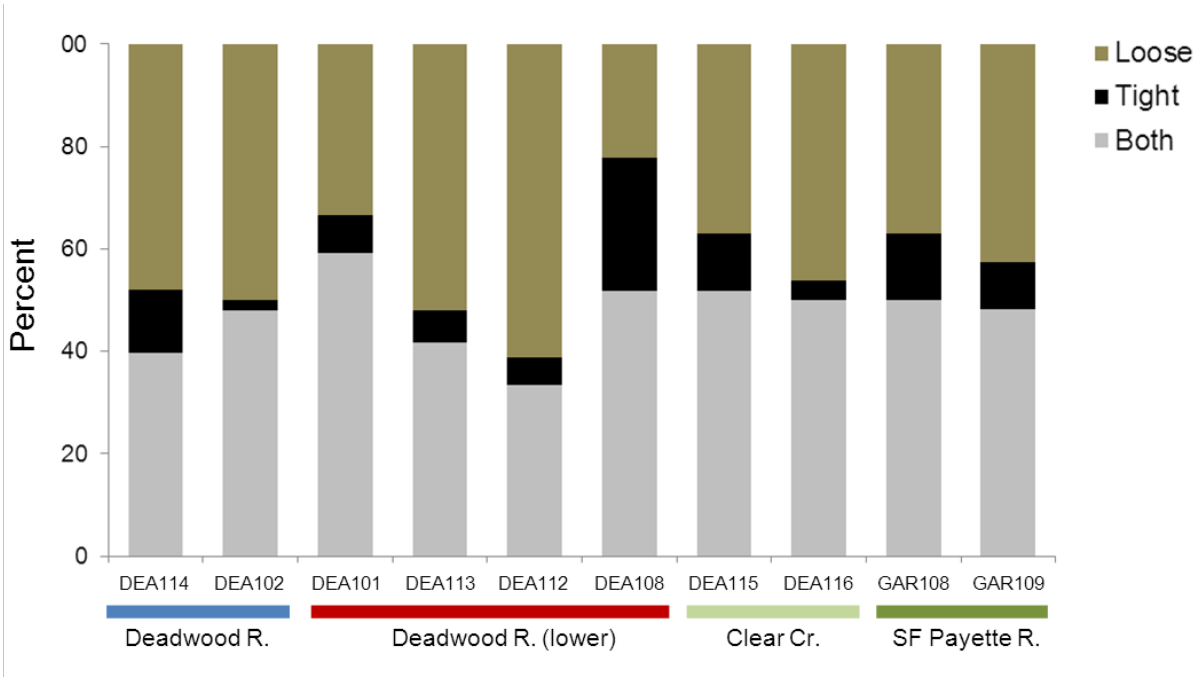


Figure 3-110. Mean percent of Hess samples that were "Loose", "Tight" or "Both" at each site. See Table 6 for descriptions of categories.

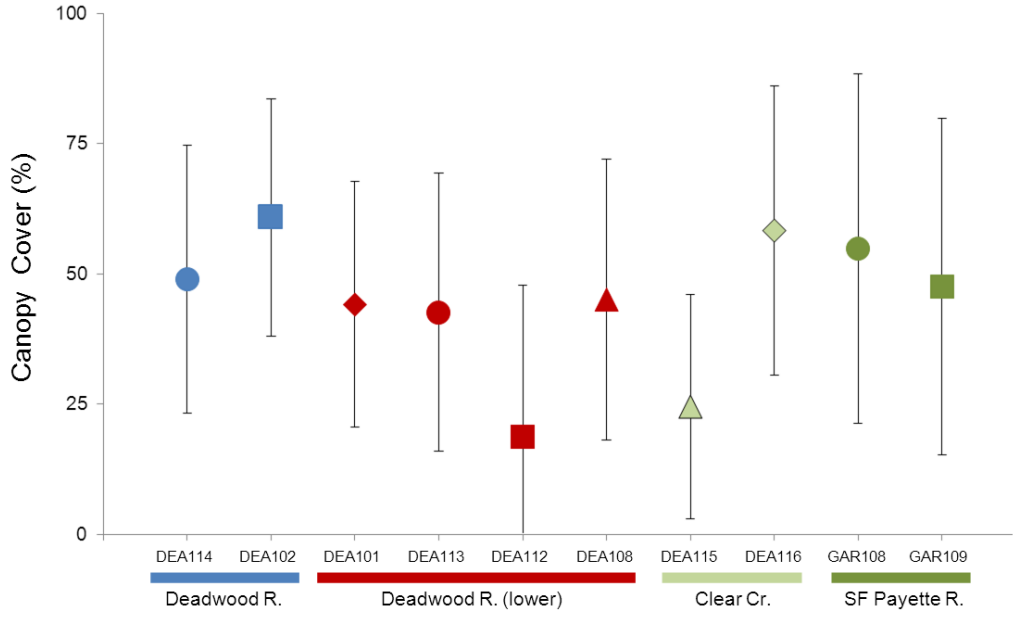


Figure 3-111. Mean (± standard deviation) percent canopy cover for each sample site.

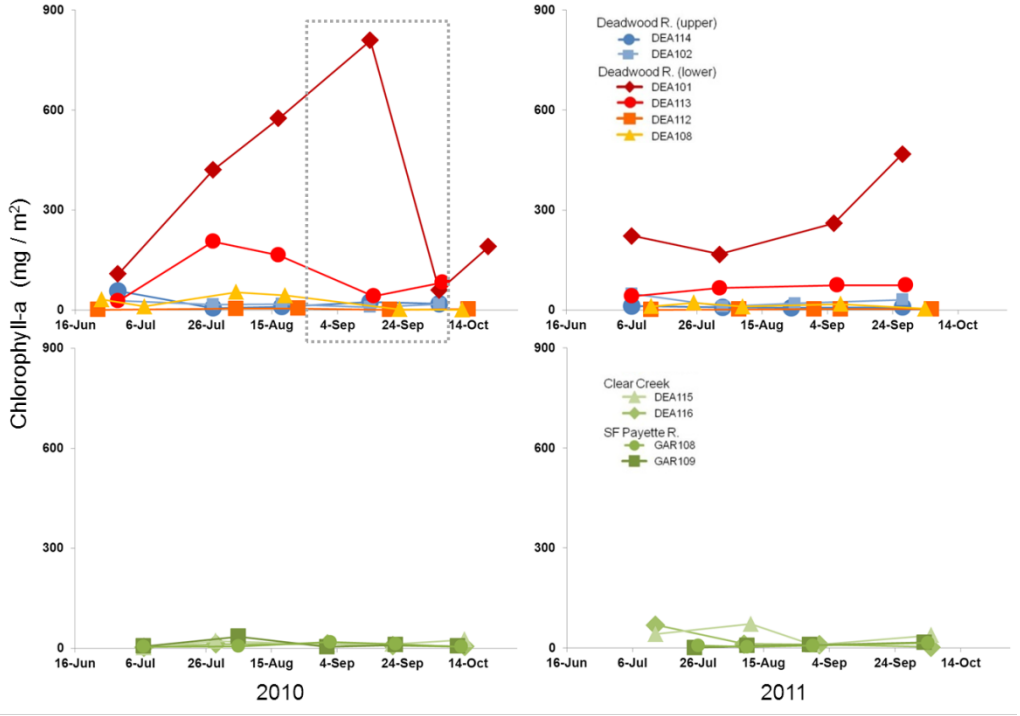


Figure 3-112. Chlorophyll *a* at sample sites. The dashed box delineates when reservoir discharge plus seepage was <5 cfs.

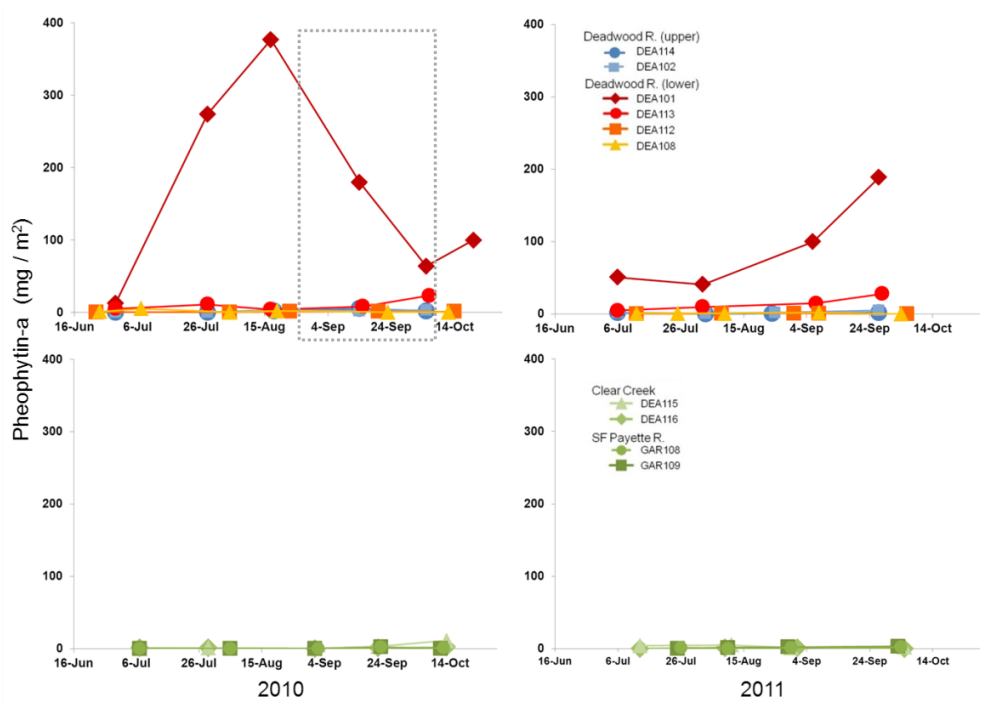


Figure 3-113. Pheophytin a at sample sites. The dashed box delineates when reservoir discharge < 5cfs.

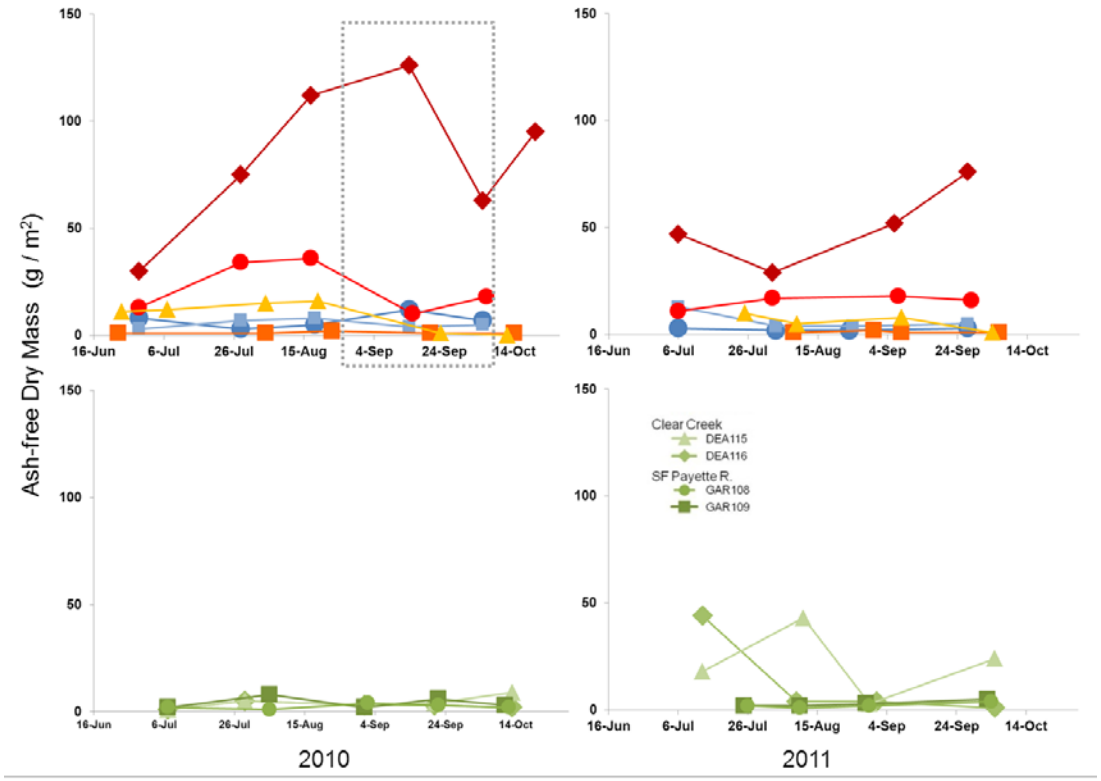


Figure 3-114. Ash-free dry mass (AFDM) at sample sites. The dashed box delineates when reservoir discharge <5 cfs.

Table 3-32. Idaho DEQ surface water quality criteria for aquatic life use designations (IDAPA 58.01.02, DEQ 2010).

	Parameter	Range	Units
General criteria			
	pH	6.5 - 9.0	
	DO	6	mg/L
	Water temperature	$\leq$ 22	^{0}C
	Water temperature (maximum daily average)	$\leq$ 19	^{0}C
	Ammonia (NH_3)		calculated in relation to temperature and pH
	Turbidity, instantaneously	$\leq$ 50	NTU
	Turbidity, 10 consecutive days	$\leq$ 25	NTU
Salmon spawning			
	DO (water column 1-day minimum)	$\geq$ 5.0	mg/L
	Water temperature	$\leq$ 13	^{0}C
	Water temperature (maximum daily average)	$\leq$ 9	^{0}C
Bull Trout criteria			
	Temperature (juvenile rearing, maximum weekly maximum temperature during Jun-Aug)	$\leq$ 13	^{0}C
	Temperature (spawning, daily average during Sep-Oct)	$\leq$ 9	^{0}C

Drift

Total (inorganic + organic) dry mass of drift material tended to decrease from early summer to fall (Figure 3-115), with most of the variability in drift rate attributable to inorganic material (sand; Figure 3-116). Drift was notably low just below Deadwood Reservoir (DEA101) but by 3.7 km downstream (DEA113), drift rate was similar to or higher than at unregulated sites (Figure 3-116). CPOM dominated the organic fraction (Figure 3-117). When present, aquatic invertebrates (0.2 – 2.5 %, mostly Ephemeroptera, Diptera, Trichoptera, and Plecoptera) and zooplankton (0.1 – 6.9 %, mostly Daphnia, Copepods, and Leptodora) were a minor component of the organic fraction (Figure 3-118 through Figure 3-121). Zooplankton were present in drift at the two sites closest to the reservoir outflow (DEA101, DEA113) during late summer and early fall.

Population- and Community-characteristics of Benthic Macroinvertebrates

Density (#/m^2) but not biomass (g/m^2) of benthic macroinvertebrates tended to increase from early summer through fall (Figure 3-122 and Figure 3-123). Density and biomass were similar among unregulated and regulated sites during all sampling periods. Percent

composition of functional feeding groups was similar among sites except for a large increase in percent gatherers and associated decrease in most other functional feeding groups at the first two sites below Deadwood Reservoir (Figure 3-124). A similar effect was seen for taxonomic richness (Figure 3-125) and diversity (Figure 3-126), which were significantly lower at the regulated site located nearest to Deadwood Dam, intermediate at the next site downstream, and similar among all other sites.

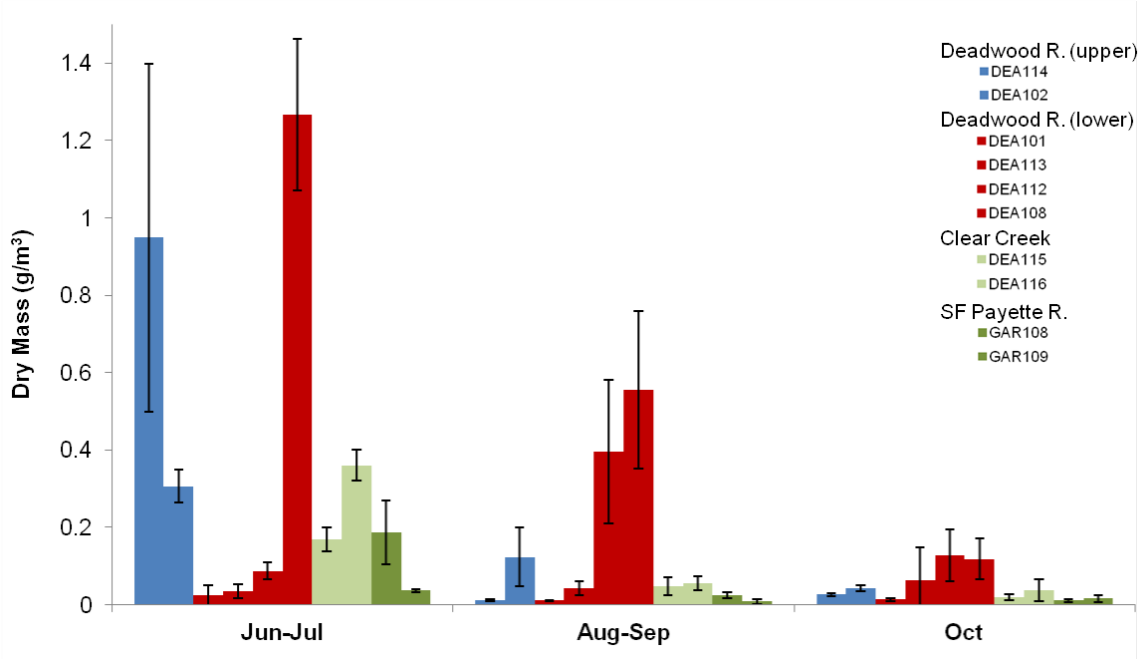


Figure 3-115. Mean (± standard deviation) dry mass of drift material in early summer, late summer, and fall, 2010.

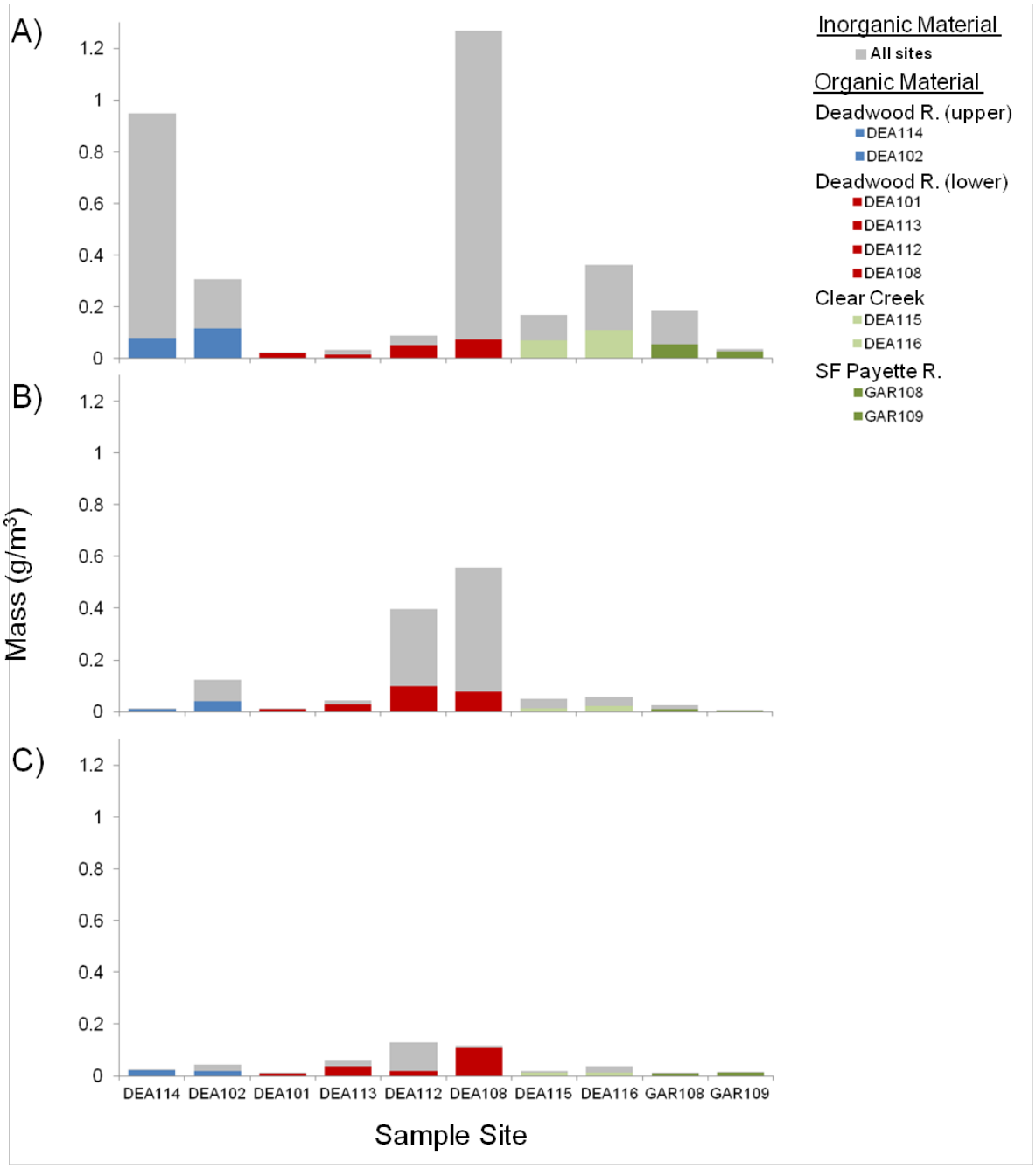


Figure 3-116. Mean drift rate and composition in A) early summer, B) late summer, and C) fall, 2010.

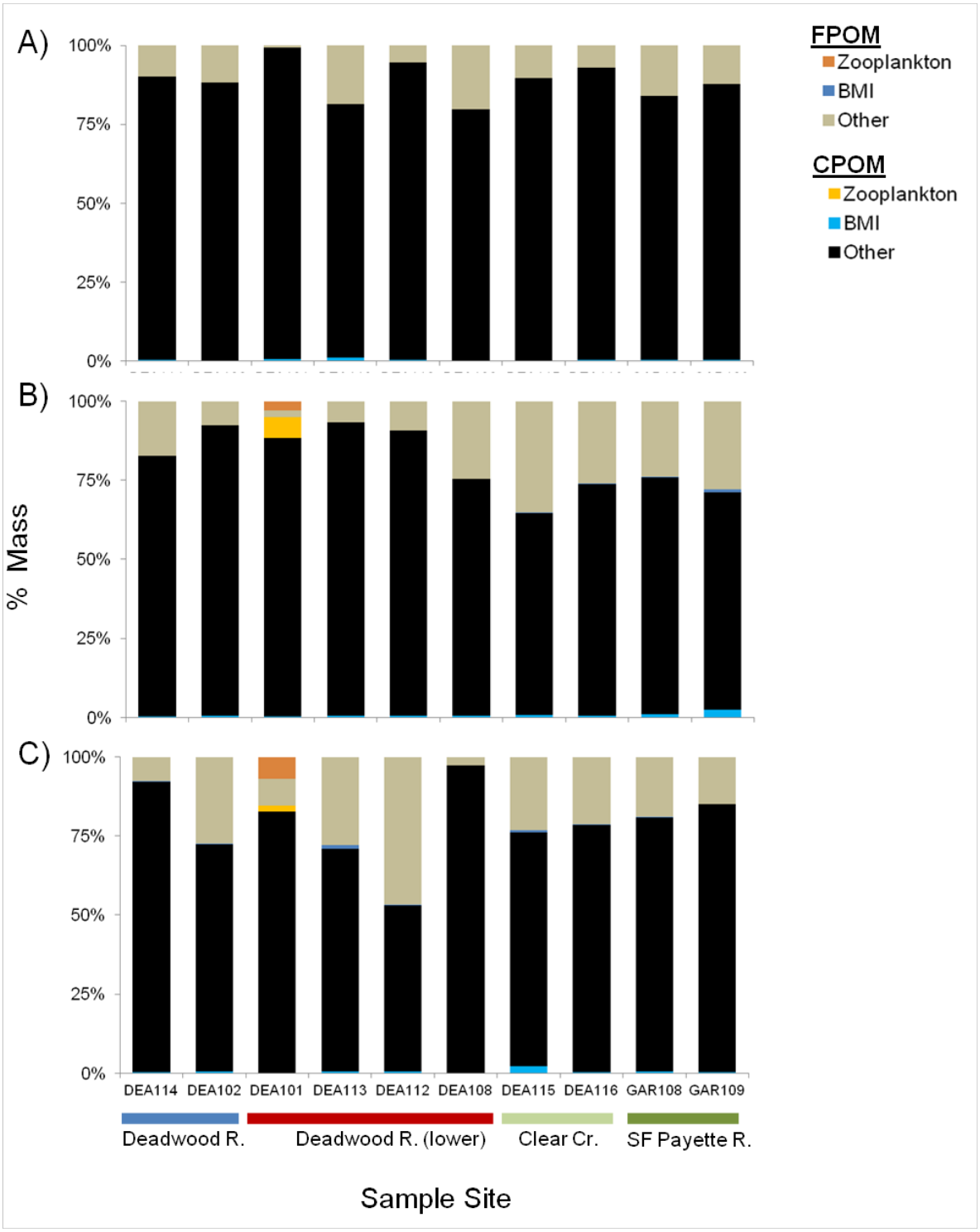


Figure 3-117. Mean percent FPOM and CPOM in the organic fraction of drift samples in early summer, late summer, and fall, 2010.

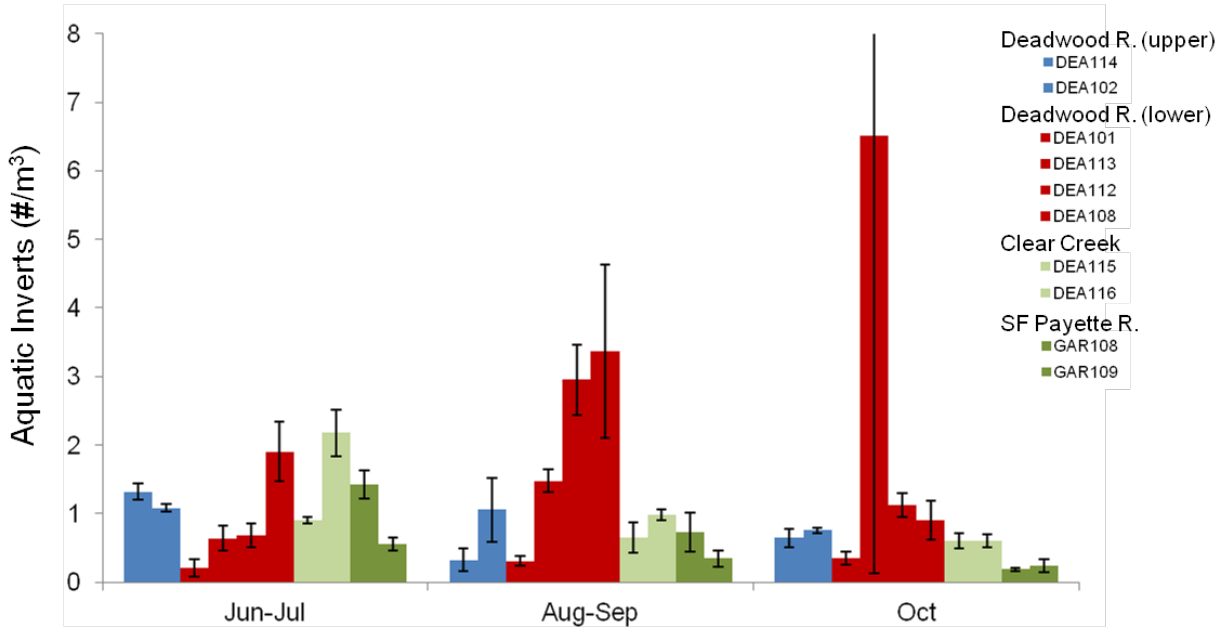


Figure 3-118. Mean (± standard deviation) density of aquatic invertebrates in drift samples in early summer, late summer, and fall, 2010. Data includes water mites, bivalves, beetles, springtails, flies, snails, worms, oligochaetes, mayflies, stoneflies and caddis flies, but excludes zooplankton.

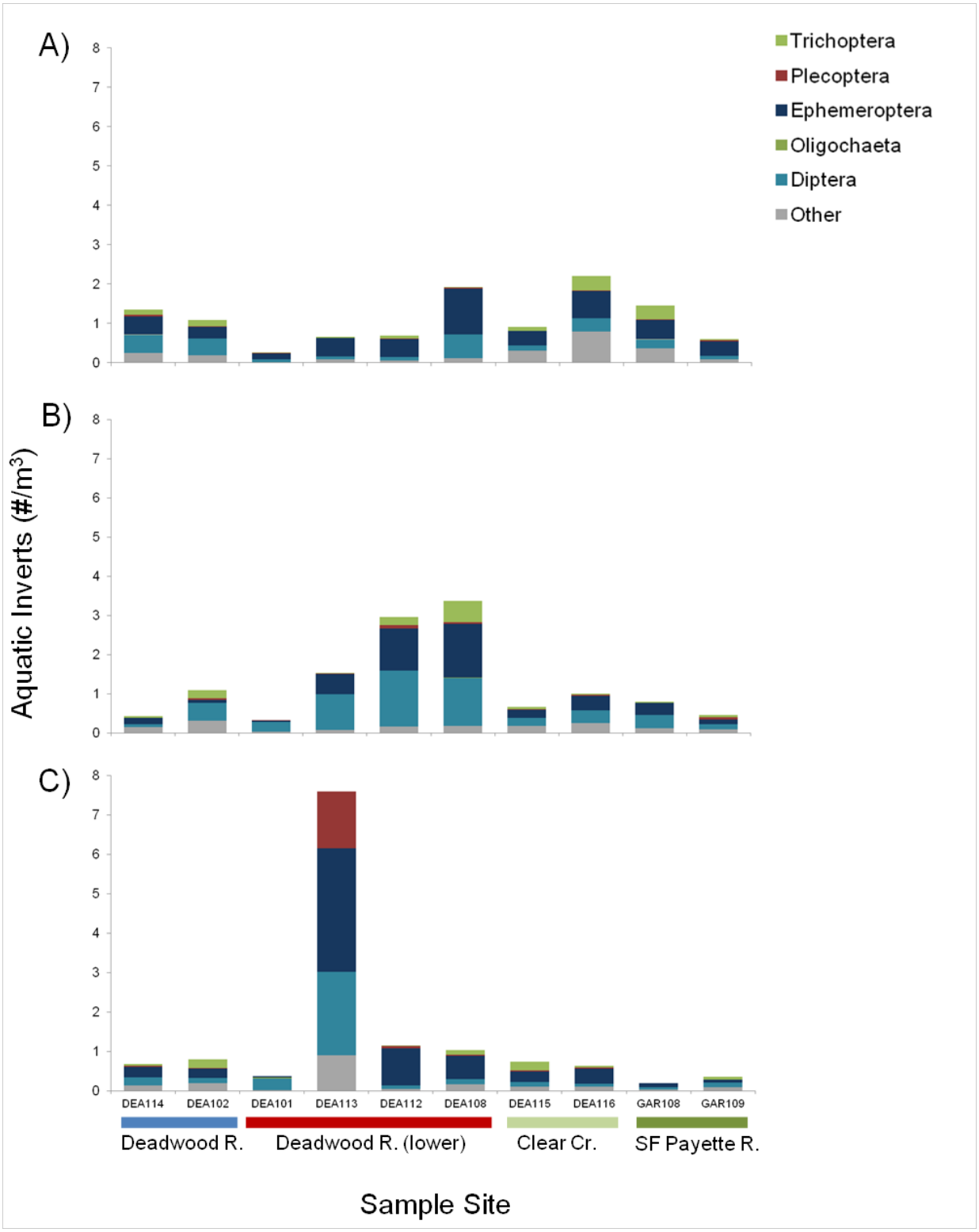


Figure 3-119. Mean abundance of aquatic invertebrate orders in A) early summer, B) late summer, and C) fall, 2010.

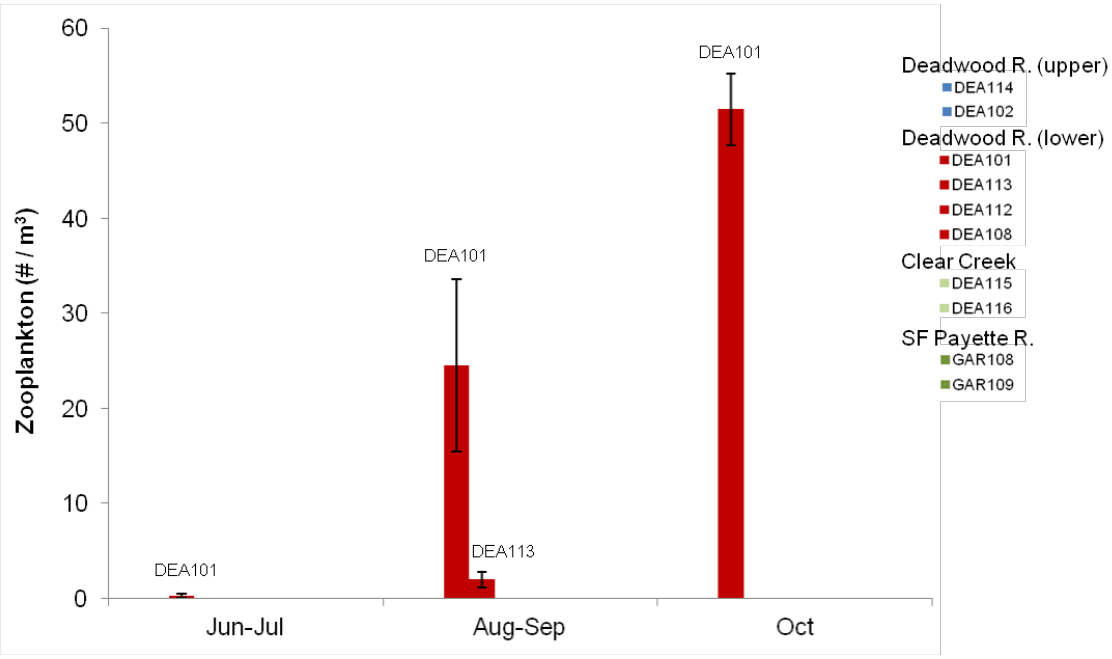


Figure 3-120. Mean (± standard deviation) density of zooplankton in drift in A) early summer, B) late summer, and C) fall, 2010.

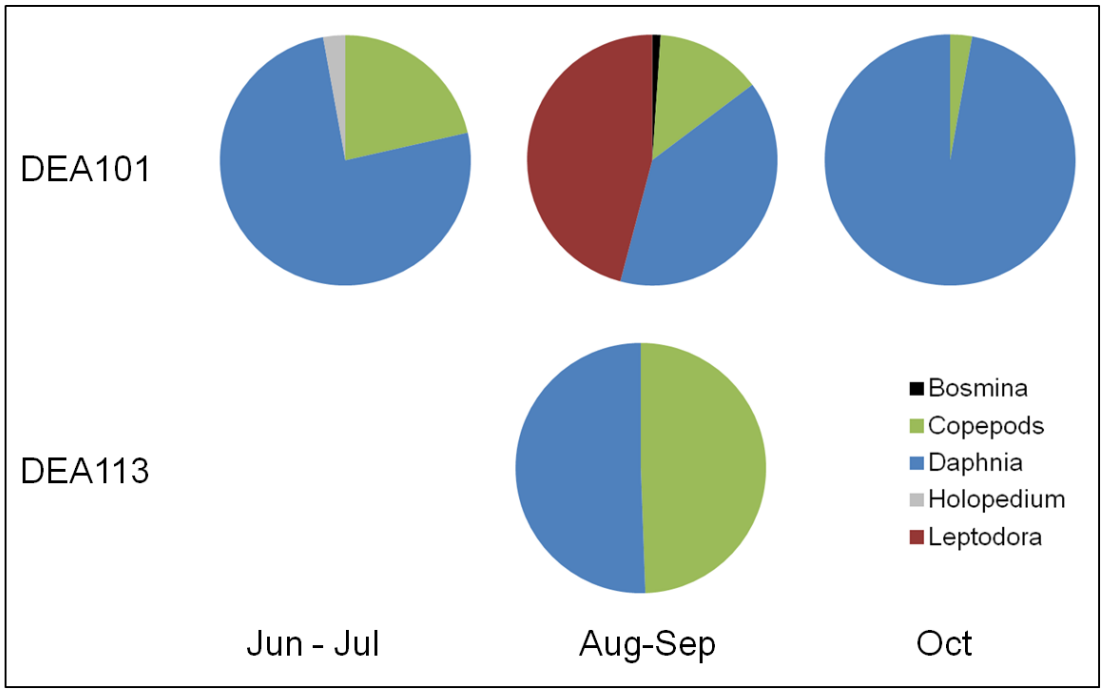


Figure 3-121. Mean percent composition of zooplankton groups in drift samples found in samples from the two sites below the reservoir.

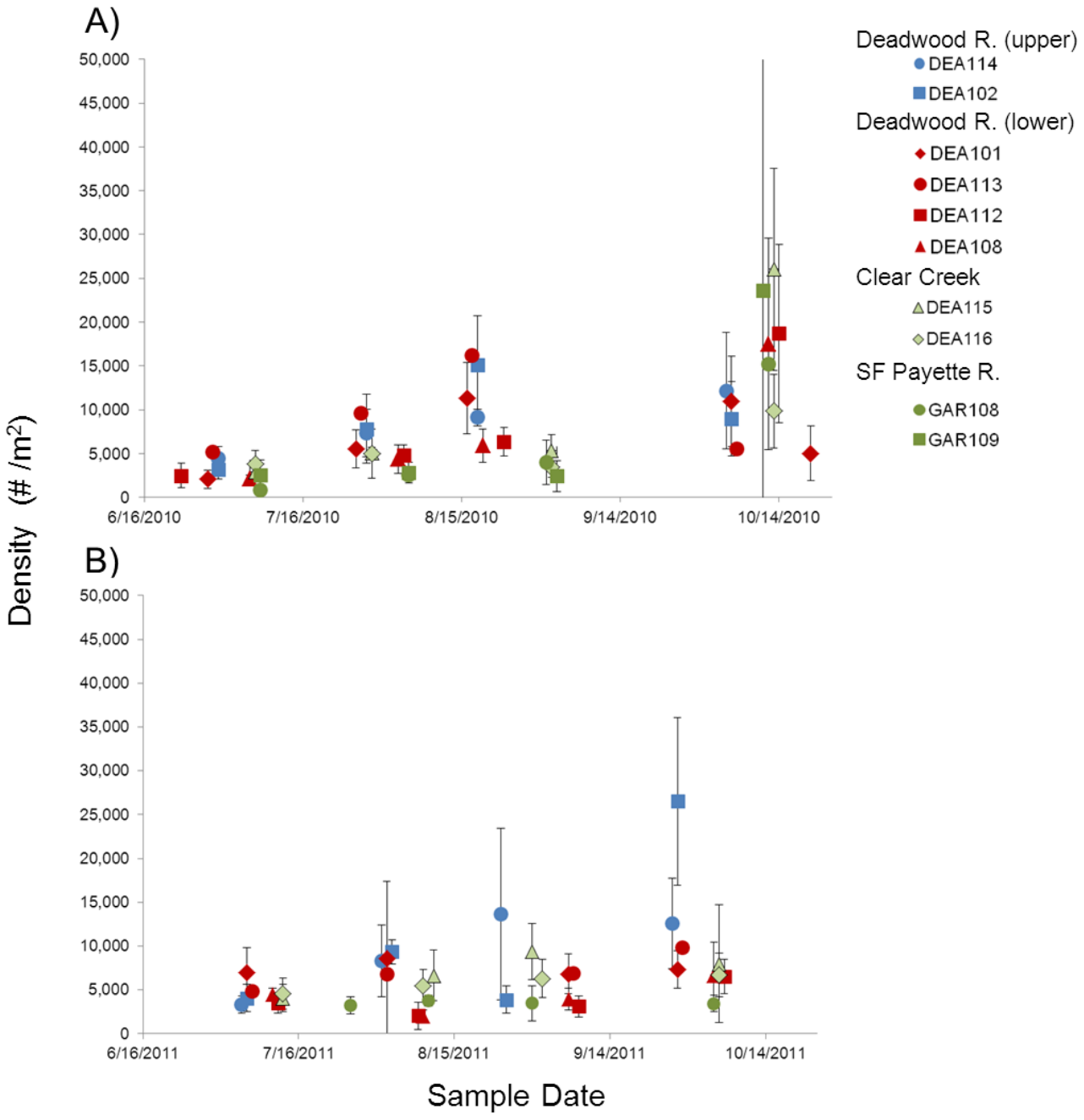


Figure 3-122. Mean (± standard deviation) density of benthic macroinvertebrates in A) 2010 and B) 2011. Each symbol represents the mean value for three samples collected on a given date and site.

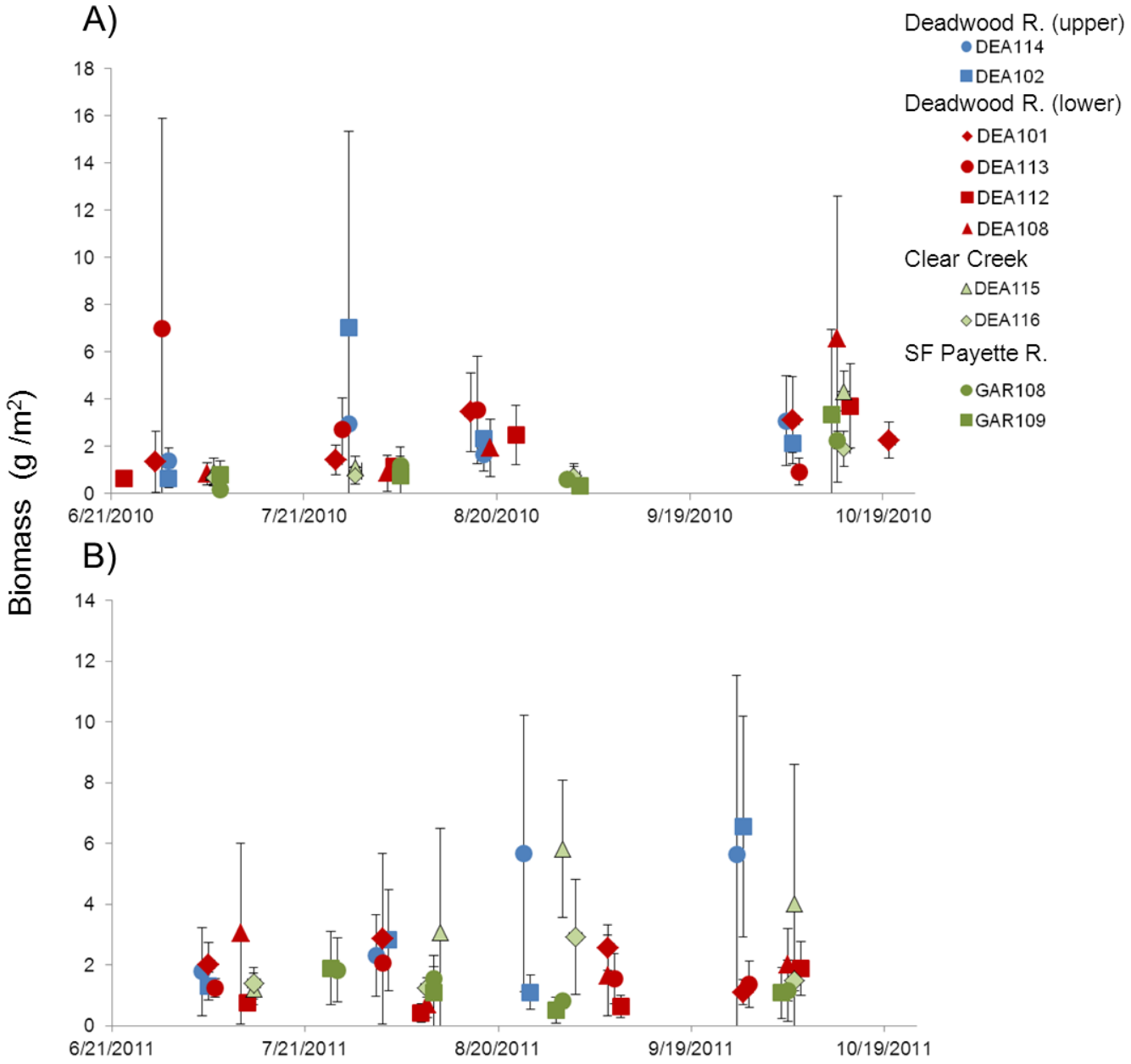


Figure 3-123. Mean (± standard deviation) biomass of benthic macroinvertebrates in A) 2010 and B) 2011. Each symbol represents the mean value for three samples collected on a given date and site.

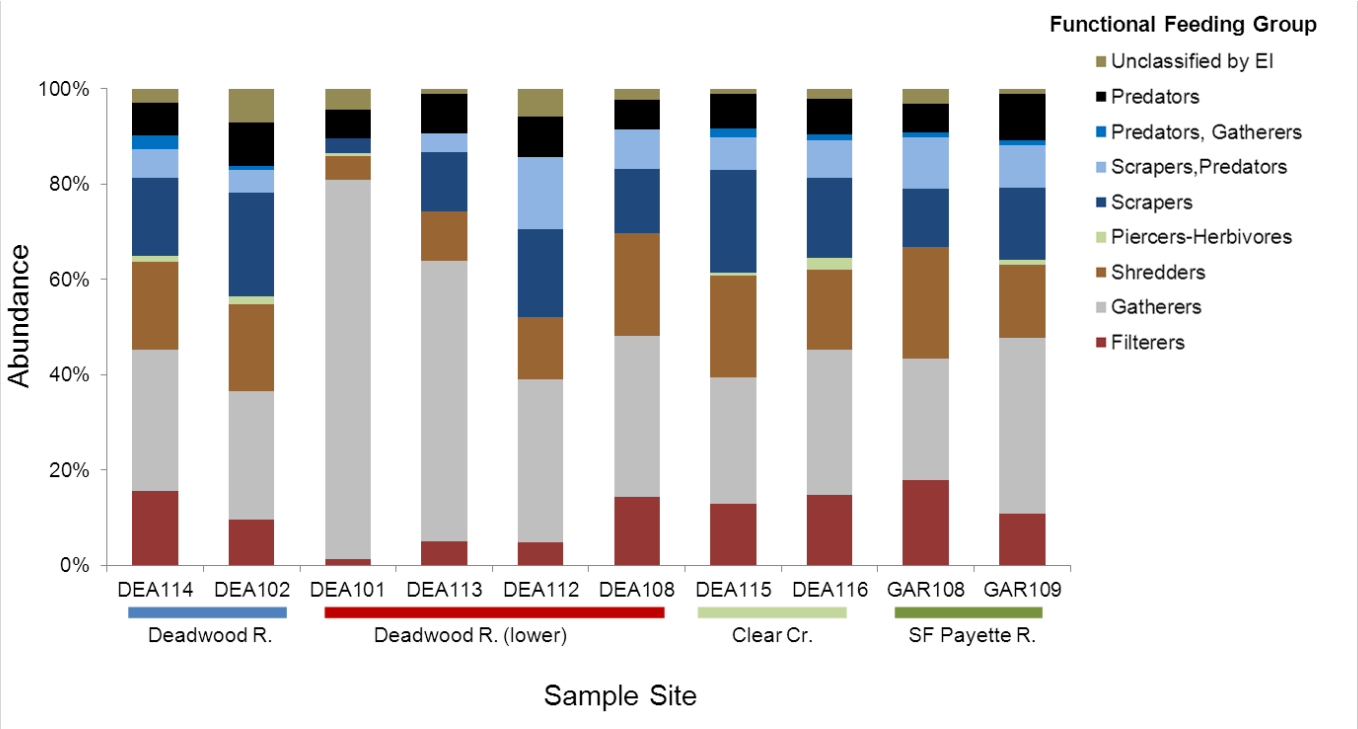


Figure 3-124. Mean percent abundance of benthic macroinvertebrate functional feeding groups for each sample site.

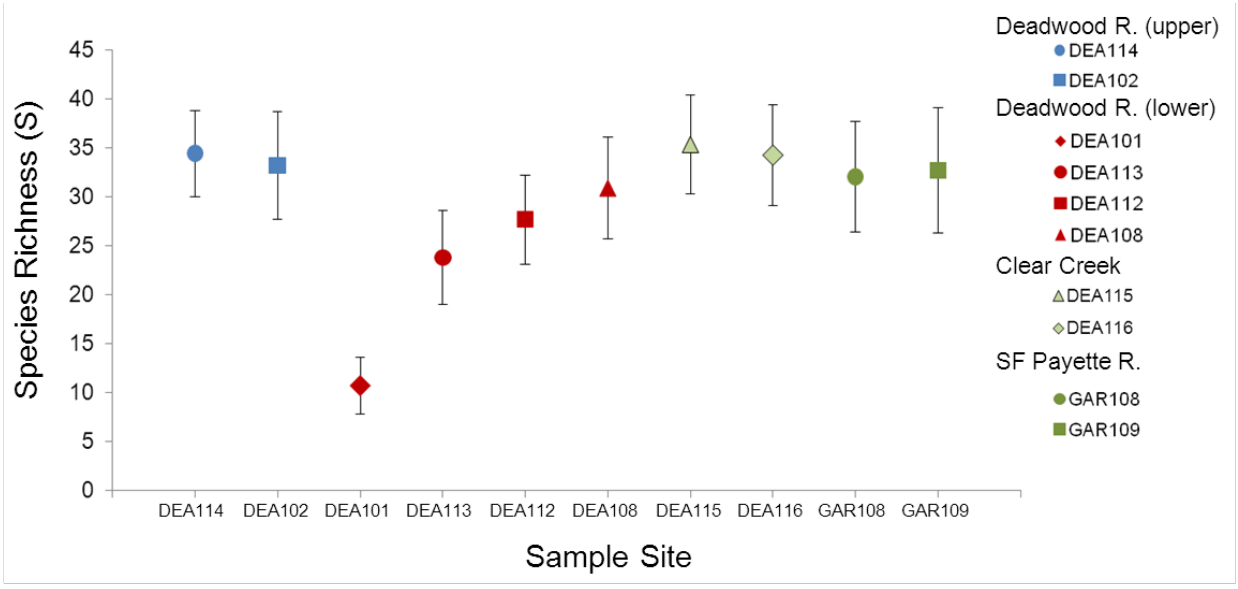


Figure 3-125. Mean species richness (± standard deviation) for benthic macroinvertebrate communities across all sample dates.

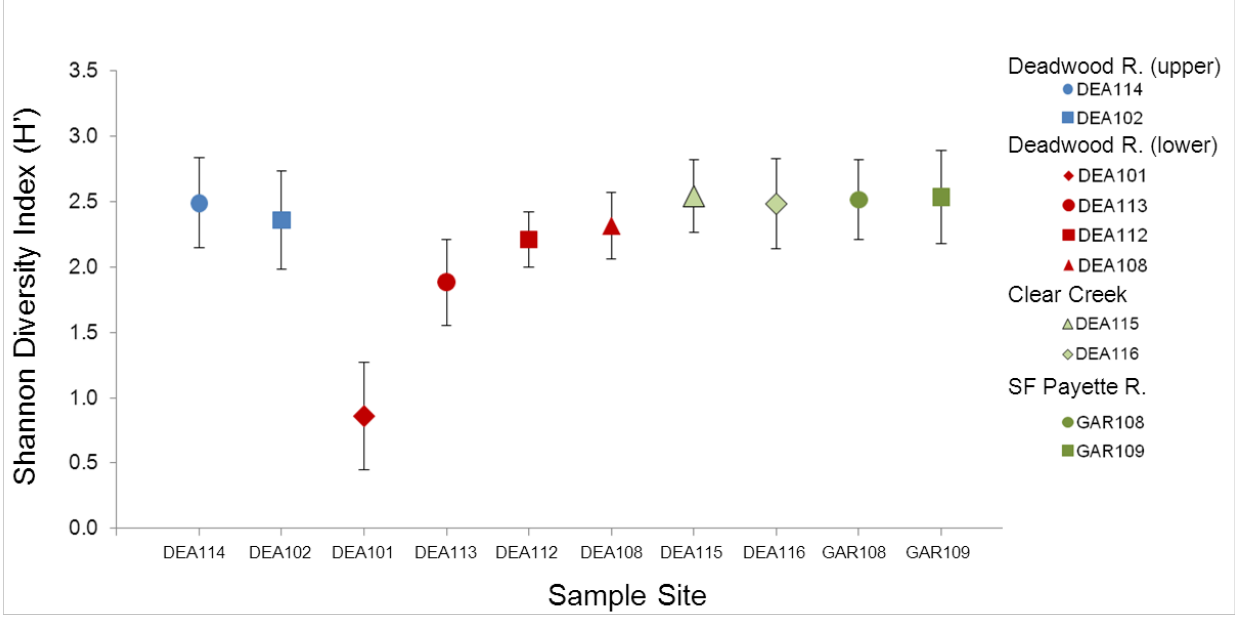


Figure 3-126. Shannon Diversity Index (± standard deviation) for benthic macroinvertebrate communities across all sample dates.

There was a significant difference in benthic macroinvertebrate community composition between sites, detected using ANOSIM for biomass data for 2010 ($R = 0.557$, $p < 0.001$) and 2011 ($R = 0.54$, $p < 0.001$). The site immediately below the reservoir outflow (DEA101) showed the largest separation in ordination space followed by samples from the next site downstream (DEA113). The lower Deadwood sites closer to the mouth (DEA112 & DEA108) were similar to each other and fell between the near dam sites and the unregulated sites (Figure 3-127). Pairwise comparisons between sites confirmed that for both years, the upper two sites in the lower Deadwood River differed from the two lower sites in the lower Deadwood River and differed from the unregulated sites (Figure 3-128). In 2010, unregulated sites grouped within rivers. In 2011, there was no significant difference in community composition between upper Deadwood River and Clear Creek, or between the two lower regulated sites and the South Fork Payette River. An identical analysis of community composition was done using abundance data; results were similar and so are not reported.

To determine which taxa drove differences in community composition between sites, we grouped sites based on the results of the ANOSIM pairwise-comparison and ran a SIMPER analysis of benthic macroinvertebrate abundance and biomass aggregated by order. For the site immediately below the reservoir outflow (DEA101), high abundance of Diptera, Chironomidae, and Oligochaeta, paired with low abundance of Ephemeroptera, Plecoptera, and Trichoptera drove the difference between it and all other sites. For the next closest site

to the dam (DEA113), Plecoptera and Ephemeroptera had high abundance and were the most discriminating orders. A variety of orders drove differences between other sites (Appendix D).

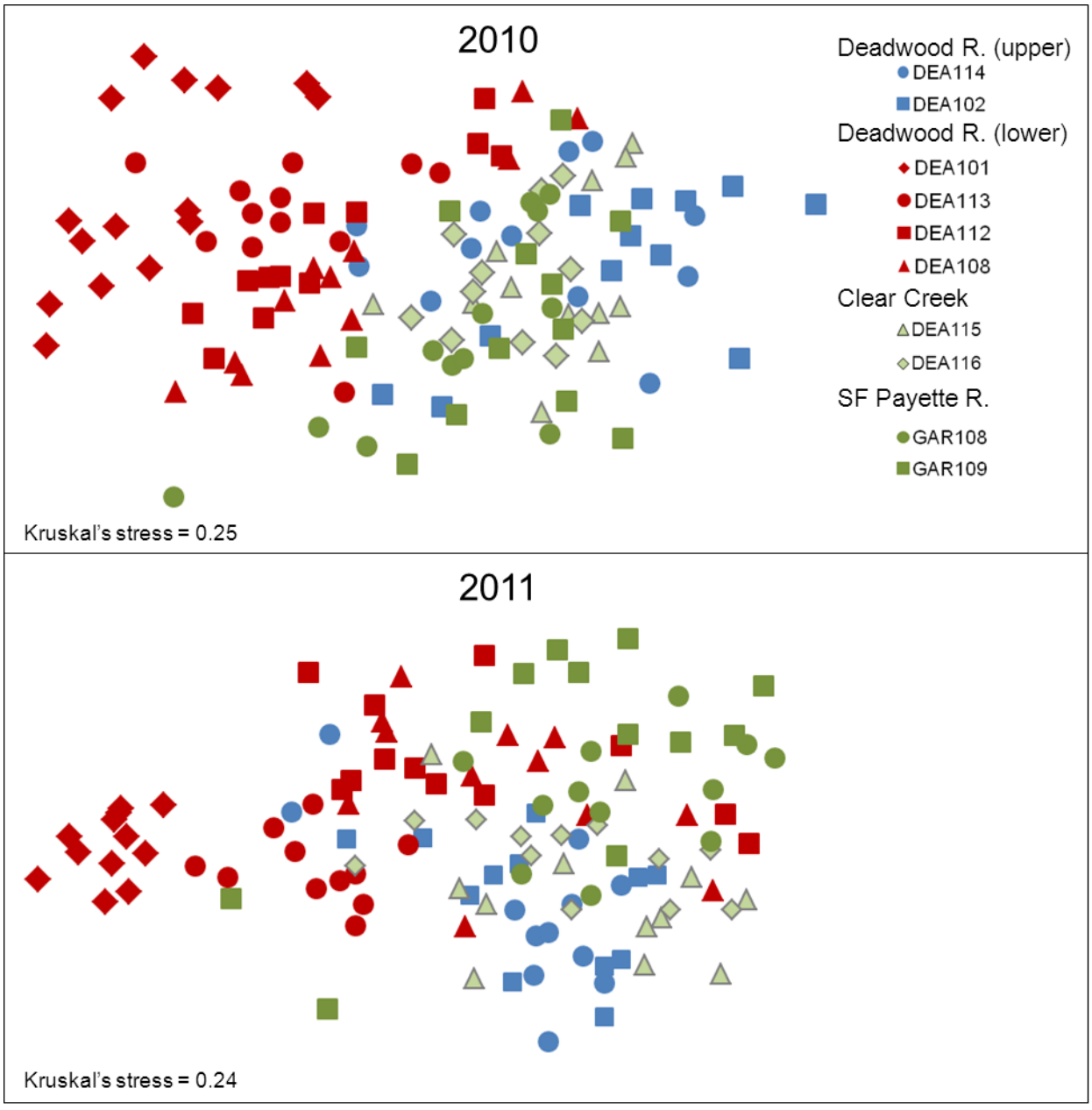


Figure 3-127. MDS plots of benthic macroinvertebrate community composition using biomass data, for 2010 and 2011. Points close together represent samples with similar community composition.

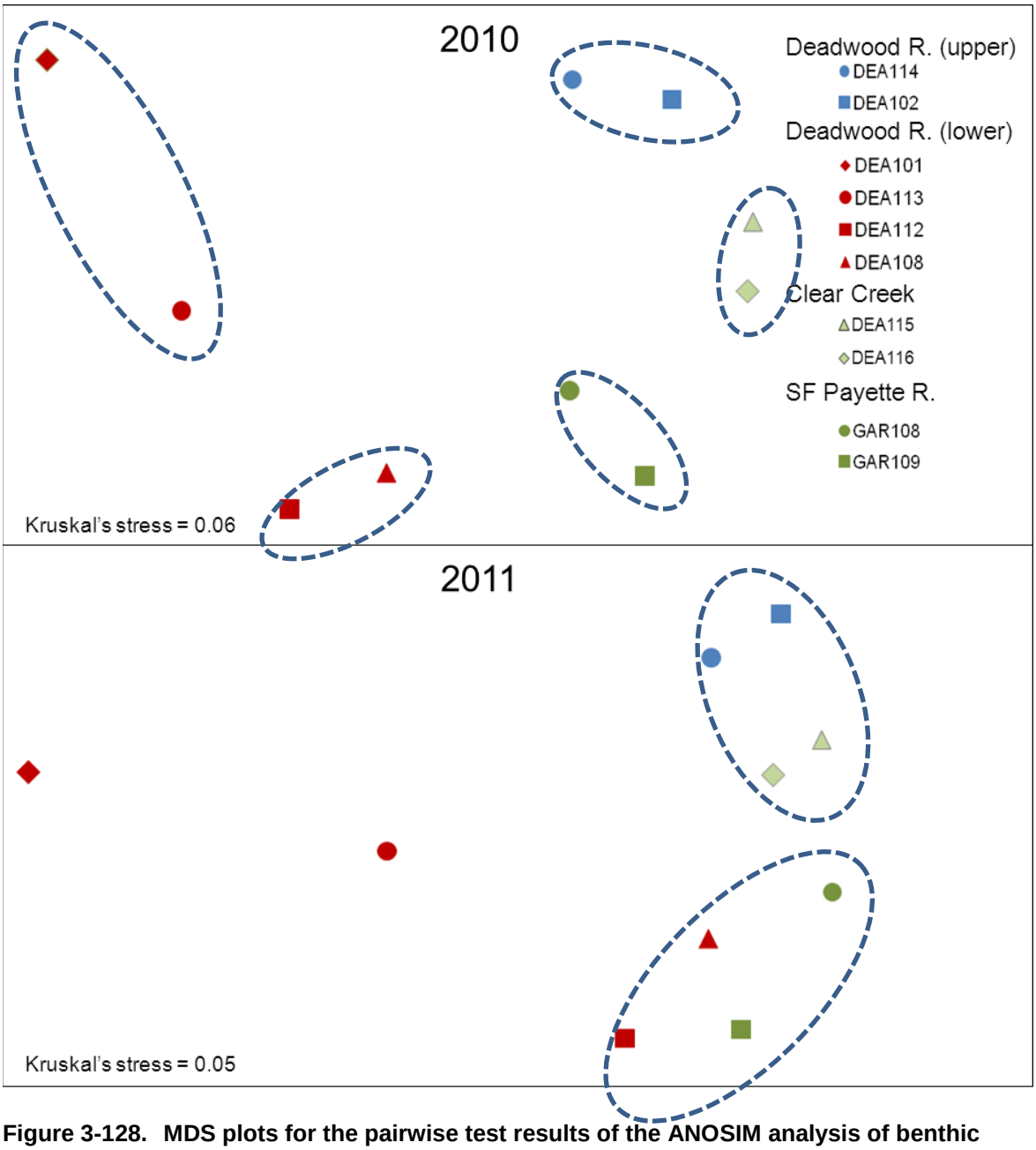


Figure 3-128. MDS plots for the pairwise test results of the ANOSIM analysis of benthic macroinvertebrate community composition using biomass data, for 2010 and 2011. Proximity of points reflects similarity in community composition; sites within an oval are not significantly different from one another.

Macroinvertebrate Production

Average daily production ranged from 8 – 154 mg/m2/d across all sites (Figure 3-129 and Figure 3-130). Productivity was higher in late summer and early fall (July – October) when water temperature peaked, and low in winter. Winter values averaged 25 mg/m2/d.

At specific sites, production was very high during certain intervals (Appendix D). In these cases, high production was due to high density of a few dominant taxa. Such high densities may be in part a sampling artifact. On each sampling date, six Hess samples were composited to three transect-scale samples for analysis. If an area of unusually high density was sampled, abundance and thus production would be overestimated for the entire site. In other cases, one or a few taxa truly may be present at very high densities across the site. For example, at Clear Creek site DEA115, interval production for August 2011 was dominated by the net spinning caddisfly, *Arctopsyche grandis* (Figure 3-131). In Idaho streams, *A. grandis* completes its five instar lifecycle in one year, with almost all growth occurring very rapidly in the summer. Therefore, high production values for this species in August are not unusual.

Mean annual macroinvertebrate production ranged from 8 – 18 g/m2/yr and was similar among regulated and unregulated sites (Figure 3-132). The observed rates were similar to the range reported by McCutchan and Lewis (2002) for St. Vrain Creek, Colorado, a forested montane stream (mean ± sd: 7.5 ± 3.3 g/m2/yr, n = 6). Unregulated sites in this study support robust populations of resident Bull Trout and other native fish. These results indicate that macroinvertebrate production is not likely to be limiting growth of Bull Trout or other fishes in the lower Deadwood River.

Effects of Reservoir Operations on Macroinvertebrate Production

Production of benthic macroinvertebrates was simulated at the four regulated sites in lower Deadwood River for all scenarios of reservoir operations (Table 3-31) except for the 0 cfs winter release scenarios at DEA101 just below the dam, where flow would be very low. Production across sites and operational scenarios ranged from 5.9 to 23.9 g /m2/yr (Figure 3-133 through Figure 3-135).

Effects of river regulation on benthic macroinvertebrate production for each scenario are visualized best by examining the difference between production for that scenario and production for the unregulated scenario (Figure 3-136). Effects of river regulation on benthic macroinvertebrate production varied from positive to negative.

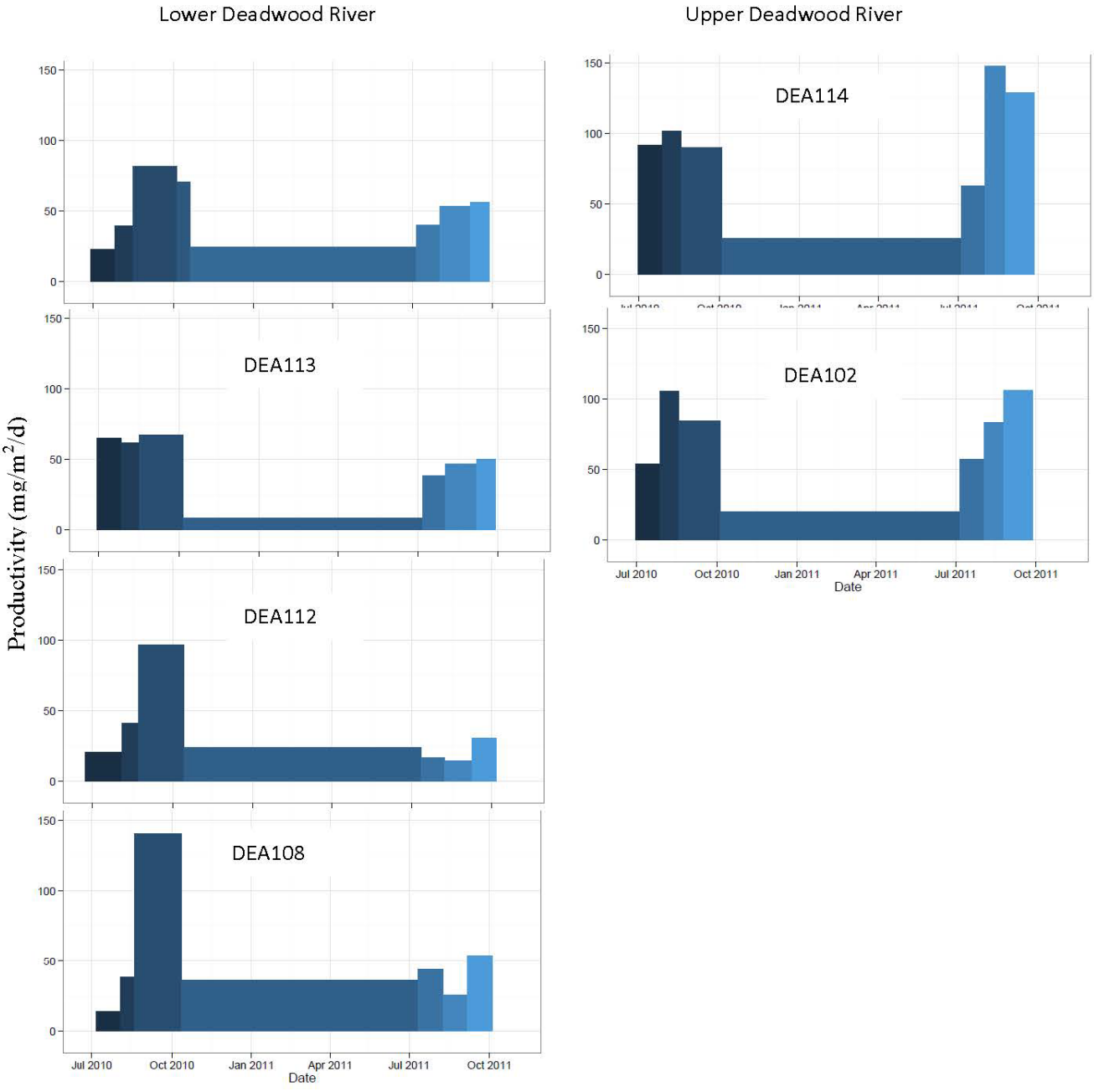


Figure 3-129. Mean daily macroinvertebrate productivity (mg/m2/d) measured at regulated sites in lower Deadwood River and unregulated sites in upper Deadwood River, July 2010–October 2011.

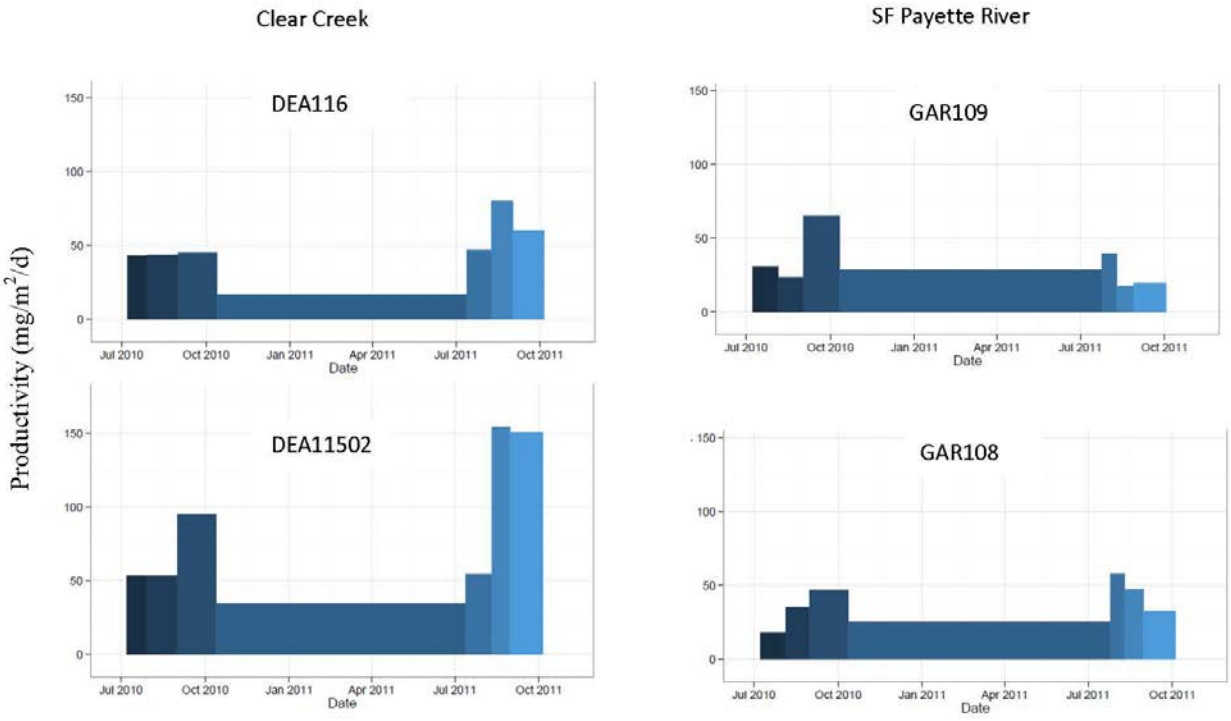


Figure 3-130. Mean daily productivity (mg/m2/d) measured at unregulated sites in Clear Creek and South Fork Payette River, July 2010–October 2011.

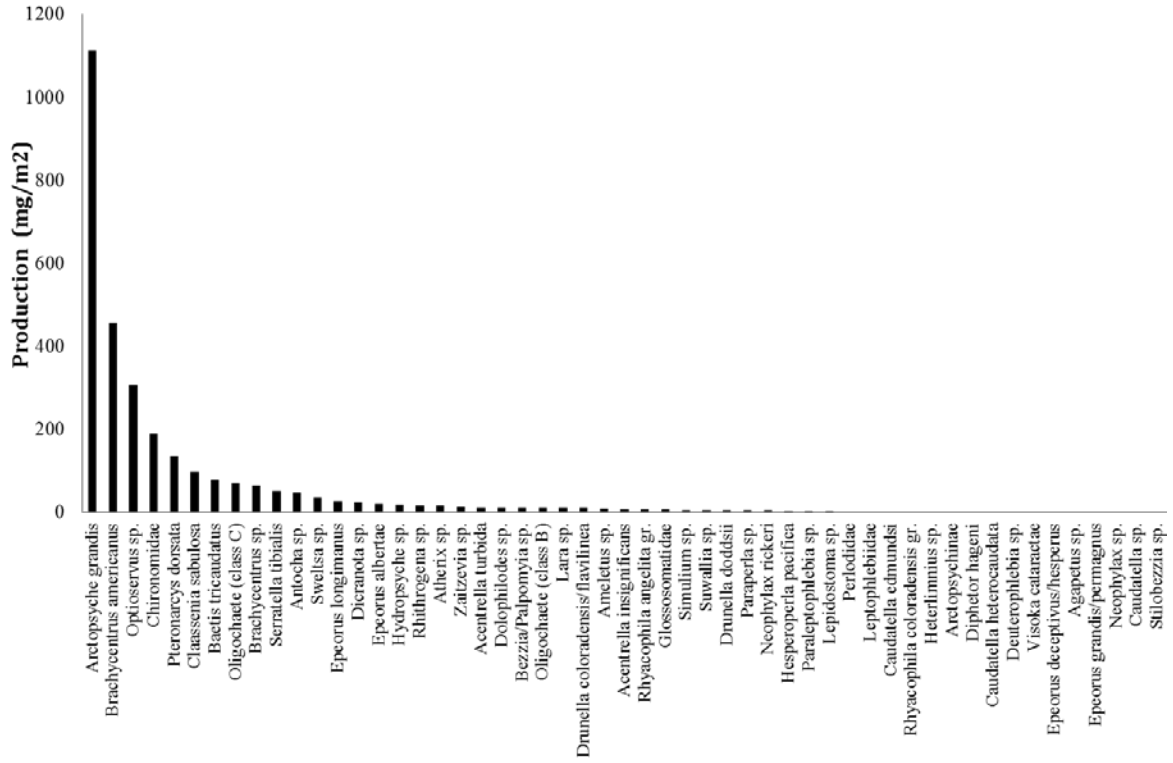


Figure 3-131. Production (mg/m2) by taxon for measurement Interval 6 (August 9 – September 1, 2011) at Clear Creek (DEA115).

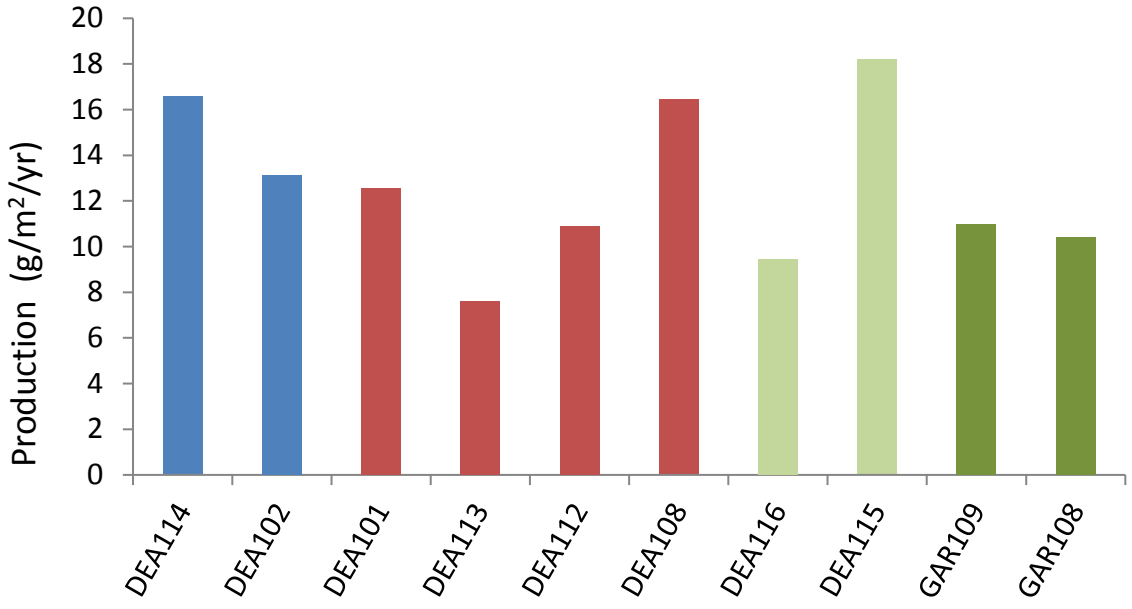


Figure 3-132. Annual macroinvertebrate production (mg/m2/yr) measured at upper Deadwood River (blue), lower Deadwood River (red), Clear Creek (light green) and South Fork Payette River (dark green), July 2010–October 2011.

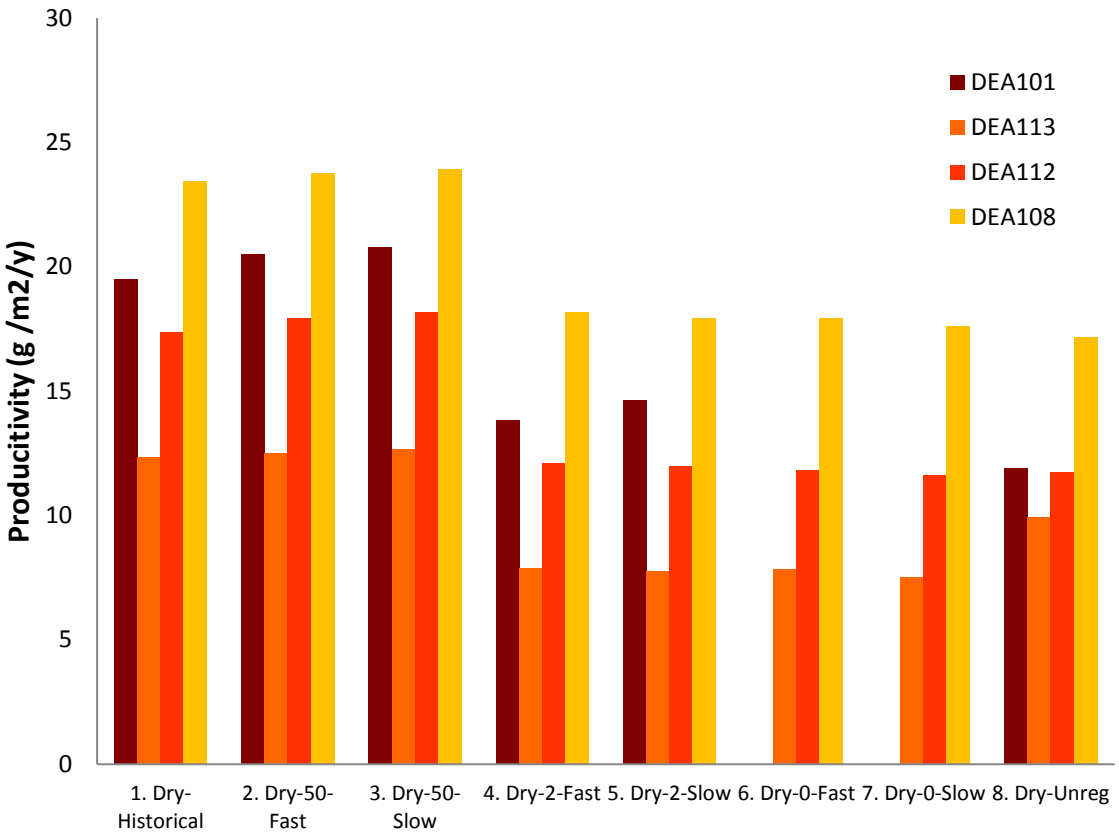


Figure 3-133. Annual macroinvertebrate production simulated for alternative reservoir operations during a dry water year (Simulations #1-8, see Table 3-31 for description). Estimates for DEA101 for winter release of 0 cfs did not account for the fact that there would be little or no flow at this site in winter; therefore, these estimates are not reported.

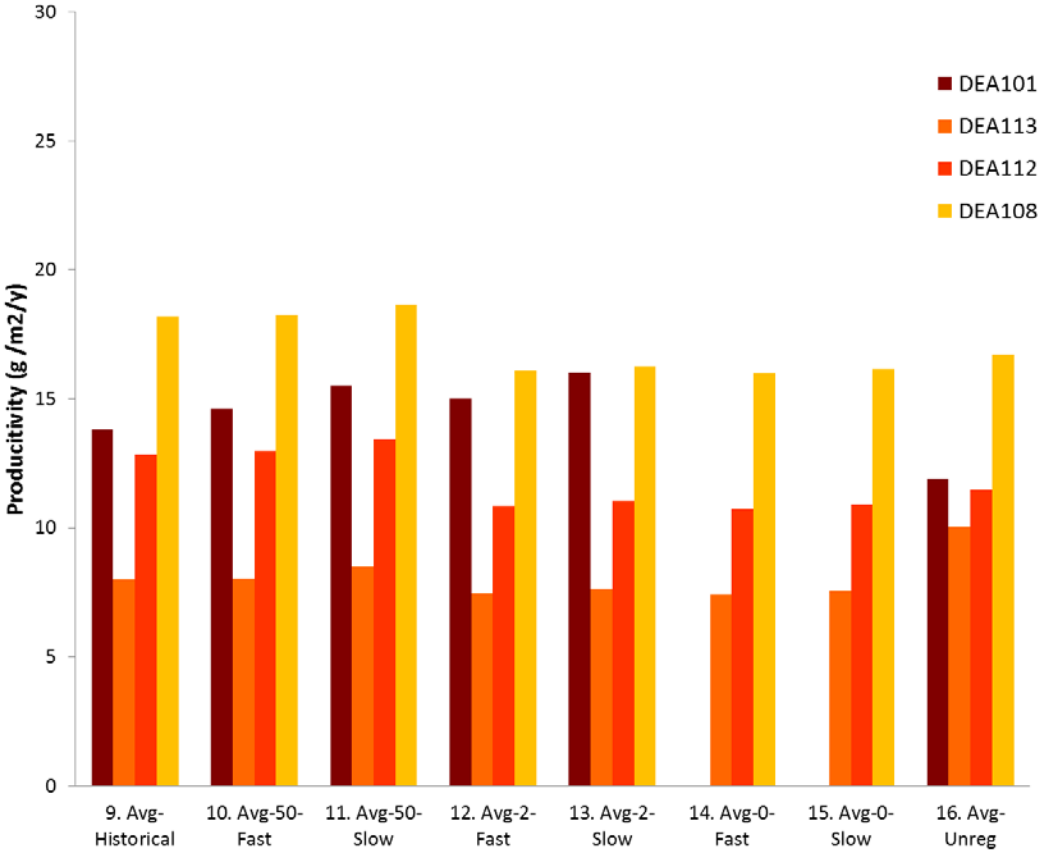


Figure 3-134. Annual macroinvertebrate production simulated for alternative reservoir operations during an average water year (Simulations #9-16, see Table 3-31 for description). Estimates for DEA101 for winter release of 0 cfs did not account for the fact that there would be little or no flow at this site in winter; therefore, these estimates are not reported.

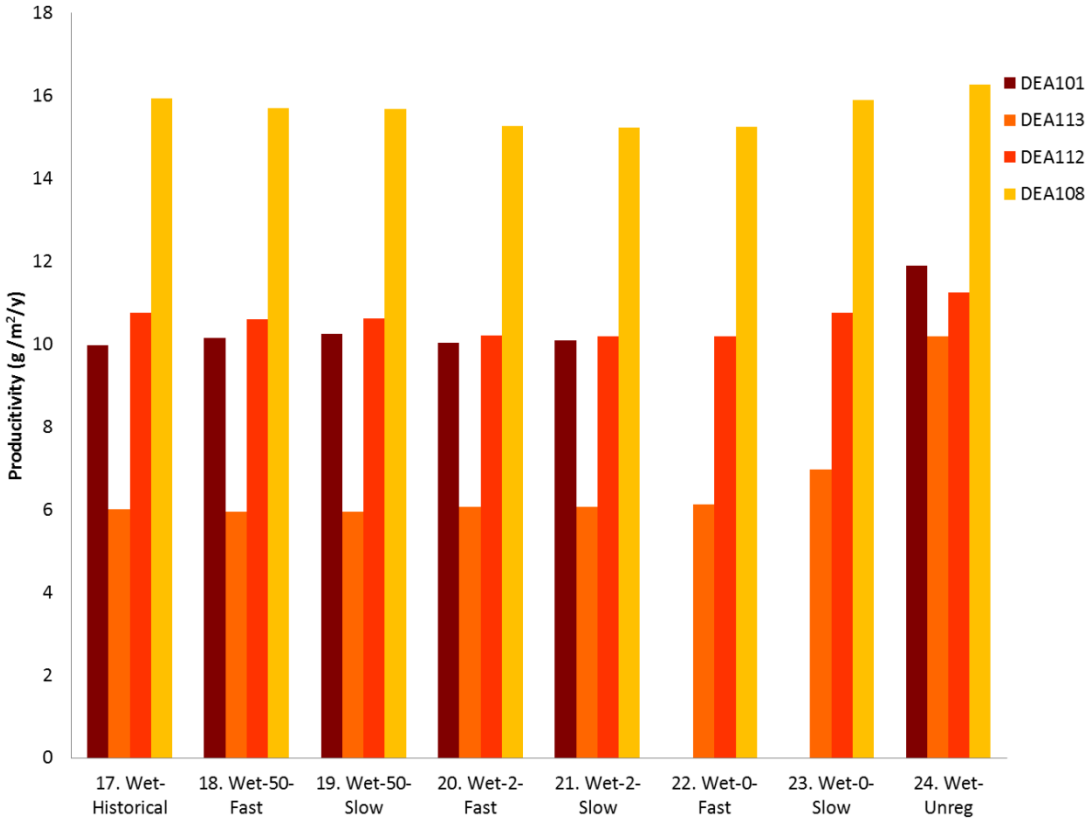


Figure 3-135. Annual macroinvertebrate production simulated for alternative reservoir operations during a wet water year (Simulations #17-24, see Table 3-31 for description). Estimates for DEA101 for winter release of 0 cfs did not account for the fact that there would be little or no flow at this site in winter; therefore, these estimates are not reported.

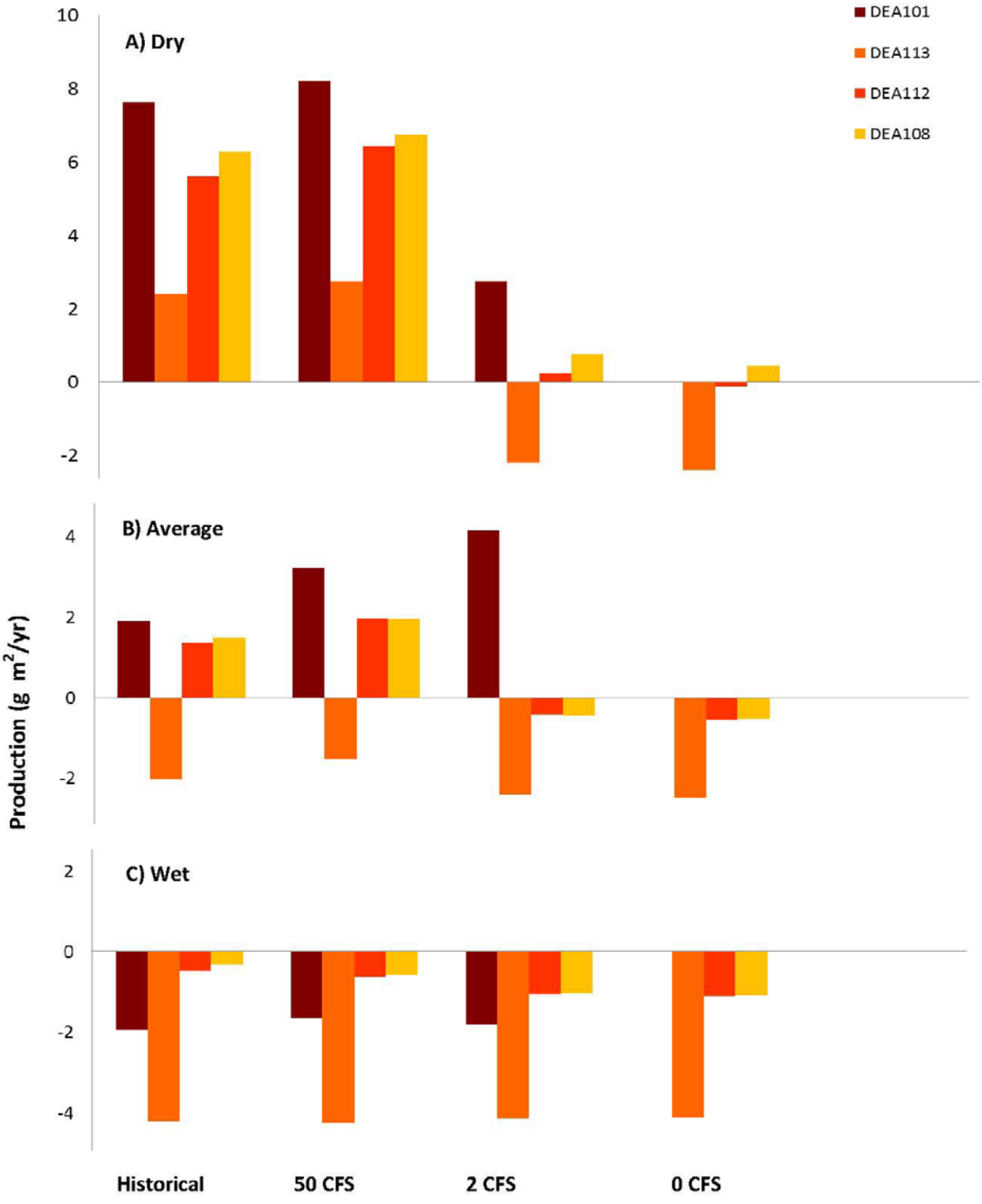


Figure 3-136. Simulated macroinvertebrate production expressed as the difference from unregulated scenarios (g/m2/yr) for A) dry, B) average, and C) wet water years. Scenarios shown had slow ramping rates and the x-axis describes winter dam releases. DEA101 at 0 cfs winter release is not shown.

3.3.4 Summary and Conclusions

There are clear effects of river regulation at the first two sites downstream of the dam (within 4 km) in terms of flow, temperature, water quality, periphyton, and macroinvertebrate community structure. Most of these effects dissipate by the next site downstream, at 24.8 km, due to tributary inflows and potentially also due to nutrient uptake and storage in aquatic biota.

Macroinvertebrate production at all regulated sites was within the range measured at unregulated sites, which support robust populations of Bull Trout. Rates of annual production measured in this study were similar to those measured at montane sites in North Saint Vrain Creek, Colorado (McCutchan and Lewis 2002).

We developed a temperature-dependent macroinvertebrate growth model for the Deadwood River, and drove the model using temperature regimes for multiple scenarios of reservoir operations. Simulation results showed that effects of reservoir operations varied with hydrological conditions and with downstream distance from the dam. Annual production was relatively high for dry years, intermediate for average water years, and relatively low for wet years. Hydrological conditions moderated effects of reservoir operations: for dry and average years, 50 cfs winter releases generally had higher production rates than did 0 and 2 cfs winter releases, which had similar annual production. During wet water years, all operations had negative effects on annual production. While the most negative impact on macroinvertebrate production was during wet hydrological conditions, reservoir managers have little ability to increase temperatures in the regulated river with a bottom-release dam.

There is no evidence that macroinvertebrate production limits Bull Trout abundance under historical operations. Furthermore, macroinvertebrate production does not appear to be a concern for any of the operational scenarios considered in this study, except perhaps very close to the dam. Historical and 50 cfs winter release scenarios generally produced the highest annual production of macroinvertebrates, particularly in dry years. There is uncertainty about effects of dewatering in 0 cfs winter releases at near-dam sites. If 0 or 2 cfs winter release operations are implemented, we encourage reservoir managers to monitor effects on macroinvertebrate populations especially within 5 km of the dam.

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Chapter 4 BULL TROUT

4.1 Bull Trout Movement and Growth in the Deadwood Basin

4.1.1 Introduction

The Deadwood Reservoir Flexibility study was initiated in 2006 to collectively address all five Terms and Conditions and their relative benefits and effects related to threatened Bull Trout in the Deadwood Basin. This chapter addresses Bull Trout movement, growth, and entrainment related to Deadwood Dam and associated water operations. The reporting requirements of the Biological Opinion (BiOp) (USFWS 2005) also direct Reclamation to monitor Bull Trout take. Reclamation combined its entrainment and take monitoring efforts to comply with these requirements.

Bull Trout exhibit several life history strategies including resident (stream), fluvial (river), and adfluvial (lake). Adult rearing location determines the life history strategy of the individual. Migratory life histories (fluvial or adfluvial) assume risks of migration but also reap benefits of attaining larger sizes and greater fitness. When reservoirs are present, Bull Trout have been documented to utilize reservoir habitats for adult rearing. These environments can provide growth benefits such as diverse prey base and deep over-wintering habitat. Reservoir rearing has been documented in many basins within the native range of Bull Trout, such as the Deschutes (Lake Billy Chinook) (Beauchamp and Van Tassell 2001), North Fork Clearwater (Dworshak Reservoir) (Erhardt and Scarnecchia 2014), and Boise basins (Arrowrock Reservoir) (Mannot et al. 2008).

Stream temperature is important in relation to tolerances and preferences of Bull Trout (Dunham et al. 2003; Howell et al. 2010). Howell et al. (2010) recorded 7-day daily average maximum summer temperatures between 14 and 18^{o}C in Bull Trout spawning and early rearing locations and 18 to 25^{o}C water temperatures in stream reaches where adult Bull Trout rear in the Grande Ronde Basin, a tributary to the Snake River in Northeastern Oregon. Individual adult Bull Trout were documented in water temperatures as high as 21^{o}C (Howell et al. 2010). Laboratory studies of age 0 and age 1 Bull Trout found that trout survive maximum temperatures up to 20^{o}C. Once temperatures exceed 20^{o}C, the trout begin to show signs of stress and reduced feeding (Selong et al. 2001). Additionally, age 1 Bull Trout tested in the lab could survive maximum temperatures up to 20.9^{o}C for up to 60 days (Selong

et al. 2001). Predicted growth in age 0 and age 1 Bull Trout measured in lab experiments is maximized at 13.2°C (Selong et al. 2001). The effect of water operations on water temperature in the Deadwood River downstream from the dam is addressed in detail in Chapters 3 and 5. Reservoir water temperatures are discussed in Chapter 2. Reservoir water temperature in relation to Bull Trout movements during this study is discussed below.

Tagging studies are used to identify migration behavior and habitat use. Tags that emit signals, such as radio tags, can be used to detect fish and animals. These provide information during periodic timeframes that are reliant on the tracking effort. Radio and acoustic tags are most useful for large movement studies as they allow Bull Trout to be located from long distances though acoustic tags are more appropriate for deep water habitats. Both tags are located with receivers that allow each tag to be uniquely identified. Receivers can either be stationary or mobile. Stationary receivers collect continuous data in one location (such as a tributary mouth or reservoir pool boundary) while mobile tracking is used to locate tagged fish in a discrete time period. Mobile tracking is accomplished in a vehicle and the location is identified by triangulation and signal strength. Archival tags are another type of tag that can record continuous data on depth and temperature. However, archival tags must be retrieved in order to download the associated data. Radio, acoustic, and archival tags are reliant on battery life and/or memory storage capacity. Passive Integrated Transponder (PIT) tags are tags that last indefinitely but do not store or transmit data. PIT tags work by using an external power source and antenna that reads a unique alpha-numeric code on the individual tag when the tag passes within range of an antenna (less than 24 inches). PIT tags can be used to monitor movement at select locations with large stationary antennas or measure growth of individual fish between recapture events.

Demographic information in populations of fish or wildlife, such as growth, age composition, mortality and abundance, can be used to assess population status. When combined with environmental or biotic data, growth data can be used to identify potential limitations to individual growth or condition. Growth varies annually and seasonally with temperatures, other environmental conditions associated with energetic demands and inter- and intra-specific rearing densities. Additionally, growth varies with location in the stream, and fish often will move between streams and habitats in short or long-range movements and experience different environmental and prey conditions in different locations. Growth rates also vary with the age of the fish where older fish grow in smaller increments than younger fish. Therefore, discerning information from the wide variation in individual growth and migrations can become complicated.

Three methods are used to estimate growth in fishes: 1) mark-recapture method; 2) aging from anatomical structures such as scales, otoliths or fin rays; and 3) aging from length-frequency data. The mark-recapture method uses empirical growth on known (marked) individual fish over a known period of time. The aging method based on anatomical structures back-calculates growth from a known length at capture, identification of growth

lines (annuli) and a proportional calculation between each annulus and the total width of the structure from a center (focal) point. Length-frequency data are used to identify age classes (or cohort groups). This method is heavily reliant on sample size and is typically only effective in identifying the smallest age class(es) from a peak in the distribution of the sizes. This method is less exact due to overlap among sizes of fish in different year classes that result in some uncertainty when not coupled with an aging technique.

The objectives of this chapter are to: 1) identify habitat use and migration timing of Bull Trout in the Deadwood Basin; 2) identify risk of entrainment; 3) identify annual growth rates for Bull Trout rearing upstream versus downstream from Deadwood Dam; and 4) relate reservoir conditions and operations to Bull Trout growth and movements.

4.1.2 Water Operations

Water is stored in Deadwood Reservoir for irrigation supply and hydropower at Black Canyon Dam. Some of the water stored in Deadwood Reservoir is also used to supplement river flows for out-migrating salmon and steelhead smolts. Water is released over the spillway, through the outlet works, or both. The outlet works at Deadwood Reservoir, from which most discharge occurs, are located at elevation 1,586.5 m (5,203 feet), 39.3 m (129 feet) below the full pool water surface elevation. The crest of Deadwood Dam is at elevation 1,627.6 m (5,340 feet) with spillway crest at elevation 1,625.8 m (5334 feet). The spillway crest at Deadwood Dam is fixed, so spillway discharges are regulated solely by the reservoir elevation. Once the reservoir elevation reaches the spillway crest, spillway discharges can be adjusted by regulating releases from the outlet works. Neither the spillway or outlet works have fish screens to prevent entrainment. The relative operation and timing of the outlet works and spillway are summarized in Chapter 3, Section 3.1.1.

Deadwood Reservoir is typically drafted from its maximum pool elevation in early July to lowest pool elevations which range from 1,612 m to 1,617 m in late August (8.8 to 13.8 m below the full water surface elevation). Reclamation operates the reservoir to maintain a minimum pool of 50,000 acre-feet, and releases a minimum of 50 cfs downstream from the dam during post-irrigation season. Figure 4-1 shows elevations of Deadwood Reservoir during the 2006–2011 time period.

Exceedance probabilities based on the historic records for Deadwood River are provided in Chapter 1. Briefly, water year 2006 (15% exceedance) was wet whereas 2007 was dry (73% exceedance). The other water years, during which Bull Trout data were collected for this study, 2008, 2009, and 2010 were near average. See Figure 4-2 for additional details.

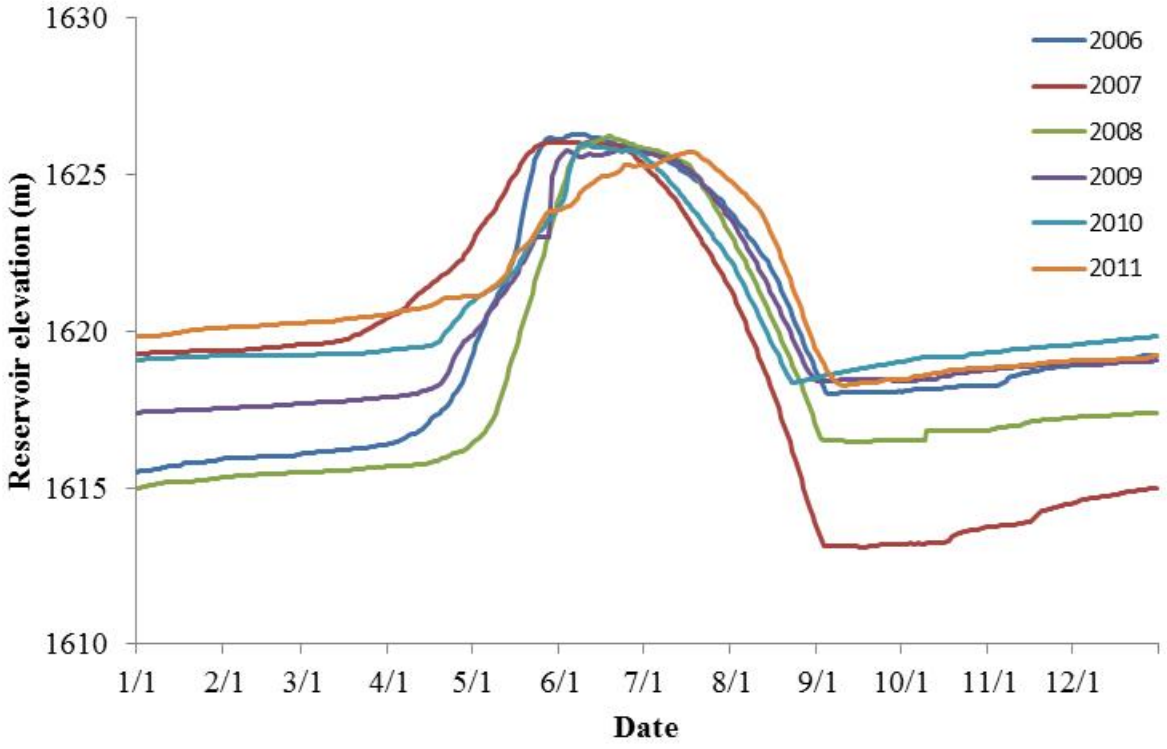


Figure 4-1. Elevations of Deadwood Reservoir, 2006-2011.

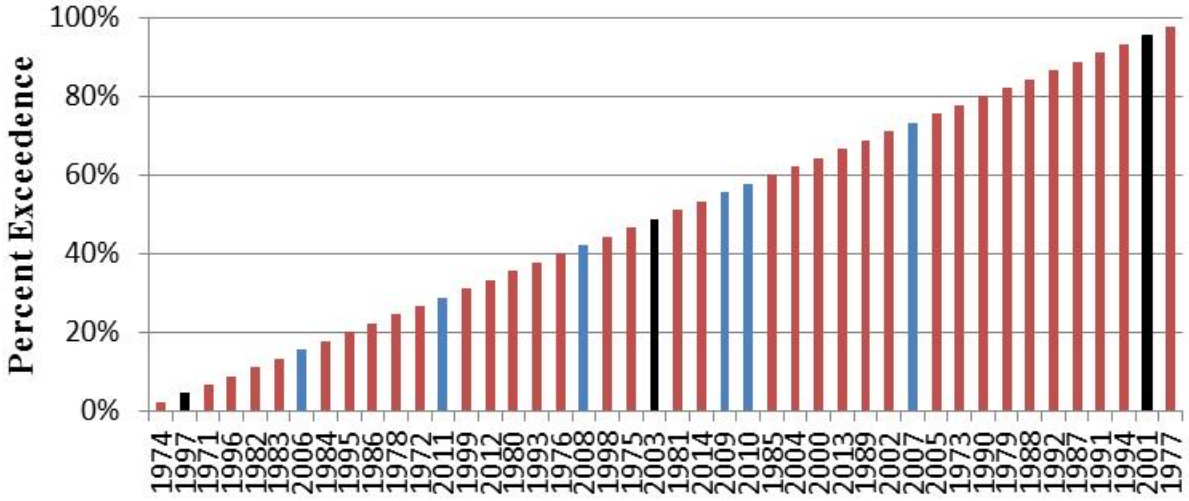


Figure 4-2. Percent exceedance of water years based on recent period of record (1971 to 2014) during the study. The blue bars represent years during data collection of Bull Trout movement and growth. The black bars represent years used in the model scenarios as wet, dry, and average climatic conditions.

4.1.3 Fish Community and Stocking Records

The Deadwood River historically supported runs of anadromous salmon and steelhead. Since the early 1900s, dams such as Grimes Pass Dam on the South Fork of the Payette River (1904, breached in 1943) and Black Canyon Dam on the lower Payette River (1924) have blocked seasonal fish passage and additional dams in Hells Canyon on the Snake River have further hampered the passage of these species and stocks of fish since the 1950s. The fish community and stocking records are presented in Chapter 2, Section 2.3.1 and discussed in more detail in relation to Bull Trout diet and production. Idaho Department of Fish and Game (IDFG) currently stock Fall Chinook Salmon (*Oncorhynchus tshawytscha*) and triploid (sterile) Rainbow Trout (*O. mykiss*) in Deadwood Reservoir. Other species stocked include: Kokanee Salmon (*O. nerka*), non-sterile Rainbow Trout (Kamloops stock), Atlantic Salmon *(Salmo salar*), Westslope Cutthroat Trout (*O. clarki lewisi*), Yellowstone Cutthroat Trout (*O. clarki bouvieri*) and Coho Salmon (*O. kisutch*) (IDFG 2015). Native fish species currently present in the Deadwood Basin include: Bull Trout (*Salvelinus confluentus*), Westslope Cutthroat Trout, Rainbow/Redband Trout, Redside Shiner (*Richardsonius balteatus*), Longnose Dace (*Rhinichthys cataractae*), Mountain Whitefish (*Prosopium williamsoni*), and Sculpin (*Cottus spp.*). All of the native species listed and Kokanee Salmon were captured above and below the dam during this study. Fall Chinook Salmon were not captured during this study and will not be discussed further, but are present in the basin due to the stocking activities. General location, species, and numbers captured during this study are listed in Appendix E.

4.1.4 Methods

Fish Capture

Between 2006 and 2011, Reclamation captured Bull Trout using a variety of gear: fyke nets (trap nets), horizontal gill nets, vertical gill nets, hook and line sampling, bag seines, electroshocking, and minnow traps. Sampling efforts differed by area and year based on conditions and study objectives at the time of sampling. The main areas of sampling were concentrated in Deadwood Reservoir, upper Deadwood River above the reservoir and lower Deadwood River below the reservoir, tributaries above Deadwood Dam, and tributaries below Deadwood Dam (Figure 4-3).

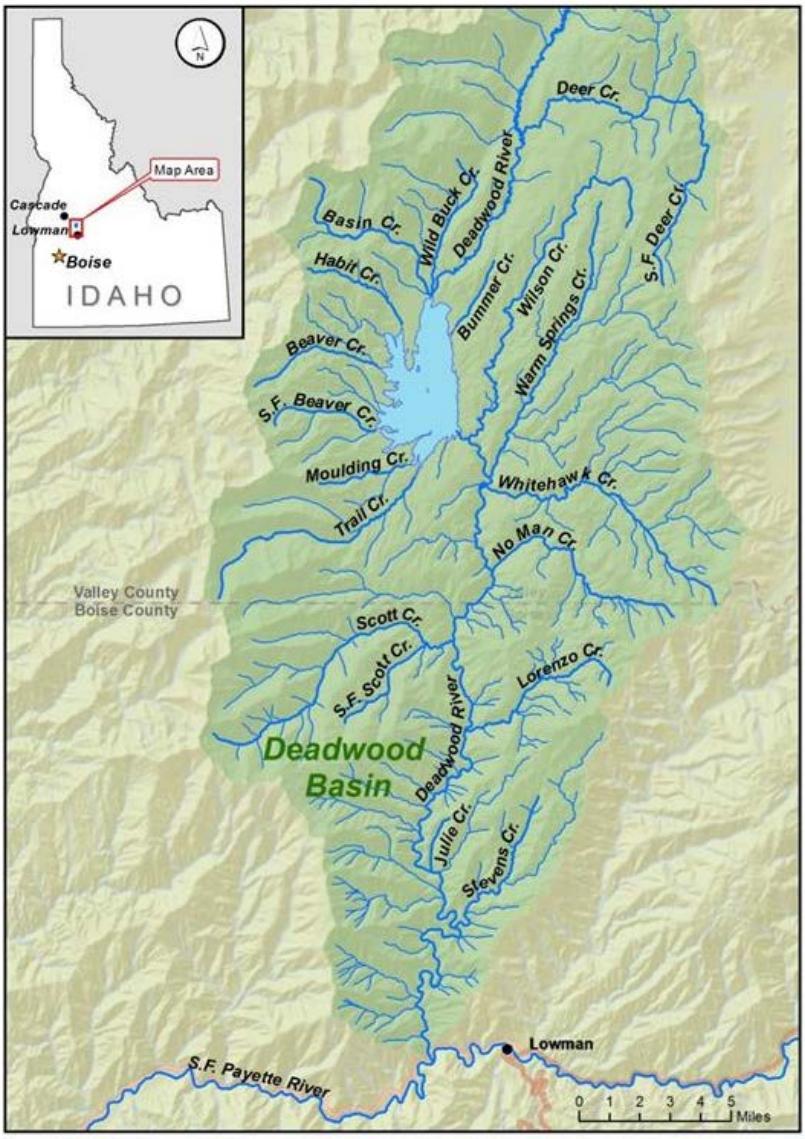


Figure 4-3. Deadwood River basin, Deadwood Reservoir, and tributaries.

Trap nets were set in the reservoir from mid-May to late September from 2006 to 2011. The earliest sampling date in the spring was reliant on road access to Deadwood Dam and Reservoir based on spring snowpack and road closures. From 2007 to 2010, trap nets were deployed in the stilling basin below the dam in addition to sites upstream from Deadwood Dam. In 2011, trap netting only occurred at sites upstream from Deadwood Dam. Trap nets were set in the stilling basin between June and October when possible to sample.

Trap nets were set at the mouths of Basin, Bummer, Beaver, Habit, Moulding, Trail, South Fork Beaver, and Wildbuck creeks as well as in the mainstem Deadwood River (Figure 4-4). Effort in the later years focus more heavily at the mouth of Trail, South Fork Beaver, and Beaver creeks based on success of Bull Trout captures. Trap nets were set for up to 24-hour

intervals 4 days per week. The trap nets measured 1.22 m by 1.22 m by 0.91 m and had 4 fykes per net and 30.48 m by 1.22 m lead lines (Figure 4-5). The trap nets were set just downstream of the convergence zone of the stream and reservoir. The trap nets set in the mouths of the tributaries started upstream and progressively had to be moved downstream as the reservoir level receded to keep them in water with the appropriate depth and temperature.

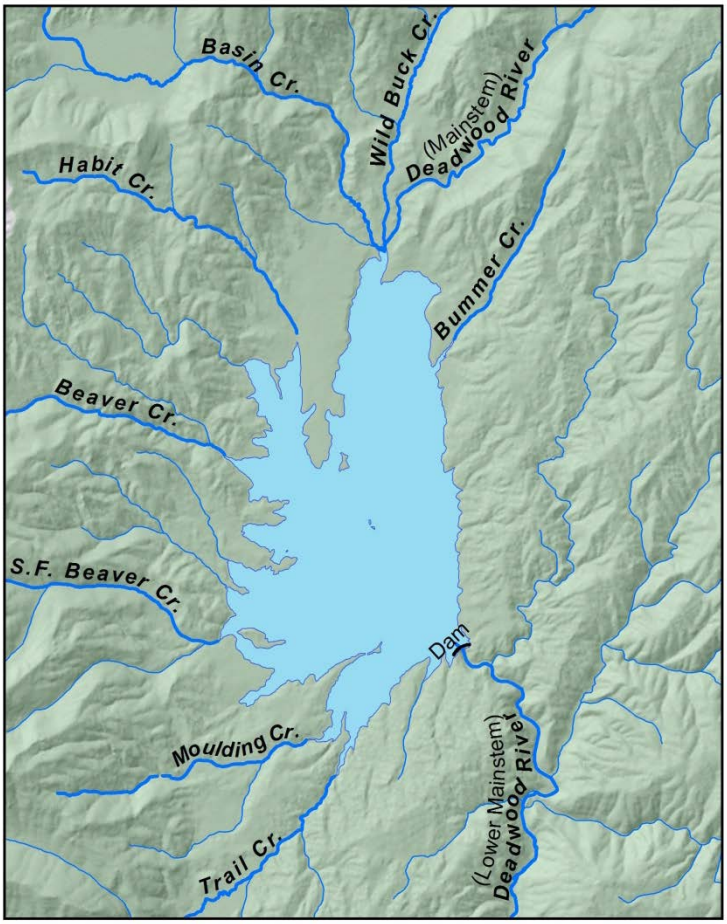


Figure 4-4. Tributaries of Deadwood Reservoir.

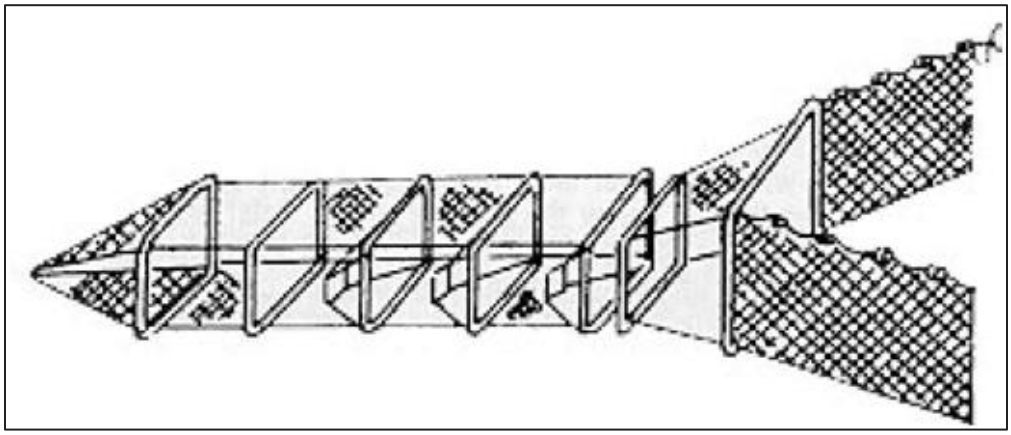


Figure 4-5. Fyke net (trap net) for capturing Bull Trout.

IDFG operated weirs on several reservoir tributaries from 1986 through 2008 and in 2010 through 2012 to control Kokanee Salmon populations and collect eggs. These weirs provided an opportunity for Reclamation staff to capture Bull Trout in cooperation with this separate project. Weirs were operated from mid-August through late September in 2005 and 2010 to 2012, and mid-August through mid-October in 2006 to 2008. No weirs were operated in 2009. Weirs were only operated on the mainstem Deadwood River and Basin Creek in 2010, and the mainstem Deadwood River and Trail Creek in 2011 and 2012.

Tributary electroshocking was conducted in July and August of 2010 and 2011. Electroshocking in the mainstem Deadwood River occurred in 2006 and 2010. Electroshocking of stranding pools disconnected from the Deadwood River below Deadwood Dam occurred in 2010, 2011, and 2012. A boat electroshocker was also used in the stilling basin in 2010. There were two goals in using this technique in the tributaries: to collect Bull Trout for genetic samples for determining natal origin, and to capture and tag Bull Trout to identify movements and habitat use. Boat shocking in the stilling basin was also part of a salvage effort trying to capture Bull Trout in the lower river between August 24 and September 3, 2010, when the flows below the dam were reduced to 0 cfs for non-discretionary structural repairs (USFWS 2010).

The other sampling efforts (gillnetting, hook and line, bag seines, and minnow traps) were used less frequently with mixed results during the length of the study. Gillnetting took place in Deadwood Reservoir and the stilling basin below the dam, hook and line occurred in nearly all of the locations sampled above and below the dam, bag seines were briefly used in 2011 in the reservoir near Trail and South Fork Beaver creeks, and minnow traps were deployed in 2009 in the reservoir near the mouths of tributaries as well as the stilling basin and river below Deadwood Dam.

Fish were either anesthetized using Tricaine Methane Sulfanate (MS222) in 2006–2011 or by electronarcosis in 2011, a method described by Hudson et al. (2011). All fishes captured

were measured (total length for non-target species; total length, fork length, and weight for Bull Trout). Bull Trout were scanned for a PIT tag and scales were collected from the area between posterior edge of dorsal fin and the lateral line. Scales were then deposited on a small piece of paper and placed in a small envelope labeled with date, location, length (mm), weight (g), and PIT tag number. Other biological samples taken on some Bull Trout included fin clips, stomach samples and muscle plugs for analyses related to this study. All live specimens were returned to their approximate sampling location except for the ten radio-tagged Bull Trout captured in the stilling basin during the 2010 salvage and released to tributaries above the dam and reservoir. Any incidental mortalities and requested voucher specimens were delivered as directed by IDFG.

Tagging and Tracking

Reclamation used four types of tags in the Deadwood River basin to track individual trout. The 12 mm PIT tags were inserted into the dorsal sinus of all Bull Trout greater than 125 mm in total length. Bull Trout larger than the minimum weight requirements were implanted with radio telemetry transmitters (radio tags Lotek models MCFT2-3BM, MCFT2-3EM, MCFT2-3FM, SR-TP11-25, and SR-TP11-35), acoustic tags (Lotek model MM-M-8-SO), and/or archival temperature recording tags (archival tags Lotek Internal model 1410 or Lotek External model 1100). Expected life on the radio-tags was 186 days for smaller size tags (inserted in smaller trout) to 585 days for larger size tags (inserted in larger trout). Radio-tag signals are expected to be received when the tag is in depths less than 10 m, whereas acoustic tags will receive a signal from tags at any water depth. During 2011, acoustic and archival tags were used to track Bull Trout in deeper water habitats and acquire measurements related to depth and temperature. Archival tags store data (depth and temperature) in an internal logger, but the tag must be retrieved for the data to be downloaded. Radio, acoustic, and internal archival tags were implanted with the modified shielded needle technique described by Ross and Kleiner (1982). Incisions were closed using sutures from 2006 to 2010, and stainless steel staples in 2011 (Swanberg et al. 1999). The external archival tags were attached with the method described by Howell et al. (2010). Note that some radio tags were shipped from the manufacturer 1 to 2 years prior to implanting in Bull Trout. Additionally, radio tags were reused in up to three Bull Trout if the tag was operable after retrieval. An unquantified loss in expected tag battery life and increase in rates of tag loss would result from these practices.

Telemetry tracking was to occur weekly by air or by ground based on weather and available resources. In the early portion of the study (2006–2008), most of Reclamation's tracking efforts were by helicopter due to the remote and rugged terrain throughout most of the study area. Summer ground tracking (by boat) was increased in 2008 after reducing the number of helicopter flights. Some helicopter tracking continued through 2011.

Tagged fish were tracked weekly by boat in 2011 to evaluate movement and habitat selection. Tracking was not possible during certain times due to weather and project resources which resulted in three periods of over 100 days between tracking events, and numerous occasions when the tracking interval was 1 to 2 months (Figure 4-6). Most of the long intervals between tracking events occurred during the winter and early spring when the study area was inaccessible. When radio-tagged fish were located, the following data were recorded at that location: time, GPS location, pressure (water depth) and temperature at the fish's location (if the tags were equipped with those sensors) as well as general comments. For each survey day the following data were also recorded: general weather, presence of surface ice cover on the reservoir, reservoir pool elevation, and general comments. Tags inserted in Bull Trout were determined to be suspected mortalities when one of the following conditions was met: 1) tag was retrieved without the fish; 2) tag recorded temperatures consistent with ambient air temperatures; and 3) tag was not retrieved but did not move for an extended period of time (>24 hrs).[1] Although these methods are used to infer mortality, an unknown number of expelled tags can be included in this count when a carcass is not found with the tag.

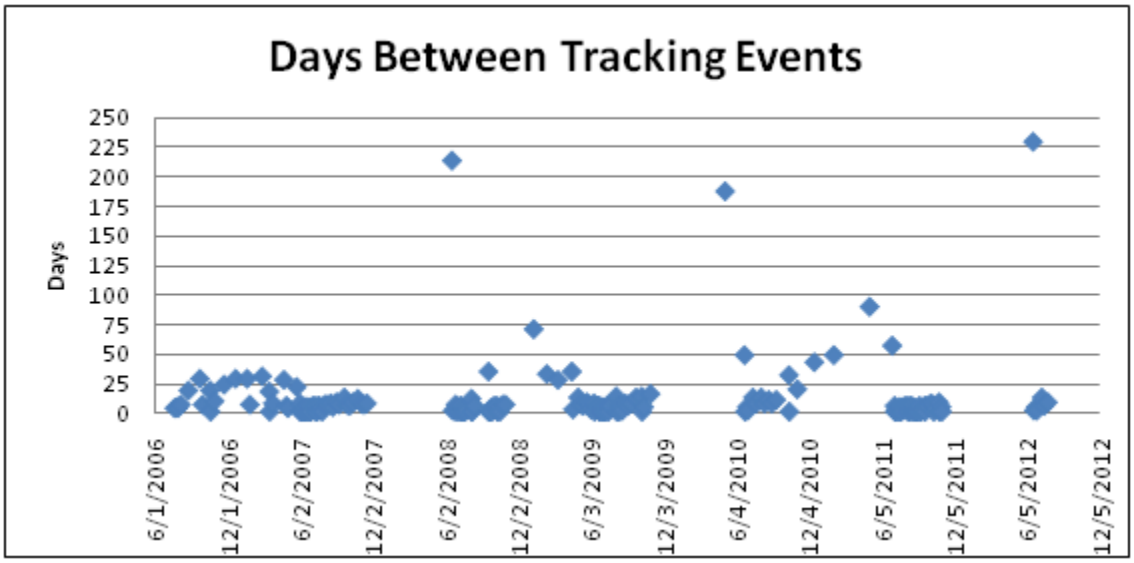


Figure 4-6. Number of days lapsed between tracking events via any method.

Tagged fish were also monitored using fixed telemetry stations at five locations in the basin. Fixed sites were located at: Cozy Cove near the Trail Creek arm in the reservoir (operated 2006 to 2010), Trail Creek near the full pool area (operated 2010 to 2015), Deadwood Dam near the spillway (operated 2006 to 2015), the confluence of Scott Creek and Deadwood

[1] Although >24 hours of stationary detection of unretrieved tags was a standard for identifying suspected mortality used in this study, disagreement exists on whether this is a sufficient timeframe from which to reliably draw a mortality conclusion. This should be considered when evaluating data.

River (operated 2010 to 2012), and the confluence of South Fork Payette River and Deadwood River (operated 2010 to 2012).

Data from mobile tracking are shown in Figure 4-9, Figure 4-10, and Figure 4-11 (shown further in this document) and used to examine potential vulnerability of entrainment in the reservoir. These data pool all mobile tracking methods which can have different spatial accuracy. Data used in the statistical analyses are solely based on stationary receivers and provide comparable detections for specific locations.

Laboratory Methods

In the laboratory, 3 to 4 scales were removed from the scale paper and placed on a Standard 25 by 76 mm glass microscope slide approximately 1 mm thick. Three to four drops of water were added to the slide to re-hydrate scales for one minute. A 24 by 60 millimeter (mm) glass coverslip approximately 0.18 mm thick was then pressed onto the scales. In 2010, scales were magnified using Leica DME microscope at 10x and photographed using a Nikon Coolpix 990 camera. In 2011, scales were magnified with an Olympus CX 31 microscope and photographed using Infinity II 3 Mega Pixel Camera. Multiple photographs were taken of each scale.

Images of all scales were displayed in PowerPoint (Microsoft Cooperation) which allowed each annuli to be marked by drawing a new line across each one. To ensure consistency, all slow growth seasons were marked at the outermost edge. The measurement scale was oriented from the center of the focus along the long axis of the fish scale (Figure 4-7). The measurement scale had no direct link to any standard unit of measurement, but it was consistent between all samples. Estimates for growth and age were applied using the direct proportion back calculation method (Devries and Frie 1996). The estimated length at each checkpoint was rounded to the nearest one hundredth of a millimeter. The distance at last check was rounded to the nearest one thousandth.

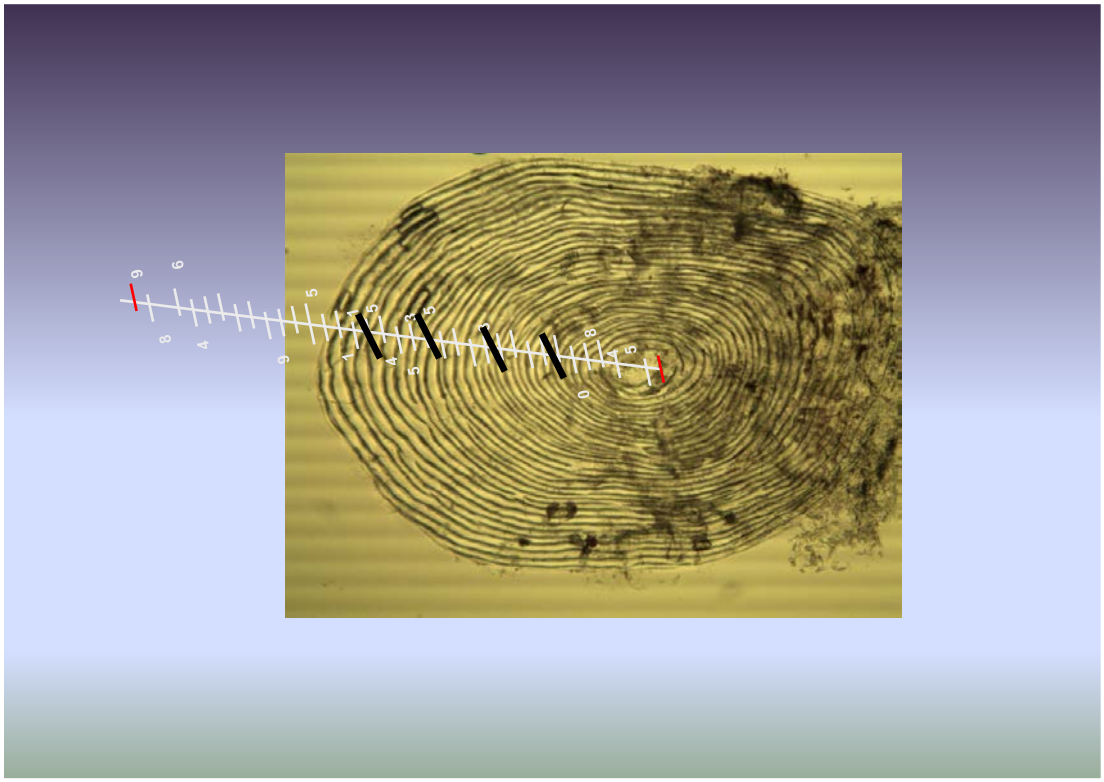


Figure 4-7. Bull Trout scale showing method of length calculations.

The length estimates were verified by using multiple personnel. Three different scale readers were used in 2010 and two different readers were used in 2011. Additional scale readers were utilized whenever there was more than 10 mm difference in length at age calculations, and if this difference could not be resolved the scale sample was not used in the statistical analysis. Scale measurements yielding a difference less than 10 mm of back-calculated length between each annulus were considered sufficient and the data from the most experienced scale reader were used in the statistical analysis. Scales were omitted if aging was too variable among the readers. Scales with bends, cracks, scalloped edges, or bulges were unreadable or unreliable and were not included in the analysis.

Statistical Analysis

Migration timing was estimated for radio-tagged Bull Trout leaving the reservoir and returning to the reservoir in 2006 to 2011. Migration timing estimates were based on when trout were last detected in the reservoir and first detected in the tributaries and vice-versa. The date was converted to the number of days after June 1 for statistical analysis.

Statistical tests were performed using R version 2.15.1 (R Development Corps Team 2010). A two-sample t-test was performed to test for differences in the mean length between radio-tagged Bull Trout in the reservoir and Bull Trout captured in the stilling basin suspected to have been entrained through the dam. A Kruskal Wallis test was used to assess annual

differences in migration timing (first detection in river and last detection in river). Bull Trout transported from the stilling basin and released into Trail Creek were not included in this analysis.

A two-sample t-test and F test were performed to test for differences in the mean and variance in growth rate between Bull Trout rearing above and those rearing in tributaries below the dam. Bull Trout captured in the stilling basin were included with the above dam group. Fish collected during 2008, 2009, and 2010 were used for this analysis as these years provided comparable sample sizes between the two groups. Differences among growth years were tested using an ANOVA. Separate tests were performed for the above and below the dam groups and growth years that provided sample sizes greater than or equal to 30 individuals were used for the analysis. Growth years 2005 to 2009 were used for samples above the dam and growth years 2008 and 2009 were used for samples below the dam. Growth was calculated in 2003, 2004, and 2010 but the sample sizes were insufficient for statistical analysis.

4.1.5 Results and Discussion

Bull Trout Captures

Reclamation captured 453 Bull Trout (recaptures included) between 2006 and 2011 (Table 4-1). In 2009, 2010, and 2011 there were 167 Bull Trout captured above the dam at the mouth of the tributaries or during electrofishing in tributary habitats and 193 captured below the dam in the stilling basin or in tributaries such as South Fork Scott Creek. Electrofishing, weirs and trap nets provided higher success capturing Bull Trout than other methods used during this study, and were fished more frequently (Figure 4-8). Most effort was put into trap netting in the reservoir and the stilling basin. The total numbers of fish captured by species and location are listed in Appendix E.

Table 4-1. Bull Trout capture totals by gear type in the Deadwood basin. The total capture counts include recaptured Bull Trout. Sampling methods without a listed location (above or below dam) were sampled at locations above the dam.

Year	Sampling Method	Bull Trout Captures
2006	Weirs	12
	Trap Nets	10
2007	Weirs	13
	Trap Nets	11
	Trap Nets/Hook and Line (Below Dam)	11
2008	Weirs	14
	Trap Nets	8
	Trap Nets/Hook and Line (Below Dam)	5
	Backpack Shocker (Above Dam Tributaries)	1
2009	Trap Nets	11
	Trap Nets (Below Dam)	13
	Hook and Line (Below Dam)	3
2010	Trap Nets	5
	Backpack Shocker (Above Dam Tributaries)	46
	Trap Nets (Below Dam)	11
	Backpack Shocker (Below Dam Tributaries)	159
2011	Weirs	9
	Trap Nets	57
	Beach Seine	3
	Backpack Shocker (Above Dam Tributaries)	34
	Hook and Line	2
	Backpack Shocker (Below Dam Tributaries)	15
Total		453

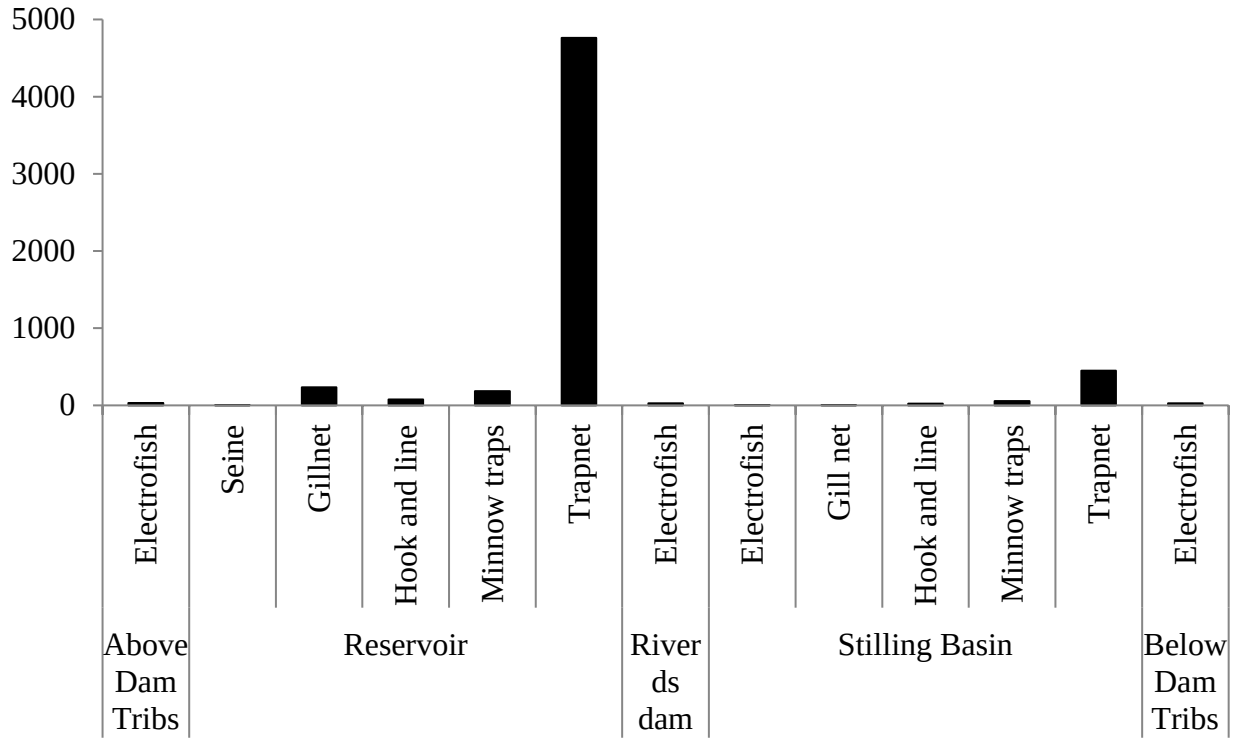


Figure 4-8. Total recorded hours each gear type was operated at the general basin locations (above dam tributaries, reservoir, river downstream from dam, stilling basin, and below dam tributaries). Note, this figure does not include electrofishing hours for capture and transport from the stilling basin and sampling stranding pools, or hours of weir operation in above dam tributaries by IDFG.

Between 2006 and 2011, Reclamation tagged a total of 99 Bull Trout with radio tags and 5 Bull Trout with acoustic tags. Of these tagged fish, seven Bull Trout were also tagged with archival tags (three internal, four external) during 2011 (Table 4-2). Bull Trout radio-tagged upstream from the dam ranged from 209 to 585 mm total length (average 413 mm). Most (89%) of the Bull Trout radio-tagged above the dam were captured in the Trail Creek arm of the reservoir. The stilling basin was sampled in 2007 to 2010 when 39 individual fish were sampled and of those 4 recaptured; total catch of Bull Trout equaled 11, 5, 16, and 11 each year, respectively. Twenty-two of the Bull Trout captured below the dam in the stilling basin were radio-tagged and released back into the stilling basin. Ten Bull Trout captured in the stilling basin in 2010 were released above the dam by direction from the USFWS fish salvage.

Table 4-2. Number of radio tags implanted in Bull Trout in the Deadwood basin, 2006 to 2011. Counts include general locations in the study area: reservoir and tributaries above the dam (above dam), stilling basin, stilling basin captures transported to tributaries above the dam (trap and haul) and Scott Creek located downstream from the dam.

Year	Above Dam	Stilling Basin	Trap and Haul	Scott Creek
2006	8	0	0	0
2007	9	10	0	0
2008	7	4	0	0
2009	5	8	0	0
2010	7	0	8	18
2011	15	0	0	0
Total	**51**	**22**	**8**	**18**

Movements and Habitat Use

Above Dam

Between 2006 and 2011, 51 individual Bull Trout were radio tagged (plus 8 Bull Trout originally captured in the stilling basin were radio tagged and released above the dam) providing 1,134 total detections during mobile tracking efforts above Deadwood Dam. The acoustic tags are able to be tracked in deep water and had limited battery life, no acoustic tags were located after August 2011. A small portion of total detections (10.0%) occurred within approximately within1 km of the dam. Tagged Bull Trout were more commonly located in tributaries and transition zones at the mouth of tributaries year-round and notably during the summer months when irrigation water was released at the dam.

Radio and acoustic tags indicate that Bull Trout upstream from Deadwood Dam utilized tributary and reservoir habitat and migrated between them seasonally. This seasonal movement has been documented in numerous other populations of Bull Trout (Fraley and Shepard 1989; Bahr and Shrimpton 2004; Salow and Hostettler 2004; Mogen and Kaeding 2005a; Muhlfeld and Marotz 2005; Hogan and Scarnecchia 2006; Nelson and Nelle 2008; Watry and Scarnecchia 2008; Muhlfeld et al. 2011). Tagged Bull Trout were dispersed throughout the reservoir during the winter and spring typically utilizing the outer portions of the reservoir (mid-to-shallow depths) (Figure 4-9 through Figure 4-11). Although this could be related to depth limitations in receiving radio tag signals, the use of the acoustic tags during 2011 showed similar patterns of detection.

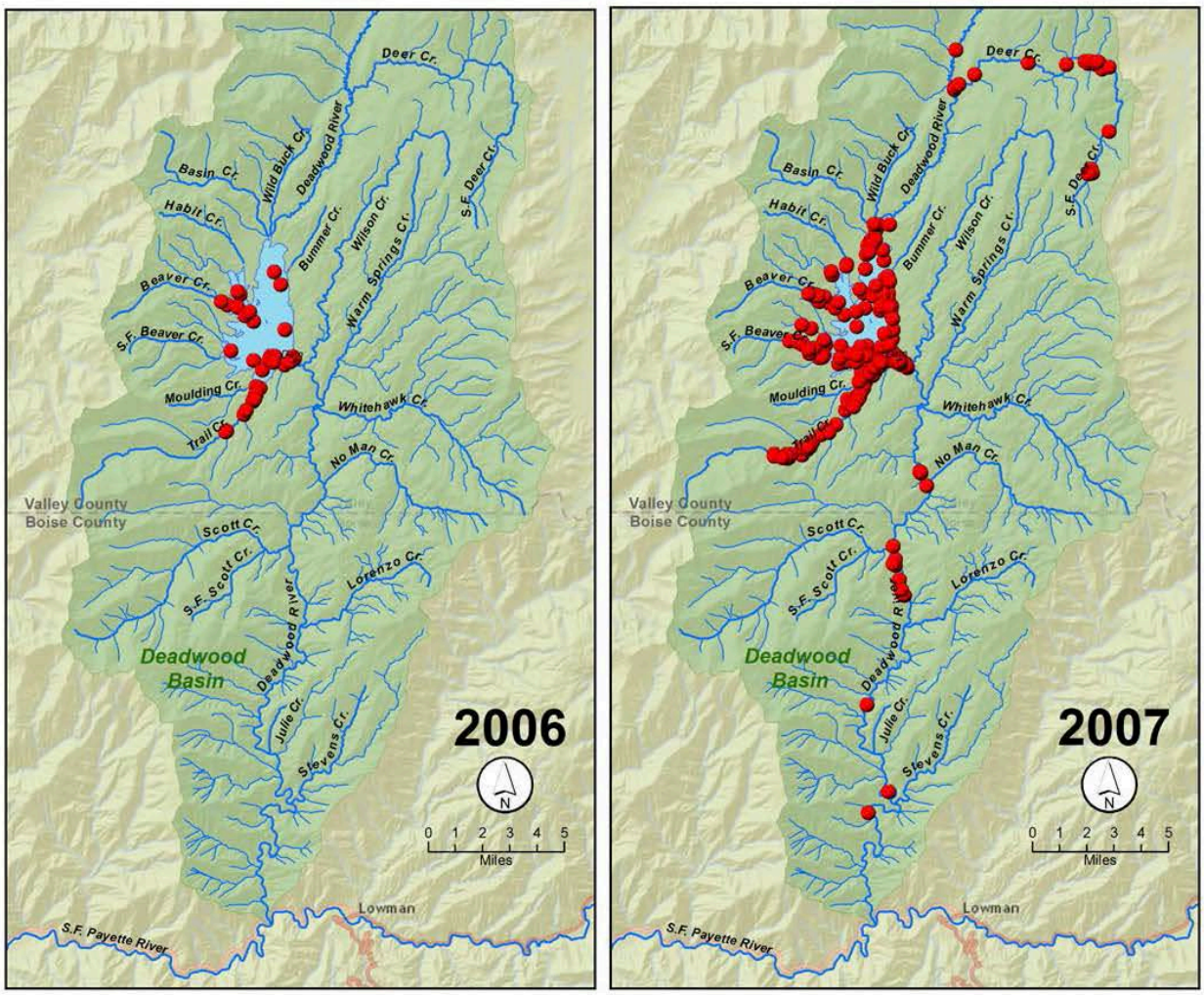


Figure 4-9. Detection of radio-tagged Bull Trout during 2006 and 2007 in Deadwood Reservoir and tributaries and lower Deadwood River, each dot represents one detection. The left figure (2006) data includes 53 total detections from 7 radio tags. The right figure (2007) data includes 319 total detections from 29 radio tags. Detections in this figure represent approximate tag locations to describe general patterns in the location of detections.

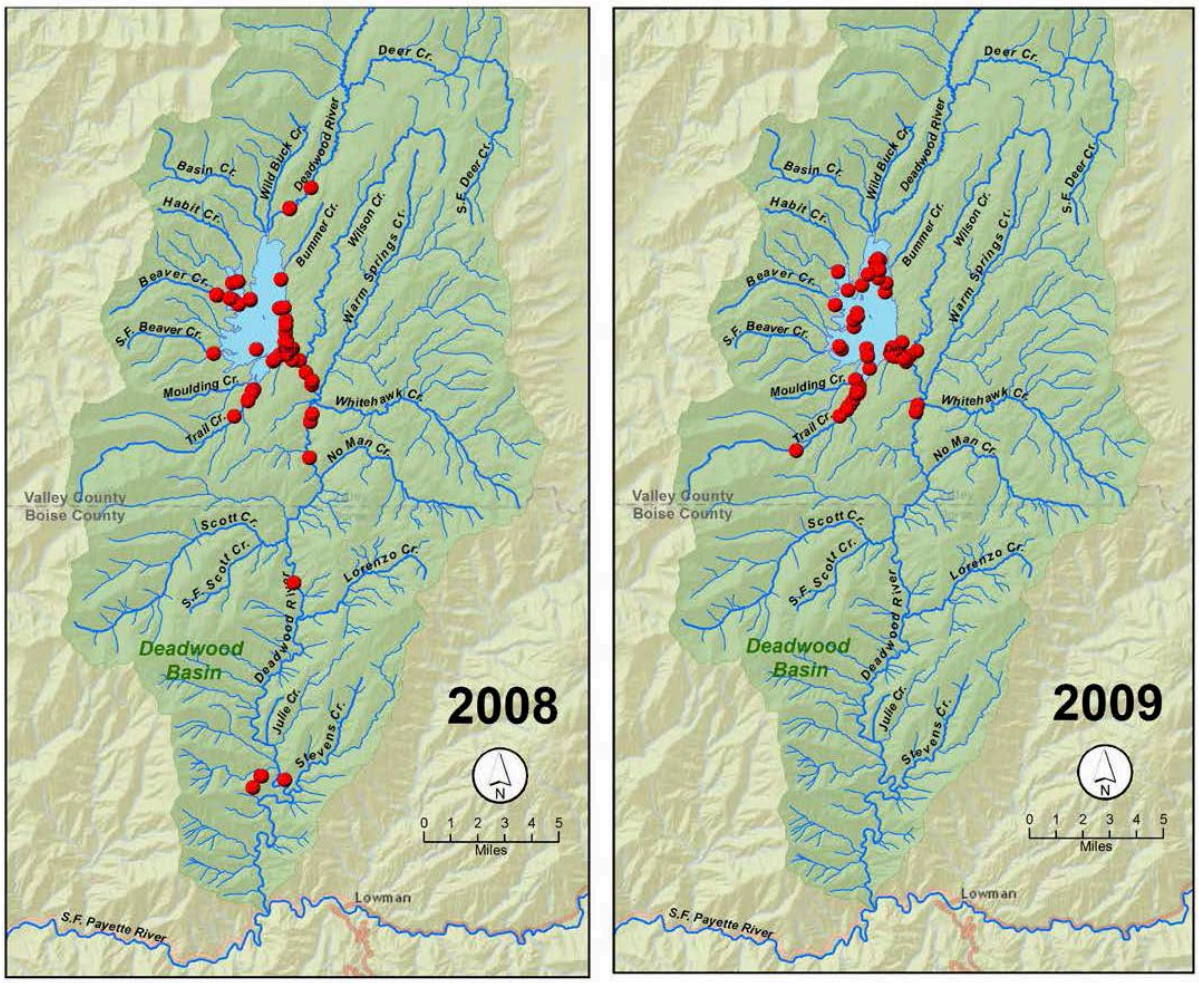


Figure 4-10. Detection of radio-tagged Bull Trout during 2008 and 2009 in Deadwood Reservoir and tributaries and lower Deadwood River, each dot represents one detection. The left figure (2008) data includes 112 total detections from 32 radio tags. The right figure (2009) data includes 140 total detections from 26 radio tags. Detections in this figure represent approximate tag locations to describe general patterns in the location of detections.

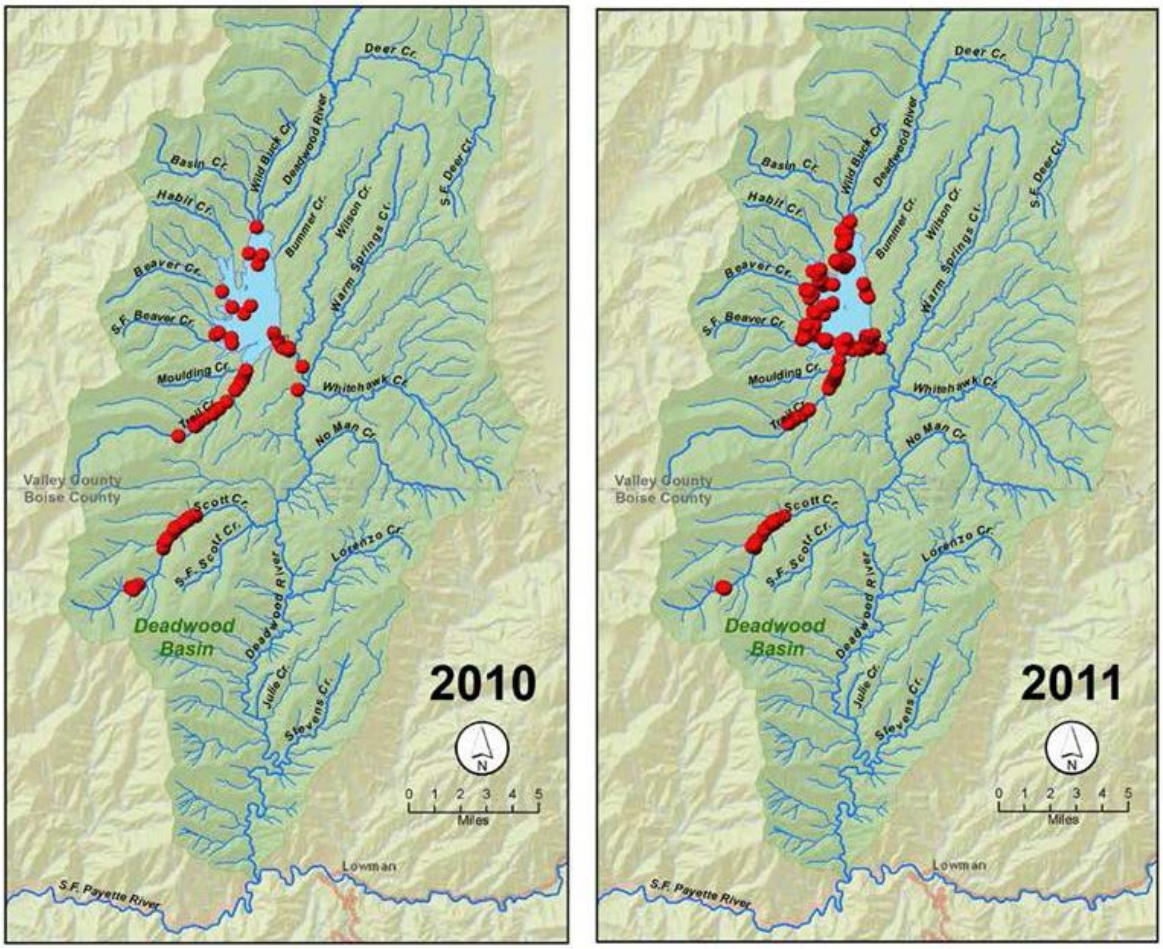


Figure 4-11. Detection of radio-tagged Bull Trout during 2010 and 2011 in Deadwood Reservoir and tributaries and Scott Creek downstream from Deadwood River, each dot represents one detection. The left figure (2010) data includes 100 total detections from 37 radio tags. The right figure (2011) data includes 410 total detections from 35 radio tags. Detections in this figure represent approximate tag locations to describe general patterns in the location of detections.

Most of the tagged Bull Trout migrated into Trail Creek during the study which is likely explained by the high proportion of Bull Trout captured from this tributary. Bull Trout were also detected in upper Deadwood River, Deer, Beaver, and South Fork Beaver creeks. During 2006 through 2010, most Bull Trout tagged during this study migrated out of the reservoir during the summer (between June and August) and returned to the reservoir in the fall (between late September and late October). During the fall (September/October), Bull Trout spawn in the tributary habitat. However, in 2011, radio tagged Bull Trout were found throughout the reservoir and near the mouths of the tributaries during the months of July through November. This was unusual compared to previous years where the tagged Bull Trout migrated out of the reservoir in the months of August and September. Migration dates were variable year-to-year for all tagged Bull Trout and individual Bull Trout that were

tracked multiple years (Table 4-3 and Table 4-4). The date of first detection in the river was significantly different across years ($p<0.01$; Figure 4-12). The data indicate that Bull Trout migrated into the tributary habitat 38 to more than 60 days earlier in 2007 than during the other years of the study. Reservoir elevation that corresponded with the average date of movement across years was 1623.7 m (SD 0.9 m). The date of last detection in the river was not significantly different ($p=0.91$) across years during the study and varied by less than 10 days (Figure 4-13).

Table 4-3. Summary of Bull Trout migration timing from mobile tracking efforts in Deadwood Reservoir and tributaries upstream of the dam. Tracking of migrations during 2009 was not performed. The 2010 data are based on the stationary receiver at the reservoir/Trail Creek confluence. Bull Trout transported from the stilling basin during 2010 were not used in this analysis.

Year	n	Last Detection Reservoir	First Detection River	Last Detection River	First Detection Reservoir	Average Days in River
2006	6	8/12/2006	9/3/2006	9/24/2006	10/11/2006	43
2007	8	7/7/2007	7/11/2007	9/23/2007	9/26/2007	78
2008	4	7/27/2008	8/18/2008	9/21/2008	10/8/2008	56
2010	2		8/18/2010	9/21/2010		34
2011	5	8/8/2011	9/11/2011	9/19/2011	9/24/2011	27.5

Table 4-4. Migration dates for individual Bull Trout across years during the study. ND indicates when additional data were not collected from the tag. Asterisk indicates Bull Trout that were transported from the stilling basin to Trail Creek. Bull Trout tags that were recorded in 2012 are included in this list, but were not included in the statistical analyses.

Fish ID	Year	Date Left Reservoir	Date Returned
10	2006	8/3/2006	10/27/2006
	2007	6/13/2007	ND
11	2006	7/23/2006	9/27/2006
	2007	6/18/2007	ND
12	2006	8/22/2006	10/16/2006
	2007	7/11/2007	9/26/2007
	2008	7/21/2008	10/6/2008
76	2010	8-25-10*	10/20/2010
	2011	7/26/2011	9/27/2011
	2012	8/6/2012	ND
77	2010	8-25-10*	9/10/2010
	2011	8/15/2011	8/29/2011
640-3	2011	8/20/2011	9/27/2011
	2012	8/8/2012	9/26/2012

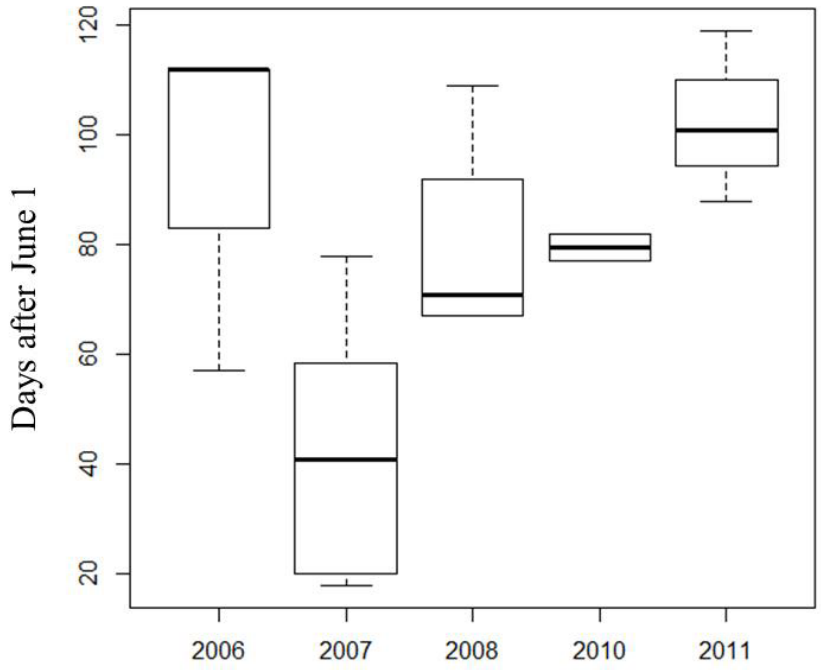


Figure 4-12. Number of days after June 1 of first detection (upstream migration) in the upper Deadwood River tributaries by year.

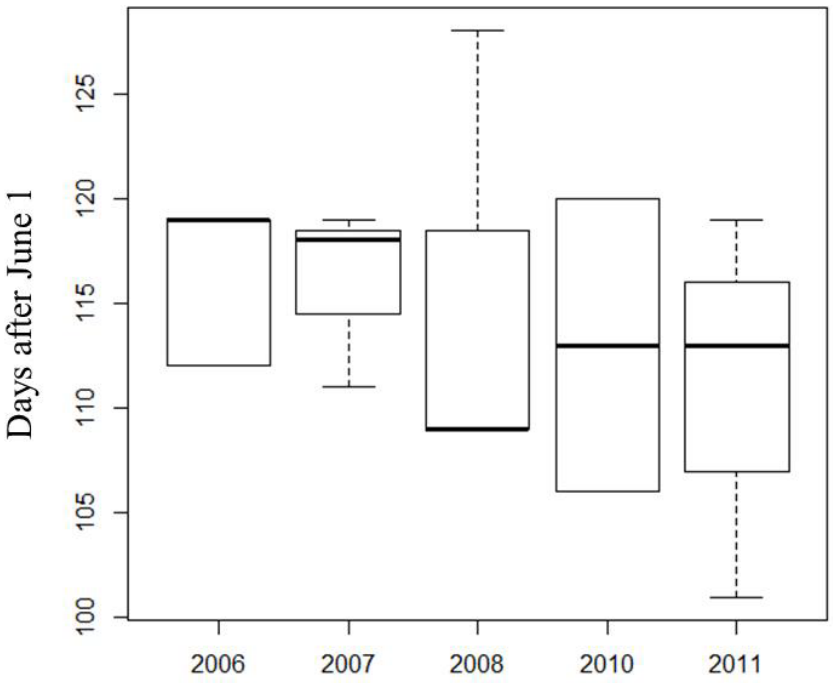


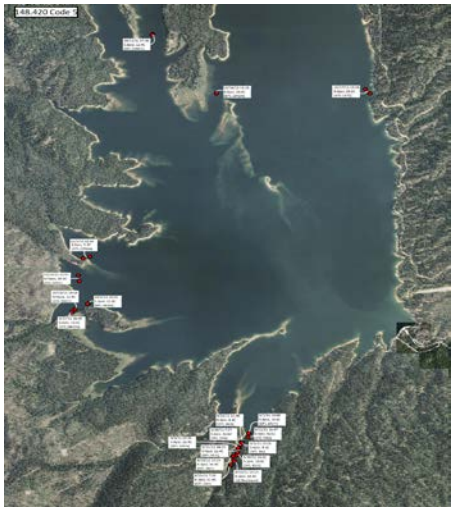
Figure 4-13. Number of days after June 1 of last detection (downstream migration) in the upper Deadwood River tributaries by year.

Only three of the seven archival tags were retrieved to provide continuous data on depth and temperature for these tagged Bull Trout. Memory storage from these tags was depleted within a few months providing data only during the fall and winter period (Table 4-5). Tags were primarily in shallow water (<2 m) with brief detections in deeper water (>5 m) typically for less than 30 min intervals. Temperature showed more variation than depth, but this variable also changes seasonally during these recording periods from warm summer temperatures in August to cold winter temperatures in January and February (Table 4-5). Interestingly, these data indicate that Bull Trout are utilizing shallow habitats for extended time periods and only briefly utilizing the deeper habitats (Figure 4-14 through Figure 4-16).

The archival tags indicate that Bull Trout in Deadwood Reservoir reared in water temperatures near the upper tolerance for this species. Data from these tags document Bull Trout that reared hours to days in water temperatures ranging from 17 to 20^{o}C. Similarly, Bull Trout have been shown to rear in water temperatures exceeding 20^{o}C for extended time periods without seeking previously identified cold/cool water refugia in the Lostine River (Howell et al. 2010). The cooler water inputs from the tributaries may provide refugia; however those temperatures would be recorded by the tags. When considering both the telemetry and archival tag data together, it appears that Bull Trout rely on tributary habitat and areas of the reservoirs near tributaries while rearing in the reservoir. It is possible, that variables other than water temperature determine the rearing location of the Bull Trout such as availability of prey.

Table 4-5. Data summary from archival tags showing start and end date of logging, depth (m) and temperature (C) (range, average and standard deviation). All tags recorded in 15 minute intervals.

Tag	Start	End	Depth (m)			Temp (C)		
			Range	Average	SD	Range	Average	SD
148.420 code 23	8/23/2011	1/19/12	0-21.5	1.1	1.1	0-20.7	8.2	4.1
148.640 code 3	8/23/2011	10/27/2011	0-16.6	0.6	1.2	3.1-19.4	4.2	10.6
148.420 code 5	8/18/2011	2/8/2012	0-45	1.1	1.4	0-19.8	7.5	4.2



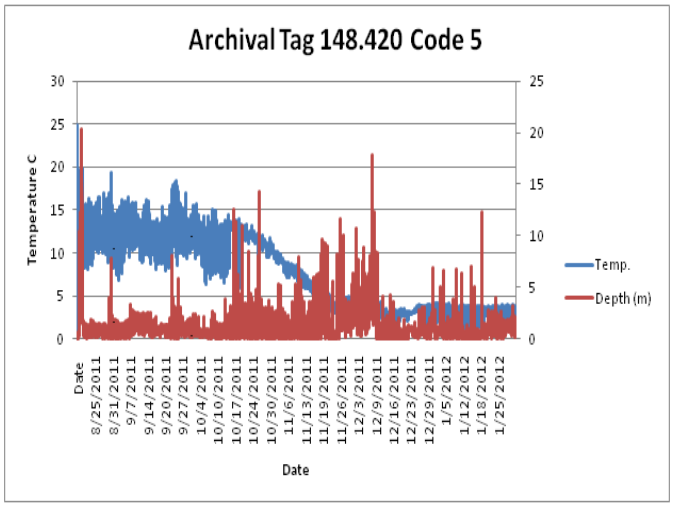
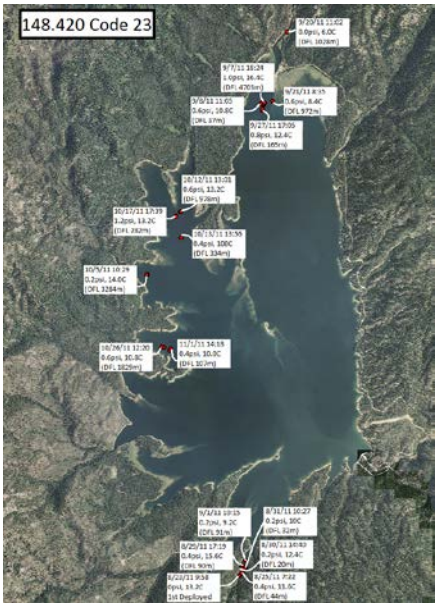


Figure 4-14. Tag locations and associated depths and temperatures recorded for tag 148.420 code 5 Bull Trout 424 mm total length in Deadwood Reservoir during 2011.



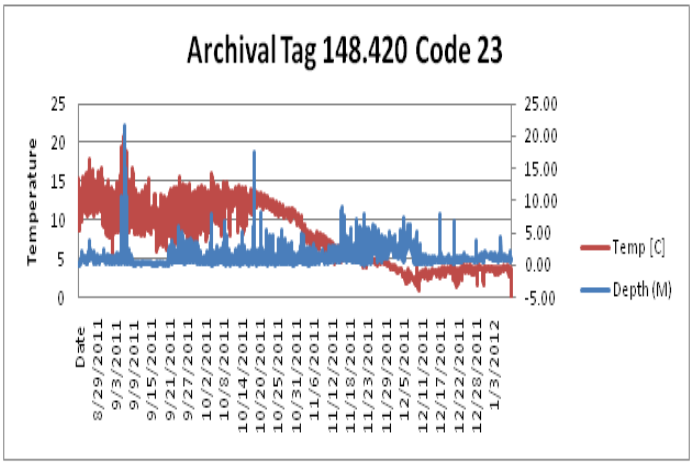


Figure 4-15. Tag locations and associated depths and temperatures recorded for tag 148.420 code 23 Bull Trout 459 mm total length in Deadwood Reservoir during 2011.



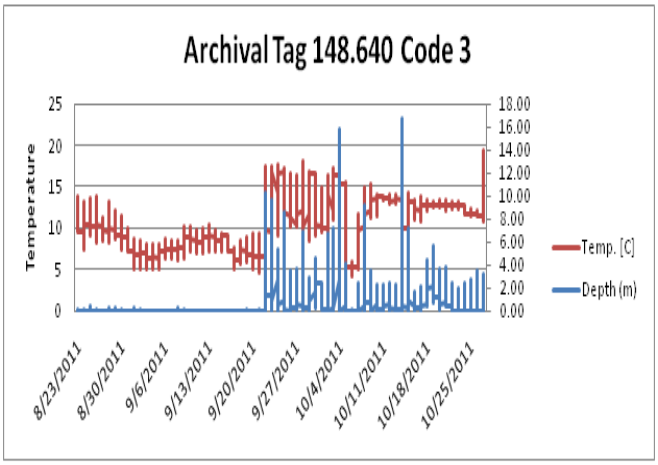


Figure 4-16. Tag locations and associated depths and temperatures recorded for tag 148.640 code 3 Bull Trout 447 mm total length in Deadwood Reservoir during 2011.

The highest temperature recorded by the archive tags was 20.7°C and Bull Trout spent most of the time at shallower water depths (< 2 m). Data from the reservoir sampling sites was examined for temperatures in the upper water column that exceeded 20.9°C. Although sampling and tag movement dates do not coincide exactly due to sampling time frames or detection probabilities, these data indicate temperatures exceeding 20.9°C near the date of movement out of the reservoir (Table 4-6). Although speculative due to small samples, the data indicate that Bull Trout may leave the reservoir as temperatures approach the maximum summer temperature which may also correspond with a certain water surface elevation in the summer months. Water surface elevation alone does not appear to be the trigger because Bull Trout are present in the reservoir at minimum reservoir elevations during the fall and winter when water temperatures are lower. Dissolved oxygen (DO), although directly related to temperature, also does not appear to be a trigger because saturation levels are high above the thermocline (7-9 m depth) in the reservoir (see Chapter 2, Section 2.2.4) and Bull Trout are typically in shallower habitat. In years when water temperatures are not above 20.5°C or reservoir elevations are not low, the Bull Trout should move out of the reservoir to spawn, but if not spawning size or mature, they could remain in the reservoir.

Radio-tag observations during 2011 indicate that some Bull Trout remained in the reservoir for the entire summer and fall period. These day may under-represent Bull Trout use of the reservoir through the summer, since fish as small as 90 mm were captured but were unable to be tagged due to the tag technology/sizes available at the time of the study. These smaller juveniles may remain in the reservoir, seeking colder water at depth, through the summer when warmer water temperatures in shallower water triggers larger Bull Trout to leave the reservoir to spawn.

Table 4-6. Comparison of the average last detection date in the reservoir to the date that water temperature exceeded 20.9°C at the water quality sampling sites in Deadwood Reservoir. NS indicates when samples were not taken at a site and IS indicates when the sample was insufficient to determine when or if temperatures exceeded 20.9°C.

	2007	2008	2011
Date last in reservoir	July 7	July 27	Aug 8
DEA004	July 9	July 28	None
DEA006	July 9	July 28	None
DEA008	July 9	NS	NS
DEA010	July 9	July 28	Aug 3
DEA012	July 9	NS	NS
DEA014	July 16	July 28	IS
DEA016	July 16	July 28	IS

Below Dam

Between 2006 and 2011, 40 individual Bull Trout were radio tagged (total includes 18 individuals in Scott Creek in 2010) providing 263 detections during mobile tracking efforts below Deadwood Dam. Bull Trout captured in the stilling basin were released in the stilling basin during 2007 (n=10), 2008 (n=4) and 2009 (n=8). During each year, these Bull Trout exhibited different ranges in movements. The Bull Trout tagged during September and October 2007 were located only between the dam and Wilson Creek (the first tributary downstream from the dam). In November, four of these Bull Trout moved downstream into the Deadwood River. In 2008, 5 tags were tracked but 2 of these 5 tags were implanted during the previous year. These Bull Trout reared in the Deadwood River. During 2009, six tagged Bull Trout were released in the stilling basin. Three of these trout migrated into Wilson Creek on October 7 and 8, 2009, and two of these Bull Trout appeared to spawn together. Bull Trout tagged in the stilling basin moved downstream in the Deadwood River as far as Stevens Creek in 2007 and 2008 (Figure 4-9 and Figure 4-10).

Tags were also implanted in 18 Bull Trout in Scott Creek during 2010. All of the tagged trout remained in Scott Creek during 2010 and 2011. None of these trout were detected leaving Scott Creek or the Deadwood River at the fixed receivers at these locations. The tagged Bull Trout in South Fork Scott Creek exhibited very small movements during the year typical of the resident life history.

Growth Estimates

Sample size prevented valid aging using length-frequency data or recapture data. Therefore, growth estimates were derived from scale-based aging methods. Scales that were collected from the stilling basin were included with the samples from upstream of Deadwood Reservoir, Basin, Trail, and Beaver basins (above dam) because these trout were suspected to have been entrained through the dam; therefore, back calculated growth from the scales would be characteristic of this habitat. Downstream from Deadwood Dam, scales were aged from the Scott and Warm Springs basins (below dam). Small sample sizes from each location prevented comparisons across tributary capture sites. Bull Trout from above Deadwood Dam and the stilling basin had higher mean growth rates than those captured from the tributaries downstream from the dam (Figure 4-17 and Figure 4-18). Maximum recorded growth rate showed variation across years while average and minimum growth year were consistent across years. Mean growth and variance in growth of trout collected above the dam were significantly larger for growth years 2008–2010 when compared to trout collected from tributaries below the dam ($p<0.001$; Figure 4-19).

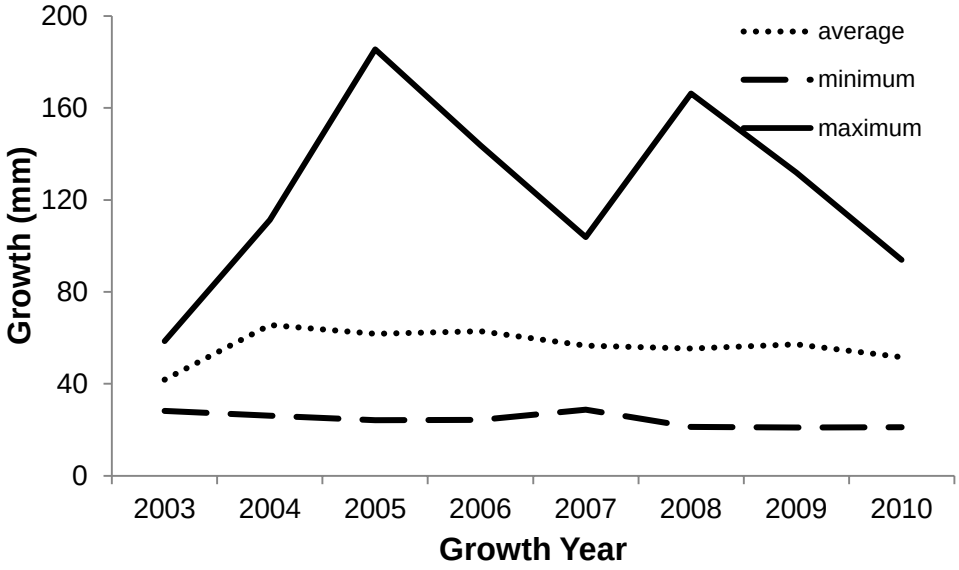


Figure 4-17. Estimated growth (mm) by year for scales collected from Bull Trout from above Deadwood Dam and in the stilling basin. Note low sample size (n=8) in 2003 and 2010 growth years influences the data values.

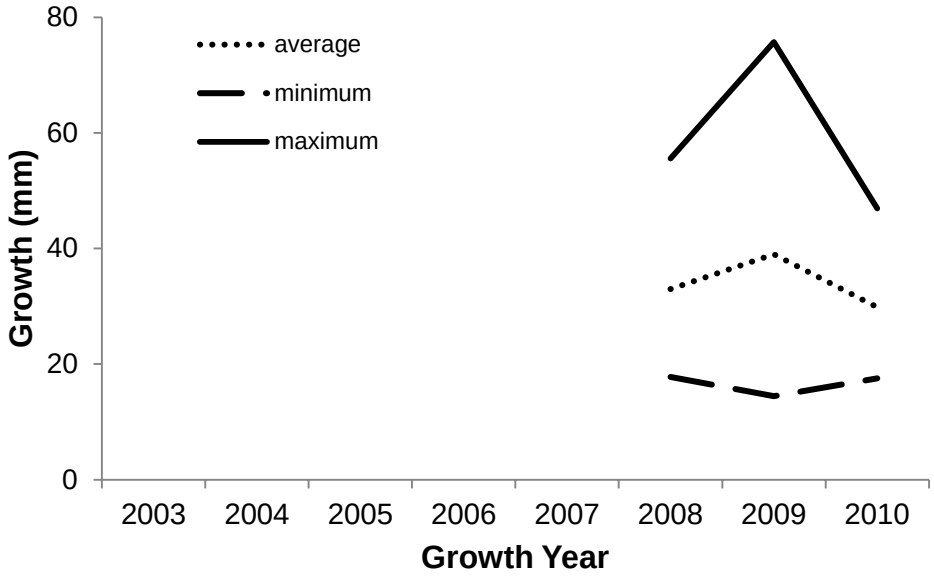


Figure 4-18. Estimated growth (mm) by year for scales collected from Bull Trout from Scott and Warm Springs creeks, tributaries located downstream from Deadwood Dam. Data from growth years 2006 and 2007 are not shown due to extremely low sample size (n=1 and 2).

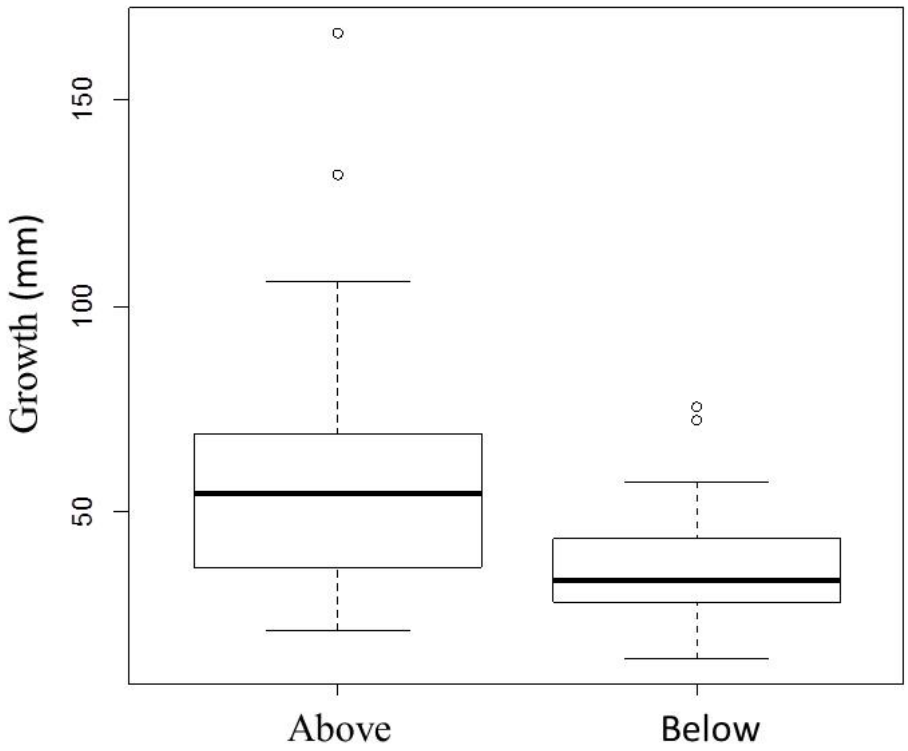


Figure 4-19. Distribution of mean annual growth (mm) of Bull Trout collected from sites upstream (above) and downstream (below) from Deadwood Dam.

Examination of actual lengths of the age 0 and 1 Bull Trout collected from tributaries above and below Deadwood Dam indicate that the tributaries below the dam have higher growth rates (Table 4-7). The tributary sites downstream from the dam are higher in elevation; therefore elevation differences do not appear to explain these data.

Table 4-7. Average total length (mm) and range in parentheses for age 0 and age 1 Bull Trout from tributaries located above and below Deadwood Dam. Bull Trout were captured between July 21 and Aug 10, 2010.

	2010		2009 and 2010	
	Sample size	Age 0	Sample size	Age 1
Above Dam	7	77.7 (71-87)	7	91.9 (73-113)
Below Dam	10	82.5 (63-107)	14	104.6 (84-135)

Growth did not vary significantly across years tested in Bull Trout above the dam ($p=0.2$) (Figure 4-20), but growth was significantly different across years tested below the dam ($p=0.02$). At the sites downstream from Deadwood Dam, mean growth was significantly higher in 2009 than in 2008 ($p< 0.05$; Figure 4-21).

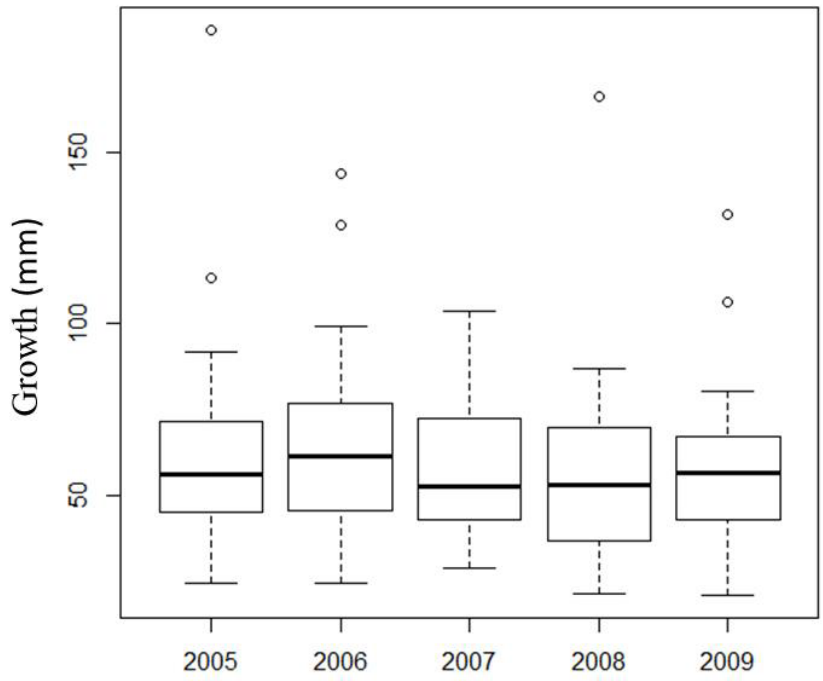


Figure 4-20. Distribution of annual growth by year for Bull Trout collected upstream from Deadwood Dam.

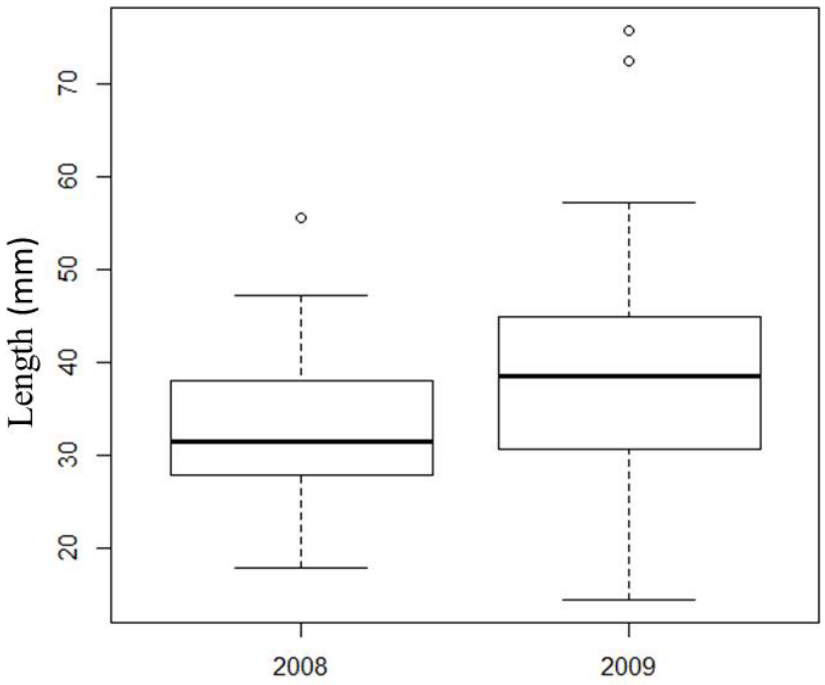


Figure 4-21. Distribution of annual growth for Bull Trout collected from tributaries downstream from Deadwood Dam.

Based on the growth estimates from the scales, annual growth for Bull Trout rearing above Deadwood Dam is nearly double the growth calculated from trout captured in tributaries downstream from the dam. However, when examining age 0 and 1 Bull Trout captured during the summer 2010, length at age was greater for Bull Trout in the below dam group.

Similar methods were used to calculate annual growth for Bull Trout in Flathead Lake, Montana. Annual growth in Flathead Lake ranged from 60 to 132 mm from trout collected between 1968 and 1981 (Fraley and Shepard 1989). Annual growth in Deadwood Reservoir had a wider range from 21 to 185.5 mm, yet, length at age is similar in the Deadwood Reservoir to the populations studied in other locations such as Flathead Lake, Priest Lake, upper Priest Lake (Fraley and Shepard 1989). The lower annual growth values were measured from Bull Trout collected in the stilling basin. These trout were included in the above dam group because the date of entrainment is unknown and back calculated growth for previous years likely occurred upstream from the dam. Low growth measurements in these trout could be a cause for attempting out-migration from the reservoir or could be due to less suitable conditions or forage in the stilling basin.

Tag Loss and Mortality

Researchers conducting tagging studies often want to identify mortality from lost tags and relate mortality to a management action or environmental condition (Holbrook et al. 2013). Causes of mortality can be natural (such as age-related), disease, and predation. For example, spawning during the fall when streamflows are lowest can make Bull Trout vulnerable to predators and some spawning mortality would be expected in ideal conditions. Separating natural mortality from an increase in mortality due to environmental conditions or stress is typically difficult. An estimate of mortality from tag losses (or retrievals) is biased by several factors such as tag malfunction, tag expulsion, tag-caused mortality, and non-detection (Holbrook et al. 2013; Sandstrom et al. 2013 and citations therein). Non-detection can result in error when a fish is alive but undetected because the tag malfunctioned, the signal may be blocked by water depth, or other obstructions, the tag is outside of the search area or the tagged trout is present but missed during tracking events. Bias is a directional error which results in inflated estimates when assuming an expelled tag is a mortality. Fish can expel tags from the body cavity over 140 days after surgery (Sandstrom et al. 2013), and the tag/antenna area can get irritated during redd excavation which creates complications when radio-tracking species that spawn multiple times during the expected life of the tag. Individual scientists surgically implanting the transmitters have significantly different tag expulsion rates even when they have similar training and experience (Sandstrom et al. 2013). Yet, relative numbers of suspected mortalities and/or tag losses can allude to altered conditions across years if other factors such as study methods and surgical personnel remain constant, and hence, do not introduce further bias into the study. Still, mortality estimates based on tag losses alone should be interpreted cautiously and considered in relation to study limitations and other study findings.

Above Dam

Tagged Bull Trout were identified as suspected mortalities based on counts of tag retrievals and stationary tag signals during all years of the study with the highest percent of tag loss and suspected mortalities occurring in 2007 (Figure 4-22 and Figure 4-23). One tag was initially identified as a mortality during the study, but the Bull Trout was recaptured at a later date. This individual was removed from the data set prior to analysis. Most tags were retrieved without a carcass or evidence of scat making determination of mortality indistinguishable from tag expulsion.[2] Of these tags, nine tags were retrieved on shore near the stream; however a predator, scavenger or angler could have moved the trout to these locations and cause is unknown. Similarly, tags retrieved in the water could be expelled tags, mortalities or tags discarded by anglers. Four tags provided some evidence of mortality: two Bull Trout carcasses were found with the tag, one Bull Trout died with signs of an infection around the tag incision and one tag was retrieved buried in a debris flow from the canyon. Additionally, one Bull Trout did not return from the spawning tributary and one tag was found on the stream bed at the tributary spawning site, indicating tag expulsion, predation during spawning or natural post-spawning mortality (Figure 4-24). One radio-tag was not retrieved, but provided unusual data to the remote station near the mouth of Trail Creek. On October 26, 2010, the temperatures recorded by the station logger increased from 1.2^{o}C to the maximum recordable temperature of the tag, 34^{o}C, within an hour and 14 minutes. Detection for this tag at the remote station stopped and then began again 39 hours later. Maximum air temperature was 2.8^{o}C on this day. It is possible that this tag was ingested by a mammal or avian predator; however, tag malfunction cannot be eliminated as a possibility. Of the unknown tag losses, one tag was suspected to be an angler mortality and two tags were retrieved in the stream near campgrounds and two tags were lost in large woody debris (LWD).

[2] Distinguishing between tag expulsion and mortality when a tag is found without a carcass entails a level of uncertainty, though this distinction has significant implications in the context of this study. If the tag is retrieved from an area that could have been inundated when the last detection in a living fish occurred, it may be considered an expulsion rather than a mortality. However, most tags retrieved during this study were found on dry land locations that could not have been inundated the last time the tag was detected in a living fish, suggestive of predation mortality.

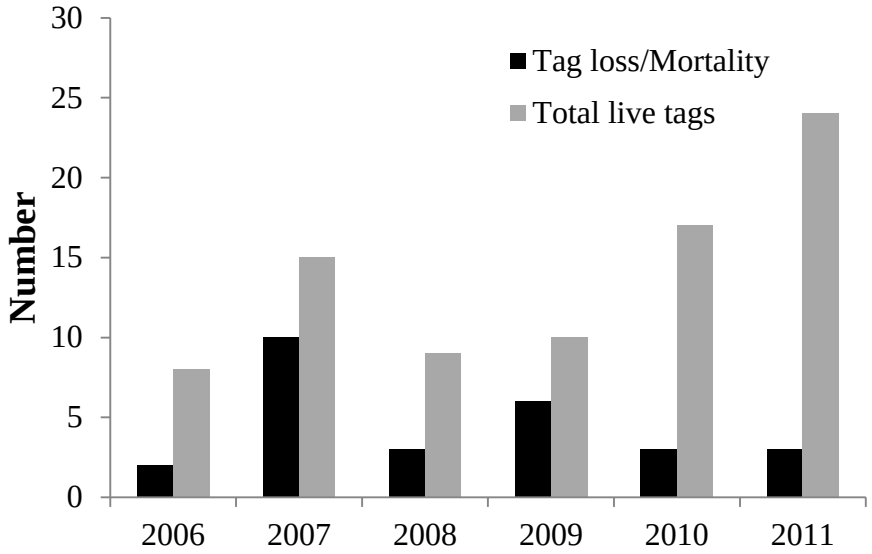


Figure 4-22. Number of tag retrievals and mortalities (black bar) and total number of tags (gray bar) above Deadwood Dam, 2006 to 2011.

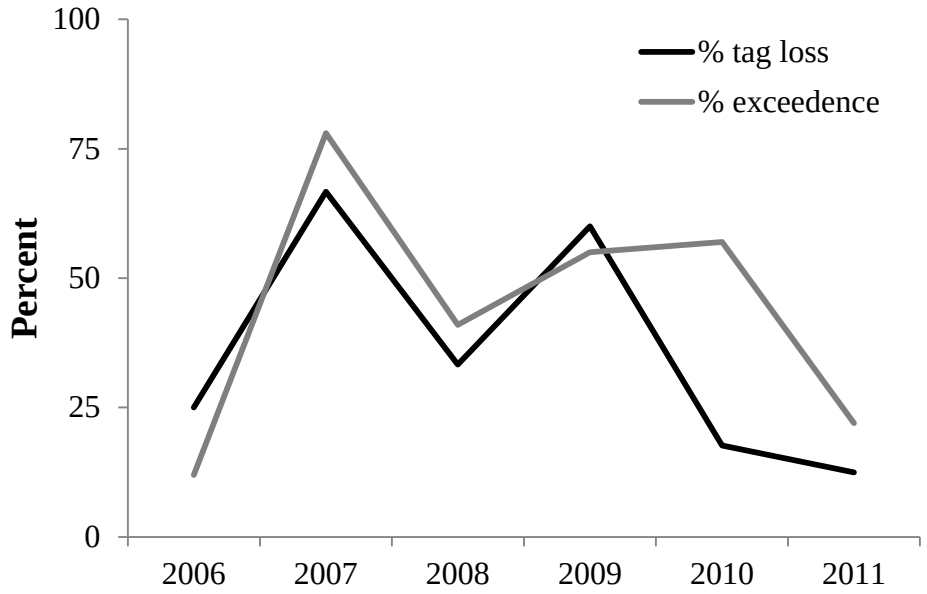


Figure 4-23. Percent of tags lost or mortality and percent water year exceedance value (y-axis) based on total inflow to Deadwood Reservoir, 2006 to 2011.

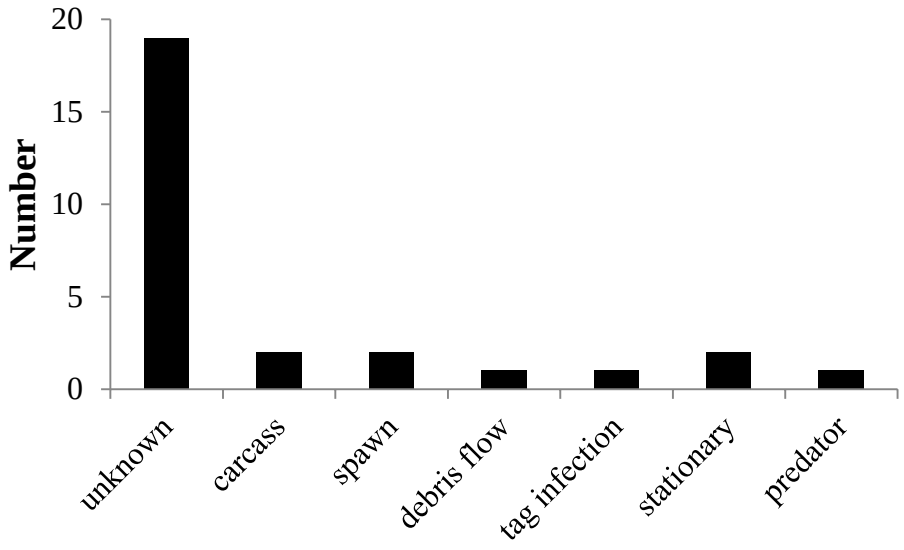


Figure 4-24. Number of radio tags considered suspected mortality or retrieved during the study, 2006-2011. Tags were classified according to: retrieved on the bank or in shallow water without an indication of cause of mortality (unknown), retrieved with a carcass (carcass), tag retrieved or lost during spawning run (spawn), tag retrieved buried in a debris flow (debris flow), trout died with signs of tag related infection (tag infection), tag was stationary and presumed separated from the trout (stationary) and tag was suspected to be mortality from predation (predator).

During the 6-year study, 29 tags (51%) were lost from tag expulsion and mortality. By year, tag loss and mortality ranged from 12.5% in 2011 to 66.7% in 2007. Tag loss and suspected mortality closely tracked the water year exceedence values based on inflows to the reservoir, except in 2010 (Figure 4-23). In 2010, atypical operational changes occurred after irrigation season to perform necessary construction projects at the dam which resulted in 0 outflow between August 26 and October 8. After this period, outflows were increased to the 50 cfs minimum streamflow for the remainder of the post-irrigation season. Potentially, the early reduced outflow from the dam increased the end of irrigation season reservoir volume which may have improved migration conditions for post-spawned Bull Trout returning to the reservoir. End of irrigation season reservoir surface elevation were similar in 2010 (5,309.69 feet) and 2011 (5,309.35 feet) when tag loss and suspected mortalities were the lowest. Another possible explanation for these data is that tag surgeries or tag tracking was more successful in 2010 than in previous years substantially reducing tag loss. An additional stationary receiver was installed in the Trail Creek arm of the reservoir in 2010 which may have improved tag detection. Most Bull Trout in the study were migrating into Trail Creek, so a large portion of fish would be affected by the operation of the additional receiver.

A similar study tracking radio-tagged Bull Trout on the Entiat River and Rocky Reach Reservoir, Washington also found high numbers of tags without any indication of cause or source of tag loss. Suspected mortality and tag loss ranged from 18% on the Mad River to

66% on the upper Entiat River with an overall suspected mortality and tag loss of 36% for the four year study. Most of the tag losses on the Entiat River were found in log jams with only 9% of mortality/tag retrievals occurring in the reservoir downstream (Nelson and Nelle 2008). Studies conducted in Idaho found post-spawning radio tag loss and/or mortality was 53% in the Lochsa River populations, 60% in the North Fork Clearwater populations, and 69% in the Rapid River population (Hanson and Schriever 2006; Schriever and Schiff 2003; Schill et al. 1994). Estimated annual mortality of Bull Trout (> 220 mm, similar in size to trout tagged in the Deadwood study) ranged from 30 to 80% in the South Fork Walla Walla River, which are similar to values documented for other salmonids (Al-Chokhachy and Budy 2008). Lastly, a radio-telemetry study conducted on Rainbow Trout in the Deadwood Reservoir identified the following tag loss and mortalities: 15% tag-caused mortality, 23% harvest from anglers, and 31% unknown suspected angler harvest (Dare and Rose 2006). Therefore, estimates of tag loss and suspected mortality are similar to other studies of migratory Bull Trout, and the tag loss and suspected mortality percentages generally follow other behavioral and environmental conditions identified during this study.

Stilling Basin and Trap and Haul

Four of the 22 radio-tags (18%) in Bull Trout released in the stilling basin were either retrieved (n=1) or stationary (n=3). Of these tags, none were lost in 2007, whereas two tags were lost in 2008 and 2009 each. Two additional tags (9%) were retrieved in Wilson Creek, a nearby tributary unaffected by water operations from the dam. Two of the eight radio-tagged Bull Trout (25%) captured in the stilling basin and released upstream of Deadwood Reservoir in 2010 were retrieved out of the water without an indication of cause.

Direct comparison of mortality rates between tagged fish below the dam and those in the reservoir are unreliable, due to the shorter battery life of tags installed in smaller fish below the dam which likely led to decreased mortality detection overall in this group of tagged fish. Data collection was also confounded by the remote nature of the habitat below the dam, which limited ability to confirm mortalities via tag retrieval before the expiration of tag battery life.

Entrainment

None of the 57 individual trout that were tagged between 2006 and 2011 in the reservoir and tributaries upstream from the dam were entrained through Deadwood Dam. These data indicated that entrainment is either relatively low (<2% across multiple years), periodic according to water and precipitation conditions, or the data set did not capture size classes and/or time periods that are vulnerable to entrainment through the dam. Comparison of the sizes of Bull Trout that were tagged in Deadwood Reservoir and tributaries, excluding those that never moved to the reservoir and therefore could not have been susceptible to entrainment, to those that were captured in the stilling basin indicated that tagged Bull Trout were significantly larger ($p<0.001$), and there was little overlap in the lengths of Bull Trout

suspected to be entrained from those that were tagged in the reservoir (Figure 4-25 and Figure 4-26). Therefore, size (and attendant behaviors much more likely to be exercised by larger adults than smaller juveniles, such as leaving the reservoir to spawn in the fall rather than remaining in cool water at depth) may partially explain why none of the sampled Bull Trout were observed entrained through the dam. However, lack of observation of a tagged Bull Trout entrained through Deadwood Dam could be due to several other factors such as small sample sizes, capture sites that relied largely on tributary locations rather than near dam locations and potential loss of tags or tagged trout between the time of tagging and the time that Bull Trout may be susceptible to entrainment. It is worth noting that if untagged reservoir Bull Trout of the same smaller size classes as observed in the stilling basin, remain in deep water near the dam through the summer and fall, they would be susceptible to entrainment through the valves. Data collected during this study does not identify the causes or timing of entrainment.

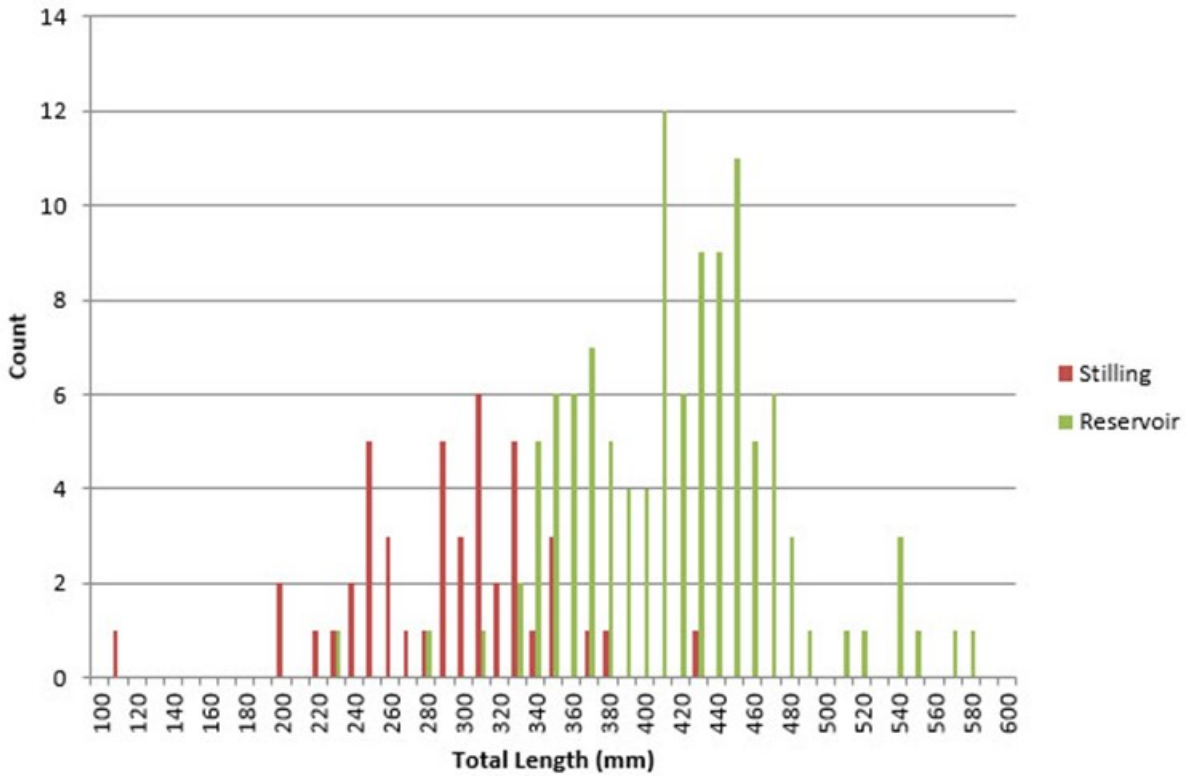


Figure 4-25. Length frequency (total length mm) of Bull Trout captured in the stilling basin at Deadwood Dam 2007-2010 and all Bull Trout radio-tagged in Deadwood Reservoir or tributaries 2006-2011.

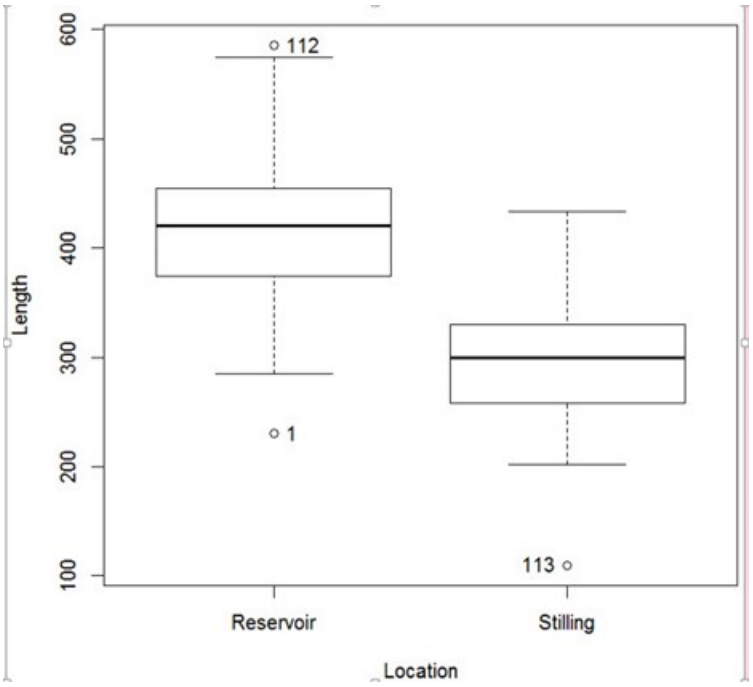


Figure 4-26. Box plot of length (mm) of Bull Trout implanted with radio-tags (n=53) in Deadwood Reservoir and Bull Trout captured in the stilling basin (n=43). Radio-tagged Bull Trout from the reservoir with a minimum of one month between tagging and last detection were included in this analysis. All fish from the stilling basin are included, even though some were too small to radio tag.

During the mobile tracking efforts, there were a total of 1,134 detections in the reservoir. Of these detections, 10%, 5%, and 3% of the total detections were within approximately 1 km, 0.2 km, and 0.1 km of the dam, respectively. When considering the higher flow period between April 1 and September 15 when the risk of entrainment may be greater, 4%, 2%, and 1% of the total detections were approximately 1 km, 0.2 km, and 0.1 km from the dam, respectively. Further, these higher risk detections in the spring represented 26, 14, and 2 individual trout within approximately 1 km, 0.2 km, and 0.1 km distances from the dam, respectively. Although these data may provide some information (within the variability of the different tracking methods) related to risk of entrainment, the radio-tag data may be biased due to more tags being installed in the spring than in the winter/fall months, leading to a greater number of active tag detections shortly after release during the spring months than the later winter/fall months due to various sources of tag loss over time.

Entrainment of Bull Trout at Arrowrock Dam was associated with high discharges through conduits within 5.8 to 30.5 m (19 to 100 feet) below the water surface elevation (Flatter 1999; Salow and Hostettler 2004). Additionally, these studies document that low winter discharges are not likely associated with high probability of entrainment (Flatter 1999; Salow and Hostettler 2004). Based on migration timing, the Bull Trout is likely most vulnerable to entrainment from the outlet works or the spillway during higher discharge periods (winter or

spring). During wet years, the higher discharges have historically occurred anytime between early December and early July (see Chapter 3, Section 3.1.1). During dry and average years, higher discharges occur between early May and late August (see Chapter 3, Section 3.1.1). The average and dry water years describe environmental conditions expected about 90% of the time. Therefore, in most conditions, Bull Trout would be susceptible to entrainment only during these spring/summer months. The outlet works are operated longer each year than the spillway thereby providing more opportunity for entrainment (see Chapter 2, Figure 2-5). Although the data indicates that Bull Trout are generally not utilizing the near surface or the deep water habitats (>5 m) where they could become entrained, the trout could be attracted to the outflows for the purposes of downstream movements.

Genetic data indicates that the Bull Trout sampled in the stilling basin likely originated from populations upstream from the dam (DeHaan and Ardren 2008). Migration among populations promotes demographic support and genetic exchange among local populations. However, entrainment is a concern if the losses of individuals from the reservoir threaten the persistence of these populations or the habitat downstream from the dam is unsuitable for the survival of entrained fish. Radio-telemetry of Bull Trout in the stilling basin from 2006 to 2009 indicate that Bull Trout survive in the Deadwood River downstream from the dam, and they also accessed tributary habitat in Wilson Creek to spawn during this study. Therefore, these Bull Trout that may be entrained from the reservoir survive and can potentially support the populations downstream from the dam, as well as colonize unoccupied habitat.

Studies conducted in Rimrock Reservoir in the Yakima Basin identified that subadult Bull Trout were susceptible to entrainment in low numbers; however, life cycle models indicated that the population was resilient to low levels of chronic (annual) entrainment (1.4% of subadults and 0.5% adults). Additionally, the population was also highly resilient to catastrophic entrainment which resulted in greater entrainment but in periodic environmental conditions (50% subadult entrainment every 15 years) (Underwood and Cramer 2007). Entrainment of Bull Trout through Deadwood Dam has likely occurred since the construction of the dam. Bull Trout populations above and below the dam indicate that populations above the dam are sustaining the existing losses to entrainment. Bull Trout tagged in the stilling basin during the study had similar tag loss and suspected mortality (18 – 27%) as those transported upstream from the dam and reservoir during salvage (25%).

4.1.6 Conclusions

Upstream from Deadwood Dam

In 2007, migration timing was 40 to 60 days earlier and tag loss/suspected mortalities were higher upstream from Deadwood Dam when the lowest reservoir pool elevations and warmest water temperatures were recorded during the study. Chapter 2, Section 2.2.4 also

identified this year as unique when the temperature, DO and reservoir content levels were also 2 to 3 weeks earlier than other years during the study, such as the date of weakened thermal stratification, date of minimum hypolimnetic DO, date of hypolimnion re-aeration and final reservoir draw down elevation. Temperatures exceeding 20.9^{o}C also occurred earlier during this summer. Therefore, it appears from the data that Bull Trout migration from the reservoir is triggered by physical conditions.

Growth upstream from Deadwood Dam was nearly double the growth estimated from populations downstream from the dam. Although 2007 resulted in earlier outmigration from the reservoir, there was no significant difference in growth. Therefore, it appears that Bull Trout can utilize other habitats with little impact when reservoir conditions are unfavorable. However, there was a reduction in the maximum observed growth during this year. This could be due to the lack of availability of the reservoir habitat for summer rearing where the individual(s) most efficient at utilizing the reservoir habitat are unable to acquire the high growth rates that the habitat provides or could be due to a random observation including a faster growing individual in the data set.

During the study, the average date of Bull Trout migration out of the reservoir coincided with surface elevations ranging from 1,622 to 1,625 m (average across years 1623.7 m). Minimum pool elevation ranged from 1,610 to 1,622 m between 1990 and 2011 (Chapter 2) and during a recent series of wet years (1995–1999) minimum elevation was >1,620 m (Chapter 2). Therefore, wetter water years that result in higher minimum pool elevations will have less impact on Bull Trout resulting in more reservoir habitat use (such as 2011) whereas the opposite is true for drier years and lower minimum pool elevations (such as 2007). Water operations that result in higher summer pool elevations will benefit the Bull Trout rearing in Deadwood Reservoir.

Downstream from Deadwood Dam

Bull Trout were scarce in the lower Deadwood River, but were captured in the stilling basin. Most or all of these trout are believed to have originated from upstream from Deadwood Dam, however the stilling basin is accessible to local populations in the tributaries. Tagged Bull Trout in the stilling basin remained in the Deadwood River and had similar survival as the Bull Trout transported from the spillway in 2010.

Entrainment

Entrainment of Bull Trout through Deadwood Dam may occur through the outlet works gates located in deeper water or over the spillway located at the crest of the dam. The outlet works are operated year-round with higher flows throughout most of the spring and summer months, whereas the spillway is typically operated for a brief period during the spring when the reservoir fills. Larger tagged trout were not detected near the dam during the period when spill occurs, where the risk of spillway entrainment would be apparently high.

However, although telemetry data suggest that Bull Trout were also not utilizing the deeper water habitat (>5 m) in the summer, it is possible that smaller individuals not tagged in high numbers during this study may remain in the reservoir rather than spawning, seeking out colder habitat at depth which results in a risk of entrainment through the outlet works gates. The size of juvenile Bull Trout captured in the stilling basin suggests that some of these are individuals from the reservoir population that may have become entrained in this way.

4.2 Physical Elements of Potential Bull Trout Habitat in the Lower Deadwood River

4.2.1 Introduction

Dams alter various hydrological and ecological processes. The dam itself has no impact on basin size or factors related to geology; however, it does alter streamflows and may also affect other flow-related habitat parameters such as sediment and LWD transport. Streamflow largely influences the amount of habitat (wetted area), depth, and associated velocities within the channel. Dams capture sediments in the reservoir from upstream reaches of the basin. The retention of fine sediments (silt and sand) in a reservoir can have beneficial effects on spawning habitat downstream of a dam; however, sediment transport of favorable spawning gravels can also be reduced. Transport of LWD can also be reduced by retention of logs in the reservoir and removal practices for necessary dam maintenance activities. The effects of reduced supplies of LWD and spawning-size gravel would be greatest in the reaches immediately downstream from the dam. Farther downstream, recruitment of sediment and woody debris from tributaries and the main channel streambanks will minimize the effects of the dam. Inferences about habitat condition and attributes are complex because parameters such as sediment and LWD sizes are also largely influenced by basin and land use characteristics. Therefore, the sizes and amounts of these parameters may not be related to dam operations. Regardless of these complexities between dam effects and land use impacts, habitat variables were used to describe current conditions and assess the potential impacts of streamflow releases from Deadwood Dam under the examined dam operation scenarios (0, 2, or 50 cfs post-irrigation streamflow releases) (see Chapter 3, Section 3.1).

Dams also directly influence the amount and quality of habitat by altering streamflow and the associated seasonal hydrology. Streamflow relates to the amount of habitat provided (physical space), as well as depth, velocity, and water quality parameters. The hydrologic effects of Deadwood Dam are analyzed in Chapter 3, Section 3.1. In this chapter, the conditions in the river downstream from the dam are examined in relation to the effects to Bull Trout and associated habitat.

Bull Trout can occupy a large range of habitat types (Rieman and Mcintyre 1995; Watson and Hillman 1997). Bull Trout are large predatory fish and tend to prefer deeper habitats. Larger fish generally tend toward occupying larger habitats; therefore, as fish age and become larger they tend to move downstream from natal habitats. Stream temperature is important in relation to tolerances and preferences of Bull Trout (Dunham et al. 2003; Howell et al. 2010). Howell et al. (2010) recorded 7-day daily average maximum summer temperatures between 14 and 18ºC in Bull Trout spawning and early rearing locations and 18 to 25ºC water temperatures in stream reaches where adult Bull Trout rear in the Grande Ronde Basin, a tributary to the Snake River in Northeastern Oregon. Individual adult Bull Trout were documented in water temperatures as high as 21ºC (Howell et al. 2010). Laboratory studies of age 0 and age 1 Bull Trout found that trout survive maximum temperatures up to 20ºC. Once temperatures exceed 20ºC, Bull Trout begin to show signs of stress and reduced feeding (Selong et al. 2001). Additionally, age 1 Bull Trout tested in the lab could survive maximum temperatures up to 20.9 ºC for up to 60 days (Selong et al. 2001). Predicted growth in age 0 and age 1 Bull Trout measured in lab experiments is maximized at 13.2 ºC (Selong et al. 2001). Although cold water appears to be a predictor of habitat use by Bull Trout, the relationship is not precise (Dunham et al. 2003; Howell et al. 2010).

The effect of water operations on water temperature in the Deadwood River is addressed in detail in Chapters 3 and 5. This section focuses on the effects of water operations and ramping rates on the river habitat downstream from the dam. The purpose of this study was to: 1) describe the river habitat downstream from the dam in relation to habitat characteristics described for Bull Trout; 2) identify potential effects of the dam on habitat variables downstream; 3) compare various habitat parameters over three winter streamflow releases (0, 2 and 50 cfs); and 4) examine the extent of disconnected pools and post-irrigation season down-ramping rates on relative numbers of fish stranded in the disconnected habitat. Objectives 1, 2, and 3 were addressed using LiDAR data coupled with on-the-ground stream habitat surveys on the lower river between the dam and the mouth to quantify the amount of habitat (width, depth) and various characteristics such as sediment sizes, LWD, and gradient.[3] Objective 4 was addressed using on-the-ground habitat surveys to identify disconnected habitats at 3 test streamflows (0, 2, and 50 cfs) coupled with fish collection in the disconnected habitat in relation to two down-ramping strategies – fast (no) ramping and slow (taking place over 10 days, with variable daily reduction rates depending on the starting flow). Since 1993, the post-irrigation minimum streamflow from Deadwood Dam was 50

[3] Although LiDAR data analysis has been included in this report, its accuracy and practical applicability should be evaluated conservatively. It has since been found that the six foot point spacing used in these surveys is of questionable usefulness in the spatial context of the steep topography along the Lower Deadwood River, and does not provide the fine resolution necessary for accurate representation of habitat characteristics being surveyed and analyzed. Reported changes in water depths calculated from LiDAR contain a high frequency of inaccuracies due to this issue. Ground surveys conducted to corroborate LiDAR findings failed to identify disconnected pools identified through LiDAR analysis. Refer to Table 4-9, showing summary data from ground surveys, for more accurate information on habitat variables at surveyed representative habitat units.

cfs. This recent post-irrigation minimum flow (50 cfs) is used as one of the three test streamflows and is considered the baseline from which to compare the effects of alternate streamflows on Bull Trout habitat downstream from the dam.

4.2.2 Water Operations

Three test post-irrigation streamflows were identified as possible effects of flexibility in operations at Deadwood Dam (0, 2, and 50 cfs). The test streamflows were compared during 2010, 2011, and 2012. Ramping rates from late season irrigation releases to post-irrigation streamflows were also tested. Fast ramping rates were implemented, during the study, by closing the outlet gates from the irrigation streamflow release to the post-irrigation streamflow release and allowing the water surface to adjust downstream from the dam. The slow down-ramping rate was implemented in 2011 by reducing the streamflow 100 cfs/day to the desired streamflow release. Streamflows and corresponding dates conducted during this study are shown in Figure 4-27. In 2010 and 2011, the gate adjustments were made in the night (at 10:00 pm) and the streamflow declines during the night time hours. In 2012, the gates were adjusted at noon and the streamflow declined steadily during the afternoon and evening (sunset) hours.

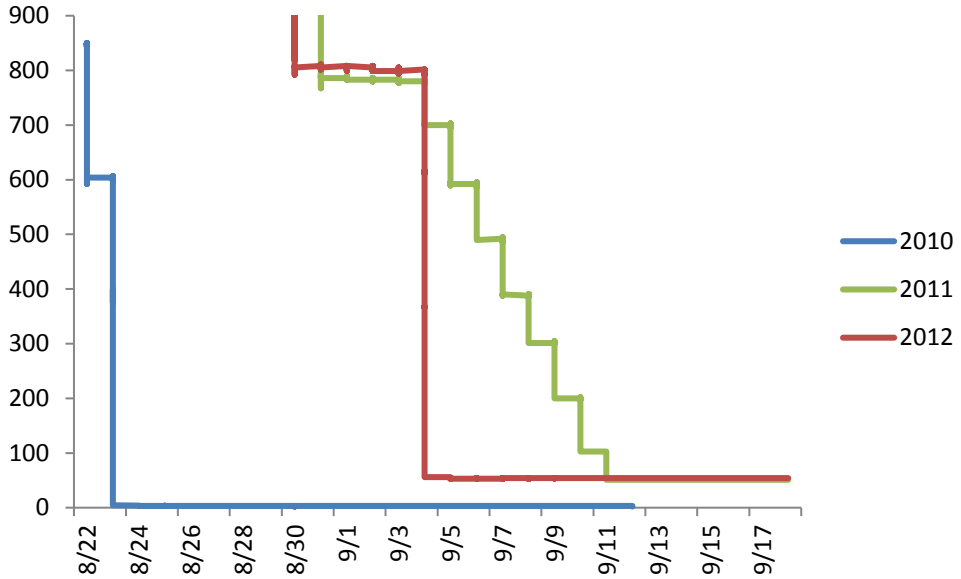


Figure 4-27. Stream discharge (cfs) during down ramping implemented at Deadwood Dam, 2010 – 2012.

4.2.3 Methods

This section focuses on examining several post-irrigation streamflow releases on the physical habitat downstream from the dam in relation to potential options in water operations. The hydrologic and water temperature effects of streamflow are analyzed in Chapter 3. The data presented here explains the effects of post-irrigation streamflow releases on the amount of wetted habitat, channel depths, and associated stream temperatures. Additionally, field surveys were conducted in a subset of reaches and habitats to estimate the effects of tested post-irrigation streamflows on available habitat characteristics such as cover.

Wetted Area Estimates

Data analyzed from the simulations in Chapter 3 were used to summarize changes in wetted area between 0, 2, and 50 cfs (Figure 4-28). Water surface elevation changes at the 0, 2 and 50 cfs post-irrigation streamflows were estimated from channel cross sections from the MIKE11 model data at locations along the lower Deadwood River. Water surface elevation was estimated from the average elevation on January 1 for each of the simulations for dry, average, and wet conditions (Simulations 3, 5, 7, 11, 13, 15, 19, 21 and 23).

Field Surveys

Habitat data were collected at a subset of reaches at each of the different test flows (Table 4-8). Habitat unit type (pool, riffle, run, etc.) was identified according to the California Salmonid Stream Habitat Restoration manual (Flosi and Reynolds 1994). Valley confinement, percentage of surface fines and Wolman pebble counts were conducted according to Overton et al. (1997).

Surveys were conducted at flows of 0, 2.3, to 2.5 cfs (we will refer to this range as 2 cfs throughout this section), and 50 cfs outflow from Deadwood Dam. GPS coordinates were collected using ArcPad in a Trimble GeoXT GeoExplorer 2008 Series at the upstream and downstream ends of each habitat unit. Accuracy of the GPS data averaged between 1 and 2 meters. Data were collected on habitat type (pool, riffle, run) and thalweg length (m). If the habitat unit was a step pool complex, the entire length was measured. In pool habitats, maximum and tail crest depths were measured using a staff rod. In the case of a dam pool (such as beaver dam or LWD), the upstream end of the pool was used at the crest depth. Pocket pools were estimated for riffle and run habitats and an average depth calculated for pocket pools within that habitat. Pocket pools were counted and average depths were measured from the first three pocket pools.

Percent cover (overhanging vegetation, LWD, substrate and depth >0.5 m) was determined using visual estimates measured as a percent wetted area at 0 cfs streamflow. Slow depth cover was an observational parameter used to describe deep habitat with little velocity. Undercut bank describes the percentage of linear bank with greater than 0.1 meters overhang

and greater than 0.1 meters water depth at bankfull. Bank stability was estimated as percent stable linear bank. LWD greater than 0.3 meters in diameter and 3 meters long was recorded as singles (length and diameter and percent submerged), aggregates (number of pieces), and root wads (number).

Channel substrate was visually identified as bedrock, boulder, cobble, gravel, sand, dirt, and wood. The top three substrate types were listed in order of most abundance. Pebble counts were done in each reach to characterize sediment size (Wolman 1954). Embeddedness was measured for each of the sediments counted during the sediment sizing.

Table 4-8. Survey effort by streamflow for field surveys in the lower Deadwood River. Reach no. surveyed, average elevation of the reach (feet), total reach length (m), and surveyed distances within each reach at 0, 2, and 50 cfs.

Reach	Elevation (m)	Reach Length (m)	Surveyed length(m) at 0 cfs	Surveyed length (m) at 2 cfs	Surveyed length(m) at 50 cfs
2	1153.7	1487.1	309.5	359.0	342.5
4	1176.5	1132.6	704.2	705.0	223.0
5	1207.0	5908.5	541.3	575.0	575.0
7	1249.7	2587.1	233.5	234.0	234.0
8	1310.6	1203.4	414.1	358.0	358.0
9	1325.9	2603.6	0	286.0	286.0
10	1353.3	1319.9	0	243.0	243.0
11	1371.6	3032.9	0	223.0	228.6
12	1432.6	5780.9	511.5	323.7	510.8
13	1475.2	1302.2	1091.3	1082.8	1091.3
14	1478.3	2897.4	263.9	268.1	263.9
15	1524.0	3553.5	389.8	0	300.5
16	1572.8	3357.3	590.4	179.1	566.0
Total			5277.8	4836.6	5222.7

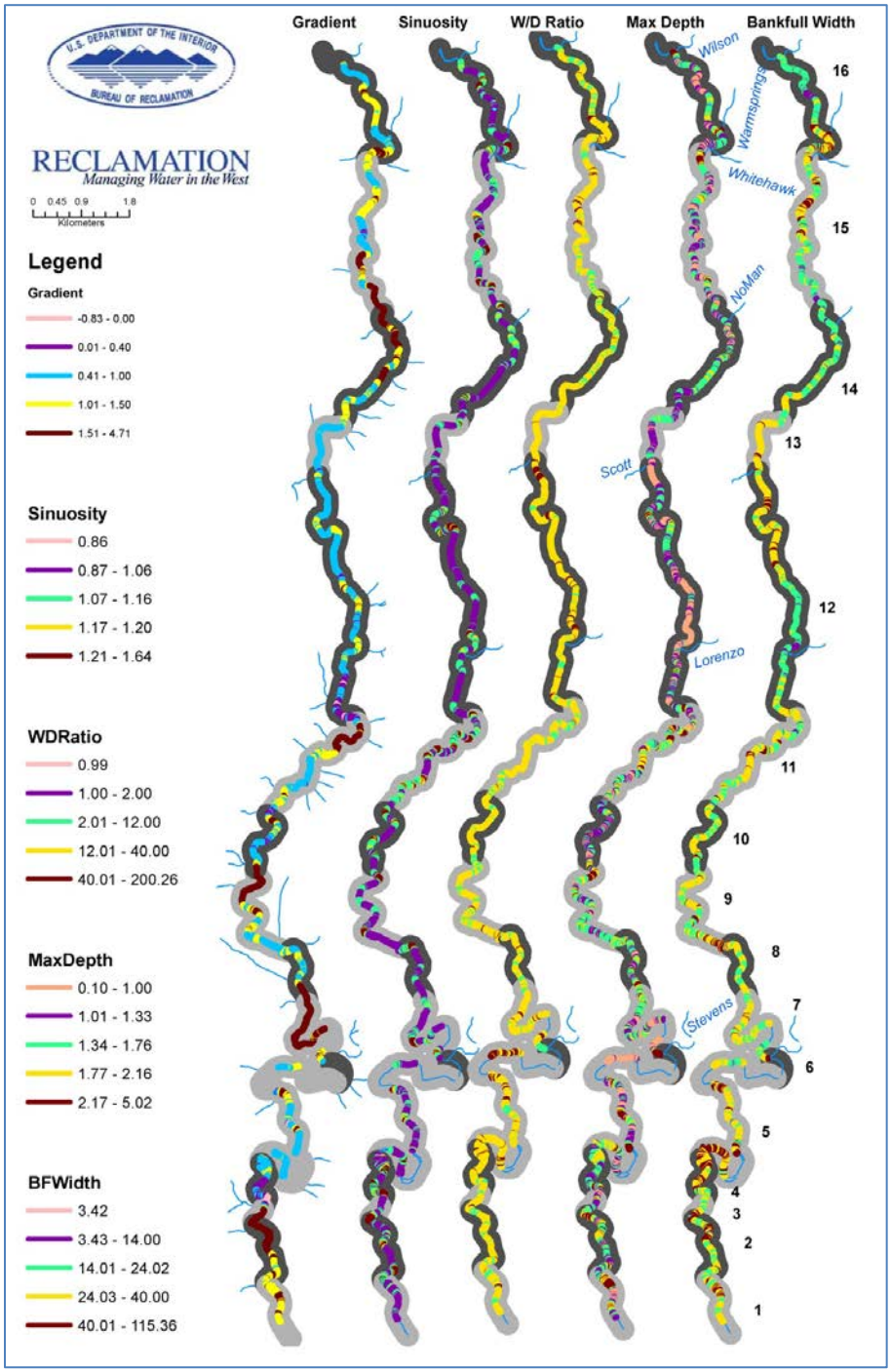


Figure 4-28. LiDAR maps showing gradient and other geomorphic features of the Deadwood River from the SF Payette Confluence up to Deadwood Dam. The dam is located at the top of the channel maps and the streamflows down to the mouth at the bottom of the maps. LiDAR data were collected in fall 2007 when 50 cfs was passed at Deadwood Dam.

Disconnected Habitat and Stranding Estimates

A subset of reaches were sampled to assess disconnected pools and stranded fish (reaches 1, 3, 4, 5, 9, 12, 13, 14, and 16). Disconnected pools were identified as watered habitat within the bankfull channel disconnected (dewatered) upstream and downstream from the streamflow in the main channel. Each disconnected pool was given a numeric identifier, reach number and the pool number (number 1 being the farthest downstream pool in a particular reach). The following data were collected at each disconnected pool: date and time, GPS coordinates, length, width, depth (at three locations along each length profile), average depth of the pool (estimated), maximum depth, substrate size, surface and bottom temperature, and surface and bottom DO. Photographs were taken of each disconnected pool; however, habitat photographs were not included in this report. GPS coordinates were collected using a Garmin Oregon 550 GPS unit. Accuracy of the GPS data averaged between 3 and 5 meters.

Dimensions (length and width) for each disconnected pool were measured with a tape measure. Length was measured along the longest axis of the pool and width was measured along the longest perpendicular axis to the length profile. Depth was measured at ¼, ½, and ¾ distance across both the length and width of the pool. Maximum depth of each disconnected pool was also measured with a staff rod.

Surface and bottom water temperature were measured at deepest location within the disconnected pool with a handheld thermometer. Surface and bottom DO were measured in the disconnected pools in reaches one through nine using a handheld DO meter at the deepest location.

Fish were sampled in pools that were large enough to sample using a Smith Root backpack electroshocker. Captured fish were identified to species or genus, measured (total length), and released into the nearest main channel slow habitat.

4.2.4 Results and Discussion

Habitat Suitability for Bull Trout

Bull Trout occur throughout the interior Columbia and the Snake River basin upstream to the Bruneau River basin near Mountain Home, Idaho. The tributaries to the Snake River upstream from Hells Canyon are in the southern extent of the species range. The climate in this area is high desert with less precipitation and higher seasonal air temperatures at lower elevations. Rieman and Macintyre (1995) found that Bull Trout occupied a wide range of habitats in the Boise River basin, adjacent to the Payette River basin, although larger Bull Trout are present below 1,550 m in elevation, spawning, and juvenile/resident rearing behaviors were not observed at elevations lower than 1550 m. Bull Trout were present in all

stream sizes (average widths sampled) greater than 2 m and average stream gradients ranging from 1 to 10%. Stream gradient was not related to presence of Bull Trout (Rieman and Mcintyre 1995). Width, basin size, and elevation were directly correlated to Bull Trout presence (Rieman and Mcintyre 1995). Additionally, these variables are closely tied to stream temperatures which are considered important to Bull Trout. Stream temperatures change seasonally due to solar radiation, elevation, tributary inputs and other climatic variables, as well as discharge from the dam (see Chapters 2 and 3 for detailed analyses).

Average stream gradients in the Deadwood River downstream from the dam ranged from 0 to 4% and stream widths ranged from 10–30 m which are values well within the range of habitat documented for Bull Trout. In brief, historic and modeled data indicate that stream temperatures are not expected to exceed 18°C in the lower river (see Chapter 3, Section 3.1.3), which falls within the temperature range tolerance for Bull Trout. Elevations in the lower Deadwood River range from 1,128 to 1,584 m, indicating that the habitat downstream from Deadwood Dam represents acceptable feeding, migration, and overwintering habitat, and may be on the threshold of habitat capable of supporting Bull Trout spawning and rearing in this eco-region. Yet, in other areas of the Snake and Salmon rivers, Bull Trout will utilize lower elevation and larger river habitat for over-wintering and migration. For example, telemetry studies in the Rapid River basin near Riggins, Idaho have identified that Bull Trout migrate from the upper reaches of this basin into the mainstem Salmon River to over-winter (about 550 m elevation) (Schill et al. 1994). Therefore, the habitat in the lower Deadwood River should be considered important to support connectivity, with the possibility that it also may provide seasonal rearing opportunities for local populations in the Deadwood and potentially South Fork River Payette basin.

Potential Effects of Dam on Sediment and Woody Debris

Depletion of certain sizes of sediment or woody debris is expected to occur for a distance downstream beyond which these materials are replaced from local stream side and tributary habitats by lateral channel processes. The distance and degree of effect would be related to factors such as stream size, land use, valley confinement, parent geology and gradient. An effect of the dam on the transport of these materials may be detected by examining trends in material amounts and sizes.

Percent embeddedness was generally low in the lower Deadwood River with little variation in the percent of gravel/cobble embedded (Figure 4-29). No trends were apparent in the data set except for the smallest but most numerous embeddedness category (<10%). These data indicate little influence of the dam on embeddedness measurements in the lower river. The larger sediment sizes were dominant in the lower Deadwood River (cobble and boulder). Sediment sizes indicate higher proportion of boulders in reaches 14 and 15 (upstream extent of survey), higher proportions of cobble size sediment in the middle reaches 5-13 and higher proportions of gravel in the lower reaches 2 and 4 (Figure 4-30 and Figure 4-31). The high

proportions of gravel size sediment in reaches 2 and 4 could be due to several factors such as source, stream size and hydraulic transport (or conversely retention). Although it is difficult to determine if this is an effect of the dam, reach 4 is a long distance (33.5 km) downstream from the dam. The steep canyon and entrenched banks in this reach of the river indicate that the lack of sources of the smaller sediment size classes could account for these observations. Therefore, bank or tributary recruitment or retention of these size sediments in this reach may be the most reasonable explanation of the data rather than sediment retention above the dam. Additionally, the middle reaches of the river are influenced by terrestrial processes, such as avalanches and debris flows from the steep canyon which likely has a direct influence on sediment and woody material in the stream channel.

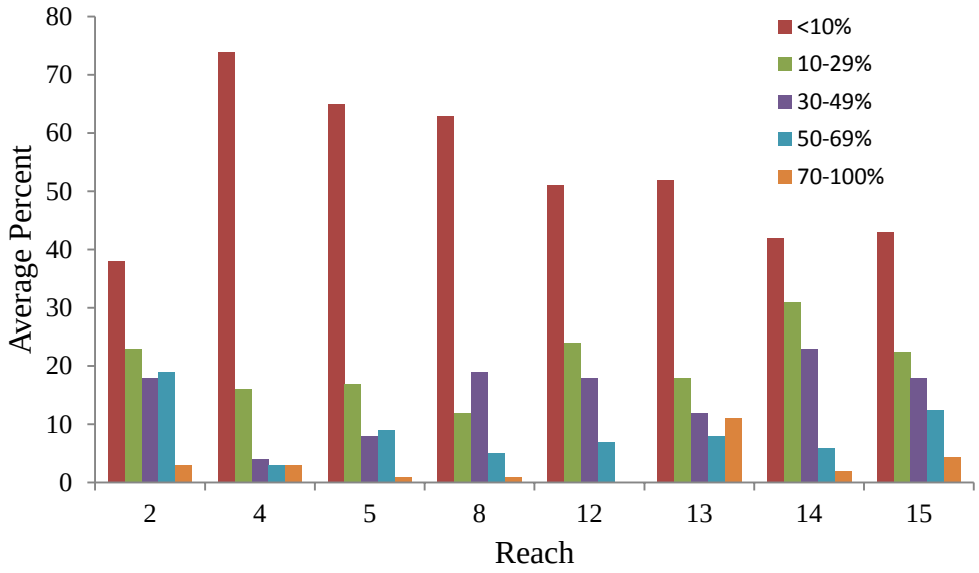


Figure 4-29. Average percent embeddedness by reach in the lower Deadwood River. Reaches are listed in ascending order from downstream (reach 2) to upstream (reach 15).

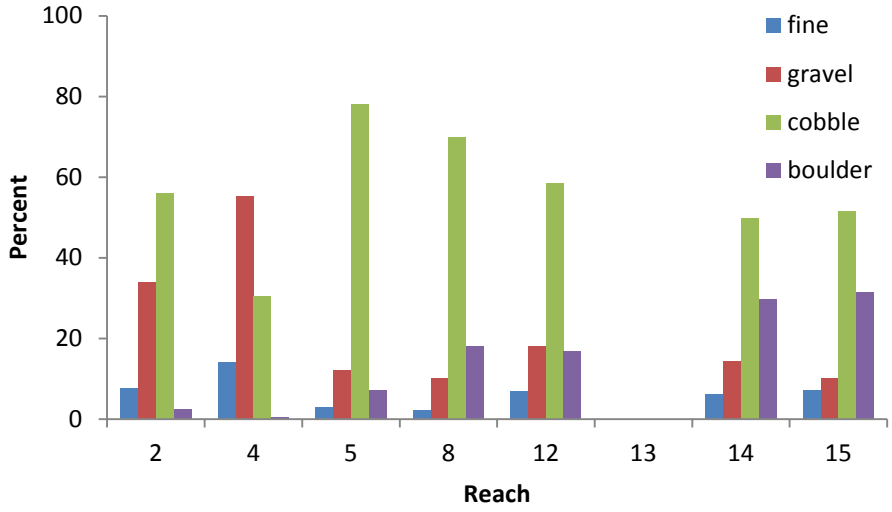


Figure 4-30. Percent sediment sizes (fines <4 mm, gravel 4-64 mm, cobble 64-256 mm and boulder >256 mm) measured in riffle and run habitats by reach in the lower Deadwood River.

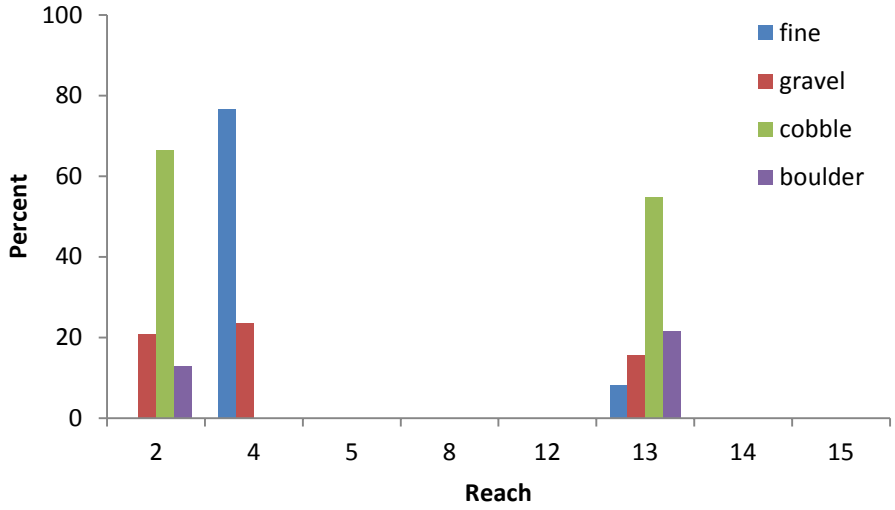


Figure 4-31. Percent sediment sizes (fines <4 mm, gravel 4-64 mm, cobble 64-256 mm and boulder >256 mm) measured in pool habitat by reach in the lower Deadwood River.

Similarly, an upward trend of the amount of LWD would be expected if the dam was reducing the supply from upstream reaches. In other words, LWD would be expected to be sparse in the upstream reaches and more numerous in the downstream most reaches. The numbers of LWD per 1,000 feet of stream were highest in the middle reaches likely due to fire, wind and avalanche/debris flow effects on the landscape, and showed a declining trend with fewer pieces of LWD in the downstream reaches (Figure 4-32). Stream and canyon characteristics will determine where LWD is retained, and the lower numbers of wood in the

downstream reaches may be due to increased stream size and increased transport. These data generally indicate that the effects of landscape, geologic, and channel characteristics are likely greater than the impacts of transport from the dam.

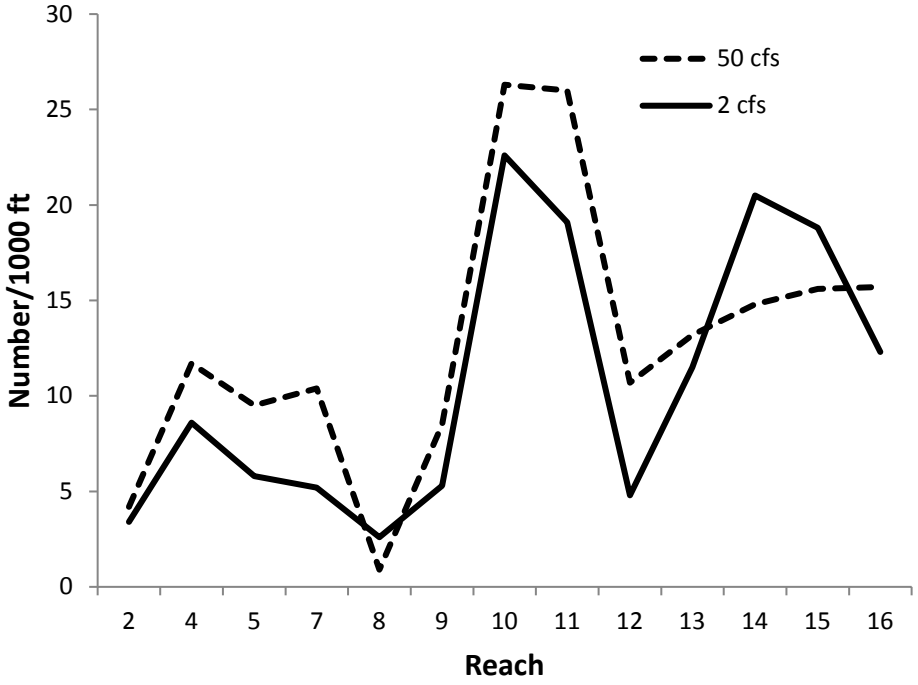


Figure 4-32. Number of LWD within the wetted width per 1,000 feet of stream counted during surveys in reaches in the lower Deadwood River at 0 and 50 cfs streamflows. The reaches are numbered from the most downstream (reach 2) to the most upstream (reach 16).

Comparison of Post-irrigation Streamflows

The dam has a direct effect on streamflows in the lower river and the associated water temperature is a relationship between streamflow from the dam, conditions in the reservoir and climatic conditions (air temperature, precipitation, etc.). These variables are analyzed and discussed in relation to water operations in Chapters 3 and 5. Streamflows and the relative amount of habitat provided at target post-irrigation streamflows are discussed in relation to Bull Trout habitat below.

Change in wetted area, change in depths, and change in other habitat variables were examined across three post-irrigation season streamflows. The 0 and 2 cfs options were compared separately to the 50 cfs (baseline) condition. The total change in wetted area varied over the precipitation and climatic conditions with the greatest reduction in predicted wetted habitat in the dry year 0 cfs streamflow (Figure 4-33 and Figure 4-34). The cumulative predicted reduction in wetted area ranged from 13–22 hectare (ha) and did not exceed 4.5 ha in any reach. Predicted change in the total wetted area deeper than 0.5 m

ranged from 2.1–2.2 ha across the dry, average and wet years. Precipitation conditions had little effect on the amount of wetted deep habitat, and comparisons differed little between the 2 and 0 cfs. Comparison of the amount of deeper water habitat (>0.5 m) across the proposed streamflows indicates a total average loss of 2.0–2.1 ha in the 0.5–1.5 m depth and 0.08 ha in the >1.5 m depth when comparing the 0 and 2 cfs to the 50 cfs streamflow (Figure 4-35).

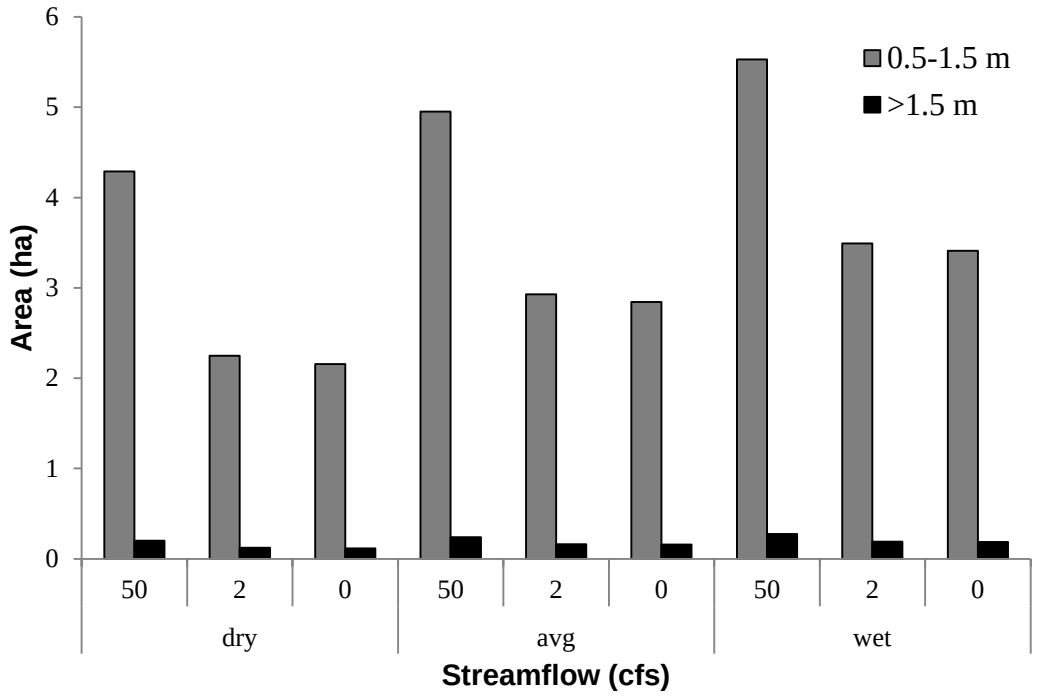


Figure 4-33. Amount of wetted habitat predicted using LiDAR during three post-irrigation streamflows (50, 2, and 0 cfs) from Deadwood Dam.

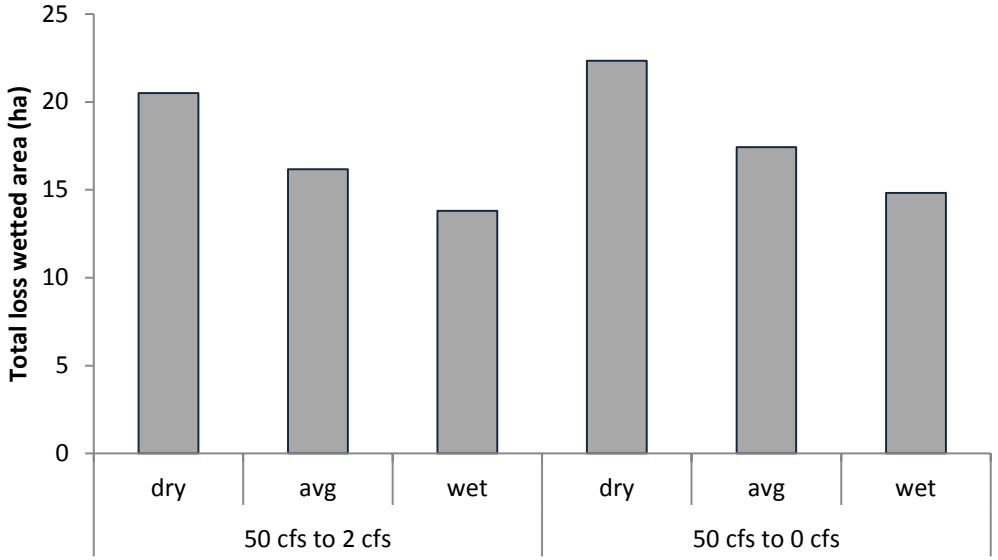


Figure 4-34. Change in total wetted area (ha) in the lower Deadwood River between 50 and 2 cfs and 50 and 0 cfs from Deadwood Dam.

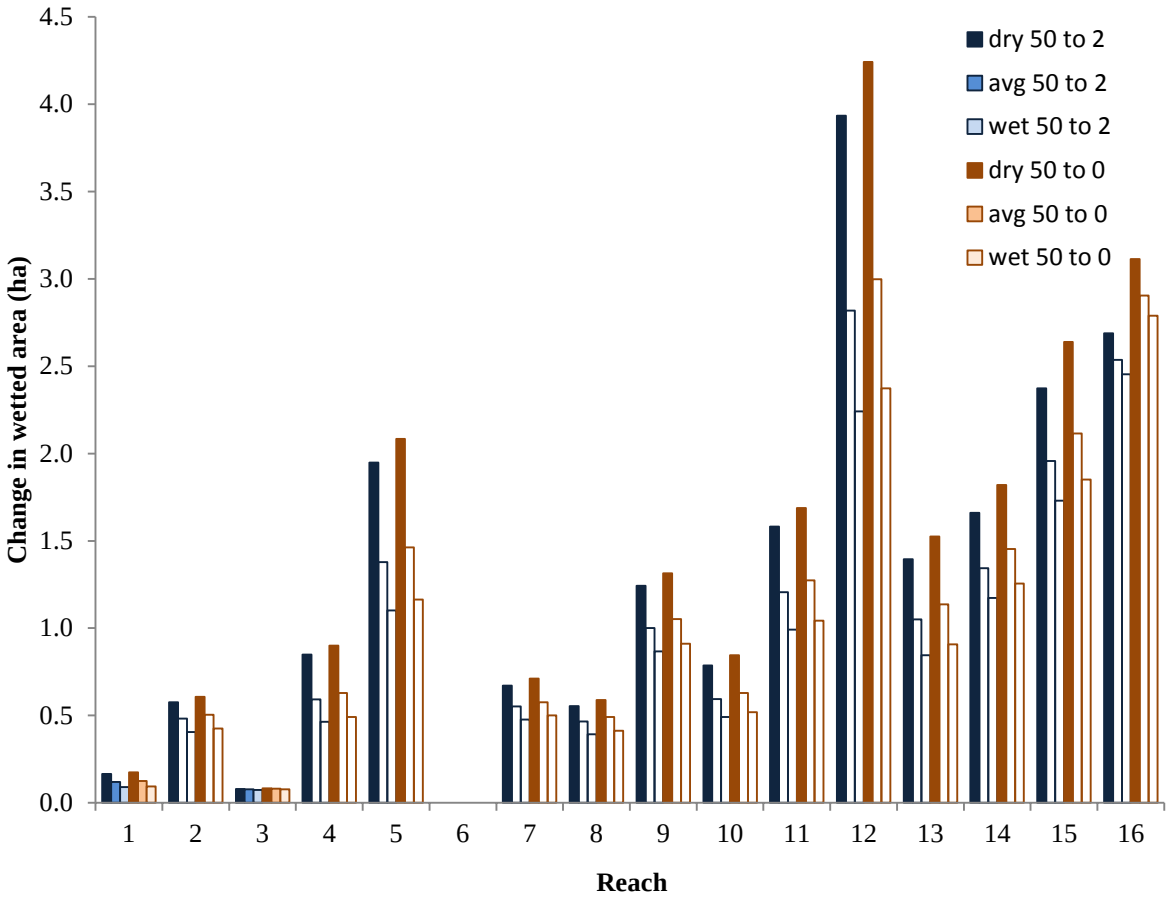


Figure 4-35. Change in total wetted area (ha) by reach in the lower Deadwood River between 50 and 2 cfs and 50 and 0 cfs. Reaches are numbered from downstream (Reach 1 near mouth) to upstream (reach 16 near dam). LiDAR data were not collected in reach 6.

Change in water surface elevation indicates the relative amount of channel depth that is lost in the aquatic habitat. Predicted change in water surface elevation ranged from 0–.1 m (average 0.16 m) in the comparisons between 50 and 2 cfs and 50 and 0 cfs in the lower Deadwood River over dry, average, and wet year conditions (Figure 4-36). On average across the water years, the difference in water surface elevation ranged from 0.06–0.63 m with the greatest differences measured at the transect 90 m downstream from Deadwood Dam. Most of the change in depth between the test flows occurs in the first 900 m downstream from the dam after which tributary inflows and channel size reduce the effect on the water surface elevation.

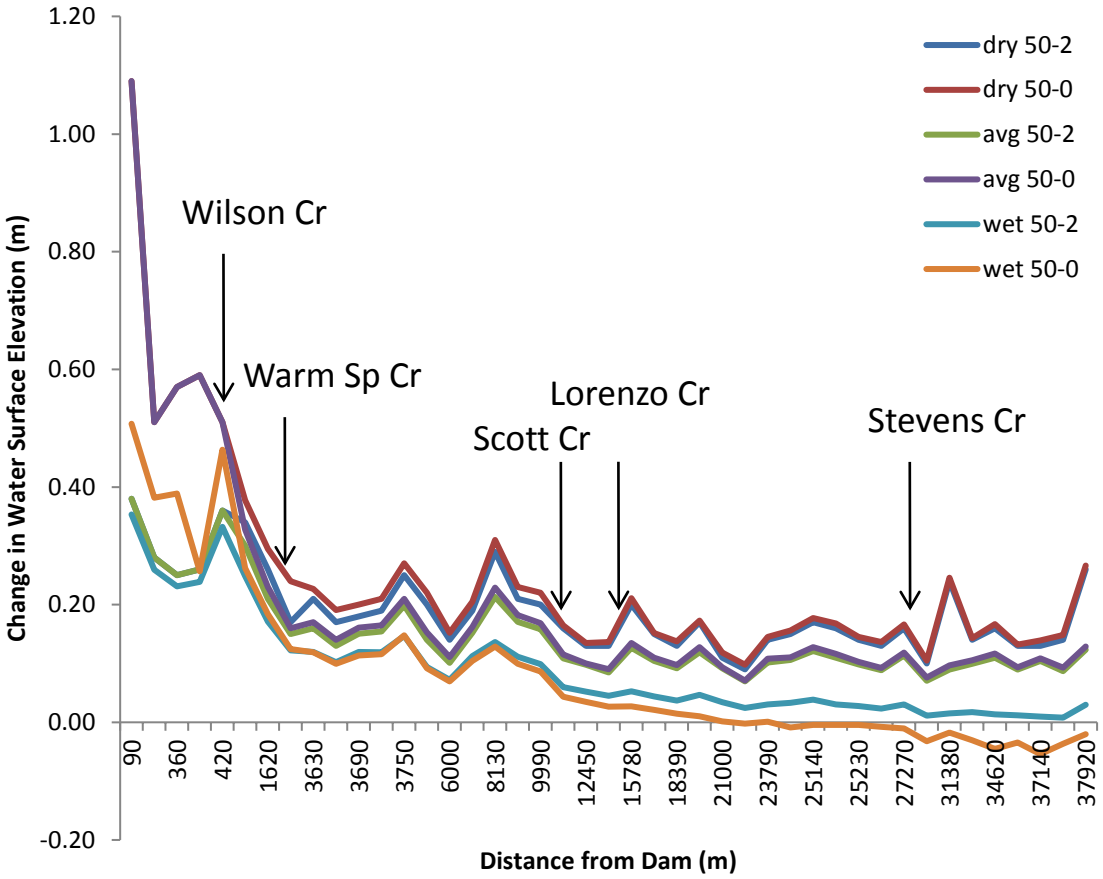


Figure 4-36. Change in water surface elevation (m) at transects from LiDAR in the lower Deadwood River.

Field survey data of the same reaches indicated little change in habitat parameters over the three tested streamflows (Table 4-9). Percent slow depth cover is greater and pocket pools are more numerous at the lower streamflows. Overall, depth and boulder cover are most impacted at the lower streamflow; however, these cover types are high in these reaches of river with 35–45% of the surveyed habitat having these cover types (Table 4-9).

Table 4-9. Average of habitat variables measured at surveyed habitat units within representative reaches of the lower Deadwood River at three test streamflows (0, 2 and 50 cfs) and the change in habitat between 50 cfs and 2 cfs. Habitat variables include percent cover from vegetation, percent cover from boulders, percent cover from deep water, percent of deep water with slow velocity, number of pocket pools, average depth of pocket pools, LWD aggregates, percent LWD cover, and number of LWD singles.

Variables	0 cfs	2 cfs	50 cfs	Change
Vegetation cover (%)	1.4	1.7	2.2	0.5
Boulder cover (%)	53.0	45.7	55.5	9.8
Depth cover (%)	38.4	41.9	54.7	12.8
Slow depth cover (%)	30.0	36.6	26.9	-9.7
Number of pocket pools	12.7	8.9	5.4	-3.5
Average depth of pocket pools (m)	0.3	0.4	0.5	0.1
LWD aggregates	1.9	1.9	1.3	-0.6
LWD cover (%)	3.7	4.4	3.5	-0.9
LWD singles	3.2	2.8	3.3	0.6

Disconnected Habitat and Assessment of Ramping Rates

Stranding of fish in disconnected pools is an indication of the relative and potential effect of streamflow alteration on the behavior, growth, and survival; survival is likely dependent on climatic and environmental conditions that vary spatially and temporally. Therefore, the effects of stranding and disconnected habitats would require repeated measurements comparing this habitat to connected habitat to quantify the exact effects. Streamflows change seasonally due to natural events and stranding of fish in disconnected habitats occurs naturally. At times, disconnected and off-channel habitats can provide more favorable rearing conditions depending on the environmental attributes and associated micro-habitat conditions. Because the streamflows related to this study are implemented during the winter months, we suspect that surface ice in the pool could result in oxygen depletion in some pools that could be adverse to the growth and/or survival of fish rearing in the disconnected habitats.

Bull Trout were not detected in disconnected pools during this study. This is likely a result of low numbers of Bull Trout present in the river downstream from the dam, but also can be the result of the habitat selection by Bull Trout to utilize the deeper water habitats that likely remain watered and connected.

Disconnected pools occurred during all flow reductions in all years studied with the 50 cfs streamflow having the lowest number of disconnected pools (Table 4-10). Although we expect to have a direct and positive relationship between the quantity of streamflow and the number of disconnected pools, the data found fewer disconnected pools at 0 cfs than at 2 cfs. We suspect that this is an artifact of the timing of sampling and potential pool drying at the 0 cfs streamflow and possibly the effect of different subsurface water elevations that would vary in different water years.

During 2010 sampling, 69 disconnected pools were counted at the 2 cfs streamflow and 55 disconnected pools were counted at the 0 cfs (no streamflow release from the dam) in the surveyed reaches. During the 2011 and 2012 surveys, 11 and 15 disconnected pools were documented at 50 cfs streamflow, respectively. Reaches 12 and 13 produced the highest number of disconnected pools at the lower streamflows (0 and 2 cfs), while reaches 4 and 5 produced the most disconnected pools at the higher streamflow (50 cfs).

Evaporation and groundwater seepage has some effect on the presence and absence of disconnected pools between flow reductions. Certain pools, though they were present at the higher flows appear to have been eliminated at the lower flows, suggesting depletion or drying between the events. For example, some pools were found at 2 cfs but then eliminated at 0 cfs, while the further reduction to zero brought about new stranding pools.

Table 4-10. Summary of the number of disconnected pools identified during field surveys during 2010, 2011 and 2012 at 0, 2, and 50 cfs streamflow from Deadwood Dam. Reaches are shown in Figure 4-28.

Reach	0 cfs	2 cfs	50 cfs in 2011	50 cfs in 2012
1	4	4	1	1
3	2	2	0	1
4	7	8	2	4
5	2	2	2	4
9	2	2	0	0
12	16	16	1	2
13	13	13	2	1
14	6	6	0	0
16	3	16	3	2

Slower ramping rates are generally assumed to reduce the impacts of stranding by allowing fish more time to adjust to the streamflow reductions and reduced wetted channel. Rate of change of the streamflow from the regulated facility is typically weakly related to the probability of stranding. Variables such as density of fish, duration of a stable streamflow (or habituation) and stream temperature are variables with greater correlation with stranding (Bradford 1997; Halleraker et al. 2003; Irvine et al. 2009). Generally, studies indicate that rates of reduction in water surface elevation < 10 cm/hr can reduce stranding. Rates < 2 cm/min have been shown to reduce stranding and making these changes over a 4 to 5 hour period can prevent stranding entirely (Irvine et al. 2009). Faster rates of change (30 or 60 cm/hr) tend to result in stranding rates around 2 to 10% (Bradford 1997; Saltveit et al. 2001; Halleraker et al. 2003; Irvine et al. 2009).

The relative number of fish captured varied among years sampled. These numbers simply provide a relative account of the effect of stranding on the species detected. We expect that the number of fish stranded is a function of abundances in these river reaches. Therefore,

without population surveys and abundance estimates for the mainstream Deadwood River in these reaches, these numbers cannot be directly compared. Down-ramping rates for 2010, 2011, and 2012 were 5.1, 0.7, 14.8 cm/hr, respectively, measured at the USGS streamflow gage downstream from the dam and averaged over the entire ramping period. Although the 2012 rate therefore appears to have been higher than the rate of <10 cm/hr recommended in the literature; this number does not accurately reflect actual ramping rates on the hourly scale, which may explain why numbers of fish in disconnected pools were still fairly low based on the surveys. While hourly rates of water surface reduction likely affect stranding rates as identified in the literature, the overall extent of flow reductions appears to have had a greater impact on the number of stranded fish, rather than the averaged rate of change in the water surface elevation.

Bull Trout were not captured during these surveys which is likely a result of few Bull Trout utilizing this reach of river. The other salmonids captured during this survey (such as Kokanee Salmon and Rainbow Trout) would provide some indication of the potential impacts of streamflow reductions on stranded fish; however, densities in the river can vary year-to-year based on spring pre-irrigation operations (Table 4-11). These data also provide an indication of the relative effects on prey species utilized by Bull Trout. Sculpin represented the only non-salmonid fish found in the stranding pools. Their habitat preferences may lead to higher rates of stranding, as they occupy stream bottom habitats and may respond to water level changes by burrowing into the sediment.

Most of the salmonids detected in the pools were the smaller size class. These young-of-year salmonids typically utilize the shallower stream side habitats where velocities are slower. Therefore, they may be more vulnerable to stranding during changes in streamflows. Stranding experiments indicate that the young-of-year salmonids are more vulnerable to stranding when the larger age classes of salmonids are present (Halleraker et al. 2003).

These factors, taken in consideration with the lack of Bull Trout found in either the pools or the main channel of the river below the stilling basin, indicate that ramping rates have no negative effect on stranding of Bull Trout in the main channel of the lower Deadwood River. Although the data suggests that prey base is lost anytime stream habitat is dewatered, the effect to the prey base is likely minimal as we expect that the habitats in the mainstem are utilized by these same species and size classes.

Table 4-11. Summary of fish stranded by species per year in disconnected pools sampled after streamflow reductions.

Species	2010	2011	2012
Bull Trout (*Salvelinus confluentus*)	0	0	0
Cutthroat Trout (*Oncorhynchus clarki lewisi*)	0	0	0
Kokanee (*Oncorhynchus nerka kennerlyi*)	46	0	0
Rainbow Trout (*Oncorhynchus mykiss*)	59	14	38
Redside Shiner (*Richardsonius balteatus)*	0	0	0
Sculpin *Cottus spps.*	124	9	11
Dace *Rhinichthys spps.*	0	0	0
Mountain Whitefish (*Prosopium williamsoni*)	1	1	6
Total	**230**	**24**	**55**

Both years with fast ramping (2010 and 2012) had more stranded fish observed in disconnected habitat during surveys (Table 4-11). The relative numbers of fish is a result of the lower streamflows implemented in 2010 (0 cfs in 2010 versus 50 cfs in 2012) which creates more disconnected pool habitat. When comparing the similar streamflow (50 cfs) between the fast and slow ramping rates implemented in 2011 and 2012, there are more fish detected in disconnected pools during the faster ramping rates.

Stilling Basin

The stilling basin, the area directly below Deadwood Dam, provides deep pool habitat with sufficient amounts of structure to provide protection from the high flows during irrigation season. Therefore, the basin acts as holding habitat and an over-wintering area. The only Bull Trout in the Deadwood River downstream from the dam captured during this study were in the stilling basin. Radio telemetry studies have detected Bull Trout utilizing stilling basin habitats in other locations (Mogen and Kaeding 2005b), and five Bull Trout tagged and released in the stilling basin during this study were re-captured the following year and some trout were tracked downstream (see Chapter 4, Section 4.1.5). The furthest downstream detection was more than 20 km downstream near Stevens Creek in the lower Deadwood River during 2007 and 2008 (Figure 4-9 and Figure 4-10).

About 70% of all the fish captures downstream from Deadwood Dam occurred in the spillway habitat during the 2010 sampling indicating high abundances of fish nearest the dam. Species captured in the stilling basin include: Bull Trout, Cutthroat Trout, Kokanee Salmon, Rainbow Trout, Redside Shiners, Sculpin, Dace, and Mountain Whitefish. The lower streamflows (0 and 2 cfs) from Deadwood Dam could impact these fish when connectivity in this upper-most reach is impacted.

4.2.5 Conclusions

The river habitat downstream from Deadwood Dam is generally suitable for seasonal feeding, migration, and overwintering of Bull Trout, and may be on the threshold of suitability for supporting spawing and rearing. However, elevations are lower than those expected for this species and eco-region (Rieman and McIntyre 1995). The removal of sediment and LWD by the dam does not appear to have a measurable effect on the habitat downstream. In drier years, the reservoir water surface elevation is reduced and warmer water from the shallower reservoir depths is passed downstream during late summer and fall. For example, during 2007 when the reservoir reached the lowest levels during the study, the water temperatures in the lower Deadwood River were 6^{o}C higher than during the other years of the study (Chapter 2, Section 2.2.4).

In the Deadwood River, down ramping has not been applied except in the test flows summarized in this report. The results from these test flows indicate that fewer salmonids were stranded when implementing the slower ramping rate. However, Chapter 2, Section 2, and Chapter 3, Section 3 indicate some temperature benefits to Bull Trout when implementing the fast (no) ramping. These findings indicate a cost to Bull Trout in the reservoir from the loss of water used for down ramping and that water being stored and available the following irrigation season, particularly during dry and average years. Studies on ramping indicate that the relatively seasonal stable streamflows related to irrigation releases can create habituation which can cause salmonids to be tentative to leave established territories when streamflows decline. Studies indicate that rates of reduction in water surface elevation <10 cm/hr can reduce stranding and rates < 2 cm/min over a 4-hour period can reduce stranding of salmonids entirely (Irvine et al. 2009). Faster rates of change (30 or 60 cm/hr) tend to result in stranding rates around 2 to 10% (Bradford 1997; Saltveit et al. 2001; Halleraker et al. 2003; Irvine et al. 2009).

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Chapter 5 WATER QUALITY MONITORING AND HABITAT SURVEYS

(During Interim Operations Fall 2013 to Spring 2014: Deadwood River Downstream from Deadwood Dam)

5.1 Introduction

Based on the results of models and streamflow presented in earlier chapters, Reclamation implemented interim post-irrigation streamflow of 2.3 cfs from Deadwood Dam during the fall and winter months of 2013 and 2014. This operation was considered an interim operation for the purpose of further studying the effects and predictions of the reduced post-irrigation streamflow (2.3 cfs). Reclamation monitored the effects of this streamflow on the river habitat (physical habitat, connectivity, water temperature, surface ice conditions, and water chemistry) using methods described below. The interim operations during these 2 years were predicted to have the following effects based on the analyses described in the previous chapters: 1) small loss in physical (wetted) habitat and stream depths; 2) water temperatures closer to natural in months outside of irrigation water delivery (fall, winter, and spring), 3) improved surface ice development due to lower winter water temperatures; and 4) variable water quality conditions dependent on reservoir elevation, dissolved oxygen (DO) concentrations, and other climatic conditions. Channel connectivity was not assessed prior to the data presented in this chapter. Although a focus of this portion of the study was to test the model predictions, underlying conditions between the model and water year 2014 were not similar (such as precipitation conditions, starting reservoir elevations, water operations and climatic conditions). Therefore, differences between the actual conditions and the model results are expected. These differences and comparisons are discussed in Appendix F and are not addressed further in this chapter.

Prior to the fall of 2013, the low flows (0 and 2 cfs) were only tested in short duration (weeks) for the purposes of experimentation and measurement of habitat and stranding estimates. The objective of this chapter is to describe the effect of the reduced post-irrigation streamflow during the entire post- and pre-irrigation seasons during water years 2014 and 2015 on Bull Trout habitat. Data collection and monitoring focus on: 1) water temperatures and ice cover, 2) water quality, and 3) physical habitat and channel connectivity. As described in the previous chapters, effects to the river downstream of the dam are influenced by water levels and associated physical conditions in the reservoir. Additionally, 13 radio-

tags were surgically implanted into 12 Rainbow Trout and 1 Bull Trout captured in the stilling basin. These fish were used to identify a response to habitat conditions in the stilling basin and river downstream during the interim streamflow in water year 2015.

5.1.1 Water Operations during Data Collection – Water Years 2014 and 2015

On August 29, 2013, streamflows were ramped down from 700 cfs to 50 cfs over 2 days (fast ramping rate analyzed in Chapter 3). On September 25, 2013, the outlet works jet flow gates were shut off reducing the outflow from Deadwood Dam to 2.3 cfs from the small hydropower generator. Streamflow between October 1, 2013 and February 28, 2014 ranged from 2.1 to 9.5 cfs at the USGS gage located downstream from the dam (USGS gage no. 13236500). In late May 2014, streamflow into Deadwood River downstream from the dam increased to more than 1,200 cfs (Figure 5-1). Water was released over the Deadwood Dam spillway from May 24 until July 1, 2014. Irrigation flows were down ramped from 700 to 350 cfs on September 1 and to 56 cfs on September 2, 2014. Flows were reduced from 56 to 2.5 cfs on September 29, 2014 (Figure 5-1).

Water surface elevation in Deadwood Reservoir ranged from 5,330 feet on July 1, 2013 to 5,296.4 feet on August 30, 2013 (Figure 5-2). Water surface elevation in the reservoir was 15.8 feet higher on September 1, 2014 than on September 1, 2013 mostly due to greater reservoir inflows in 2014, which resulted in greater reservoir content (and higher water surface elevation) throughout the summer irrigation season.

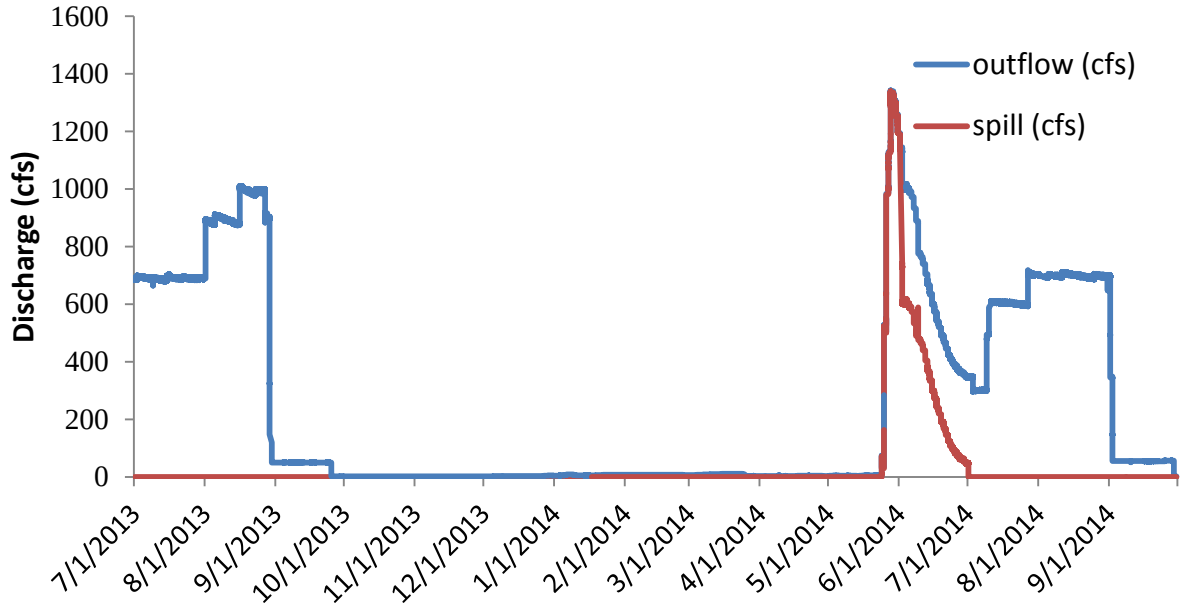


Figure 5-1. Discharge from Deadwood Dam into the Deadwood River July 1, 2013 to September 30, 2014. The blue line indicates the amount of total outflow from the dam. The red line indicates the amount of the streamflow released over the spillway (Reclamation 2015).

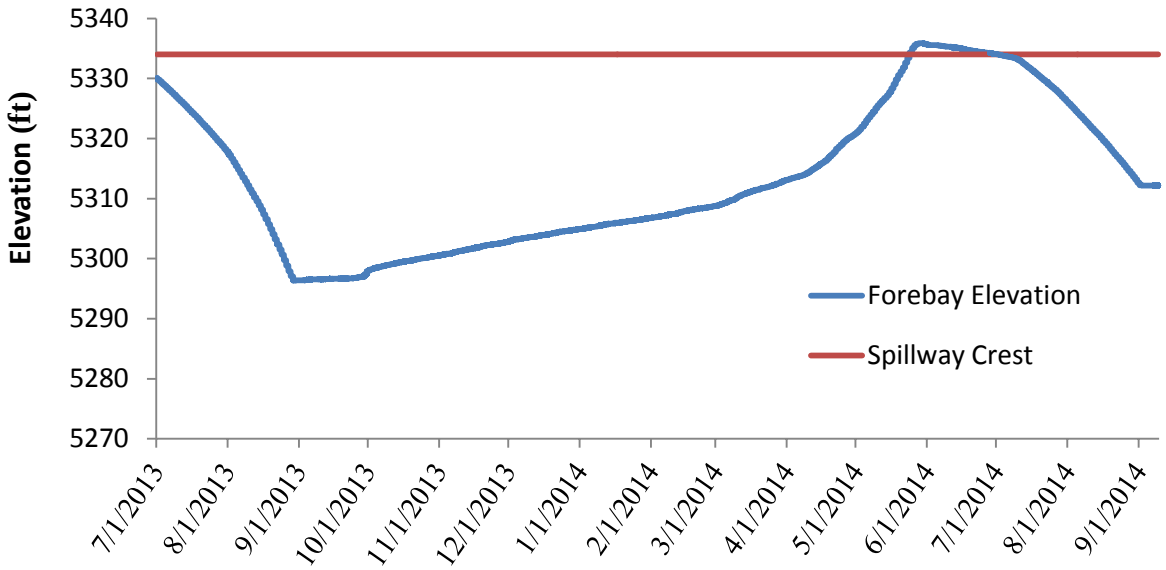


Figure 5-2. Deadwood Reservoir water surface elevations July 1, 2013 to September 30, 2014 (Reclamation 2015).

At the end of the 2014 irrigation season, outflows from Deadwood Dam were ramped down on September 1 from 698 cfs to 56 cfs on September 2. Streamflows were reduced during the night time hours (about 8:00 pm to 10:00 am). On September 29 the streamflows were reduced from 56 cfs to the 2.3 cfs post-irrigation streamflow. Streamflow was reduced during the day time hours (about 11:00 am to 2:00 pm). After September 29, 2014, streamflow ranged from 0.5 to 4.6 cfs (average 2.5 cfs). Outflow from the dam increased on April 26, 2015 for pre-irrigation release from 1.8 to 51 cfs, and increased again on April 29, 2015 from 52 to 147 cfs (Figure 5-3). Pre-irrigation outflow peaked on May 16 at 525 cfs. Reservoir surface elevation steadily increased from 5312.6 to 5334 ft, which is the spillway crest elevation (Figure 5-4).

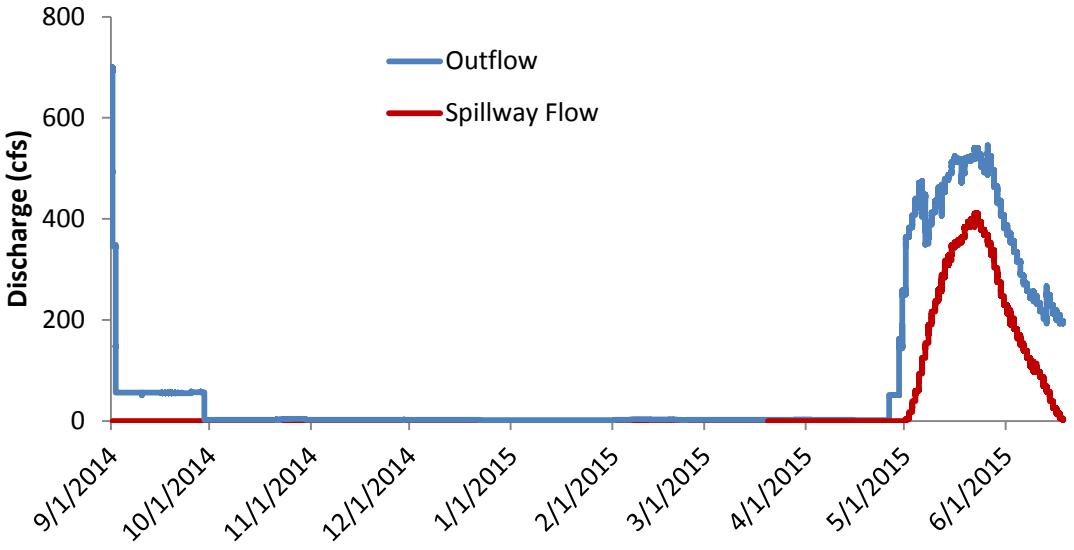


Figure 5-3. Discharge from Deadwood Dam into the Deadwood River September 1, 2014 to June 18, 2015. The blue line indicates the amount of total outflow from the dam. The red line indicates the amount of the streamflow released over the spillway (Reclamation 2015).

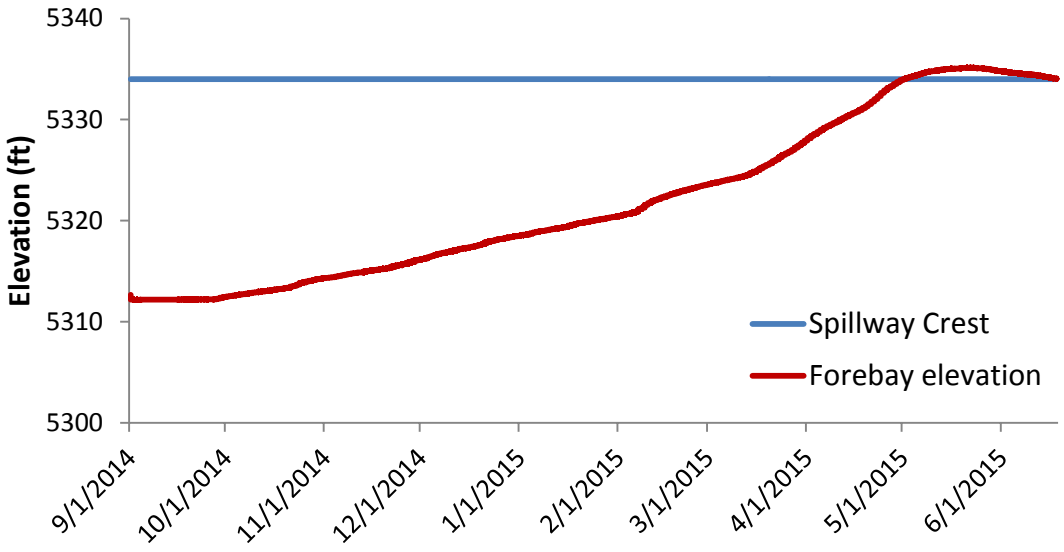


Figure 5-4. Deadwood Reservoir water surface elevations September 1, 2014 to June 18, 2015 (Reclamation 2015).

5.2 Methods

5.2.1 Stream Temperature and Ice Cover

Stream temperature data were collected at numerous sites upstream and downstream from Deadwood Dam (Figure 5-5). Water temperature was measured in hourly intervals using HOBO Tidbit data loggers (loggers). Upstream from Deadwood Dam, loggers were located on Deadwood River and Trail Creek above the reservoir influence. These loggers measured temperature of inflows into the reservoir. Downstream from Deadwood Dam, loggers were located along the lower Deadwood River and near the mouths of several tributaries. The loggers on the mainstem Deadwood River downstream from the dam measured the temperature influence of the reservoir outflows combined with tributary inflows longitudinally downstream to the mouth. Loggers were also located just upstream of the mouth of tributary inflows to measure water temperatures from each tributary. Data were summarized by site progressing downstream from the dam to the mouth to show summer (August) and winter (January) low flow temperatures during 2013/2014. Two locations representing conditions 0.5 km from the dam (near Wilson Creek) and 27 km from the dam (near Stevens Creek) on the Deadwood River were compared to nearby tributary temperatures to assess comparable water temperature conditions at the site. The data collected during the post-irrigation season at 2.3 cfs (water year 2014) are compared to data collected during water year 2009 at 50 cfs streamflow. These years were selected for comparison with similar total annual inflow values and available logger data when 50 cfs was

implemented during the post-irrigation season with similar climatic conditions. Although weather conditions will not be identical in different years, these data provide some context of the water temperature effects of the proposed streamflow during the water year.

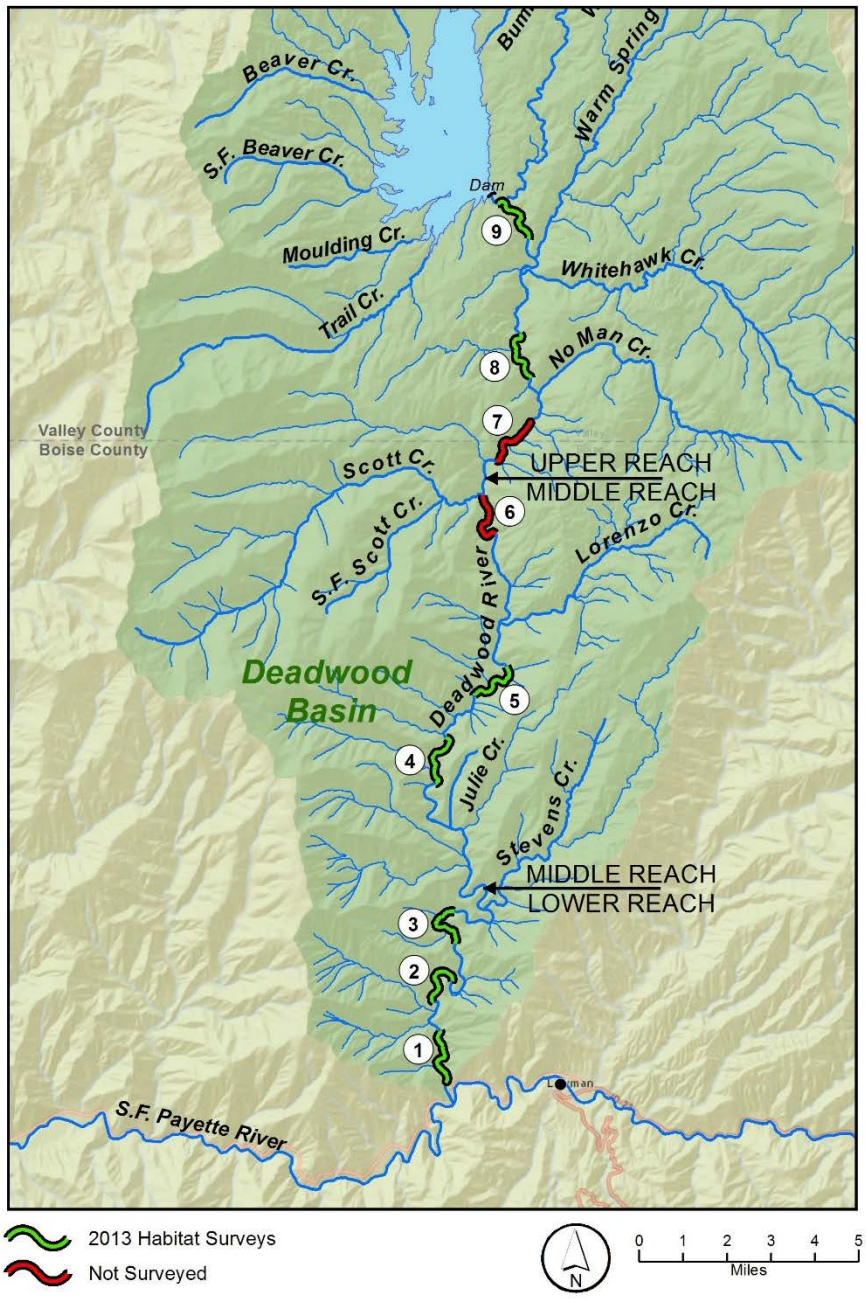


Figure 5-5. Stream sections surveyed in fall of 2013 with 2.3 cfs being released from Deadwood Dam. Connectivity surveys were conducted from the dam downstream to NoMan Creek and from the top of section 5 (just below Lorenzo Creek) downstream to the mouth.

Winter ice cover was monitored using remote mounted digital cameras (Bushnell TrophyCam HD 2013 Model). Ten cameras were deployed during fall 2013, and were set to take photographs in hourly intervals. Cameras included in this analysis were located along the Deadwood River downstream from the dam: at the stilling basin bridge looking downstream, the Road 555 Bridge looking upstream, below the Wilson Creek confluence looking upstream, below Lorenzo Creek looking downstream, and downstream from the Julie Creek Bridge. All of these camera locations were set to monitor slow water habitat (pool or run) where surface ice cover develops. Sites located near the Deadwood River on the South Fork Payette River and Clear Creek were included as comparison sites (Figure 5-6). Hourly photos for the sites were examined for ice cover for the winter months beginning December 1, 2013 and ending February 28, 2014. The number of days where there was no ice, <50% ice cover, and ≥ 50% ice cover in the pictured pool habitat were compared across sites. Although there was little daily variation in ice cover at the sites, the photographs taken in the morning (8:00 or 9:00 a.m.) were used to represent the ice cover for that day. These represented the coldest part of the day when light was sufficient for an image to be recorded and provided a consistent point in time for data collection across sites.

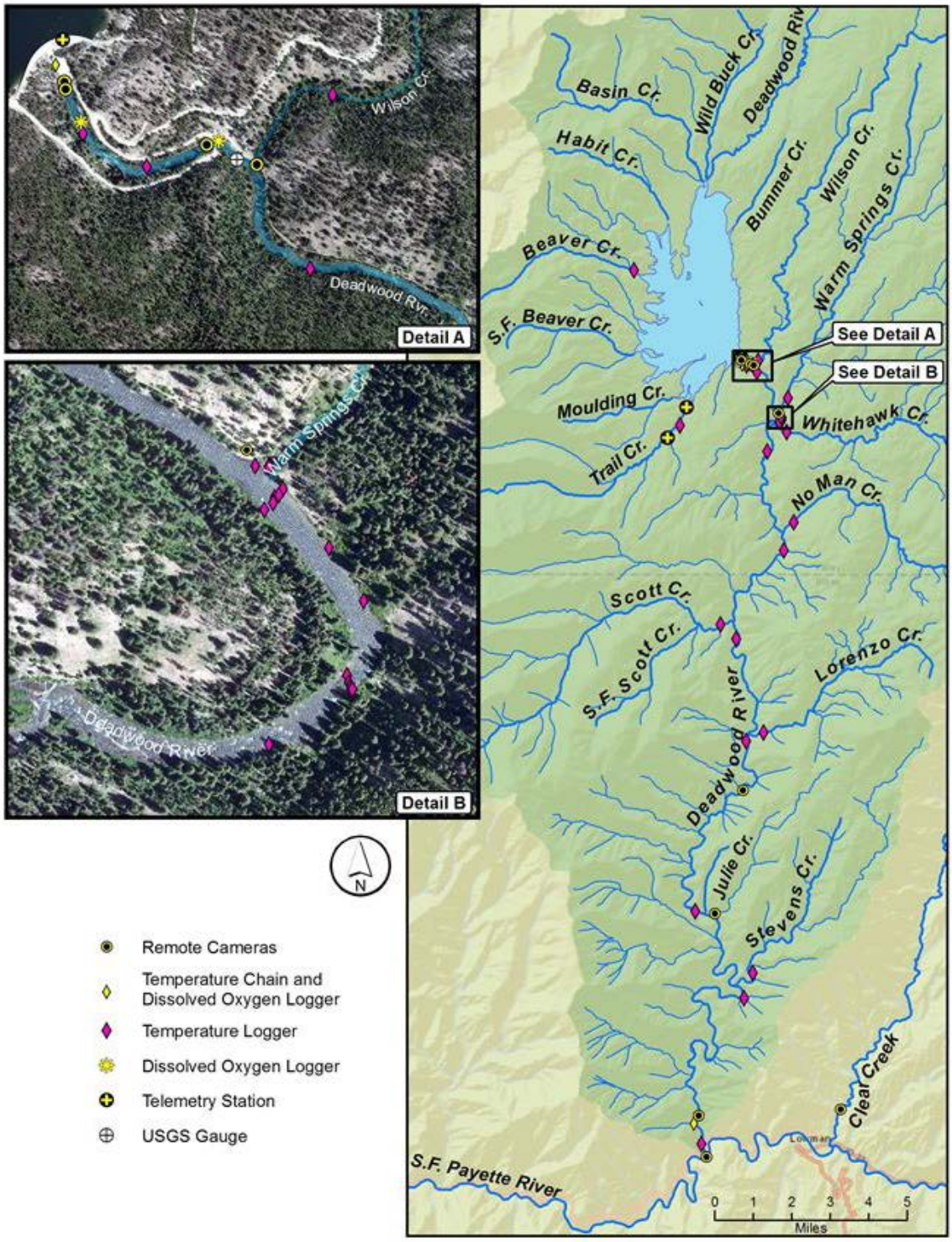


Figure 5-6. Locations of remote equipment in the Deadwood Basin (winter 2013–2014).

5.2.2 Water Chemistry Analysis

DO and temperature measurements were collected in the stilling basin at 10-minute intervals using data loggers (miniDO2T, Precision Measurement Engineering, Inc.). These loggers were suspended on chains at 1 m, 3 m, and 5 m below the water surface. These loggers are placed after the irrigation streamflow releases and removed prior to spring high water (pre-irrigation release). During the 2013/2014 fall/winter, two logger chains were located in the stilling basin (one immediately downstream from the dam and one on the downstream end of the basin). During the fall 2014, one logger chain was replaced at the upper chain site in the stilling basin and single loggers were placed at intervals downstream at the following sites: downstream extent of stilling basin pool, between the bridge downstream from the dam and Road 555 Bridge, and at the Road 555 Bridge.

Water chemistry analyses were performed at the Reclamation Pacific Northwest Regional Water Quality Laboratory (Boise, Idaho) for eight sites below Deadwood Dam, two sites on Deadwood Reservoir, and one site in the Deadwood River upstream from the reservoir periodically collected between April 2014 and April 2015 (Figure 5-6). Commonly sampled chemical components and associated abbreviations are listed in Table 5-1.

Table 5-1. List of water quality parameters and associated abbreviations

Parameter Name	Abbreviation
Nitrate plus nitrite	NO_3/NO_2
Ortho phosphorus	Ortho-P
Total Phosphorus	T-Phos
Total Dissolved Ammonia	NH_3-Diss
Total Organic Carbon	TOC
Dissolved Organic Carbon	DOC
Total Kjeldahl Nitrogen	TKN
Iron	Fe
Manganese	Mn

The samples were tested for NO_3/NO_2, T-Phos, TKN, chlorophyll *a*, and Fe. The reservoir outflow samples were collected from the hydro-generator after the flow was reduced to 2.3 cfs. Detailed laboratory methods and quality control are described in Reclamation (2011).

5.2.3 Physical Habitat Measurements and Channel Connectivity

Physical habitat was measured on the Deadwood River downstream from the dam to examine the effect of the reduced post-irrigation streamflow on wetted channel characteristics. The Deadwood River below Deadwood Dam was divided into three reaches (upper, middle, and lower). Three survey sections were randomly selected within each of these reaches for a stratified random sample (Figure 5-5). Each survey section was 1 mile long. Habitat data were collected at seven of these survey sections between October 23 and November 14, 2013. Sections 6 and 7 were drawn in the stratified random design, but were not surveyed in 2013 because the Government shutdown interrupted the field season.

Outflow from Deadwood Dam was 2.3 cfs during the field surveys. The nearest streamflow gage that provides the closest measurement for an indication of natural basin conditions to indicate run-off is located on the South Fork Payette River at Lowman (USGS gage no. 13235000) upstream from the confluence of the South Fork Payette and Deadwood rivers. During the fall months, particularly October, streamflow at the Lowman gage can range from about 330 cfs to more than 1,000 cfs. The purpose of this physical habitat survey is to understand the effect of the interim post-irrigation streamflow of 2.3 cfs on stream habitat to identify potential impacts to the listed Bull Trout. To understand the extent of the greatest impact to Bull Trout, data were collected during the lowest streamflow possible. Because the streamflow was set in late September in 2013 and 2014 and the autumn weather can be unpredictable, there is only a brief window when these data can be collected during a base flow period.

GPS coordinates were collected using ArcPad in a Trimble GeoXT GeoExplorer 2008 Series at the upstream and downstream ends of each habitat unit as well as at the surveyed cross section. Accuracy of the GPS data averaged between 1 and 2 meters. Data were collected on habitat type (pool, riffle, run). Maximum and minimum thalweg depths were measured with a stadia rod for each habitat unit. A representative cross section was identified for runs and riffles. In pools, a cross section was completed halfway between the maximum depth and the downstream extent (tail water) of the pool. A width measurement was taken with a fiberglass tape measure or a battery-operated rangefinder at each cross section as well as depth measurements using a stadia rod at 20, 40, 60 and 80% of the channel width to calculate an average depth at the transect.

Percent cover (overhanging vegetation, large woody debris, substrate and depth >0.5 m) was determined using visual estimates as a percent of wetted area. Photographs were taken at the upstream end of each habitat unit looking downstream, from bankfull at the cross section looking across, and from the downstream end looking upstream. Additional photographs were taken at some habitat units to document unusual characteristics.

Disconnected pools were identified as watered habitat within the bankfull channel disconnected upstream and downstream from the streamflow in the main channel. Each disconnected pool was identified by the section number and an alpha-numeric identifier. The following data were collected at each disconnected pool: date and time, GPS coordinates, length, width, and maximum depth of the pool. Photographs were taken of each disconnected pool. GPS coordinates were collected using a DeLorme PN-60w GPS device. Habitat photographs were not included in this report.

Reaches were surveyed to assess channel connectivity and disconnected pools where fish may be stranded when streamflows are reduced. The channel was walked in 2013 to identify general locations where connectivity may be an issue; however, supporting data were not collected during this survey. This survey was used to focus efforts for additional data collection in the fall 2014. In 2014, the channel was walked by biologists from the dam downstream to Scott Creek. Below Scott Creek, five locations identified during 2013 were revisited. Locations less than 0.15 m deep in the thalweg were identified as potential passage problems (Auble et al. 2009). During the 2014 survey, data were collected on the minimum thalweg depth (when less than or equal to 0.15 m depth), length of stream at this depth and photographs. Coordinates for all locations that were less than the identified passage criteria were recorded with a GPS unit (DeLorme PN-60w). Observers also recorded whether the habitat appeared passable or not passable to adult and juvenile Bull Trout.

5.2.4 Radio-tagging Trout in Stilling Basin

Methods for radio-tagging and tracking trout are described in Chapter 4. Rainbow Trout were used for tagging due to lack of Bull Trout of adequate size to tag and to minimize impact to the threatened species. Tags were surgically implanted between September 30 and October 15, 2014 after outflow from the dam had been reduced to the 2.3 cfs interim post-irrigation streamflow.

Two stationary antennas were installed to collect continuous data from the stream with coverage spanning from the stilling basin to Wilson Creek. Mobile and foot tracking with receivers was conducted on February 17 and March 31, 2015 to locate any tags between the dam and Warmsprings Creek. On April 23, 2015 the lower portion of the Deadwood River (downstream from Julie Creek Bridge) to the mouth and the South Fork of the Payette River between the Middle Fork Payette and Clear Creek was searched for tags. No tags were detected during the April 23, 2015 tracking event.

5.2.5 Results and Discussion

Water Temperature and Ice Cover – Water Year 2014

As discussed in Chapters 2 and 3, reservoir content and seasonal thermal stratification determines the temperature of the water released through the dam into the river downstream. Temperature effects of the 50 cfs post-irrigation streamflow identified in the temperature modeling (Chapter 3, Section 3.1) resulted in reduced summer temperatures and higher winter temperatures when compared to unregulated conditions. Due to the warmer winter water that is released through the outlet works gates from the bottom of Deadwood Reservoir (4°C), ice cover was identified as a potential limitation to the winter habitat downstream of the dam and a benefit of reduced post-irrigation streamflow (see Chapter 3, Section 3.1). Therefore, ice cover was monitored to determine if winter temperature effects at the reduced streamflow allows more surface ice formation by reducing the amount of warm water inflow into the river from the reservoir. The surface ice formation was identified as an indicator of reduced frazil ice formation which is an undesired winter stream condition that can occur when the water is super-cooled by air temperatures (see Chapter 3, Section 3.1.5).

Continuous water temperature measurements were stable in the stilling basin, as expected due to depth of the outlet works gates measured by the loggers from September 2013 to April 2014. Specifically, these data exhibited little diurnal variation and closely track the expected reservoir temperatures (Figure 5-7). Recorded temperatures in September 2013 are near 14°C which is the expected reservoir temperature. Water temperature then declines to about 4°C during October and November when the climatic conditions cool the water and solar inputs are reduced releasing the reservoir stratification. During October, the reservoir mixes between the surface and the bottom layers. At 4°C water reaches its greatest density and sinks to the bottom of the reservoir. Therefore, the water being released from the lower portion of the reservoir is expected to be a constant 4°C. Temperature in the stilling basin was recorded at 3°C in early December 2013 which results from heat loss to the air and ground during colder air temperatures. Because of the small size of the stilling basin and reduced solar input during the winter season, the stilling basin did not develop a thermal stratification.

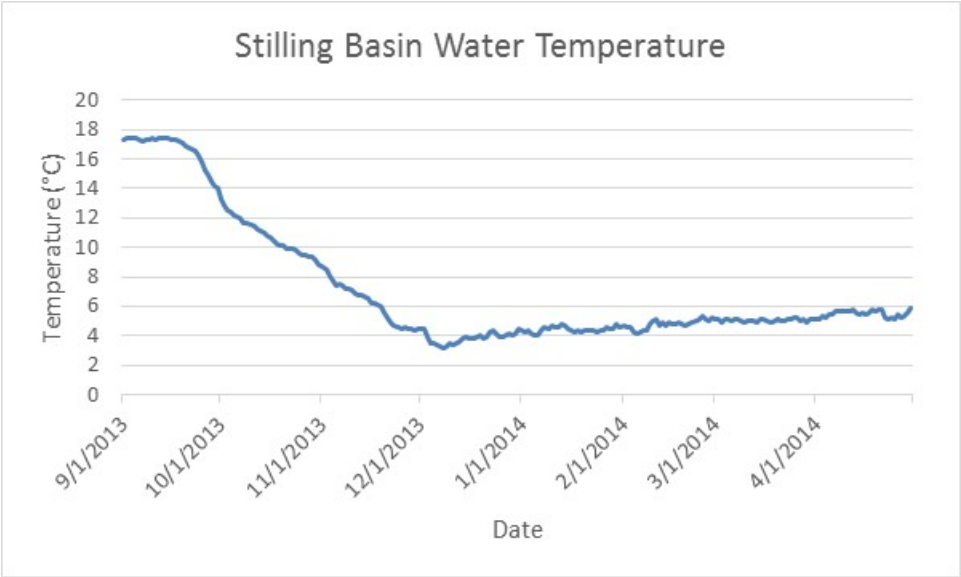


Figure 5-7. Water temperatures (C) recorded in the stilling basin downstream from Deadwood Dam, September 2013 through April 2014.

Water temperatures in the river downstream from the dam during 2013 and 2014 were generally close to natural water temperatures measured at nearby tributaries except during the irrigation season, when the river was 5 to 10ºC cooler. For the purposes of comparison, the temperatures from the month of August and January are discussed because these are periods of seasonal extremes that have been the focus of this study. August water temperatures in 2014 are about 5ºC cooler than in 2013 due to the higher reservoir elevation and hypolimnetic water that remained in the reservoir. Daily water temperature data for all loggers are shown in Appendices G and H.

Temperature loggers placed in the mainstem Deadwood River (below Deadwood Dam) from the upstream-most site near Wilson Creek downstream to the confluence with the South Fork Payette River are compared to the loggers placed at the mouth of the tributaries (Appendix G). The loggers at the mouths of tributaries are not influenced by operations and reflect the natural or unaltered water temperatures for basins flowing into the Deadwood River downstream from the dam (Appendix H). In general, these tributaries (excluding Warmsprings Creek that has geothermal influence) have monthly mean August water temperatures ranging from 10 to 14ºC (Figure 5-8 and Figure 5-9). The mainstem, which is directly influenced by water operations from the dam, has mean monthly water temperatures in August 2013 ranging from 13 to 14ºC (Figure 5-10). However, in August 2014, the monthly mean water temperature was lower ranging from 7.8 to 11ºC (Figure 5-11).

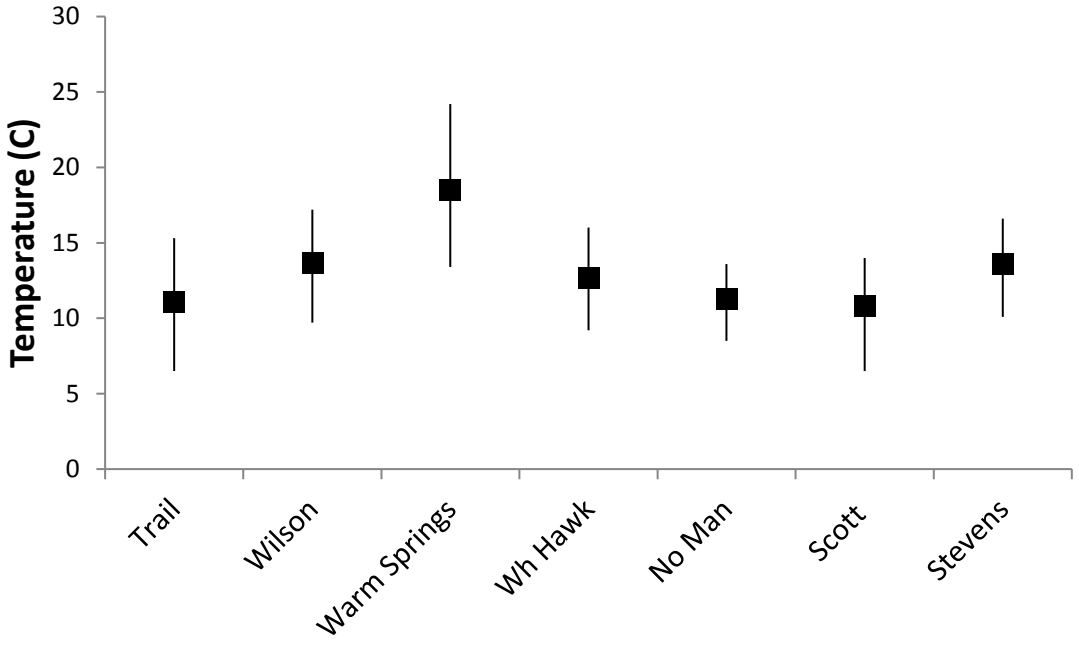


Figure 5-8. Monthly mean (box), minimum and maximum (whiskers) water temperature (C) for loggers located in tributaries to the Deadwood River, August 2013. Logger locations are listed from left to right from the most upstream to downstream. Note that Trail Creek is located upstream from Deadwood Reservoir. All other tributaries are located downstream from Deadwood Dam.

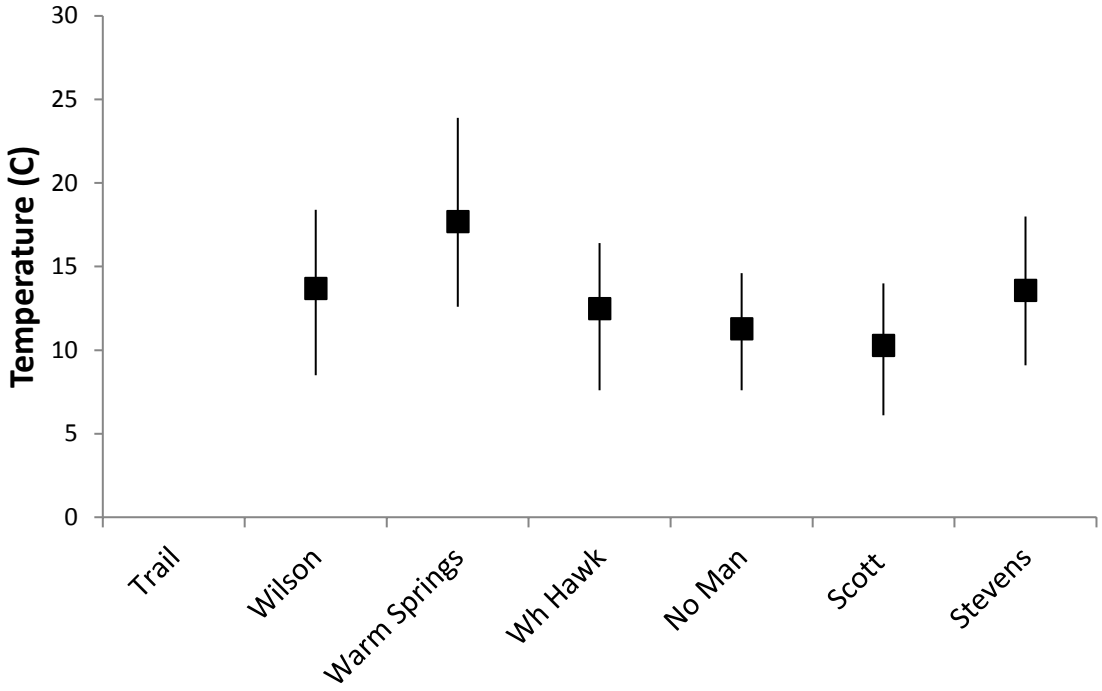


Figure 5-9. Monthly mean (box), minimum and maximum (whiskers) water temperature (C) for loggers located in tributaries to the Deadwood River, August 2014. Logger locations are listed from left to right from the most upstream to downstream. Note that summer data was not collected at Trail Creek located upstream from Deadwood Reservoir. All other tributaries are located downstream from Deadwood Dam.

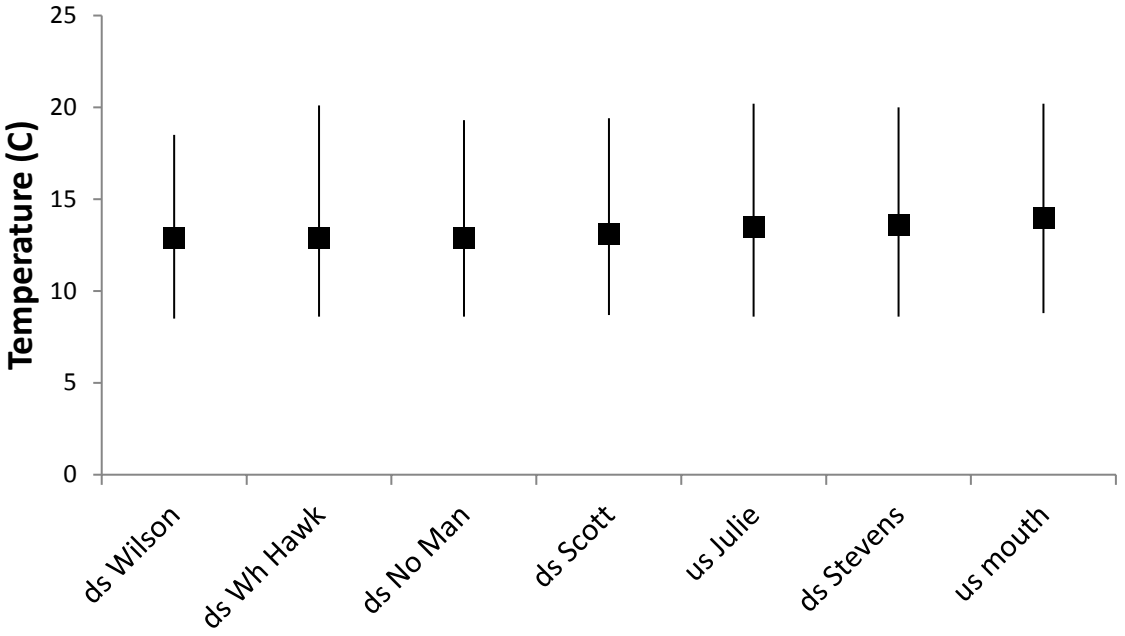


Figure 5-10. Monthly mean (box), minimum and maximum (whiskers) water temperature (C) for loggers located in the Deadwood River between the dam and the mouth for August 2013. Logger locations are listed from left to right from the most upstream to downstream. Loggers are located upstream (us) or downstream (ds) from the tributary.

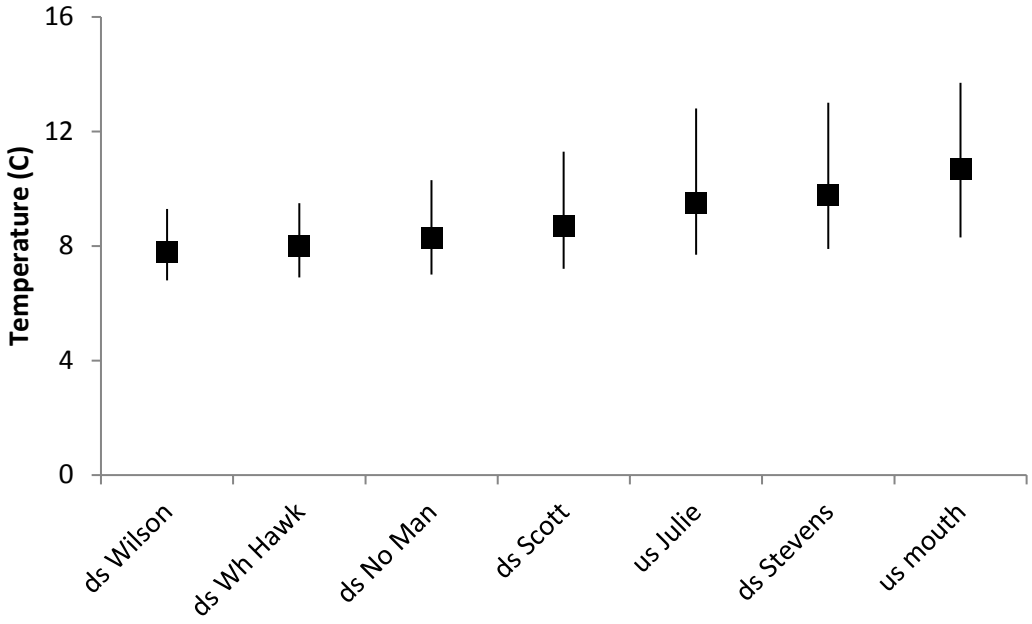


Figure 5-11. Monthly mean (box), minimum and maximum (whiskers) water temperature (C) for loggers located in the Deadwood River between the dam and the mouth for August 2014. Logger locations are listed from left to right from the most upstream to downstream. Loggers are located upstream (us) or downstream (ds) from the tributary.

The interim post-irrigation streamflow result in increased reservoir content the following spring/summer (see Chapter 2, Section 2.1 for comparative analyses). On September 1, 2014, reservoir elevation was 15.8 feet higher than this date the previous year. This increased reservoir elevation is mostly due to greater reservoir inflows in 2014 and the increased storage and carry over from the 2.3 cfs post-irrigation streamflow than previous operations that release 50 cfs post-irrigation streamflow. This increased reservoir content has water quality, temperature, and reservoir habitat effects that carry forward into the summer months. Therefore, the reservoir drawdown during the irrigation season did not exceed the hypolimnion which creates colder water temperatures from the hypolimnetic release measured during August 2014 in comparison to August 2013.

Mean January temperatures in the tributaries in 2014 ranged from 0 to 1^{o}C, excluding Warmsprings Creek that had an average monthly temperature at 6^{o}C (Figure 5-12). Winter temperatures in the mainstem showed less than 2^{o}C variation from upstream to downstream sites with the monthly mean temperatures ranging from -0.1 to 1.7^{o}C in January 2014 (Figure 5-13).

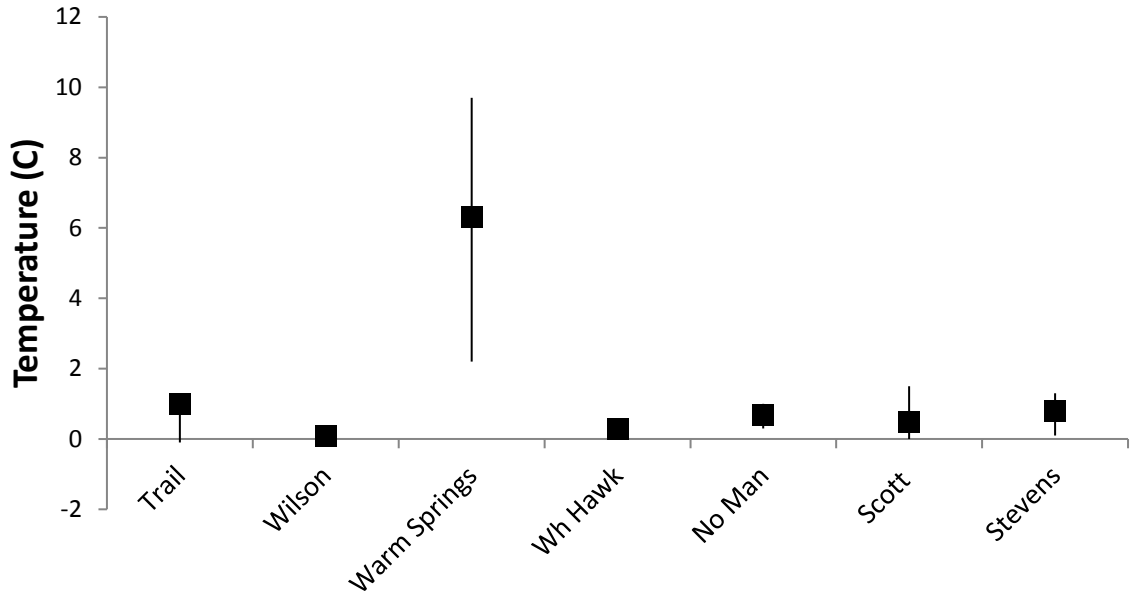


Figure 5-12. Monthly mean (box), minimum and maximum (whiskers) water temperature (C) for loggers located in tributaries to the Deadwood River, January 2014. Logger locations are listed from left to right from the most upstream to downstream. Note that Trail Creek is located upstream from Deadwood Reservoir. All other tributaries are located downstream from Deadwood Dam.

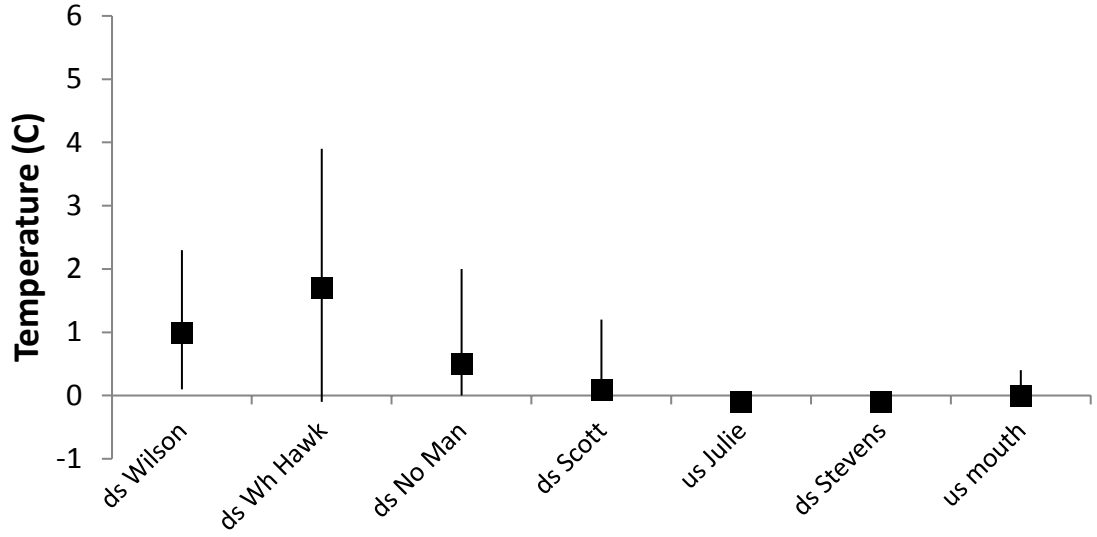


Figure 5-13. Monthly mean (box), minimum and maximum (whiskers) water temperature (C) for loggers located in the Deadwood River between the dam and the mouth for January 2014. Logger locations are listed from left to right from the most upstream to downstream. Loggers are located upstream (us) or downstream (ds) from the tributary.

Water temperatures in the mainstem Deadwood River downstream from the dam were compared to nearby tributaries for water years 2010 and 2014 when post-irrigation operations were 50 cfs and 2.3 cfs, respectively (Figure 5-14 and Figure 5-15). These data show that the reduced (2.3 cfs) post-irrigation streamflow results in water temperatures closer to tributary temperatures than water temperatures at the 50 cfs post-irrigation streamflow (Figure 5-14 and Figure 5-15). The average water year in 2014 provided sufficient run-off to refill the reservoir and meet irrigation water delivery without drawing down the reservoir past the thermal stratification. Therefore, because the reservoir water surface elevations are higher toward the end of the summer irrigation releases, the river temperatures remain colder throughout the later portion of the summer (Figure 5-14). Likewise, the September 2014 water temperatures are cooler than the previous year.

This analysis compares differences in water temperature between the mainstem and the Wilson and Stevens Creek inflows. These sites were selected for this comparison because they provide temperature data for high elevation tributary streams that enter the Deadwood River at the location where the comparisons are relevant. Using the modeled natural flows would only apply if the analysis were examining conditions without the presence of the dam, and water temperatures upstream from the reservoir would not be representative of the conditions or the sites relevant to the comparisons downstream from the dam. Therefore, these data were identified as the most suitable data for direct comparisons within the same time frames for sites downstream from the dam.

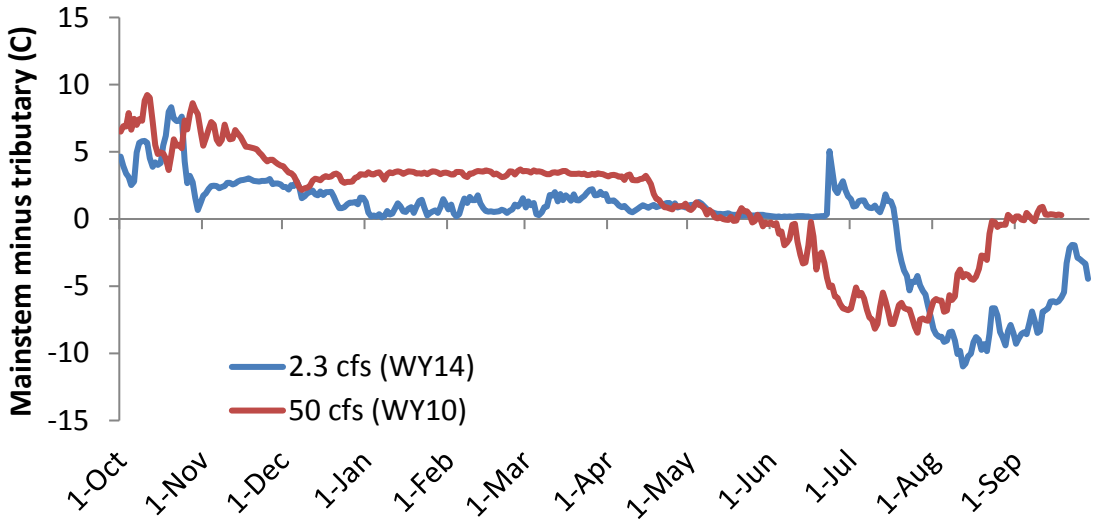


Figure 5-14. Comparison of the water temperatures (C) at the Deadwood River below Wilson Cr to the Wilson Creek water temperatures (C) at 2.3 cfs (water year 2014) and 50 cfs (water year 2010). A temperature profile identical to natural temperatures would graph as 0 difference along the y-axis. Values above the 0 value on the y-axis indicate that the mainstem Deadwood River is warmer than expected natural temperatures. Values below the 0 value on the y-axis indicate that the mainstem Deadwood River is cooler than expected natural temperatures.

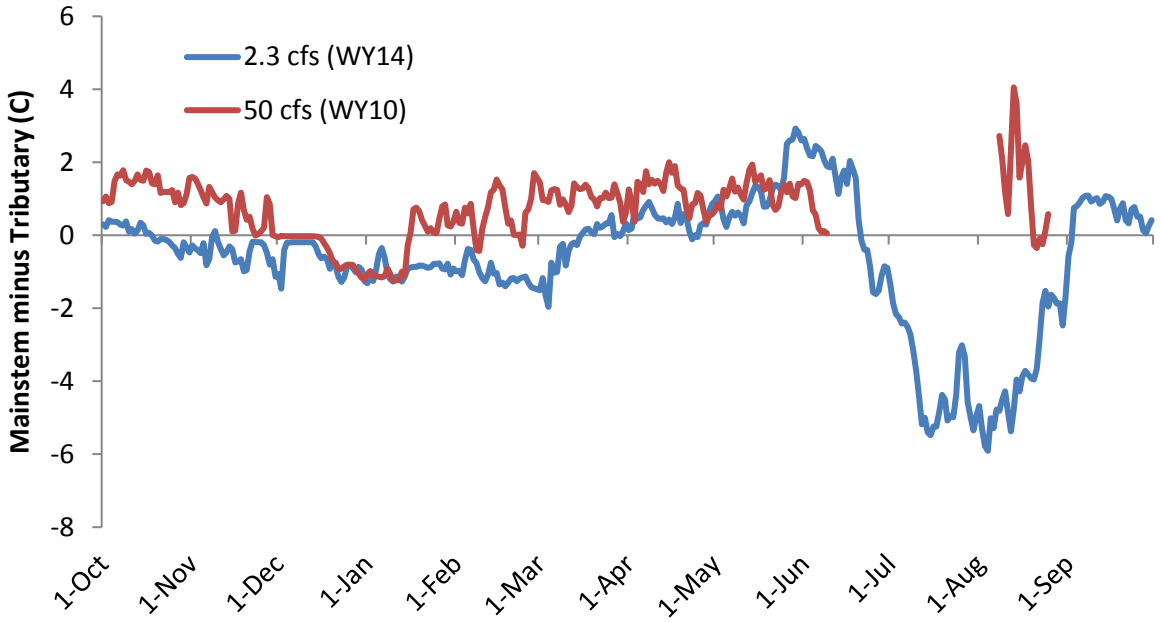


Figure 5-15. Comparison of the water temperatures at the Deadwood River below Stevens Creek to Stevens Creek (C) at 2.3 cfs (water year 2014) and 50 cfs (water year 2010). A temperature profile identical to natural temperatures would graph as 0 difference along the y-axis. Values above the 0 value on the y-axis indicate that the mainstem Deadwood River is warmer than expected natural temperatures. Values below the 0 value on the y-axis indicate that the mainstem Deadwood River is cooler than expected natural temperatures. A break in water year 2010 values reflects a period of no available data.

Ice cover at locations monitored with the automated cameras showed that winter ice conditions vary by site and air temperature. Generally, the cameras downstream from the dam exhibited less stable ice cover than those farther downstream on the lower Deadwood River and at comparison sites (Figure 5-16). The ice formation at the three sites closest to the dam was strongly influenced by air temperature which would create ice conditions that would form during colder periods and then recede when air temperatures approached 0°C. Although the sites lower in the river also respond to air temperature, these sites accumulated more snow and ice cover during the winter and were able to maintain the ice cover for a longer duration. Additionally, the ice cover at these sites increased as the winter progressed, minimizing the effect of periods with warmer air temperatures until after the winter season.

The pool downstream from Lorenzo Creek on the lower Deadwood River and Clear Creek, a nearby (unregulated) tributary, developed the most ice cover during the 2013/2014 winter, although it should be noted that photos from monitoring locations do not show truly stable cover anywhere on the river when winter outflows were at 50 cfs. Julie Creek also developed some intermittent ice cover; however, snow accumulated near the camera during the month of February that partially blocked the view of the stream, so extent of ice cover could not be clearly determined from photographs. The Payette River basin has geothermal

influences throughout the area and it is important to note that the South Fork Payette and Deadwood rivers (near Warmsprings Creek) have geothermal springs that flow into the rivers. Therefore, we do not expect these sites to develop winter ice cover similar to sites without warm water inflows, and the data from the photographs indicate that the South Fork Payette River near Deadwood River had a lower proportion of days with >50% ice cover behaving more like the sites closer to the dam (Figure 5-16).

The hydrologic analysis performed in Chapter 3, Section 3.1.7 mentions that the warmer water from the reservoir bottom released through the dam had an effect on the lower Deadwood River to Lorenzo Creek where ice cover became more stable. However, it is important to note that the inflows from Warmsprings Creek into the Deadwood River are warmer during the winter than the outflow from the dam and it is likely that this water also impacts winter ice cover formation in the river, until the effect attenuates further downstream. The thickest ice cover occurred during the latter part of the winter on Clear Creek, the unregulated site. Ice cover in the upper-most monitoring sites indicate that ice cover at the lowest streamflow from the dam was the least developed likely due to warmer outflow temperatures at the dam. Surface ice opened and closed at these sites with the increases and decreases in air temperature. The sites in the lower portion of the lower Deadwood River were able to maintain surface ice for more days during the winter (downstream from Lorenzo Creek and near Julie Creek) despite being lower in elevation than the upper sites (Figure 5-16). Photographs of ice cover conditions during the 2013/2014 winter are included in Appendix I.

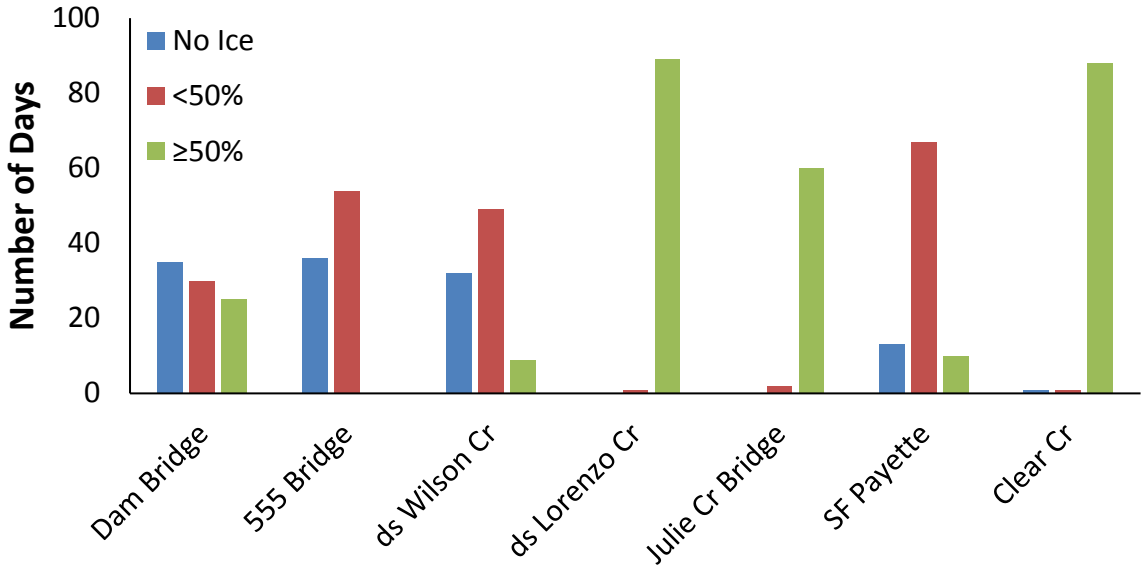


Figure 5-16. Number of days of ice cover (no ice, <50%, ≥50%) between December 1, 2013 and February 28, 2014 for sites along the Deadwood River and nearby comparison sites. Sites are listed in order from upstream-most at the dam bridge to near Julie Creek. Two comparison sites are shown on the right side of the x-axis, the South Fork Payette River at Deadwood River and Clear Creek. Note that the Julie Creek camera only includes photos from December and January.

Water Chemistry – Water Years 2014 and 2015

Physical and chemical processes in the reservoir determine the quality and chemical attributes of the water that passes through and over Deadwood Dam. Most of the water passing the dam is released through the outlet works which draws water near the reservoir bottom. Therefore, stratification of the reservoir is used to predict the effects of the water operations in the river downstream (see Chapter 2, Section 2.1 for more detailed analysis). The Lake Diagnostic System (LDS) (described in Chapter 2, Section 2.2) shows that the reservoir's thermal structure begins to break down in October, and by late October full column convective mixing has typically begun. Mixing continues through mid-December. Following the establishment of an inverse thermal structure, the hypolimnion is isolated again and DO depletion resumes from sediment, chemical and biochemical oxygen demand. Typically the oxygen concentration in the reservoir reaches winter maximums of 8 to 9 mg/L near mid-December. Oxygen concentrations decrease throughout the winter and the LDS demonstrated hypoxic conditions in late April, with DO concentrations ranging from 3 to 4 mg/L (Chapter 2, Section 2.2.4). These late winter/early spring hypoxic conditions will influence the oxidation and precipitation processes and resulting water chemistry.

During winter 2013–2014, the logger located 1 m from the water surface of the stilling basin exhibited very strong diurnal fluctuations in DO in comparison to the middle and bottom

loggers located on both arrays. These fluctuations are in some cases extreme, but may be influenced by biofouling of the equipment sensors. In other studies, biofouling has occurred in as little as 5 days, and can result in both high and low erroneous values (Suplee and Sada 2013). For example in the early October data, percent saturation climbs to over 200 percent during the day light hours with DO concentrations over 20 mg/L. At night or in low light periods DO often falls to 0 mg/L (Figure 5-17). These data suggest that either the algal populations have been invigorated by the increased delivery of nutrients from the reservoir, or that the top data logger has developed a biofilm that is producing oxygen during the daylight hours and respiring during the dark period. Both of these situations would be enhanced by the adequate light levels of the season, warm water relative to the season being delivered from the thermally mixed reservoir, and biological activity aerating the top 3 feet of the stilling basin above what is seen in the reservoir. Night-time DO depletions in this data set are often measured in very eutrophic conditions as a result of increased biological respiration and limited or no oxygen production from photosynthesis. Nutrients liberated from the reservoir sediments during hypoxic conditions replicate eutrophic conditions in the stilling basin. By November, the loggers at the 1 m depth track the reservoir minimum oxygen concentrations but still exhibit some daylight hour oxygen production. As the winter progresses this production declines, likely from decreasing light conditions during the day and temperature inhibition as the water cools to 3 to 4°C (Figure 5-18).

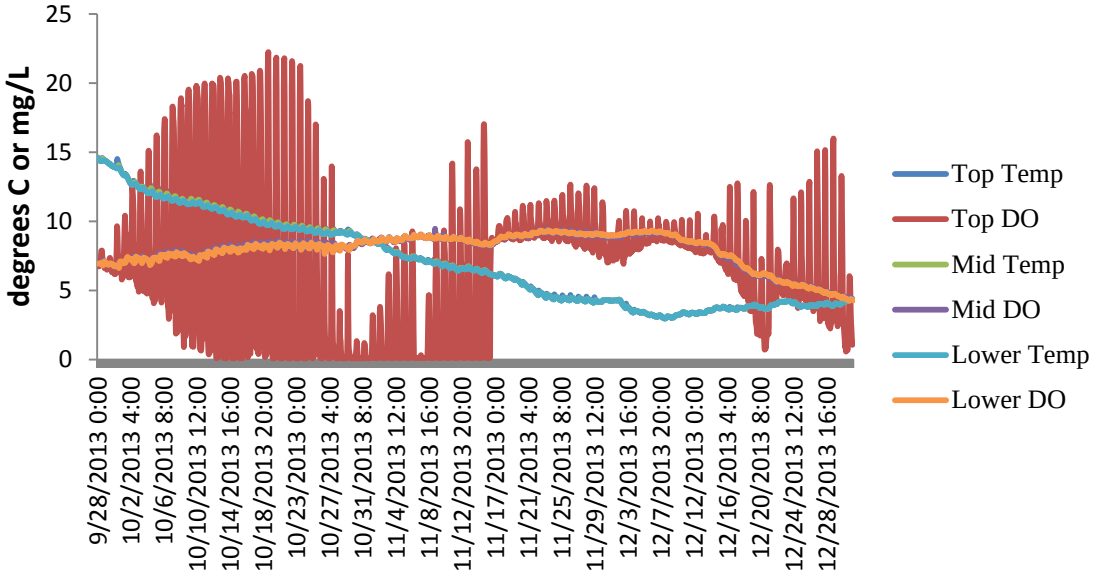


Figure 5-17. Water temperature (C) and DO (mg/L) recorded at the upper site in the stilling basin downstream from Deadwood Dam, September 27 through December 31, 2013. The loggers are located at the following depths: 1 m (top), 8.5 m (mid), 14.5 m (lower). Note that the mid and lower DO and temperature measurements are similar and plots overlay in the figure.

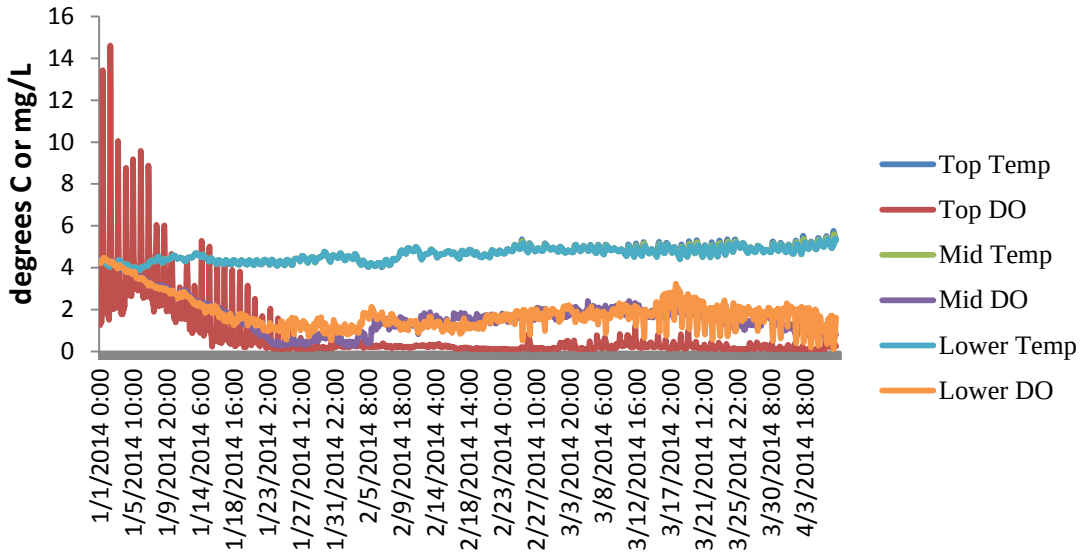


Figure 5-18. Water temperature (C) and DO (mg/L) recorded at the upper site in the stilling basin downstream from Deadwood Dam, January 1 through April 8, 2014. The loggers are located at the following depths: 1 m (top), 8.5 m (mid), 14.5 m (lower).

The middle and bottom loggers (located at 2 m and 5 m below the surface) are more consistent and closely track the expected DO concentration of the reservoir (Figure 5-17 and Figure 5-18). In October, the expected DO concentrations in the reservoir should be 8 to 12 mg/L as the reservoir mixes and re-aerates the hypolimnion. During the winter, the reservoir will develop an inverse thermal stratification with the warmest water near the bottom (4^{o}C) and the colder, less dense water near the top. Once this thermal stratification develops, DO concentrations are expected to fall over time until the spring turn-over re-aerates the deep water again. Therefore, hypoxic or anoxic conditions will develop toward later winter/early spring (see Chapter 2, Section 2.1). As expected from the model predictions, DO concentrations fall during January 2014 and remain consistently low into April (Figure 5-18).

During the fall 2014, reservoir content is higher mostly due to greater reservoir inflows in 2014. Modeling predicted that the colder hypolimnetic water would remain at this depth after irrigation season releases when implementing the low post-irrigation streamflow; however, the water would be depleted of DO (see Chapter 2, Section 2.1). Monitoring data verified that in September 2014 colder, anoxic hypolimnetic water remained in the reservoir. At 50 cfs the water aerates in the stilling basin through turbulence, but when the streamflow was reduced to 2.3 cfs at the dam on September 26, DO declines in the stilling basin but increases to 8 to 10 mg/L by November 10, 2014 (Figure 5-19 and Figure 5-20). The logger downstream from the bridge below the dam has the same DO values as the stilling basin; however, the DO values recover by November 10, 2014 (Figure 5-21). The late winter and

early spring DO values during 2015 range from 2.9 to 4.6 mg/L (Figure 5-22). The loggers further downstream indicate that there is still an effect of the reduced oxygen levels between the dam and Road 555 Bridge, but this effect is alleviated when the water passes the Road 555 Bridge (Figure 5-21 and Figure 5-22).

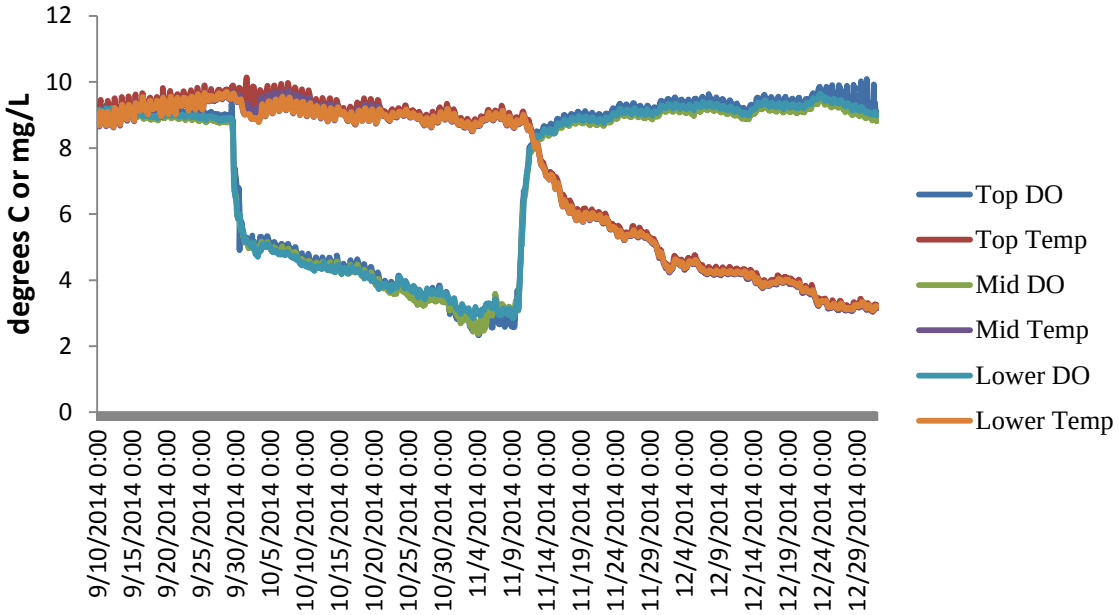


Figure 5-19. Water temperature (C) and DO (mg/L) measured at the upper site in the stilling basin at Deadwood Dam, September 10 through December 31, 2014.

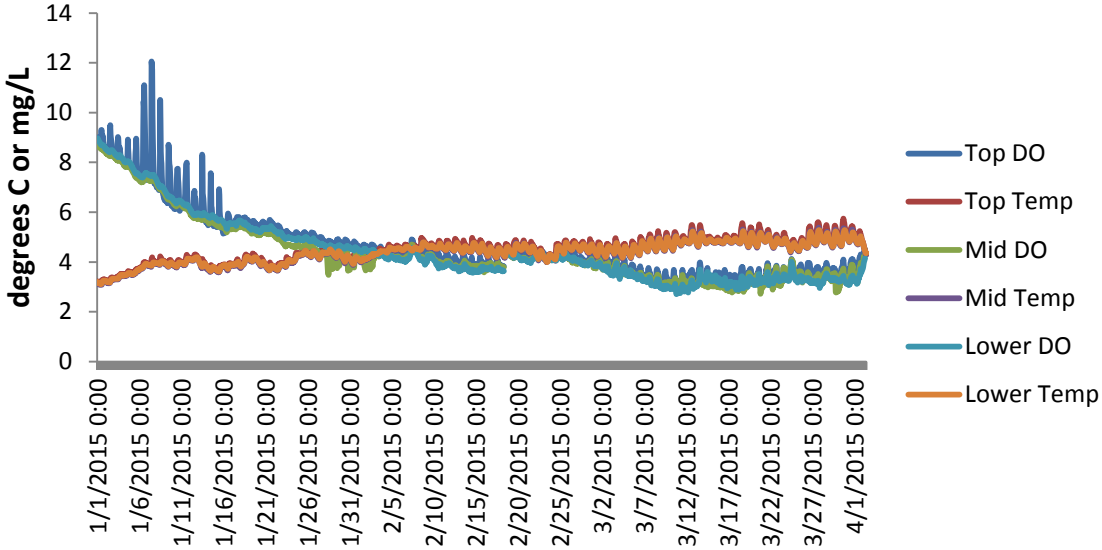


Figure 5-20. Water temperature (C) and DO (mg/L) measured at the upper site in the stilling basin at Deadwood Dam, January 1 through April 2, 2015.

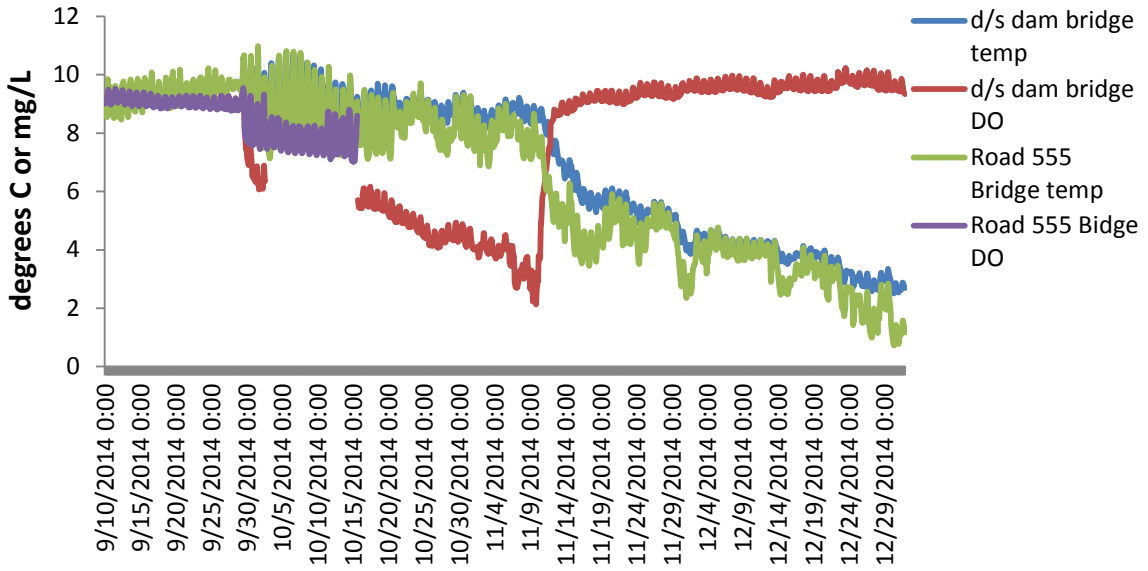


Figure 5-21. Water temperature (C) and DO concentrations (mg/L) measured downstream from the dam bridge and at the Road 555 Bridge downstream from Deadwood Dam, September 10 through December 31, 2014. A break in the downstream dam bridge DO values reflects a period of no available data.

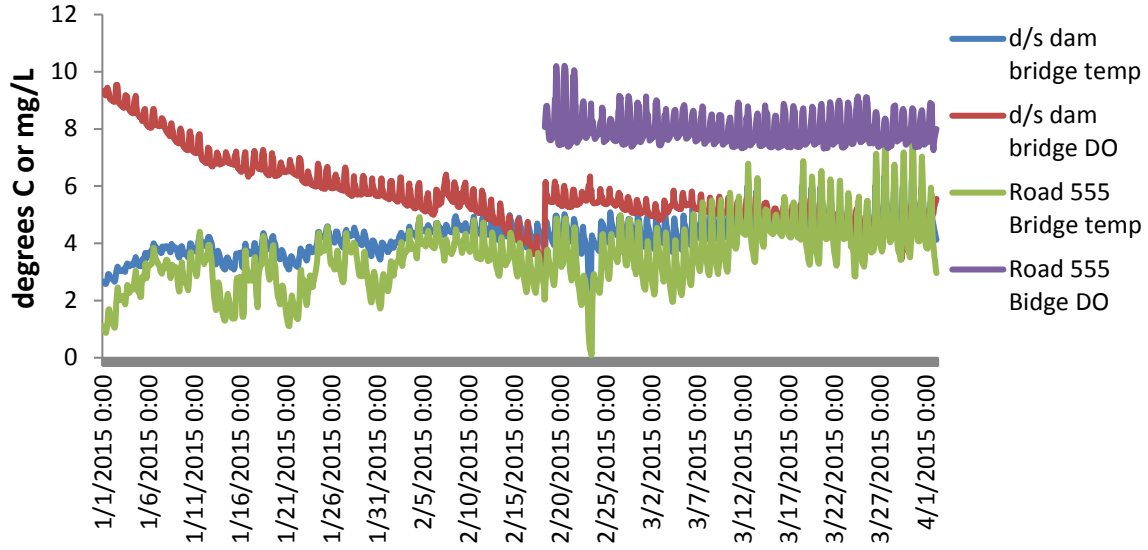


Figure 5-22. Water temperature (C) and DO concentrations (mg/L) measured downstream from the dam bridge and at the Road 555 Bridge downstream from Deadwood Dam, January 1 through April 2, 2015.

When DO concentrations are not depleted, levels of the water quality constituents (phosphorus, nitrogen, and chlorophyll-a) in the Deadwood River below Deadwood Reservoir are very low, indicating in most all cases, a lower loading and less degradation of water quality as compared to nearby rivers, such as the Snake and Lower Boise Rivers (Table 5-2 and Table 5-3). The average TP concentrations discharged from the reservoir during April, September, and October 2014 is 0.05 mg/L. In comparison, nuisance aquatic vegetation is often seen when TP in rivers is greater than 0.100 mg/L (EPA 1986, pg. 240). Concentrations of total phosphorous greater than 0.05 mg/L are measured in the Deadwood River downstream from the dam when anoxic conditions occur in the reservoir (Figure 5-23). The Snake River Hells Canyon Total Maximum Daily Load set nutrient targets for many of the tributaries to the Snake River in Oregon and Idaho at 0.07 mg/L (IDEQ and ODEQ 2004), and periodically measurements in the lower Deadwood River exceed this target.

Table 5-2. Water chemistry measurements for nitrate:nitrite (NO_3/NO_2), total phosphorous (TP), Kjeldahl nitrogen (TKN), total nitrogen (TN), total nitrogen:total phosphorous (TN:TP), chlorophyll *a* (Chl a) and total iron (Fe) from two sites on Deadwood Reservoir.

Site	Date	Depth	NO_3/NO_2 mg/L	TP mg/L	TKN mg/L	TN	TN:TP	Chl a mg/m^3	Fe µg/L
0.9 km north of dam	9/11/2014	Surface	< 0.01	0.014	0.2	0.2	14.28	4.3	< 20
	9/11/2014	≥1.5 m above bottom	0.02	0.028	0.19	0.21	7.5	0.8	290
	10/1/2014	Surface	< 0.01	< 0.01	0.26	0.26		2.6	< 20
	10/1/2014	≥1.5 m above bottom	0.04	0.032	0.34	0.38	11.87	1	330
Face of dam	9/29/2014	Surface	< 0.01	< 0.01	0.19	0.19		2.7	< 20
	9/29/2014	≥1.5 m above bottom	< 0.01	0.025	0.19	0.19	7.6	1.8	240
	10/1/2014	Surface	< 0.01	0.015	0.2	0.2	13.33	2.2	20
	10/1/2014	≥1.5 m above bottom	0.04	0.015	0.14	0.18	12	2.9	140
	10/16/2014	Surface							
	10/16/2014	≥1.5 m above bottom	0.05	0.03	0.18	0.23	7.67		340

Table 5-3. Water chemistry measurements for nitrate:nitrite (NO_3/NO_2), total phosphorous (TP), total Kjeldahl nitrogen (TKN), total nitrogen (TN), total nitrogen:total phosphorous (TN:TP), chlorophyll *a* (Chl a) and total iron (Fe) from six sites on Deadwood River.

Site	Date	Outflow (cfs)	NO_3/NO_2 mg/L	TP mg/L	TKN mg/L	TN	TN:TP	Chl a mg/m^3	Fe µg/L
Reservoir Inflow									
Deadwood R (0.9 km upstream reservoir)	4/11/2014		0.028	0.01	0.24	0.27	26.8		106.2
	9/11/2014		< 0.01	< 0.01	0.09	0.09	9		30
	9/29/2014		< 0.01	0.021	0.18	0.18	8.6		140
	10/1/2014		< 0.01	0.01	0.11	0.11	11		50
	10/16/2014		< 0.01	< 0.01	< 0.05	0.05	5		20
	2/18/2015		0.05	0.01	0.18	0.23	23	<0.5	6
	4/1/2015		0.04	0.017	0.15	0.19	11.2		110
Deadwood River downstream from Dam									
Stilling Basin (0.1 km downstream dam)	9/11/2014	58	0.03	0.045	0.25	0.28	6.22	5.4	510
	9/29/2014	57	0.04	0.06	0.35	0.39	6.5	1.3	690
	10/1/2014	2.4	0.04	0.102	0.49	0.53	5.20	2	1210
	10/15/2014	1.8	0.06	0.112	< 0.05	1	8.93	1.7	1780
	2/18/2015	2.3	0.03	0.26	0.66	0.69	2.67	2.2	3680
	4/2/2015	3.3	0.07	0.2	0.54	0.61	3.05	2.1	3060
1000 ft ds dam (0.4 km downstream dam)	9/11/2014	58	0.02	0.043	0.2	0.22	5.12	1.2	480
	9/29/2014	57	0.05	0.051	0.39	0.44	8.63	1.3	610
	10/1/2014	2.4	0.12	0.073	0.24	0.36	4.93	0.9	800
	10/16/2014	1.7	0.16	0.089	0.25	0.41	4.61		1320
	2/18/2015	2.3	0.14	0.182	0.58	0.72	3.96		2550
near Wilson Cr (0.5 km downstream dam)	4/11/2014	3.8	0.01	0.037	0.42	0.429	11.60		308
	9/11/2014	58	0.02	0.042	0.22	0.24	5.71	1.5	470
	9/29/2014	57	0.05	0.051	0.49	0.54	10.59	1.1	560
	10/1/2014	2.4	0.05	0.043	0.14	0.19	4.41860 5	< 0.5	430
	10/16/2014	1.7	0.09	0.051	0.13	0.22	4.31		670
	2/17/2015	2.3	0.04	0.055	0.16	0.20	3.64		610
	4/2/2015	3.3	0.01	0.046	0.16	0.17	3.70		450
50 m upstream Warm Spr Cr (2.5 km downstream dam)	9/29/2014	57	0.08	0.049	0.25	0.33	6.73	1.6	550
	10/1/2014	2.4	0.06	0.038	0.12	0.18	4.74	0.5	350
	10/16/2014	1.7	0.1	0.042	0.08	0.18	4.29		570
	2/17/2015	2.3	0.06	0.062	0.15	0.21	3.39		650
	4/1/2015	3.3	<0.01	0.043	0.11	0.11	2.56		450
Near mouth (37.7 km downstream dam)	9/29/2014	57	< 0.01	0.024	0.16	0.16	6.67	1.9	150
	10/1/2014	2.4	< 0.01	0.014	0.13	0.13	9.29	1.3	
	10/16/2014	1.7	< 0.01	0.012	0.08	0.08	6.67		20
	4/2/2015	2.8	<0.01	0.018	0.13	0.13	7.22		100

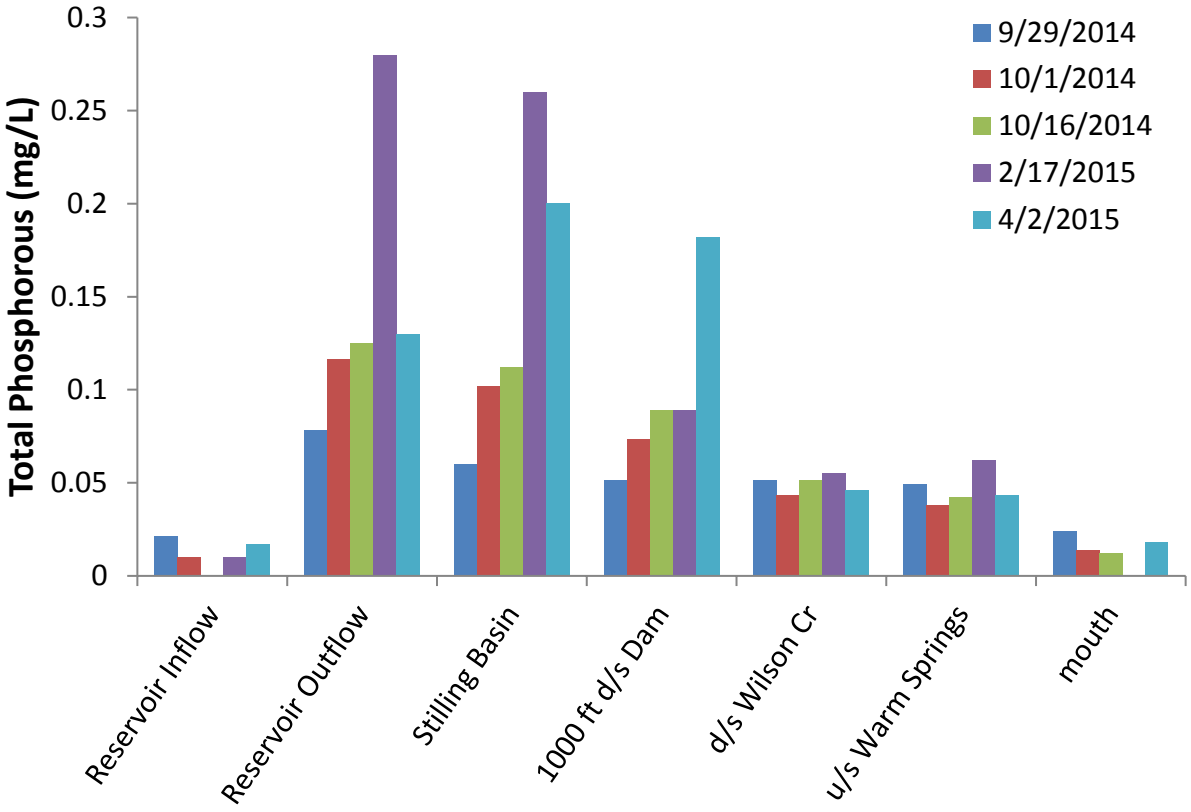


Figure 5-23. Total phosphorous (mg/l) measured in the inflow to Deadwood Reservoir, outflow from the Reservoir, stilling basin and in the Deadwood River (1,000 feet downstream from the dam, downstream from Wilson Creek, upstream from Warmsprings Creek and near the mouth) in fall 2014 and spring 2015. Sites were not sampled consistently each date, so a zero value indicates not sampled. Distances to each site are shown in Table 5-4.

As discussed in Chapter 2, Section 2.1, the hypoxia trending toward anoxia in the hypolimnion as the season progresses releases nutrients into solution. Additionally, it was measured during the spring 2014 that iron and manganese are also released from the sediments during anoxic conditions. Manganese values ranged from 19 to 1100 µg/L and the range of iron concentrations was 106 to 6,985 µg/L. Because both of these constituents, along with total phosphorus, are readily released from hypoxic and anoxic waters, future samples will not include the redundant information provided by manganese concentrations. Other water chemistry variables, such as DO, pH and electric conductivity (EC), are much different than expected in unregulated conditions. DO is described in detail in context of the logger data above, pH averages 6.8 and EC averages 44.8. Only levels of DO fall below State of Idaho cold water biota criteria of 6 ppm.

The water quality samples collected by Reclamation indicate elevated levels of iron, manganese, and total phosphorous which would be liberated from anoxic reservoir sediments. Iron values were elevated in the fall 2014 with both the 50 cfs and the 2.3 cfs

outflow. Concentrations with the 50 cfs outflow were more than triple in the inflow (background) estimate even though the water was aerated in the spillway. However, concentrations increased to more than 30-times the inflow (background) estimate during the 2.3 cfs outflow (Table 5-4). High levels of iron are the likely cause of the orange color of water and sediments observed downstream from the dam in both spring and fall of 2014. Aeration in the hypolimnion during spring reservoir mixing and increased outflow from the dam during July 2014 showed that iron concentrations had decreased to about 40 µg/L. Similarly, manganese concentrations declined from 955 µg/L in April 2014 to 10 µg/L in July. Samples collected longitudinally in the river downstream from the dam show declining iron and phosphorous concentrations with increased distance downstream. The highest values of iron and phosphorous are measured between the dam and Wilson Creek (Figure 5-23 and Figure 5-24). The water discharging at the mouth of the Deadwood River measures similar to background conditions (Table 5-4; Figure 5-23 and Figure 5-24).

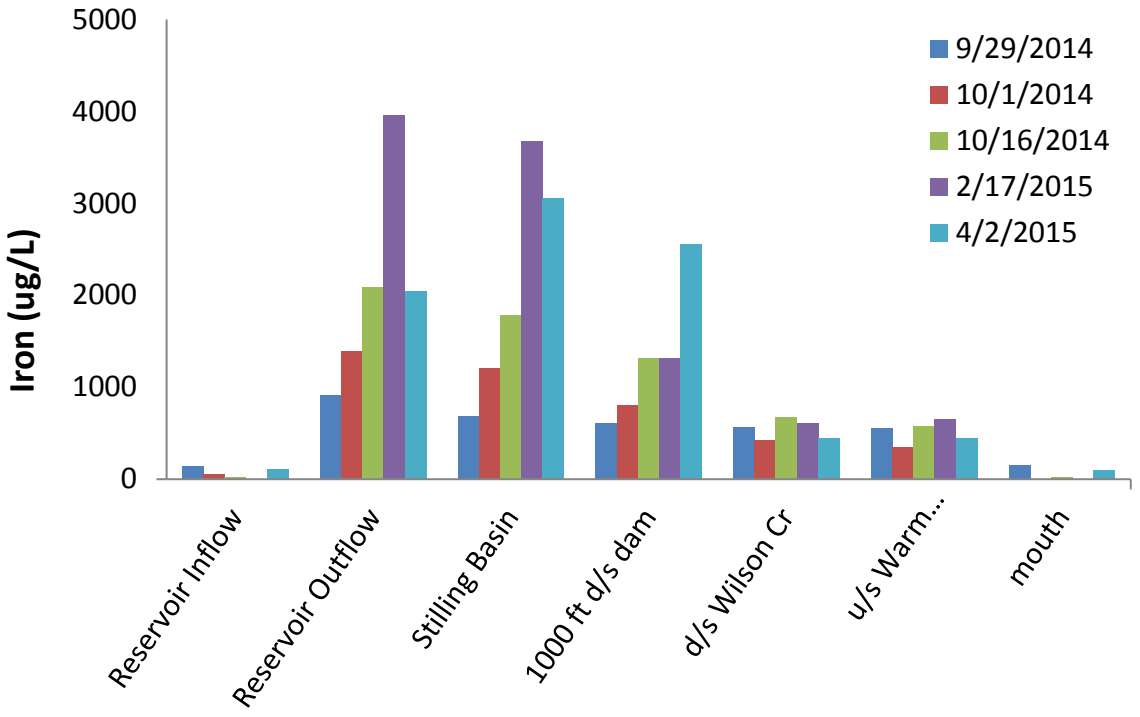


Figure 5-24. Iron concentrations (µg/L) measured in the inflow to the reservoir, outflow from the reservoir, stilling basin, and in the Deadwood River at various sites downstream (1,000 feet downstream from the dam, downstream from Wilson Creek, upstream from Warm Springs Creek and near the mouth) in the fall 2014 and spring 2015. Sites were not sampled consistently each date, so a zero value indicates not sampled. Distances to each site are shown in Table 5-4.

The national recommended aquatic life criterion for chronic iron exposure is 1,000 µg/L (EPA 2009; Sturdevant 2010). However, this criterion is generally applied to dissolved ferrous iron (Fe++). The oxidization of Fe++ is dependent on the pH of the system, and in

the presence of oxygen, iron readily oxidizes to an insoluble ferric iron (Fe +++) oxyhydroxides (Vouri 1995). Ferric iron oxyhydoxides are essentially harmless to animal health, but can have indirect effects on aquatic animals. In addition, the ferric iron oxyhydoxides precipitates can stain water an orange/rust color (Photograph 5-1). While the discoloration from elevated levels of iron can be aesthetically unpleasing, iron is not expected to impact the survival of Bull Trout and other aquatic organisms downstream from the dam. In some cases, elevated iron has been linked with decreased macroinvertebrate populations (Vuori 1995) via indirect effects to the invertebrates rather than toxicity. Some of these indirect effects include increased activity costs for cleaning mouth parts or iron deposits forming on gill and other morphological structures. Macroinvertebrate data collected as part of this study (Chapter 3, Section 3.3) indicate that the populations below the dam are somewhat depressed in comparison to nearby unregulated sites. Reduced invertebrate densities are often documented below other storage reservoirs and the cause is often attributed to nutrient limitation in the rivers as the reservoirs retain phosphorus during the majority of the year which results in reduced primary production and hence food limitation for the macroinvertebrate populations.



Photograph 5-1. Red-brown sediment being suspended due to disturbance on the Deadwood River bed between Wilson and Warmspring creeks. Color of sediment indicates precipitated oxidized iron. Photograph taken by A. Prisciandaro, Reclamation, October 25, 2013.

In addition to the water quality impacts from chronic exposure, the presence of ferrous iron and hypoxic conditions can lead to the growth and development of iron bacteria. These bacteria create a slime covering often seen in groundwater seeps and in hypoxic wells that have been previously contaminated with iron bacteria. However, iron bacteria are also beneficial in that they rapidly oxidize Fe++ to Fe+++ and should be considered an indicator

of elevated ferrous iron. Iron bacteria were detected in water samples from the Deadwood River downstream from the dam during the April 2014 sample, but were not present in samples taken in July 2014 after the reservoir had fully mixed and the hypolimnion was re-aerated. The oxidization of Fe++ to Fe+++ plays the biggest role in the development of the orange color in the stilling basin. Oxygen diffused into the stilling basin from the atmosphere and the presence of oxidizing iron bacteria can convert the dissolved ferrous iron to ferric oxyhdroxides. As described above, this rate of conversion is highly dependent on the pH of the system. In the Deadwood River stilling basin the pH is such that the half-life of dissolved ferrous iron at 10^{o}C would approach 4 hours to 16 days. The rate of oxidization approximately 1,000 feet below the stilling basin would be closer to the 4-hour rate as the pH has buffered, and by Warmsprings Creek the half-life would be approaching 2 to 3 minutes. At all of these locations the conversion rate would slow with temperature reductions while the presence of other trace metals, iron bacteria, and phosphorus would accelerate this rate (Vuori 1995). This has probably been occurring for many years as it has been noted that the rocks below the reservoir are an orange-color which could be from deposited ferric iron or from red-orange colored biofilm (Photograph 5-1).

To better understand the possible fate and transport of iron in the system, Reclamation conducted a simplified iron loading analysis along the longitudinal axis of the river from the dam to below Whitehawk Creek. Iron samples were collected at nine monitoring locations covering the area from the dam, through the stilling basin, the Deadwood River, and several of the major tributaries below the dam. Discharge measurements were collected or estimated for each of the nine monitoring locations. Iron load was then calculated from the concentration and discharge measurements to assess the relative changes in iron load. The loading analysis is a method to normalize concentrations with flow, or to place concentration data in context with discharge.

For example, discharge from the dam during the interim post-irrigation streamflow is very low, at 2.3 cfs while iron concentration is very high. Conversely, the iron concentration at several of the tributaries is very low while the discharge is very high. The loading analysis normalizes this relationship to make comparisons between sites. Loads are often calculated for water quality improvement documents such as total maximum daily loads, and are an expression of mass per unit time. The calculation of load is concentration (mg/L)* discharge (cfs)* a conversion factor (5.39).

The average iron load exported from the reservoir through the dam during the winters of 2014 and 2015 was approximately 24 lbs/day. Over the same period the average iron load at the end of the stilling basin was 22.58 lbs/day or nearly all of the iron moved through the stilling basin. Moving downstream from the dam iron continues to drop out of the system. At the monitoring site 1,000 feet below the dam, iron loading has dropped to 13.24 lbs/day.

Wilson Creek adds some iron back into the Deadwood River near this location. Iron loading from Wilson Creek during this time period averaged 9.51 lbs/day. By simple mass balance the Deadwood River should be carrying approximately 23 lbs/day. The monitoring site downstream from the Wilson Creek tributary averages about 27.5 lbs. This serves as a check on the deposition rate measured and estimated from the upstream locations. Additionally this illustrates the effect of a lower concentration stream with higher flows as iron load from Wilson Creek adds a similar amount of iron back into the system. The next tributary downstream, Warmsprings Creek, was only sampled twice during the time period. The average iron load for those two samples was 39 lbs/day. This is substantially more than that of Wilson Creek, but was expected due to the geothermal sources located within the creek system. Whitehawk Creek also contributes approximately 27 lbs/day of iron to the Deadwood River. Again using a mass balance approach the Deadwood River below Whitehawk Creek should carry approximately 96 lbs/day. Monitoring data collected at the sample location measured 110 lbs/day on average for the two sample events. Some of the additional iron may be coming from small unmeasured sources or is simply an artifact of the very small sample size. However, it does illustrate that at the interim flow of 2.3 cfs, the iron loading from tributaries is a substantial portion of the iron load in the system. At 2.3 cfs, even with the high concentration delivered from the reservoir, the iron load from the reservoir only makes up approximately one-fourth of the total iron load.

A simple comparison can be made between the (2.3 cfs) interim discharge iron loading and a hypothesized iron load at the normal post-irrigation flows of 50 cfs. Assuming that the iron concentration during the post-irrigation reservoir anoxic period is similar, at 50 cfs the iron load from the hydrogen averages 529 lbs/day. The range in load over the sample period would be 245 to 1,067 lbs/day. This is substantially more iron loading into the Deadwood River in comparison to the 2.3 cfs outflow (11 to 49 lbs/day at 2.3 cfs). As previously discussed, iron, phosphorus, and magnesium are only seen at elevated concentrations, and therefore, higher loads, during hypoxic and anoxic reservoir conditions.

Given the rate of deposition seen during the sample period, most of this iron would pass through the stilling basin and begin dropping out through the Deadwood River to Wilson Creek. At this loading level the iron loads from the tributaries would be substantially lower than from the stilling basin. At this time, Reclamation is unsure if the seasonally high levels of iron loadings prior to the 2.3 cfs interim discharge rate were impacting the aquatic biota in the Deadwood River. Other factors such as high flows, seasonally increasing temperature, and seasonal changes in pH could have moderated any impacts from the brief, but very high iron loads likely seen at 50 cfs. However, if iron loading was depressing the aquatic biota between the dam and Wilson Creek the significant ($p=0.004$) difference in mean load between 2.3 and 50 cfs may reduce any concerns over iron loading in the future.

Manganese, like iron is a required trace element and is very soluble in anoxic conditions, forming manganous salts. While the concentration of manganese is quite high when the

reservoir is anoxic, there does not appear to be any impairment of the biota below the reservoir due to these episodic events. It also oxidizes and precipitates out of solution as manganic oxide. These oxides will often deposit on rocks and cause a noticeable black color. Manganese can be toxic when consumed in high doses. In addition, EPA recommends a criterion of 50 µg/L to reduce aesthetic issues such as staining and other color issues under their human health criteria. There are no recommended water quality criteria for manganese (EPA 2009). However, to protect human health the EPA recommends less than 100 µg/L (water plus organism consumption).

Physical Habitat and Channel Connectivity – Water Years 2014 and 2015

Outflow from the dam was stable at 2.3 cfs during all of the data collection. Stream habitat data were collected over 7 days (October 23, 24, 28–30, and November 13–14). The Deadwood River does not have an operational streamflow gage downstream from the USGS gage located immediately downstream from the dam. This gage only records streamflow released at the dam and does not include water contributions from the basin and tributaries downstream. Therefore, the USGS streamflow gage on the South Fork of the Payette River near Lowman, Idaho (USGS gage no. 13235000) is used as an indicator of relative streamflow conditions in the area which are affected by similar local precipitation and runoff. Streamflow during habitat measurements ranged from 333 cfs to 362 cfs – close to the lowest streamflow measured during this season in the period of record for the streamflow gage at Lowman, Idaho.

Because the amount of predicted physical habitat is measured throughout the lower Deadwood River downstream from the dam from the LiDAR data (described in Chapter 3, Section 3.1), it is not possible to directly compare the 2013 field surveys to the estimated habitat without estimating a substantial portion of unsampled areas. LiDAR data provides comparable estimates over the entire river including areas deeper than wading will allow (>1.5 m depth). Conversely, wadeable measurements provide measurements in the shallower areas that have increments smaller than the error associated with the LiDAR data. Therefore, both data sets inform stream habitat conditions, but have different coverages and biases. Additionally, the section numbers and locations were not the same between 2010 and 2013 surveys, and during the 2013 survey the goal was to collect stratified random data over about 33% of the stream. There has not been any large streamflow or channel forming events during these years of the study, so we did not expect substantial changes in the measured habitat values. As expected, habitat varied among the habitat types (riffle, pool, and run) and among the sections (Table 5-4; Figure 5-25). Average depths were at least 0.3 m in the riffle habitats and more than 0.5 m in the pool habitats.

Table 5-4. Summary of physical habitat data collected from the lower Deadwood River (Deadwood Dam to the confluence with the South Fork Payette) during October and November 2013. Sections are numbered from downstream (section 1) to upstream (section 9).

Reach	Section	Avg Width (m)	Avg Depth (m)	No. Pools	Avg Max Pool Depth
Lower	1	16.3	0.46	7	1.26
	2	18.5	0.37	6	0.91
	3	18.2	0.40	9	1.18
Middle	4	19.1	0.58	19	1.57
	5	17.7	0.64	14	1.58
Upper	8	13.6	0.57	14	1.35
	9	10.4	0.32	28	0.8

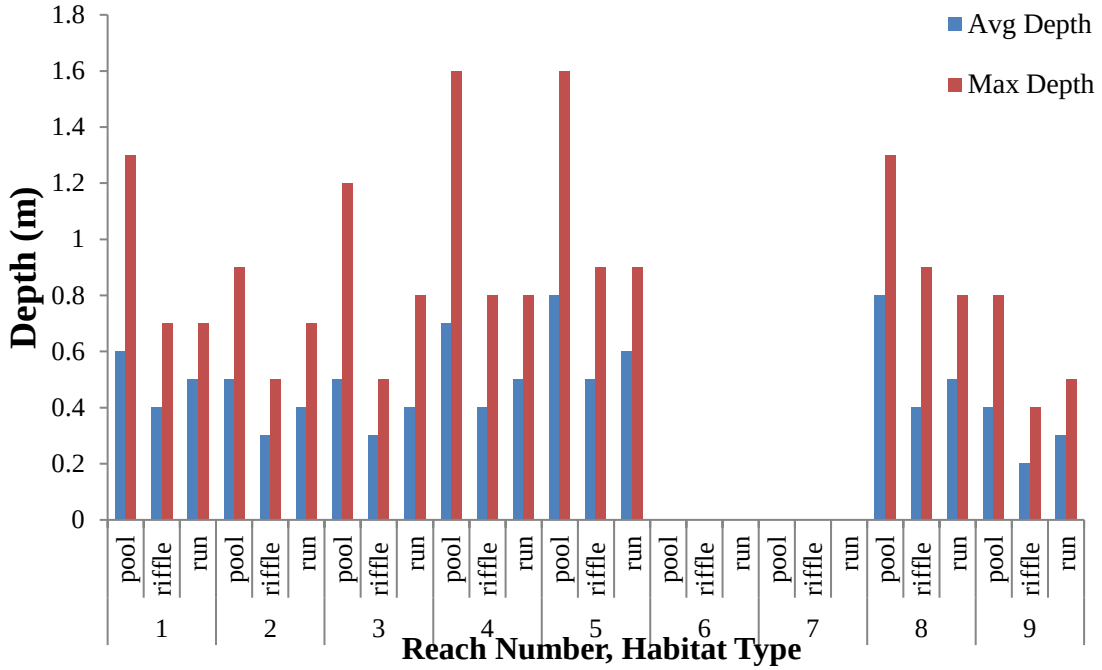


Figure 5-25. Average and maximum stream depths (m) by reach and habitat type in the Deadwood River between Deadwood Dam and the confluence of the South Fork Payette River. Reaches 6 and 7 were not surveyed. Location of reach numbers depicted in Figure 5-5.

Cover estimates can be compared over all the surveyed reaches between the different sample years. These data indicate that percent cover estimated by the field personnel were similar except for the boulder cover which was much lower in 2013 than in the 2010 survey described in Chapter 4 (Figure 5-26). This difference could be due to observer variation and/or the exclusion of the canyon area in sections 6 and 7 that were not included in the 2013 survey.

The physical habitat data indicates that the wetted habitat during the 2.3 cfs post-irrigation streamflow provides suitable habitat for Bull Trout during the lowest expected streamflow conditions. The amount and expected effects of the reduced winter streamflows are discussed in Chapter 4. Precipitation events are common during the fall and winter months, and streamflow are oftentimes higher than when data were collected. Therefore, under most conditions, additional habitat – particularly deeper water – is likely to occur in the lower river where numerous tributaries would contribute streamflow.

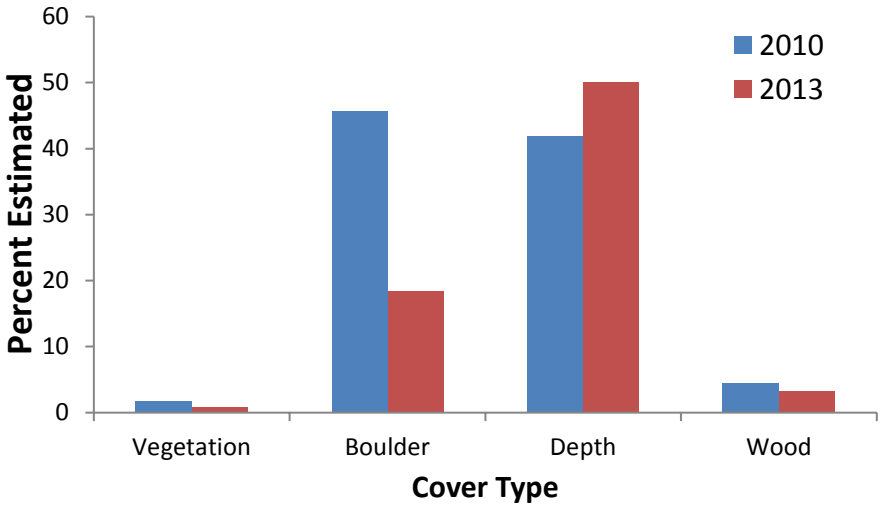


Figure 5-26. Estimated percent area covered by cover type comparing surveys conducted during fall 2010 and 2013 at 2.3 cfs outflow from Deadwood Dam.

During the 2013 surveys, 28 pools were counted disconnected from the stream. Pool length (m) ranged from 0.7 to 40 m (average 7.5 m). Pool width ranged from 0.7 to 8 m (average 2.6) and depth ranged from 0.1 to 1.0 m (average 0.32). The previous survey in 2010 counted 69 disconnected pools at 2.3 cfs outflow from the dam, but did not survey the entire river downstream from the dam. The survey conducted in 2010 determined that these disconnected pools did contain several species of fish, but no Bull Trout were observed (see Chapter 4, Section 4.2.3).

Channel connectivity is an important aspect of physical habitat particularly during the fall months when Bull Trout move from spawning locations to overwintering habitat. Connectivity surveys were conducted on October 1 and 2, 2014 between the dam and Scott Creek (Figure 5-27). The additional locations between Scott Creek and the mouth were conducted on October 8 and 28, 2014. During these surveys, the streamflow at the USGS gage located at Lowman, Idaho was 385 to 391 cfs during October 1 and 368 to 374 cfs during October 2, 333-339 cfs during October 8 and 403-409 cfs during October 28. The long-term mean during October for the site is about 345 cfs, streamflow during the survey were only slightly higher than the long-term mean. Due to the slightly elevated streamflow

during the survey period, all sites that were 0.15 m deep are included as data points shown on the map (Figure 5-28). Photographs from the connectivity surveys are provided in Appendix J.

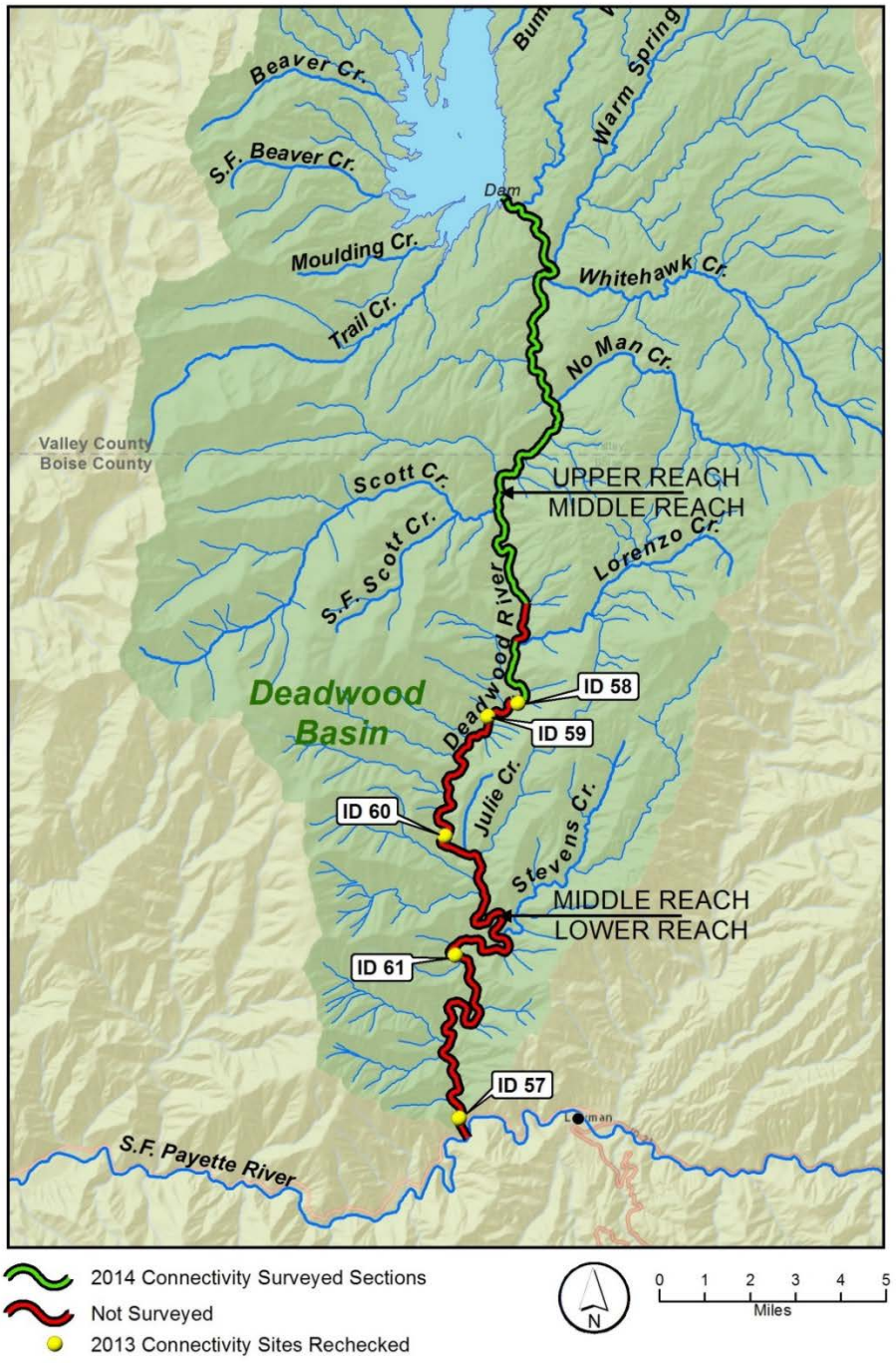


Figure 5-27. Map of lower Deadwood River showing locations of connectivity survey during fall post-irrigation streamflows in 2014.

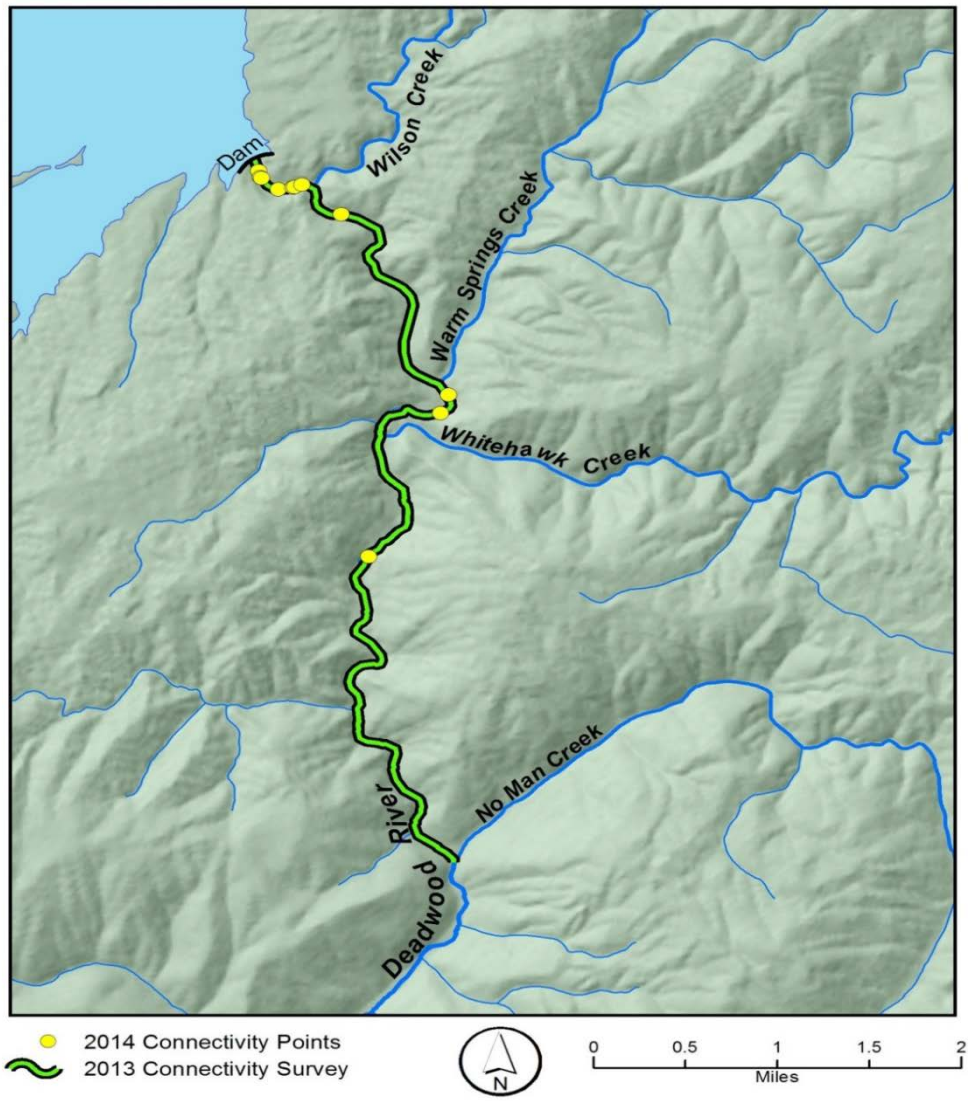


Figure 5-28. Map of locations identified as having shallower depths than preferred for Bull Trout passage (≤0.15 m) maximum thalweg depth.

During the survey, 12 locations were less than or equal to 0.15 m depth – the target depth for passage of adult Bull Trout (Figure 5-28). Of these 12 locations, measured depths ranged from 0.1 to 0.15 m and 8 of these 12 locations were equal to the 0.15 m depth criteria. The locations identified in the connectivity survey ranged in stream length from 0.4 to 8.0 m. As expected, the shallowest points in the stream are concentrated in the river where streamflows are lowest downstream from the dam with nine of the 12 locations between the dam and Warmsprings Creek. No connectivity problems were identified downstream from No Man Creek where tributary inflows add to the stream discharge. Observers visually identified all locations as passable to adult and juvenile Bull Trout with only one location between the dam and Wilson Creek as questionable for adult passage.

An instream flow study conducted in 1975 identified that an outflow at the dam of less than 25 cfs would provide adequate passage conditions for Bull Trout in the river downstream from the dam (Pruitt and Nadeau 1978). Yet, the 50 cfs post-irrigation streamflow has not increased the numbers of Bull Trout utilizing this habitat over the last 20 years. Pruitt and Nadeau (1978) use a passage depth requirement of 0.12 m depth with maximum velocity of 4 feet per second for at least 25% of the stream width. Average wetted width in the Deadwood River near the mouth is 30 m (Chapter 4, Section 4.2.4). Therefore, 25% of this average width would equal a target passage channel of about 0.12 m deep and 7.5 m wide at each transect, or with the stated minimum criteria of 10% continuous width over the study reach about 0.12 m deep and 3 m wide. More recent and comprehensive studies may provide better passage criteria (e.g., Auble et al. 2009). Auble et al. (2009) identified the ideal passage dimensions as 0.15 m deep and 0.45 m wide, but also found that depth was more important than width when predicting Bull Trout passage. The depth criteria used to assess connectivity during this study was 0.15 m deep with width sufficient enough for a fish to swim (about 0.1 – 0.15 m wide). Channel transects located in areas where passage conditions are less than target depths will provide more information on the amount of streamflow needed to provide target passage requirements. Additionally, a different streamflow from those analyzed in this study would require new analyses to address the associated benefits and impacts because some of the benefits identified at the 2.3 cfs post-irrigation streamflow could be reduced at a higher streamflow.

Radio-tagging Trout in Stilling Basin – Water Year 2015

One Bull Trout and 12 Rainbow Trout were radio-tagged and tracked between October 2014 and March 2015. Data are summarized by species in Table 5-5. Note that on November 20, the stationary receivers ran out of battery power and were not re-powered until February 20, 2015. Therefore, fish movement data between November 20, 2014 and February 17, 2015 is unknown.

Table 5-5. Summary of radio-tag tracking data for rainbow and Bull Trout tagged in the stilling basin below Deadwood Dam, fall 2014.

No. Tagged	Species	Total Length (mm)	No.	Result of Tracking
1	Bull Trout	377	1	Migrated to Warmsprings Creek area and back to stilling basin in October; tag detected in stilling basin during winter months of 2014/2015. Tag detected between Wilson and Warmsprings during summer months of 2015.
12	Rainbow Trout	430	1	Tag out of water near stilling basin, no data on tag
		240-340	5	Overwinter, detected Feb/Mar 2015
		240-400	6	Unknown, tag detected until mid-November 2014 at stationary receivers but tag not detected again

The radio-tagged trout generally remained in the stilling basin and/or between the stilling basin and Wilson Creek within the range of the stationary receivers until mid-November 2014. The Bull Trout left the stilling basin on October 7, 2014 and returned to the stilling basin on October 25, 2014 where it remained until the 2015 irrigation season when it was detected (via ground tracking) in July, August, and September between Wilson and Warmsprings creeks. The Rainbow Trout all remained the in the stilling basin at least until mid-November. Most of the trout that were recorded leaving the stilling basin occurred between November 12 and 17, 2014; however, some trout remained in the area of the stilling basin until November 20, 2014 when the stationary tag receiver ceased operation.

Most of the connectivity problems were identified between the stilling basin and Wilson Creek (Figure 5-27) and 11 out of 13 radio-tagged fish regularly moved upstream and downstream through this area. Additionally, four Rainbow Trout had furthest detections as far downstream as Warmsprings Creek, near White Hawk Creek, and between Wilson and Warmsprings Creeks. The two other Rainbow Trout were detected downstream from Wilson Creek. Although five sites were identified as marginal connectivity based on depth criteria or observer determination (see above subsection), several Rainbow Trout were documented migrating through these shallow areas and successfully overwintering in the river downstream from the dam. After limited searching for tags in March 2015, 1 of the 13 (6.6%) radio tags were located on shore near the stilling basin and 6 of the 13 tagged trout (46.2%) were detected alive within the area searched. The remainder of the tags were undetected.

These radio-tag data indicate that trout remained in the stilling basin despite lower DO concentrations until at least November 20 which was the last data collected from the basin. Trout did not appear to avoid the stilling basin, and interestingly, did not start to move to other areas until mid-November when water temperature steadily declined from 9 to 3^{o}C. This decline in water temperature could trigger trout to seek overwintering habitat; however, the tag information cannot determine the cause of movement. It is noteworthy that the movement from the stilling basin occurs after the DO values increase from the lowest value of 3 mg/L to >8 mg/L (Figure 5-19).

5.3 Literature Cited

Parenthetical Reference	Bibliographic Citation
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Sturdevant 2010	Sturdevant, D. 2010. "Water quality standards review and recommendations: Iron and Manganese." Oregon Department of Environmental Quality, Issue Paper, Attachment D, December 9, 2010 EQC meeting. 24pp.

Parenthetical Reference	Bibliographic Citation
Suplee and Sada 2013	Suplee, M. and R. Sada. 2013. "Technical Memorandum: Best use of MiniDOT Loggers for Dissolved Oxygen Measurement in Streams and Rivers, Part 2, May 13, 2013." Montana Department of Environmental Quality. Water Quality Standards Section. 8 pp.
Vuori 1995	Vuori, K. M. 1995. "Direct and indirect effects of iron on river ecosystems." *Annual Zoology Fennici* 32:317-329.

Chapter 6 SYNTHESIS

6.1 Background

The preceding chapters discuss the multiple analyses and data collection for this comprehensive study identifying the flexibility of water operations on the physical and biological ecosystem processes. The analyses examine various hydrologic and ecological models which describe reservoir and associated river conditions downstream. Interdependence of variables between the reservoir and the river downstream from the dam, as well as time interdependences (season-to-season, year-to-year) make the direct identification of cause and effect among these data sets difficult. Due to the fact that storing water in the reservoir removes water from the river downstream from the dam, operational decisions can result in a trade-off between the reservoir habitat or river habitat which can complicate the understanding and interpretation of the many details and data sets examined in this study. Chapter 5 includes monitoring data collected between September 2013 and June 2015 when implementing the interim 2.3 cfs post-irrigation streamflow with the fast ramping rate for two consecutive seasons. These data give context to the expected ecological conditions when implementing this streamflow.

Post-irrigation streamflows (fall to spring) and ramping rates were the areas investigated to identify the ecological effects of operations. Although Reclamation has some flexibility in the shape and duration of pre-irrigation (spring) streamflow releases when they occur, these aspects of operations were not tested in this study. From 1993 to 2013, the post-irrigation and winter operation was a 50 cfs minimum streamflow which is about equivalent to the inflows to Deadwood Reservoir during dry year conditions (Table 6.1). This minimum streamflow is provided during dry and average climatic conditions, but during wet years, the outflow can be double the average estimated inflow in order to create flood control space in the reservoir (nondiscretionary action) (Table 6.1). Analyses indicated that post-irrigation streamflow releases of 50 cfs resulted in higher than natural water temperatures during the fall and winter months downstream from the dam. The higher post-irrigation streamflow releases from the reservoir necessary during wet climatic conditions will increase winter stream temperatures from the current post-irrigation streamflow of 50 cfs and impede ice formation (see Chapter 3, Section 3.1.5) under any of the operation scenarios examined (i.e., 0, 2, or 50 cfs, fast or slow ramping rates). These high post-irrigation water releases are necessary to manage reservoir content for public safety and flood control.

Table 6-1. Estimated inflows (cfs) to Deadwood Reservoir and measured outflows from Deadwood Dam for November 1 to February 28 for wet (1997), dry (2001), and average (2003) water years examined in the study.

	Minimum (cfs)	Maximum (cfs)	Average (cfs)	Standard Deviation
Estimated Inflow				
Dry	30	142	58.9	16.8
Average	25.7	265.6	81.6	41.4
Wet	62	942.9	175.7	139.3
Measured Outflow				
Dry	52	57	53.6	1.3
Average	52	54	52.8	0.8
Wet	51	1300	317.6	330.5

This study tested the current minimum post-irrigation streamflow of 50 cfs against the reduced streamflows of 2.3 and 0 cfs. The lower post-irrigation streamflows were predicted to allow a more natural winter river temperature regime downstream from the dam, due to the reduced amount of warmer (4^{o}C) water from the reservoir. This was predicted to allow better surface ice cover formation in the river which would insulate the channel from super-cooling and forming frazil ice (see Chapter 3, Section 3.1.5). In turn, the reduced post-irrigation streamflow would result in less water released from the reservoir, which, depending on subsequent yearly water conditions (i.e., if the reservoir would have otherwise filled or not in the following spring/summer) may result in higher reservoir content in the following spring/summer in years when the reservoir would not otherwise have filled. This directly affects the summer reservoir level, thermal stratification and resulting water chemistry (e.g., DO levels).

Two ramping rates were investigated as part of the scenarios (fast and slow). The fast ramping rate alters the streamflow up or down in a 2-day period, whereas the slow ramping rate alters the streamflow over a 7 to 10-day period. Ramping the streamflow over an extended period of time requires more water to be released from the reservoir during down-ramping. However, the slower ramping rates are thought to result in lower impacts to fisheries downstream allowing for more time to adjust to the alteration and dewatering of habitat. This analysis determined that the rate of up ramping at the beginning of the irrigation season streamflow did not result in measurable differences in the water temperatures downstream from the dam. However, analyses of down-ramping rates at the end of the irrigation season streamflow found that the fast ramping rate (2-day change in flow) resulted in water temperatures closer to natural in the river downstream from the dam. Additionally, the water saved with the fast ramping (as opposed to slow ramping) would

remain in reservoir storage to provide additional temperature and reservoir content benefits particularly during Bull Trout migrations.

Reservoir elevation and climatic variables are directly responsible for the thermal stratification which in turn directly affects the water quality. Unlike a lake which has a balanced inflow/outflow point, Deadwood Reservoir's outlet structures are located deep in the reservoir. While irrigation water releases are being made during the summer months, the reservoir is drained from the lowest and coldest thermal strata –the hypolimnion. As the summer progresses, the reservoir can be drawn down to the extent that the hypolimnion no longer exists, as the remaining (shallower) reservoir depth is influenced by solar heating. At this point, warmer water from the metalimnion is released through the dam to the river downstream.

Overall, the various analyses found trade-offs between optimal reservoir habitat conditions and optimal river conditions downstream for Bull Trout and other species. The higher post-irrigation season reservoir elevation creates better rearing and migration conditions for Bull Trout the entire year, but can create some conditions in the river, such as summer temperatures that remain about 5ºC colder into late summer than measured with the 50 cfs post-irrigation streamflow. This chapter discusses the effect to each variable studied and summarizes the findings in terms of each Term and Condition from the BiOp for Deadwood Dam and Reservoir.

6.2 Temperature

Temperatures in Deadwood Reservoir are influenced by the climate, volume, residence time, and the seasonal thermal stratification. As described above, water operations influence temperatures in the reservoir by altering lake depth (and volume) and the thermal stratification. The deepest water ranges from about 4 to 15ºC; whereas the surface temperatures change seasonally from 0ºC in the winter to >20ºC during the summer. Surface temperature during the spring (April) and fall (October) is around 9 to 1ºC. Of the operational scenarios modeled, the 2.3 and 0 cfs winter streamflow improved water temperature in comparison to the 50 cfs option over most months of the year.

Data collected during this study indicated that the effect of the dam can be measured 3.7 km downstream. After this point, the inflows from tributaries, springs and surface air exchange bring the temperatures closer to natural, although effects to ice cover from altered temperatures extend throughout the lower Deadwood River below the dam. Data collected during a 50 cfs minimum streamflow showed that the river temperatures in the Deadwood River downstream from the dam were typically warmer than unregulated rivers in the winter (3ºC versus 0ºC) and slightly cooler in the summer at 11–12ºC compared to 12–15ºC at unregulated sites (see Chapter 3, Section 3.1.3). The earlier part of the summer is cooler than

natural, and then temperatures from the outflow become more similar to natural in the later part of the summer as the cold water in the hypolimnion of the reservoir is depleted.

Monitoring data collected during the fall of 2013 showed a sharp reduction (from 16 to 9ºC over 3 days) in water temperature when reducing the streamflow from 50 to 2.3 cfs. This reduction in flow brought water temperatures close to natural (unregulated) water temperatures, thus reducing the effect of higher than normal water temperatures that extended into November with the 50 cfs post-irrigation streamflow release. However, this sharp reduction in stream temperature could be detrimental for fishes and other aquatic organisms, and a ramping rate somewhat slower than the fast (2-day) rate might slow this temperature effect and give additional time for the biota to adjust. However, this drastic temperature reduction was not present in September 2014 due to the higher reservoir level from increased storage and the extended presence of the colder hypolimnion.

During the spring 2014, temperatures were fairly close to natural during pre-irrigation streamflow release. In 2014, the fall temperatures (late August through September) were cooler than previous operations likely due to the two consecutive low (2.3 cfs) post-irrigation streamflow releases combined with average climatic conditions and precipitation and higher reservoir levels, with this colder water remaining in the hypolimnion.

Water operations have a direct effect on reservoir level and resulting thermal stratification at the end of the irrigation season, as well as on water temperatures in the river downstream from the dam, particularly between July and November. Water temperatures downstream from the dam have a lower summer maximum (8 to 13ºC) for the lower post-irrigation streamflow scenarios (0 and 2 cfs), whereas the 50 cfs scenarios result in summer maximum temperatures about 18 to 20ºC during average and dry climatic conditions. The later summer temperatures expected with the lower post-irrigation streamflow are colder than the unregulated (natural) inflows. The lower post-irrigation streamflows also reduce the water temperatures downstream from the dam during the fall. During the winter, the lower post-irrigation streamflow scenarios were closer to natural water temperatures (0ºC) and showed some development of surface ice cover. During dry years, pre-irrigation water is not released at the dam so spring water temperatures from the reservoir should be close to natural. However, during average and wet years water is spilled from the reservoir surface which is substantially warmer than the natural water temperatures during the spring snowmelt; this ability to modulate spring downstream temperatures through spilling surface water rather than releasing deeper (colder) water through the outlet works does represent an operational flexibility for Reclamation. Summer irrigation releases are cooler than natural; however, the temperatures predicted in this study identified water temperatures that will be colder than natural during early summer and then close to natural later in the summer season for the

average and dry climatic conditions. During wet climatic conditions, temperatures remain warmer than natural during the winter and colder than natural during the rest of the year.[1]

A number of operational strategies can be used to control water temperatures in the river downstream during pre-irrigation streamflow releases. Using the deeper water outlet works gates earlier in the spring will provide water that is close in temperature to natural (approximately 5ºC in April/May). The natural water temperatures increase steadily to approximately 10ºC in June and 15ºC in July. Spill typically occurs between late May and early July. Therefore, unregulated water temperatures during this time are higher than the water temperatures at the deeper outlet gates. The surface water that spills over the top of the dam will be a higher temperature than natural, unregulated water temperatures in the river. Therefore, mixing the surface water spill with the deeper outlet works will provide some flexibility to alter water temperatures. During April and May, the pre-irrigation water release should utilize the outlet works gates, as the deeper water is close to natural temperatures. During June, the pre-irrigation release could be mixed with some surface spill to increase the outflow temperature. During late June/early July, the surface spill will be closest to the natural stream temperatures and pre-irrigation outflows should have more surface spill and less colder water from the outlet works gate. These findings indicate that there is significant potential for beneficial application of intentional spill, and suggest that a re-evaluation of the guidance of the current terms and conditions, which direct that spill is to be avoided, may be warranted.

Successive years of the low post-irrigation streamflow were not investigated in the water operations and temperature models. Based on the analyses in this report, the low winter streamflow has benefits during the dry and average climatic conditions; however, there may be excess water in the system during wet conditions which could result in higher winter streamflow than implemented during the 50 cfs minimum streamflow. Because climatic conditions cannot be predicted and they can occur in any sequence (i.e., wet-wet, dry-wet, etc.), it is impossible to identify the amount of pre-irrigation water release needed across future years. Random stochastic analyses and analyses based on 20 or more year's previous water records could be performed with a hydrologic model, and may provide information to optimize water operations strategies. For example, wetter climatic conditions combined with the lower post-irrigation streamflow could result in higher reservoir volume at the end of the irrigation season.

[1] Interpretation of modeled thermal regimes below the dam is limited because water temperature in each scenario was modeled using empirical data sets collected within the study location in 2009. Calibrating the model demonstrated that modeled water temperatures accurately represent the empirical data. It is significant to note that while 2009 offered the most robust data set for the purpose of modeling water temperatures, operations during 2009 did not include use of the spillway. During spillway use, water temperatures downstream of the dam are expected to increase (a result of warmer surface water from the reservoir being released) but this phenomena is not depicted in the modeled data. Spill, and the corresponding downstream temperature increase, would be expected for wet or average years.

6.3 Water Quality

Water quality is largely affected by temperature and associated DO levels. Deadwood Reservoir shows thermal stratification typical of deep lakes and reservoirs. The bottom of the reservoir ranges from 4 to 15 ^{o}C which is cooler than the surface in the summer and warmer than the surface in the winter. During these two seasons, this cold layer of water (the hypolimnion) is isolated from exchange of oxygen with the atmosphere and hence has a limited supply of oxygen for the season. The hypolimnion in Deadwood Reservoir can become anoxic as the winter or summer seasons progress, similar to eutrophic water bodies (Chapter 2, Section 2.2.4).

Water chemistry data from the reservoir indicated a high nutrient load that is largely from nutrient recycling from reservoir bottom sediments released during anoxic conditions in the hypolimnion. Nutrients are also delivered into the reservoir from the watershed during run-off events. The historic water operations and effect of the dam likely played a role in the accumulation of the internal nutrient load in the reservoir (Chapter 2, Section 2.2.6). Additionally, recent and extensive forest fires are also suggested as a mechanism for increased nutrient loads in the reservoir (Chapter 2, Section 2.2.5). Regardless of the possible source of nutrients, the current conditions clearly show that the internal nutrient load stimulates primary production in the upper strata of the reservoir which was observed during the fall after thermal release (turn-over) of the reservoir and recirculation. When this abundant algal community dies, it settles to the reservoir bottom where the decay creates additional biochemical oxygen demand in the hypolimnion during the winter months and resulting anoxia prior to spring turn-over of the reservoir (Chapter 2, Sections 2.2.3 – 2.2.4). Water quality downstream from the dam had high concentrations of nutrients (Chapter 5, Section 5.2.5) during periods of reservoir hypoxia, but DO concentrations directly below the dam in the stilling basin were unfavorably low at 2.3 cfs winter releases.

During 2014, monitoring data indicates that iron and manganese are changing oxidation states and become more soluble under anoxic conditions. These metals were passed through the dam during the post-irrigation streamflow and remain in solution until the water becomes aerated through turbulence and interaction with the surface. This condition appears to be exacerbated by the anoxic conditions in the hypolimnion which is extended when implementing the lower post-irrigation season streamflow (0 and 2.3 cfs). However this condition also occurs when implementing the 50 cfs post-irrigation streamflow, and lower post-irrigation streamflows reduce the total load of metals to the river downstream. Iron bacteria were also present downstream from the dam. Although these conditions create unusual color to the river bottom, the condition is not considered to be toxic to aquatic biota (Chapter 5).

When considering water operations, there is a trade-off between the thermal benefits of the colder hypolimnetic water in the late summer with the deoxygenation. When examining the low post-irrigation streamflows (0 and 2 cfs), the model predicted higher reservoir levels, more extensive hypolimnion and anoxic conditions developing late summer and fall (Chapter 2, Section 2.1.3). Yet, nutrient and metal loads were reduced with the lower post-irrigation streamflow (0 or 2.3 cfs). Low oxygen concentrations occur in the stilling basin for about 2 or 3 weeks in the fall when implementing the 2.3 cfs post-irrigation streamflow prior to reservoir turn-over, but the water is reaerated within a 0.5 km distance downstream from the dam (Chapter 5, Section 5.2.5). Late winter deoxygenation of the hypolimnion occurs with any of the operational scenarios. While the 50 cfs outflow reaerates the water entering the stilling basin, lower 2.3 cfs winter releases result in unfavorably low DO concentrations in the stilling basin.

6.4 Productivity

Productivity in Deadwood Reservoir is driven by nutrient availability for primary production which is related to the levels of DO in the hypolimnion. Data collected in the reservoir regularly indicated super-saturated DO near the thermocline (approximately 9 m depth) during the summer months, and increased primary production and chlorophyll *a* concentrations in the late fall (Chapter 2, Section 2.2.4). Water with higher nutrient concentrations is passed through the dam into the river downstream resulting in higher chlorophyll *a* and pheophytin-a. Additionally, the organic material (measured as ash free dry mass) was greater downstream from the dam than other sites in the mainstem Deadwood River and Clear Creek likely due to filamentous algae below the dam (Chapter 3, Section 3.3).

Water operations had little influence on net primary production in the reservoir, but hydrologic conditions had a strong influence with wet years 134 to 156% more productive than dry years. The greatest difference was between wet and dry years with 50 cfs release due to the lower reservoir volume in the spring during the dry years when production rates are greatest. Production was about 15% higher when implementing the lower (0 and 2 cfs) post-irrigation streamflow in comparison to the 50 cfs post-irrigation streamflow (Chapter 2, Section 2.3.3).

Annual production of macroinvertebrates showed the greatest differences across sites sampled and hydrologic conditions. Highest values of production were measured at the most-downstream site near the mouth of the Deadwood River. The average reduction in annual macroinvertebrate production from the 50 cfs to 2.3 cfs post-irrigation streamflow with fast ramping rates were 30%, 11%, and 0% for dry, average, and wet conditions, respectively. However, lower post-irrigation flows leading to increased winter storage enable increased springtime spillway usage, which can be utilized to raise downstream

temperatures, leading to increased springtime production. This may in fact offset any reduction in fall productivity associated with lowered post-irrigation flows.

6.5 Available Habitat

Bull Trout have been detected throughout the reservoir and some of the tributaries upstream. Bull Trout were not frequently recorded utilizing the deeper water in the reservoir, and it is unclear if this is due to the physical limitations of radio tags to be detected in deeper water (greater than 10 m in depth), inhospitable (anoxic) habitat, or simply some other habitat preference such as location of preferred prey. Tagged Bull Trout spent the majority of time in water <2 m deep. Based on Bull Trout abundance and growth rates, the reservoir habitat appears to be suitable; however, during 2007 when the reservoir was drawn down during the summer irrigation releases and climatic conditions were dry, Bull Trout migrated out of the reservoir into the tributaries upstream. Water temperatures during this time were approaching the upper tolerance for Bull Trout. Conversely, during 2011, when reservoir content was higher and the climatic conditions were average, the Bull Trout remained in the reservoir during the entire summer and fall. It should be noted that while it is likely that this change in behavior between years is, to some degree, due to the varying water temperature conditions discussed, it may also be simultaneously related to the increase in the Bull Trout population between these years. Increased population size and pressure has been shown to be associated with alternate-year spawning behavior, which could explain some Bull Trout remaining in the reservoir rather than spawning.

Reduced reservoir surface elevation exposes a varial zone which is reservoir habitat during higher reservoir elevations and stream habitat during the lower reservoir surface elevations (USFWS 2014). These varial zones tend to be shallow with little to no instream or bank cover due to the annual cycles of inundation and dewatering. Additionally, these areas tend to accumulate fine sediments that are transported and deposited during periods of higher streamflow entering the reservoir. Effects of reservoir operations can include lack of passage due to disconnected streamflow, deterred passage from shallow water depths and increased predation due to visibility and exposure to predators (USFWS 2014).

Bull Trout in Deadwood Reservoir have to pass through a shallow varial zone during the spawning season (August through October) to access spawning habitat in the tributaries. Minimum thalweg depth measured using cross-section transects in the varial zone during 2013 was 0.3 m in the Deadwood River upstream from the reservoir and 0.15 m in Trail Creek (Reclamation, unpublished data). Water depth measured during August 2013 was minimal for adult Bull Trout migrating to spawning habitat in Trail Creek. Bull Trout and Kokanee Salmon have been observed swimming through this area with their backs above the water surface. Water operations that minimize reservoir elevations less than 5,297.5 feet (1,614.68 m) could reduce the effects of predation or stress during the spawning migration.

Possibly more beneficial than any specific reservoir elevation target, however, would be an increased water level at the time of migrations through the varial zone. With post-irrigation releases of 50 cfs, the water level in the reservoir remains relatively stable and the varial zone delta expands, creating additional barriers for Bull Trout migrating through these varial zones. Under a reduced post-irrigation flow scenario, these shallow varial zone deltas are more rapidly flooded, dramatically improving migratory habitat and reducing the risks associated with impaired passage.

The river habitat downstream from the dam appears to be suitable; however, few Bull Trout were found utilizing this habitat. Water operations directly determine water temperature, chemistry, amount of watered channel, and associated water depths. Post-irrigation streamflow did not have a great effect on the physical habitat or disconnected pools; however, the lower flows provided less deep water habitat and more disconnected pools, as expected. Yet, these effects were not substantial and adequate habitat and depths were provided at all streamflow tested (Chapter 4, Section 4.2.4). Substrate size was not significantly different between regulated and unregulated sites (Chapter 3, Section 3.3) and there was not a detectable effect of the dam on sediment size or amount of woody debris (Chapter 4, Section 4.2.4). The low winter streamflow provided connectivity for adult and juvenile fish – although five of the shallow locations provided marginal stream depth for passage of adult Bull Trout.

6.6 Prey

Bull Trout were difficult to capture and stomach samples were limited in the study. All of the diet samples from Bull Trout were captured in the reservoir. The samples collected indicated that Bull Trout in the reservoir primarily consumed fish (Cyprinids and Sculpin) with a small portion of terrestrial and aquatic invertebrates. Kokanee Salmon were not identified in Bull Trout stomachs sampled in our study; however, Bull Trout likely feed on Kokanee when available and they were identified as part of the Bull Trout diet in the isotope analyses (Chapter 2, Section 2.3.3).

The dam affected the river habitat, periphyton, and macroinvertebrate community structure for at least 3.7 km downstream from the dam. The increased nutrients and organic matter from the reservoir likely alters the composition of the community downstream where, for example, there was a higher proportion of gatherers – insects that collect and process organic matter. Additionally, in this 3.7 km reach insect drift was lower. Although diet samples were not examined from the river, we could expect less available prey or diet shifts of prey species in the 3.7 km downstream from the dam where the invertebrate community was altered. Further downstream on the Deadwood River, there were no measureable effects of the dam or altered operations on macroinvertebrate, drift, density, biomass, or production in

comparison to unregulated sites (Chapter 3, Section 3.3). All species of fish present in the reservoir and tributaries were present in the stilling basin and river downstream (Chapter 4).

When considering water operations, the 2.3 cfs post-irrigation streamflow supported the most biomass of Bull Trout and other species of fish during dry and wet climatic conditions. Average climatic conditions had little difference among the potential biomass supported by the different water operations scenarios. Ramping rate also had no effect on biomass of prey. Downstream from the dam, the 50 cfs post-irrigation streamflow had the highest annual production of macroinvertebrates. However, invertebrate production was not a concern for any of the water operational scenarios considered (Chapter 3, Section 3.3), and this analysis is comprehensive accounting for production, respiration and mortality driven by water temperatures in the river.

6.7 Bull Trout

The potential production of Bull Trout in the reservoir ranged from 7,000 to 11,000 kg/yr among the water operations scenarios. Reservoir operations had little effect on the potential biomass of Bull Trout and other fish for average and wet climatic conditions, but in dry climatic conditions the potential for Bull Trout production was about 15% higher under the low post-irrigation streamflow releases compared to the 50 cfs streamflow release (Chapter 3, Section 3.3). Annual growth of Bull Trout in the reservoir is high; nearly double the measured growth in Bull Trout captured in the tributaries of the lower Deadwood River (Chapter 4, Section 4.1.5). These analyses indicate that the production of Bull Trout in the reservoir is not limited by food. In other words, the food base can support more Bull Trout than are present in the reservoir/stream populations upstream from the dam; therefore, there are other factors likely limiting population size, such as spawning habitat quality or quantity, temperatures or DO.

Bull Trout rearing in the reservoir exhibited significantly different behaviors under different years and associated reservoir conditions. In 2007, when the reservoir level declined and water temperatures approached 20 ^{o}C, Bull Trout left the reservoir and reared in the tributaries. Yet, growth was not affected by this shift in habitat. In 2011, when the reservoir level was higher, Bull Trout remained in the reservoir for the entire summer and into the fall. Acoustic tag data indicated that Bull Trout utilized the shallower areas of the reservoir (< 2 m depth) and were oftentimes located near the tributaries (Chapter 4, Section 4.1). Although Bull Trout appear to adjust to reservoir levels and shift habitat use, these analyses indicate that higher summer reservoir levels benefit the Bull Trout and associated prey upstream from the dam.

Bull Trout were only captured in the stilling basin downstream from the dam. However, local resident populations are present in nearby tributaries and in the South Fork Payette

River; therefore, the habitat downstream from the dam should be considered accessible for Bull Trout migration and rearing. The Bull Trout captured in the stilling basin were genetically assigned to source populations sampled upstream from the dam (Chapter 4, Section 4.1.5). At the lower post-irrigation streamflow, DO levels become low in the deeper water in the stilling basin. However, a tagged Bull Trout tracked in 2014 overwintered in the stilling basin while those conditions were recorded and the tag was detected moving in and out the stilling basin the following spring. Formerly, the USFWS required salvage and transport of the Bull Trout rearing in the stilling basin at the end of the season when implementing the short-term and interim post-irrigation streamflows of 0 and 2.3 cfs; however, mortality was similar for relocated Bull Trout in 2010 to Bull Trout that remained in the stilling basin in previous years (near 25%).

In summary, Bull Trout populations appear to be depressed in the South Fork Payette and Deadwood drainages with fewer Bull Trout present than the habitat can likely support. The reservoir and water operations directly affect the river habitats downstream; however, prey and macroinvertebrate production does not seem to be affected more than approximately 3.7 km downstream from the dam. Other reasons for low population densities could be due to climatic conditions and trends or due to tributary spawning/rearing habitat quantity and quality – both factors were not examined in this study. Additionally, distribution studies indicate that the Deadwood Dam may be on the edge of suitable habitat within the Payette Basin (Chapter 4, Section 4.1).

6.8 Biological Opinions

The USFWS issued two BiOps to Reclamation related to operations at Deadwood Dam. The first includes the operation and maintenance of the dam (USFWS 2005) which initiated the activities of this study. The second includes the critical habitat in Deadwood Reservoir and the lower Deadwood River (USFWS 2014). Brief summaries are provided below in relation to each Term and Condition of the 2005 BiOp (USFWS 2005) and then in relation to critical habitat (USFWS 2014).

6.8.1 Terms and Conditions (USFWS 2005)

3a. Determine whether there is flexibility within the action as proposed to operate Deadwood Dam to reduce the effects to Bull Trout when winter streamflows in the Deadwood River below Deadwood Dam are less than inflows to Deadwood Reservoir upstream. Cooperate with the Service to identify and implement any actions that can be taken to facilitate winter flows that more closely approximate reservoir inflows to reduce effects to Bull Trout.

Examination of the detailed effects of several water operations scenarios has identified benefits of low (2.3 cfs) post-irrigation streamflow from Deadwood Dam on the temperature regimes in the river downstream, which in turn enable the development of more natural ice conditions, resulting in reduced negative effects to Bull Trout downstream from the dam. The flexibility identified in the effects of operations indicates that low (2.3 cfs) post-irrigation streamflow may have benefits to listed Bull Trout and the ecosystem as a whole. All of the benefits documented for Bull Trout and associated prey will occur when implementing the lower post-irrigation streamflow from the fall after irrigation season releases end until the spring when outflows are increased for pre-irrigation releases (flood control). During wet years, this period is shortened to the winter (December/January) when flood control releases begin.

3b. Determine whether there is flexibility within the action as proposed to operate Deadwood Dam to reduce harm and harassment of Bull Trout associated with extreme low temperatures in the river below the dam. Cooperate with the Service to identify and implement any actions that can be taken to increase water temperatures from their present range of 3 to 7ºC to a range that better supports an adequate and diverse prey base for Bull Trout.

Seasonal water temperature effects are discussed in Chapter 3. These analyses indicate that low post-irrigation streamflows combined with spilling approximately 22,000 acre-feet of water in the spring resulted in water temperatures downstream from Wilson Creek closer to natural water temperatures in all seasons except during the early summer irrigation releases (July). During wet years the predicted winter and spring streamflow are greater than 50 cfs. Therefore, during wet conditions, the predicted water operations and associated water temperatures would remain similar to previous analyses. The water temperatures described in this Term and Condition coincides with spring temperatures that remain lower than natural seasonal temperatures in the stream. The only operational flexibility to increase these water temperatures includes using the spillway to mix warmer surface water with colder hypolimnetic water from the outlet works (see Term and Condition 3d below for additional detail).

Empirical data on production of benthic invertebrates and a temperature-dependent invertebrate growth model both suggest that the invertebrate prey base for Bull Trout is adequate in the lower Deadwood River below the dam.

3c. Determine and implement ramping rates for both increases and decreases of flows that reduce harassment and harm of Bull Trout in the Deadwood River below Deadwood Dam.

Two ramping rates for both up ramping and down ramping, were examined in the operational scenarios – fast (2 day) and slow (7 to 10 day). Analysis of up-ramping in the spring/summer found no detectable difference between water temperatures in the river downstream from the dam. However, the analysis of down ramping at the end of the irrigation season identified that the fast ramping rates provide water temperatures closer to natural water temperatures sooner than slow ramping and allowed for greater reservoir content which has several benefits to Bull Trout in the reservoir. The low post-irrigation streamflow tested in this study reduced fall temperatures to close to natural conditions; however, in September 2013 when the reservoir was drafting from shallower depths, the temperature reduction associated with a fast ramping rate was somewhat drastic and could be detrimental to fish. This effect was not observed in September 2014 when the reservoir elevation was higher and colder hypolimnetic water remained in the reservoir. When reservoir conditions are drafting higher temperature water at the end of irrigation season, a slightly slower ramping rate (such as a 4-day reduction in streamflow) would allow a slower reduction in stream temperature to allow the aquatic biota additional time to adjust. A 5–6^{o}C diurnal fluctuation in temperature can occur in unregulated streams in the Deadwood River basin. Therefore, this amount of temperature fluctuation should be acceptable over a 12-hour period. Operations that could create greater temperature fluctuations should consider a slower ramping rate to reduce effects to salmonids in the river downstream from the dam.

Another impact of ramping rate is the stranding of fish in habitats that become disconnected to the river at the lower streamflow. Slower ramping rates are generally assumed to reduce the impacts of stranding by allowing fish more time to adjust to the streamflow reductions and reduced wetted channel. Rate of change of the streamflow from the regulated facility is typically weakly related to the probability of stranding. Variables such as density of fish, duration of a stable streamflow (or habituation) and stream temperature are variables with greater correlation with stranding (Bradford 1997; Halleraker et al. 2003; Irvine et al. 2009). Generally, studies indicate that rates of reduction in water surface elevation <10 cm/hr can reduce stranding. Rates < 2 cm/min have been shown to reduce stranding and making these changes over a 4 to 5-hour period can prevent stranding entirely (Irvine et al. 2009). Faster rates of change (30 or 60 cm/hr) tend to result in stranding rates around 2 to 10% (Bradford 1997; Saltveit et al. 2001; Halleraker et al. 2003; Irvine et al. 2009).

Disconnected pools occurred during all flow reductions in all years studied with the 50 cfs streamflow having the lowest number of pools (Chapter 4, Section 4.2.4). Stranded fish were also identified in the disconnected pools during all years of the study. Although direct comparisons of the number of stranded fish could not be determined from the data collected during this study, the number of stranded fish was higher when implementing faster ramping rates. Bull Trout were not detected in the stranding surveys, but this was likely due to the lack of Bull Trout found in the river downstream from the dam. Therefore, it appears that ramping rates have no negative effect on stranding of Bull Trout in the Deadwood River below the dam. Although the data and logic suggests that prey base is lost anytime stream habitat is dewatered, the effect to the prey base is likely minimal as we expect that the habitats in the mainstem are utilized by these same species and there is likely some compensatory effect to mortality prior to over-wintering.

Conditioning is a practice that has some potential to reduce rates of stranding by encouraging fish movement with short-term fluctuations in streamflow; however, conditioning was not assessed during this study. Conditioning is done by altering the flow for a short period (about 1 day), rewatering the habitats and then reducing the streamflow to the intended rate (Irvine et al. 2009). Conditioning is intended to break habituation of a fish to a location making the fish more likely to alter position in relation to streamflow and depths.

3d. Determine whether there is flexibility within the action as proposed to manage flow from Deadwood Dam, particularly during the spring, to minimize take through harassment associated with disruption of Bull Trout biological processes, particularly migratory cues.

Seasonal water temperature effects are discussed in Chapter 3. In relation to spring pre-irrigation water release, the timing, amount, and method of the release of pre-irrigation water can be altered to more closely resemble the natural seasonal water temperatures. Attempts were made during the 2014 spring spill to mimic natural streamflow, and water temperatures were closer to the natural stream temperatures than measured during former water operations. Spring spill creates a number of options to control water temperature. Using the deeper outlet works gates earlier in the spring will provide water that is close in temperature to natural (approximately 5^{o}C in April/May). As the spring progresses, the natural water temperatures increase steadily to approximately 10^{o}C in June and 15^{o}C in July. Pre-irrigation water release typically occurs between late May and early July. Therefore, natural water temperatures during this time are higher than the water temperatures at the deeper outlet gates. Yet, the surface water that spills over the top of the dam is a higher temperature than natural. Therefore, mixing the surface water spill with the deeper outlet works will provide some ability to control the water temperatures. During April and May, the pre-irrigation water release should utilize the outlet works gates, as the deeper water is close to natural temperatures. During June, the pre-irrigation release could be mixed with some surface spill, when available, to increase the downstream temperatures. During late June/early July, the

surface spill will be closest to the natural stream temperatures and pre-irrigation outflows should have more surface spill and less colder water from the outlet works gate.

3e. Minimize the frequency, duration, and extent of discharge of water over the spillway at Deadwood Dam to avoid and reduce the effects of entraining Bull Trout.

Bull Trout were not observed to be entrained over the spillway during the study. These data indicated that entrainment is either relatively low (<2% across multiple years), periodic according to water and precipitation conditions or the data set did not capture size classes and/or time periods that are vulnerable to entrainment through the dam. The outlet works are generally operated throughout most of the spring and summer months whereas the spillway, when used, is operated for a brief period during the spring. Tagged Bull Trout were not observed utilizing the deeper water habitat (>5 m) where the outlet works would be located, nor the forebay where the spillway would be located resulting in little risk of entrainment. However, the presence of Bull Trout in the stilling basin indicates that some trout pass the dam either over the spillway or through the outlet works. It is unclear when this occurs – whether during spring or during summer irrigation releases. Bull Trout in the stilling basin survive year to year, and there is no indication that entrainment rates are detrimental to the populations upstream from the dam. Salvage and transport had similar tag loss/suspected mortality as the Bull Trout that remained in the stilling basin (approximately 25%).

6.8.2 Critical Habitat (USFWS 2014)

Overall, the 2014 BiOp for critical habitat found that the Reclamation projects in the action area (Southeast Oregon and Southwest Idaho) are not likely to adversely modify critical habitat (USFWS 2014). However, seasonal adverse effects were identified related to habitat in the varial zone of the Deadwood Reservoir during the fall spawning migration period, and the following Conservation Measure was identified specific to Deadwood Reservoir:

> **Evaluate how reservoir elevations influence the varial zones of the tributaries, particularly during the fall migration period. If possible, adjust operations to improve depth and structure within the varial zones where needed and to minimize length of the varial zone.**

Although affects to the varial zones are by nature an impact that is associated with the presence of the dam and the storage and delivery of irrigation water, increased reservoir content associated with the reduced post-irrigation streamflow could be used to mitigate for some effect of reservoir impacts. When implementing the 2.3 cfs streamflow on September 29, 2013, the increase in water surface elevation was 0.05 feet (0.02 m) per day. The shallowest habitat that was shown to slow fish migrations occurs near the transition from reservoir to tributary. At Trail Creek in 2013, the lowest water year with surveys, this area extended a maximum of 116 m upstream from the reservoir with an average estimated slope

of 0.53 degrees. Reservoir elevations would need to be increased by 0.33 m to inundate all 115 m of the most impaired habitat documented in 2013. If the streamflow reduction was implemented 3 weeks earlier (in early September) this habitat could be inundated to benefit post-spawned Bull Trout returning to the reservoir. Other actions for the varial zone could include habitat alteration or improvements, but these were not analyzed during this study.

6.9 Literature Cited

Parenthetical Reference	Bibliographic Citation
Bradford 1997	Bradford, M.J. 1997. "An experimental study of stranding of juvenile salmonids on gravel bars and in side channels during rapid flow decreases." *Regulated Rivers: Research & Management* 13(5):395-401.
Halleraker et al. 2003	Halleraker, J.H., and coauthors. 2003. "Factors influencing stranding of wild juvenile brown trout (Salmo trutta) during rapid and frequent flow decreases in an artificial stream." *River Research and Applications* 19(5-6):589-603.
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Saltveit et al. 2001	Saltveit, S.J., J.H. Halleraker, J.V. Arnekleiv, and A. Harby. 2001. "Field experiments on stranding in juvenile atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) during rapid flow decreases caused by hydropeaking." *Regulated Rivers: Research & Management* 17(4-5):609-622.
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Chapter 7 CONCLUSIONS

7.1 Conclusions

This chapter discusses the findings supported by this study which is the most comprehensive scientific analysis of the operations and associated effects of Deadwood River and Reservoir on the aquatic ecosystem and threatened Bull Trout. This study responded to the Terms and Conditions in the BiOp for the operation and maintenance of Deadwood Dam that direct Reclamation to identify operational flexibility to reduce various impacts to threatened Bull Trout (USFWS 2005). Flexibility of operations identified in this study were the minimum post-irrigation streamflows (September through June) and ramping rates for seasonal irrigation streamflows. The post-irrigation streamflow releases are limited by mechanical constraints which only allow minimum streamflows of 0, 2.3, or 50 cfs. Post-irrigation streamflows in between these rates were not examined as they are not possible with the configuration of the dam without causing structural damage to the facility. Minimum post-irrigation streamflows greater than 50 cfs were not considered, as it would impact reservoir storage and content for irrigation delivery.

Some Terms and Conditions in the 2005 BiOp (USFWS 2005) cause incongruence in water management and operation; however, the study findings address each of these Terms and Conditions and identify where effects have not been validated by the study (Chapter 6). Specifically, Terms and Conditions 3b and 3d request that Reclamation identify flexibility of water operations that will improve spring temperatures and support biological processes and migratory cues for Bull Trout in the river downstream from the dam. However, Term and Condition 3e requests minimizing flows over the spillway. Yet, the spillway flows are the only option to increase river temperatures downstream from the dam during the spring and present an opportunity for operational flexibility. This study has not identified that Bull Trout entrainment is occurring via the spillway crest, and other studies suggest that the deeper outlet works gates are the more likely cause of entrainment (Chapter 4, Section 4.1.5; Chapter 6, Sections 6.7 and 6.8). Entrainment estimates are low in Deadwood Reservoir (<2%), so there appears to be only a small effect to Bull Trout when utilizing the spillway during the spring pre-irrigation releases.

This study examines the ecosystem in detail from the physical and chemical processes to primary production, secondary production, diet, and prey base. These analyses center on the ability of this system under different operational scenarios to support Bull Trout (Chapter 1). Bull Trout, the top predator of the food chain, benefit from an ecosystem-based management

strategy due to expected longevity of individuals (up to 9-year life span), limited freshwater movements available upstream from Deadwood Dam, and a high reliance on a piscivorous prey base. Deadwood Reservoir and tributaries upstream support the full life cycle for Bull Trout (spawning to adult rearing); however, the river downstream from Deadwood Dam appears to support few Bull Trout and only individuals thought to be entrained through the dam. A 50 cfs minimum post-irrigation streamflow has been implemented since 1993; however, this has not resulted in increasing the numbers of Bull Trout in the river downstream from the dam over the last 20 years.

Macroinvertebrate production downstream from the dam was not significantly different than nearby reference (unregulated) sites indicating that secondary production is not the likely cause of low abundances of Bull Trout and other species of fish in the Deadwood River downstream from the dam. Macroinvertebrate production in the river downstream from the dam showed more variation across sites and hydrological conditions than across operational scenarios indicating that climate and habitat attributes have a greater effect on macroinvertebrate production than water operations (Chapter 3, Section 3.3).

Findings from this study support the 2.3 cfs post-irrigation streamflow from as early as possible in September through the beginning of the pre-irrigation releases (generally June) during dry and average climatic conditions. Wet climatic conditions typically result in winter and spring water releases greater than the 50 cfs minimum streamflow, so little change is expected from existing conditions during wet years (Chapter 3, Section 3.1). Fast (2 day) ramping rates showed improvements to the river temperatures downstream from the dam and allow faster refill in the reservoir to expedite inundation of the varial zone. The 2.3 cfs post-irrigation streamflow resulted in greater reservoir volume which improves conditions for Bull Trout rearing in the reservoir. The effects of a low post-irrigation streamflow of 2.3 cfs from Deadwood Dam are summarized in Table 7.1. Operational effects identified by the study to reduce various impacts to threatened Bull Trout are summarized in Table 7.2 and discussed in more detail below.

Table 7-1. Benefits and impacts of implementing a low post-irrigation streamflow of 2.3 cfs in relation to the current minimum streamflow of 50 cfs based on findings of this study. Blank cells in the table indicate no change in the parameter.

Month	Effect	Reservoir		River	
		Benefit	Impact	Benefit	Impact
Jan/Feb	Water temperature			Water temperatures close to natural in dry/average water years; improved ice cover.	
	Water quality			Reduced loading of metals and nutrients in outflow (≥200 lbs/day).	Low DO in water in stilling basin as the reservoir inversely stratifies and reduced turbulence in stilling basin.
	Physical habitat				
Mar/Apr/May	Water temperature			Water temperatures close to natural in dry/average water years.	
	Water quality			Lower loading of metals and nutrients in outflow (≥200 lbs/day).	Reservoir remains anoxic longer into the spring. Stilling basin is anoxic from lack of turbulence until reservoir mixes.
	Physical habitat			Higher pre-irrigation release (flood flow) for habitat maintenance.	
Jun/Jul/Aug	Water temperature	Lower water temperatures (in dry years)		Water temperatures close to natural in dry/average water years for June and early July when mixing spill and water out of the outlet works. Cooler temps than natural in mid to late July and August more suitable for Bull Trout rearing.	
	Water quality				

Month	Effect	Reservoir		River	
		Benefit	Impact	Benefit	Impact
	Physical habitat	Higher reservoir elevations			
Sept/Oct	Water temperature	Lower water temperatures		Water temperatures close to natural.	
	Water quality		Reservoir mixes at a later date; hypoxia extended into fall 2 to 3 weeks	Lower loading of nutrients in outflow amount dependent on duration of anoxic conditions and rate of outflows.	Low DO in stilling basin until reservoir mixes.
	Physical habitat	Higher reservoir elevations; improved migration through varial zone migration corridor			Reduced watered habitat; marginal connectivity for 3.0 km downstream of dam.
Nov/Dec	Water temperatures	Lower water temperatures		Water temperatures close to natural; improved surface ice cover.	
	Water quality				
	Physical habitat	Higher reservoir elevations		Lower loading of metals and nutrients in outflow (≥200 lbs/day) during anoxic periods.	Reduced watered habitat; marginal connectivity for 3.0 km downstream of dam.
Annual	Production			Potential for increased spring macroinvert production in average water years if spill is utilized to raise temperatures.	Reduced macroinvertebrate production 30% in dry and 11% in average climatic conditions.

Table 7-2. Summary of recommended water operations for Deadwood Dam based on findings of this study to reduce various impacts to threatened Bull Trout.

Season	Flows	Approximate Date	Ramping
Fall/winter	2.3 cfs minimum flow *(50 cfs minimum flow)	Based on end of irrigation season and recreational flows early to mid-September. *(Based on end of irrigation season and recreational flows.)	Outflow reductions over 2 days not to exceed 10 cm/hr rate of change in depth in river downstream from dam. *(Outflow reductions over 2 days.)
Spring	50 cfs minimum flow Controlled release of water through the spillway and up to approximately 700 cfs through the outlet works to mimic natural river temps. *(No controlled release through the spillway to limited controlled release through the spillway and up to approximately 900 cfs through the outlet works.)	Implement between mid-April and early May to increase stream production and support spring spawning Rainbow Trout May through June *(May through June)	Outflow increased in accordance with Standard Operating Procedures Outflow increased in accordance with Standard Operating Procedures. Utilizing outlet works gates in April/mid-May and combining spill in mid-May/June to mimic natural temperatures *(Outflow increased in accordance with Standard Operating Procedures.)
Summer	Irrigation flows	Late June/July through end of irrigation releases	
*Information is current operations in accordance with Standard Operating Procedures and the 2005 BiOp.			

Water Operations

The 2.3 cfs post-irrigation streamflow from September to spring pre-irrigation water release (dates analyzed are June in dry/average conditions, December in wet conditions) improved conditions in the reservoir and river.

A reduction in post-irrigation streamflow to 2.3 cfs in early September will provide more benefits to spawning Bull Trout and Kokanee Salmon that migrate through the varial zone when the reservoir elevations are low (August through October), and will decrease water temperatures downstream from the dam to values closer to natural water temperatures during the fall and early winter. Additional benefits occur during the winter and spring when implementing the 2.3 cfs post-irrigation streamflow. Operations close to those modeled will provide the benefits described in this study. Key findings include:

- Water temperatures downstream from the dam have a lower summer maximum (8 to 13^{o}C) for the 2.3 cfs post-irrigation streamflow scenarios, whereas the 50 cfs scenarios have summer maximum temperatures about 18 to 20^{o}C during average and dry climatic conditions.
- The 2.3 cfs post-irrigation streamflow reduces the water temperatures downstream from the dam during the fall season keeping temperatures closer to the critical habitat target of 2 to 15^{o}C (USFWS 2014).
- During the winter, the lower post-irrigation streamflow scenarios were closer to natural water temperatures (0^{o}C) and showed some development of surface ice cover which would minimize undesired effects to fishes in the river from frazil and anchor ice formation.
- Higher reservoir surface elevations during dry water years from August to November, and in all water years from September to November, that will provide better conditions for Bull Trout rearing and migration in August to November.
- Higher reservoir surface elevations create conditions more favorable to supporting Bull Trout populations upstream from Deadwood Dam. For example, data collected during 2011 indicated Bull Trout utilizing the reservoir habitat for longer duration with lower rates of tag loss/suspected mortality (12.5%), whereas 2007 showed Bull Trout leaving the reservoir significantly earlier than other years and higher rates of tag loss/suspected mortality (66.7%).
- Measureable increase (15%) in primary and secondary production in the reservoir in dry years, when implementing the 2.3 cfs post-irrigation streamflow in comparison to the 50 cfs post-irrigation streamflow.

- The 2.3 cfs post-irrigation streamflow improved conditions which would theoretically support higher amounts of Bull Trout biomass and prey species[1] in Deadwood Reservoir during dry climatic conditions. Wet and average climatic conditions did not show any substantial difference between the operational scenarios.

A 50 cfs minimum streamflow starting between mid-April and early May will support migration and prey production (vertebrate and invertebrate) in the river downstream from the dam.

Increasing streamflow from 2.3 cfs to 50 cfs earlier than analyzed based on previous operations can provide a boost to macroinvertebrate production to support native fish after over-wintering, and can improve channel passage conditions. A boost to spring macroinvertebrate production during dry and average years could somewhat reduce the predicted loss of production from a 2.3 cfs post-irrigation streamflow. Rainbow Trout are an important prey species for Bull Trout. Resident Rainbow Trout spawn between mid-March and mid-August with the peak in spawning occurring between mid-May and mid-July (Zimmerman and Reeves 2000; Dare and Rose 2006). An increase to 50 cfs releases during this time would positively impact habitat directly below the dam; high tributary inflows during this time of year already increase wetted usable area for this and other prey species further downstream and support invertebrate production, an essential prey base for native species. Typical spring (April, May) water temperatures are between 2 to 6^{o}C, so releasing 50 cfs from the outlet works gates should not disrupt the spring temperature regime. The short duration of the 50 cfs minimum streamflow (4 to 6 weeks) is not expected to substantially change the predicted seasonal benefits of reduced winter flows to the river and reservoir ecosystems.

Higher pre-irrigation streamflows for habitat maintenance in average and wet years with an effort to mimic natural spring water temperatures (i.e., spring flood flows) will create more natural hydrologic and physical conditions to support Bull Trout and other aquatic species downstream from the dam.

Higher pre-irrigation releases to support habitat for aquatic species and stimulates the natural hydrograph. Operational flexibility between the outlet works and the spillway can be utilized to increase the water temperatures downstream from the dam and mimic the increase in water temperature during the spring season (from 5^{o}C to 15^{o}C). High spring flows, when available, allow for the transport of large woody debris, sediments that benefit native species, flood plain connection, groundwater recharge,

[1] Arguably, the increase in bull trout biomass is unlikely to be realized, as even if prey base biomass increases, it does not appear to be the limiting factor in bull trout biomass in the reservoir.

and side channel habitats shown to be productive for fisheries. To the extent possible while following flood control protocol, springtime water releases can be shaped to be less in peak flow but longer duration (like a rounded hilltop) or shorter duration with a sharp, high peak. Within the flexibility limitations of flood control rule curves, the relationship between expected inflows, the occurrence and timing of reservoir fill to utilize the spillway crest, and associated water temperatures can influence the optimal shape of the spring hydrograph. This flexibility in operations was not investigated during the modeling analyses conducted in this study and can be explored further with additional hydrologic and temperature analyses to identify outflows and thermal targets.

7.1.1 Ramping Rates

The fast ramping rate improved water temperatures downstream from the dam and increased reservoir surface elevation at the end of irrigation season. Ramping rates should not exceed 10 cm/hr.

The analysis of down ramping at the end of the irrigation season identified that the fast ramping rates provide water temperatures closer to natural water temperatures sooner than slow ramping and allowed for greater reservoir content which has several benefits to Bull Trout in the reservoir. The 2.3 cfs post-irrigation streamflows tested in this study reduced fall temperatures to close to natural conditions in the river downstream from the dam (Chapter 3, Section 3.1).

Although this study found higher counts of fish stranded in pools when implementing a fast ramping rate, the tests were done over different years and do not have supporting abundance estimates necessary to evaluate and compare the effects of the ramping rates. Literature indicates that the rate of change of the streamflow from the regulated facility is typically weakly related to the probability of stranding. Variables such as density of fish, duration of a stable streamflow (or habituation) and stream temperature are variables with greater correlation with stranding (Bradford 1997; Halleraker et al. 2003; Irvine et al. 2009). Generally, studies indicate that rates of reduction in water surface elevation < 10 cm/hr can reduce stranding of salmonids. Rates <2 cm/min have been shown to reduce stranding and making these changes over a 4 to 5-hour period can prevent stranding entirely (Irvine et al. 2009). Faster rates of change (30 or 60 cm/hr) tend to result in stranding rates around 2 to 10% (Bradford 1997; Halleraker et al. 2003; Saltveit et al. 2001; Irvine et al. 2009).

Down ramping at the end of the irrigation season sometimes occurs in several events from the peak irrigation streamflow to an intermediate streamflow to 50 cfs. The down ramp from 50 cfs to 2.3 cfs occurs in one event. The multiple down-ramping events may provide some conditioning to fish in the stream. The fast down-ramping rates implemented in September

2013 and 2014 reduced outflow over 11.25 hr and 6.25 hrs, respectively. Down-ramping rate from irrigation streamflow (703 cfs) to 50 cfs was 11.8 cm/hr in 2013 measured at the USGS streamflow gage located downstream from Deadwood Dam. Otherwise, the ramping rates during 2013 (50 to 2.3 cfs) and 2014 ranged from 7.6 to 9.3 cm/hr measured at the USGS streamflow gage located downstream from Deadwood Dam. Reducing streamflows over longer periods (e.g., 24 to 48 hours) will reduce the ramping rate and should minimize stranding of salmonids.

7.2 Literature Cited

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APPENDICES

APPENDIX A
STANDING OPERATING PROCEDURES

3. GENERAL FILLING SCHEDULE AND RELEASE PROCEDURES

Except for flood control operations as noted in section 5, all inflow to Deadwood Reservoir should be held for irrigation, power generation, and/or salmon recovery flow augmentation use and released to satisfy these demands. Filling is monitored by the hydromet remote data station at the dam which reports reservoir level and discharge as well as temperature, precipitation, and snow water content. Reservoir operations are directed by the Snake River Area Office in cooperation with the Water Systems Operation Group in the Regional Office.

NOTE: Water is currently being released during the winter months (50 cfs) to meet fish requirements.

Except in an emergency, the following schedule governs releases made from the reservoir for the protection of fishermen and others along the stream:

A. When starting from zero release, releases will be added in increments as follows:

(1) 100 cfs on the first day

(2) 200 cfs on the second and third days, and

(3) 250 cfs on the fourth and fifth days to bring the total release to 1,000 cfs.

(4) The above change in releases should be made at night between the hours of 8:30 p.m. and 10:00 p.m. Before the changes are made, a check will be made of the river to the end of the road to warn any people along the stream. It takes about 6 hours for water to travel from the dam to the mouth of the river. By making the releases before 10:00 p.m., the increased flow will reach the mouth of the river before daylight hours.

B. When adding releases to a discharge of less than 1,000 cfs:

At any time it is desired to add a release when the outflow at the time is less than 1,000 cfs the release will be made in conformance with section 3A above. For example, if the flow is 500 cfs and it is desired to release an additional 500 c.f.s., it will be added in two 250 cfs increments on successive nights.

C. When discharge is less than 1,000 cfs a discharge increase of up to 50 cfs may be made anytime, day or night, to improve downstream flow regulation.

D. When the release is already at the 1,000 cfs or greater level, releases may be added as follows:

Add in increments of not more than 250 cfs with a minimum of 3 hours between increments. These releases may be made during the day or night.

APPENDIX B
WATER YEAR RANKINGS

Water year rankings and percent exceedance of Deadwood Reservoir inflows for the period of record and for recent conditions (1971 to present).

Entire Period of Record				1971- present (recent conditions)			
Year	Total Inflow, ac-ft	Rank	Exceedance	Year	Total Inflow, ac-ft	Rank	Exceedance
1974	307790.59	1	1.18%	1974	307790.59	1	2.22%
1997	**300150.06**	**2**	**2.35%**	**1997**	**300150.06**	**2**	**4.44%**
1971	299324	3	3.53%	1971	299324	3	6.67%
1965	268113.19	4	4.71%	1996	254978.05	4	8.89%
1996	254978.05	5	5.88%	1982	251494.97	5	11.11%
1982	251494.97	6	7.06%	1983	242166.77	6	13.33%
1956	251292.75	7	8.24%	2006	217647.03	7	15.56%
1943	242472.03	8	9.41%	1984	217162.33	8	17.78%
1983	242166.77	9	10.59%	1995	216945.05	9	20.00%
2006	217647.03	10	11.76%	1986	216230.39	10	22.22%
1984	217162.33	11	12.94%	1978	211464.03	11	24.44%
1952	217025.86	12	14.12%	1972	210978.95	12	26.67%
1995	216945.05	13	15.29%	2011	209540.84	13	28.89%
1986	216230.39	14	16.47%	1999	204446.53	14	31.11%
1978	211464.03	15	17.65%	2012	198644.36	15	33.33%
1972	210978.95	16	18.82%	1980	191598.63	16	35.56%
1938	210151.27	17	20.00%	1993	191140.58	17	37.78%
2011	209540.84	18	21.18%	1976	191057.63	18	40.00%
1958	206816.84	19	22.35%	2008	182673.98	19	42.22%
1999	204446.53	20	23.53%	1998	180437.06	20	44.44%
1970	204096.17	21	24.71%	1975	172442.19	21	46.67%
1969	203223.67	22	25.88%	**2003**	**170538.77**	**22**	**48.89%**
1946	199138.33	23	27.06%	1981	168071.63	23	51.11%
2012	198644.36	24	28.24%	2014	166448.52	24	53.33%
1963	196357.67	25	29.41%	2009	158456.86	25	55.56%
1954	195911.52	26	30.59%	2010	156458.75	26	57.78%
1957	194495.44	27	31.76%	1985	143103.92	27	60.00%
1951	194406.11	28	32.94%	2004	139833.11	28	62.22%
1953	194333.66	29	34.12%	2000	137028.47	29	64.44%
1980	191598.63	30	35.29%	2013	135350.83	30	66.67%
1993	191140.58	31	36.47%	1989	134725.03	31	68.89%
1976	191057.63	32	37.65%	2002	130593.02	32	71.11%
1950	190500.58	33	38.82%	2007	127904.88	33	73.33%
2008	182673.98	34	40.00%	2005	127492.59	34	75.56%
1947	182445.38	35	41.18%	1973	124711.9	35	77.78%
1998	180437.06	36	42.35%	1990	116212.07	36	80.00%
1967	177841.98	37	43.53%	1979	109049.59	37	82.22%
1948	172755.34	38	44.71%	1988	94244.12	38	84.44%
1975	172442.19	39	45.88%	1992	91770.81	39	86.67%
2003	**170538.77**	**40**	**47.06%**	1987	90989.13	40	88.89%
1932	168457.09	41	48.24%	1991	90327.61	41	91.11%

Entire Period of Record				1971- present (recent conditions)			
Year	Total Inflow, ac-ft	Rank	Exceedance	Year	Total Inflow, ac-ft	Rank	Exceedance
1981	168071.63	42	49.41%	1994	80324.3	42	93.33%
2014	166448.52	43	50.59%	**2001**	**72083.71**	**43**	**95.56%**
1959	166425.2	44	51.76%	1977	52914.97	44	97.78%
1962	165475.56	45	52.94%				
1949	164340.69	46	54.12%				
2009	158456.86	47	55.29%				
2010	156458.75	48	56.47%				
1964	155079.02	49	57.65%				
1936	154526.77	50	58.82%				
1940	149995.55	51	60.00%				
1960	149467.05	52	61.18%				
1942	148194.97	53	62.35%				
1941	143881.61	54	63.53%				
1985	143103.92	55	64.71%				
1933	141573.91	56	65.88%				
1945	140903.78	57	67.06%				
1968	139944.67	58	68.24%				
2004	139833.11	59	69.41%				
2000	137028.47	60	70.59%				
2013	135350.83	61	71.76%				
1989	134725.03	62	72.94%				
1955	134492.22	63	74.12%				
2002	130593.02	64	75.29%				
1934	130230.85	65	76.47%				
1961	129209.55	66	77.65%				
2007	127904.88	67	78.82%				
2005	127492.59	68	80.00%				
1935	125611.48	69	81.18%				
1973	124711.9	70	82.35%				
1966	118722.6	71	83.53%				
1990	116212.07	72	84.71%				
1979	109049.59	73	85.88%				
1939	105415.2	74	87.06%				
1937	101089.1	75	88.24%				
1988	94244.12	76	89.41%				
1944	93710.16	77	90.59%				
1992	91770.81	78	91.76%				
1987	90989.13	79	92.94%				
1991	90327.61	80	94.12%				
1931	81738.8	81	95.29%				
1994	80324.3	82	96.47%				
2001	**72083.71**	**83**	**97.65%**				
1977	52914.97	84	98.82%				

APPENDIX C – HYPORHEIC MODEL

Mathematical Description of Hyporheic Flow

To better understand the processes that take place along the Lower Deadwood River it is suitable subdivide it in subsystems that are hydrologically connected to each other (Fisher et al. 1998). These subsystems include the parafluvial and riparian areas laterally and the hyporheic zone underneath the streambed (Fischer et al., 1998). In particular, the hyporheic zone is the saturated volume of sediment surrounding the stream and providing the linkage between the river and the aquifer, while the riparian area acts as buffer between hillslopes and rivers affecting to a large extent runoff generation and solute transport at the reach scale. Parafluvial areas represent stream lateral expansion zones characterized by bedform that cover the saturated sediment: entirely during high flow level and partially during low flow level. The Lower Deadwood River flows in a narrow canyon with limited depositional material along the banks. This may allow to assume that the river has non-erodible banks (no interaction with the riparian areas) with limited lateral exchange through meanders. Stream water exchanges into and out of the hyporheic zone due to several mechanisms, which depend on variations of near-bed pressure, hydraulic conductivity, thickness of the alluvium, and turbulence (Tonina and Buffington, 2007). Among these, the most important advective mechanism that mixes surface and pore waters is called pumping, and stems primarily from near-bed pressure variations induced by the interaction between stream flow and channel morphology (Elliott and Brooks, 1997a; b). In modeling pumping is important to consider that the flow system analysis is primarily based on the concept of hierarchical groundwater flow system (Zijl, 1999). In particular, to account for the head variations at the stream bed interface caused by both small (dune, ripples, boulders) and large scale (pool and riffle, meander) morphological features, the hyporheic flow is modeled by decoupling the two effects and superposing their contributions via spectral analysis.

Groundwater flow model

Transient flow equation

The two-dimensional non-stationary flow in a homogeneous aquifer with hydraulic conductivity vector $K=(K_x,K_z)$ was solved assuming the medium is anisotropic with preferential direction. The equation is:

$$\boldsymbol{K_x \frac{\partial^2 h}{\partial x^2} + K_z \frac{\partial^2 h}{\partial z^2} = S_S \frac{\partial h}{\partial t}} \quad (1\text{-}2)$$

where *h(x,z)* is the hydraulic head and S_S is the storage coefficient. In particular, S_S represents the water volume discharged by the sediment after a unit drawdown of the hydraulic head. Typical value of S_S, for gravel-cobble sediment, is on the order of 10^{-5} m^{-1}. Similar analysis was performed by Boano et al. (2007) for a sand-bedded river with dunes under the hypothesis of homogeneous and isotropic medium. In saturated sediments, the pressure variation responsible for water storage is smaller than its spatial variation. According to these considerations, we assumed the non-stationary head variation to be negligible:

$$S_S \frac{\partial h}{\partial t} \sim 0 \quad (1\text{-}3)$$

Considering the transient flow as a succession of steady state flows, we solved the following equation:

$$K_x \frac{\partial^2 h}{\partial x^2} + K_z \frac{\partial^2 h}{\partial z^2} = 0 \quad \boldsymbol{K_x \frac{\partial^2 h}{\partial x^2} + K_z \frac{\partial^2 h}{\partial z} = 0} \quad (1\text{-}4)$$

Steady state flow equation

The stationarity hypothesis implies that the stream water discharge is constant or slowly varying over a time scale on the order of the particle residence time (the time that a particle spent traveling within the hyporheic zone). Similar analysis was performed by Elliott and Brooks (1997a; 1997b) for a sand-bedded river with dunes under the hypothesis of a homogeneous and isotropic medium. The governing equation reduces to the Laplace equation and the associated boundary conditions are:

$$\nabla^2 h = 0 \quad (1\text{-}5)$$

$$\begin{cases} \boldsymbol{h(0,z) = 0} \\ \boldsymbol{h_T(x,0) = h_s(x,0) + h_L(x,0) + h_{slope}(x)} \\ \boldsymbol{\left.\frac{\partial h}{\partial z}\right|_{z=-zd_d} = 0} \end{cases} \quad (1\text{-}6)$$

Boundary condition at the stream bed interface *z=0* is the near-bed pressure $h_T(x,0)$, which is obtained by applying the superposition method on (see Figure 3-61):

1) small scale topography variations;

2) water surface oscillations;
3) streambed slope.

The resulting computational domain is bounded in the vertical direction by $z = 0$ and $z = -z_d$, with z_d the depth of alluvium.

Small scale head variations

The head distribution at the streambed interface due to small-scale topography variations were represented in terms of the Fourier series of the signal of the bed amplitude obtained through wavelet analysis. From the wavelet analysis, the oscillations of bed topography were represented in terms of the mean square root of the signal of bed amplitude oscillations (σ_b). Following the approach proposed by Stonedahl, *et al.* (2010), the amplitude of the dynamic head fluctuations are:

$$h_m(x) = 0.28\frac{V^2}{2g\sqrt{2}\sigma_b}\begin{cases}\left(\frac{2\sqrt{2}\sigma_b(x)}{0.34Y_0}\right)^{3/8} if\ \frac{2\sqrt{2}\sigma_b(x)}{Y_0} \le 0.34\\ \left(\frac{2\sqrt{2}\sigma_b(x)}{0.34Y_0}\right)^{3/2} if\ \frac{2\sqrt{2}\sigma_b(x)}{Y_0} > 0.34\end{cases} \quad (1\text{-}7)$$

where $h_m(x)$ is the amplitude of head distributions, V is the mean stream velocity, g is the gravitational acceleration, Y_0 is the mean flow depth. The small-scale head distributions at the streambed interface were represented in terms of the Fourier analysis of the bed amplitude oscillations, as:

$$h_S(x,0) = 2h_m(x)\sum_{i=1}^{N} \mathrm{a_{S,i}}\sin\left(\lambda_{S,i}x - \varphi_{s,i}\right) \quad (1\text{-}8)$$

where $a_{S,i}$ and $\varphi_{S,i}$ are the amplitude and phase of the topography data of Fourier harmonics, $\lambda_{S,i}=2\pi i/L_S$ is the wave number, L_S is the small scale wave length, N is the number of harmonics considered in the expansion along the longitudinal direction and x is the longitudinal direction. The number of harmonics considered in the expansion along the longitudinal direction was set to be one less than half of the number of data points to comply with the Nyquist frequency cutoff.

Large scale head variations

For large-scale topography, the head distribution at the streambed interface was represented in terms of the Fourier series of the water surface elevation:

$$h_L(x,0) = 2\sum_{i=1}^{M} \mathrm{a_{L,i}} \sin\left(\lambda_{L,i}x - \varphi_{L,i}\right) \quad (1\text{-}9)$$

where $\varphi a_{L,i}$ and $\varphi_{L,i}$ are the amplitude and the phase of the water surface elevation of Fourier harmonics, $\lambda_{L,i}=2\pi i/L_L$ is the wave number, $L_L$is the large scale wave length and M is the number of harmonics considered in the expansion along the longitudinal direction. The form of the groundwater flow equation, utilizes the superposition method, representing the head distribution as:

$$\boldsymbol{h_T(x,0) = h_S(x,0) + h_L(x,0) + h_{slope}(x)} \quad (1\text{-}10)$$

where h_{slope} is the head distribution due to the reach slope (s_0). The solution to equation (4) with the boundary and initial conditions (5-9) is:

$$h(x,z) = xs_0 + 2h_m(x)\sum_{i=1}^{N} a_{S,i}\sin\left(\lambda_{S,i}x - \varphi_{S,i}\right)\left[\frac{\exp(2\lambda_{S,i}z_d)\exp\left(\lambda_{S,i}z\right)}{1+\exp(2\lambda_{S,i}z_d)} + \frac{\exp\left(-\lambda_{S,i}z\right)}{1+\exp(2\lambda_{S,i}z_d)}\right] +$$

$$2\sum_{i=1}^{M} a_{L,i}\sin\left(\lambda_{L,i}x - \varphi_{L,i}\right)\left[\frac{\exp(2\lambda_{L,i}z_d)\exp\left(\lambda_{L,i}z\right)}{1+\exp(2\lambda_{L,i}z_d)} + \frac{\exp\left(-\lambda_{L,i}z\right)}{1+\exp(2\lambda_{L,i}z_d)}\right] \quad (1\text{-}11)$$

Once the pressure distribution is known within the hyporheic zone, the velocity field can be solved with the Darcy equation, which relates velocity to the gradient of the pressure head:

$$u(u,w) = \left(-\frac{K}{\phi}\frac{\partial h}{\partial x}, -\frac{K}{\phi}\frac{\partial h}{\partial z}\right) \quad (1\text{-}12)$$

whose components are represented as:

$$u(x,z) = -2h_m(x)\frac{K}{\phi}\sum_{i=1}^{N}\lambda_{S,i}a_{S,i}\cos\left(\lambda_{S,i}x - \varphi_{S,i}\right)\left[\frac{\exp(2\lambda_{S,i}z_d)\exp\left(\lambda_{S,i}z\right)}{1+\exp(2\lambda_{S,i}z_d)} + \frac{\exp\left(-\lambda_{S,i}z\right)}{1+\exp(2\lambda_{S,i}z_d)}\right] -$$

$$2\frac{K}{\phi}\sum_{i=1}^{M}\lambda_{L,i}a_{L,i}\cos\left(\lambda_{L,i}x - \varphi_{L,i}\right)\left[\frac{\exp(2\lambda_{L,i}z_d)\exp\left(\lambda_{L,i}z\right)}{1+\exp(2\lambda_{L,i}z_d)} + \frac{\exp\left(-\lambda_{L,i}z\right)}{1+\exp(2\lambda_{L,i}z_d)}\right] - \frac{K}{\phi}s_0 \quad (1\text{-}13)$$

$$v(x,z) = -2h_m(x)\frac{K}{\phi}\sum_{i=1}^{N}\lambda_{S,i}a_{S,i}\sin\left(\lambda_{S,i}x - \varphi_{S,i}\right)\left[\frac{\exp(2\lambda_{S,i}z_d)\exp\left(\lambda_{S,i}z\right)}{1+\exp(2\lambda_{S,i}z_d)} - \frac{\exp\left(-\lambda_{S,i}z\right)}{1+\exp(2\lambda_{S,i}z_d)}\right] -$$

$$2\frac{K}{\phi}\sum_{i=1}^{M}\lambda_{L,i}a_{L,i}\cos\left(\lambda_{L,i} - \varphi_{L,i}\right)\left[\frac{\exp(2\lambda_{L,i}z_d)\exp\left(\lambda_{L,i}z\right)}{1+\exp(2\lambda_{L,i}z_d)} - \frac{\exp\left(-\lambda_{L,i}z\right)}{1+\exp(2\lambda_{L,i}z_d)}\right] \quad (1\text{-}14)$$

where ϕ is the sediment porosity that, according to the sediment characteristics, are assumed equal to 0.38.

We observe that along the Lower Deadwood River sediment are mainly composed of gravel and cobble on the surface and sand filling the interstices below the armor layer. Therefore, the

hydraulic conductivity is assumed to be K=0.005 m/s in all simulations. This value was verified with the temperature probes.

Solute transport was modeled numerically with the particle tracking technique (Dagan, *et al.* 1992) in order to obtain the distribution of the residence time and the mean upwelling flux (Tonina and Bellin 2007).

Solute transport within the hyporheic zone: residence time distribution

Solute transport was modeled by the particle tracking method, a Lagrangian approach in which solute mass is divided into a large number of non-interacting particles, which move according to the flow field and are tracked from areas of downwelling to upwelling. The following set of integral-differential equations are solved numerically:

$$\begin{cases} X(t;\bar{a}) = \int_0^t u\,[X(\tau;\bar{a}), Z(\tau;\bar{a})]d\tau \\ Z(t;\bar{a}) = \int_0^t w\,[X(\tau;\bar{a}), Z(\tau;\bar{a})]d\tau \end{cases} \quad (1\text{-}15)$$

where ($X(t;\bar{a}); Z(t;\bar{a})$) is the trajectory of the particle released at time $t=0$ at location $\bar{a}$ within the downwelling area. The system of equations (14) was solved numerically by using the following explicit scheme:

$$\begin{cases} X(t;\vec{a}) = X(t-\Delta t;\bar{a}) + u[X(t-\Delta t;\bar{a}), Z(t-\Delta t;\bar{a})]\Delta t \\ Z(t;\vec{a}) = Y(t-\Delta t;\bar{a}) + w[X(t-\Delta t;\bar{a}), Z(t-\Delta t;\bar{a})]\Delta t \end{cases} \quad (1\text{-}16)$$

Thus, particle trajectories were predicted by applying the set of equations (1-16) recursively with a variable time step, as required by the highly variable curvature of the streamlines. Short streamlines with high curvature require small time steps to obtain accurate particle trajectories, on the other hand long streamlines with small curvature allow large time steps without compromising accuracy. After a number of preliminary simulations, the following rule for selecting the time step dynamically was derived:

$$\Delta t = \frac{100}{|k(s)|} \quad (1\text{-}17)$$

where $k(s)$ is the curvature of the streamline, which is represented by the ratio between the versor (unit vector) tangent to the trajectory of two successive points and the arc length connecting them.

In the same Lagrangian framework, the transport of a nonreactive solute was considered within the hyporheic zone. The mass flux of a nonreactive solute at the exit surface of a control volume, resulting from a pulse injection of an unitary mass of solute within the entry surface, is given by the probability density function (pdf) of the residence (travel) time of the particles within the volume (Dagan, *et al.*, 1992; Jury, *et al.*, 1986). In this case, the control volume is the hyporheic zone, the exit surface is the upwelling area, while the solute enters the control volume through the downwelling area. Thus, the residence time pdf ($f(\tau)$) of the solute particles can be used to represent the concentration breakthrough curve (BTC) at the upwelling area under the hypothesis that the solute is well mixed in the stream ($C_0(t)=C_0=const$). Therefore, the function for the breakthrough curve , defined as the ratio between the concentration at the upwelling area ($C_F(t)$) and the source concentration (C_0), became:

$$\begin{cases} BTC = \frac{C_F(t)}{C_0} = \int_0^t f(\tau')d\,\tau' = F(\tau) \\ F(\tau) \simeq \frac{\int_{A_{dw}} q(x_0,0)R(x_0,t)dA_{dw}}{\int_{A_{dw}} q(x_0,0)dA_{dw}} \end{cases} \quad (1\text{-}18)$$

where $F(\tau)$ is the Cumulative Distribution Function (CDF) of the particle residence time τ and represents the fraction of the particles released at time $t = 0$ with the pulse injection that at time t are within the control volume. A_{dw} is the downwelling area, q is the water flux into the bed and R is a binary variable, which is equal to 1 if the particle released at the location x_0 is within the control volume at the time t since solute injection, and 0, if the particle exited the control volume through the upwelling surface at an earlier time (Elliott and Brooks 1997b). The term on the right side of the second expression (1-18) converges to the CDF of the residence time as the number of particles grows large and the mass carried by a single particle tends to zero. The water-sediment interface was divided into a finite number of nodes with variable spacing. The spacing was small enough to stabilize the CDF computed with equation (1-18). The values of Dx along individual reaches varies between 0.02m and 0.05 m. The vertical component of the velocity field is computed at each node to delimit downwelling and upwelling areas.

Modeling Temperature Variation along the Deadwood River

Temperature is a key parameter in controlling water quality of aquatic ecosystems because of its influence on biogeochemical reactions and processes. These processes include uptake of

dissolved oxygen, nutrients and contaminants, metabolism of aquatic organisms, plant photosynthesis rates, and timing, rate, and direction of fish migration. Stream water downwells into the sediment and upwells into the stream due to hyporheic fluxes. Consequently, daily temperature fluctuations of downwelling stream water influence pore-water temperature within the sediment due to hyporheic exchange. To analyze the effects of hyporheic flows on pore-water temperature along the Lower Deadwood River, a process-based model was developed, which predicts temperature distribution within the hyporheic zone and its role in different stream discharge scenarios.

Heat Transport Model

Each reach was considered as a single morphological unit characterized by different values of discharge and slope, where the pumping mechanisms, which is the advective mechanisms which exchange surface and pore waters, chiefly controls the hyporheic exchange (Elliott and Brooks 1997b; Stonedahl *et al.* 2010). In particular, the pIt was assumed that the water temperature is well-mixed, spatially constant over one morphological unit (e.g. bed feature such as dunes and riffles), and varies temporally following a daily cycle (Figure 1-76).

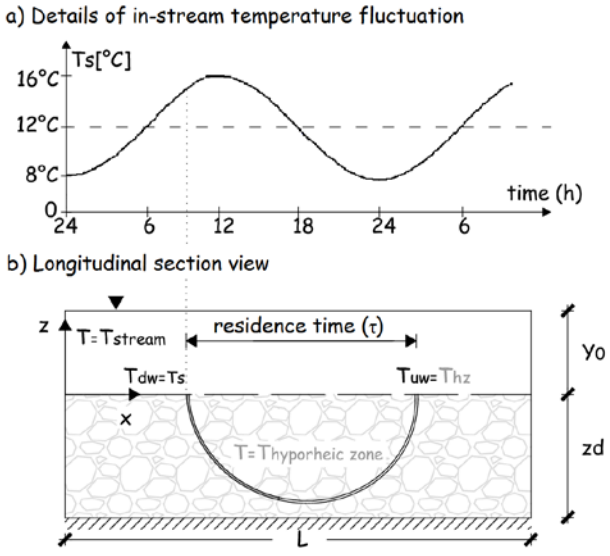


Figure 1-77. Sketch of temperature boundary conditions and a hyporheic flow path (Modified from (Marzadri, Tonina, & Bellin, 2012)

No lateral or bottom heat exchange is specified in the model in order to focus attention on the vertical exchange only. The streambed material was considered to be in local thermal

equilibrium and have homogeneous and isotropic hydraulic conductivity (K=0.005 m/s). The assumption of local thermal equilibrium implies that at each point the sediment and water temperatures are similar and the effective volumetric heat capacity of the sediment, C, and effective thermal conductivity, K_T, characterize the composite medium of sediment and water (Cardenas and Wilson 2007a). Under these assumptions, the transport equation for advection, conduction, and dispersion is:

$$C\frac{\partial T}{\partial t} = \frac{\partial}{\partial x_i}\left(K_T\frac{\partial T}{\partial x_i}\right) + \frac{\partial}{\partial x_i}\left(\phi C_w D_{ik}\frac{\partial T}{\partial x_k}\right) - C_w\phi u_i\frac{\partial T}{\partial x_i} \quad (1\text{-}19)$$

where T is the temperature, C_w is the volumetric heat capacity of water, x_i (i = 1, 2, 3) are Cartesian coordinates, D_{ik} is the mechanical dispersion coefficient tensor, and u_i (i = 1, 2, 3) are the components of the sediment flow velocity u. D_{ik} depends mainly on the longitudinal component α_L of the dispersivity because the transversal is typically an order of magnitude smaller (thus $\alpha_T=0$ and $D_{ik} = \alpha_L u$). Equation (1-19) can be written in a more convenient way for the following analytical treatment by applying mass conservation along a stream tube (Bellin and Rubin, 2004 ; Gelhar and Collins, 1971). The advective, convective and dispersive terms are represented by means of a travel time, τ:

$$\tau = \int_0^l u(\xi)^{-1} d\,\xi \quad (1\text{-}20)$$

where the integration were performed for any particle along its streamline of length l. Moreover, heat conduction, which stems from the velocity gradient along the trajectories and which is important only deep in the sediment (Cardenas and Wilson 2007a) is considered to be negligible because velocity gradients are small within the alluvium except near the streambed. Thus, the heat transport equation along any streamline simplifies to:

$$\frac{\partial T}{\partial t} = D\frac{\partial^2 T}{\partial \tau^2} - C_T\frac{\partial T}{\partial \tau} \quad (1\text{-}21)$$

where

$$D = \frac{\phi \alpha_L C_w}{C|u|} + \frac{K_T}{C|u|^2};\ C_T = \phi \frac{C}{C_w} \tag{1-22}$$

We assume the groundwater temperature (T_{GW}) as initial condition within the sediment *T(τ,0)* for Equation (1-21), that downwelling fluxes have stream temperature *Ts(t)* and that temperature gradients are negligible at the upwelling end of any streamline:

$$\begin{cases} T(\tau,0) = T_{GW}(\tau,0); \\ T(0,t) = T_s(t); \\ \left.\frac{\partial T}{\partial \tau}\right|_{\tau\to\infty} = 0 \end{cases} \tag{1-23}$$

The in-stream temperature daily variations can be represented in terms of the Fourier series as a superposition of a constant mean (T_0) and a periodic fluctuation:

$$T_S(t) = T_0 + 2\sum_{i=1}^{NT} T_{A,i1}\ \sin(\omega_i\, t) + 2\sum_{i=1}^{NT} T_{A,i2}\ \cos(\omega_i\, t) \tag{1-24}$$

with

$$\begin{cases} T_0 = a_{T,0}\ \sin(-\varphi_{T,0}) \quad ; \\ T_{A,i1} = a_{T,i}\ \cos(-\varphi_{T,i})\ ; \\ T_{A,i2} = a_{T,i}\ \sin(-\varphi_{T,i}) \end{cases} \tag{1-25}$$

where $a_{T,i}$ and $\varphi_{T,i}$ (i=0…NT) are the amplitude and the phase of the temperature data of the NT Fourier harmonics, respectively.

Following the approach proposed by Alshawabkeh and Adrian (1997), the general solution of Equation (1-21) with initial and boundary conditions of Equations (1-23) and (1-24), is:

$$T(\tau,t) = \frac{T_0 - T_{GW}}{2}\left[exp\left(\frac{C_T}{D}\tau\right) erfc\left(\frac{\tau + C_T t}{2\sqrt{Dt}}\right) + erfc\left(\frac{\tau - C_T t}{2\sqrt{Dt}}\right)\right] + \sum_{i=1}^{NT} \frac{T_{A,i1}}{2}\left\{exp\left(\frac{C_T\tau}{2D} - a_i\right)\left[\left(1 - F_{2,i}\right)\sin(\omega_i t - b_i) - G_{2,i}\cos(\omega_i t - b_i)\right] + exp\left(\frac{C_T\tau}{2D} + a_i\right)\left[\left(1 - F_{1,i}\right)\sin(\omega_i t + b_i) - G_{1,i}\cos(\omega_i t + b_i)\right]\right\} - \sum_{i=1}^{NT} \frac{T_{A,i2}}{2}\left\{exp\left(\frac{C_T\tau}{2D} - a_i\right)\left[\left(1 - F_{2,i}\right)\cos(\omega_i t - b_i) + G_{2,i}\sin(\omega_i t - b_i)\right] + exp\left(\frac{C_T\tau}{2D} + a_i\right)\left[\left(1 - F_{1,i}\right)\cos(\omega_i t - b_i) + G_{1,i}\sin(\omega_i t - b_i)\right]\right\} + T_{GW} \tag{1-26}$$

where F_{1i}, G_{1i}, F_{2i} and G_{2i} are complex functions reported in Alshawabkeh and Adrian (1997), while a_i and b_i are defined as follows:

$$a_i = \sqrt{r_i}\tau \cos\left(\vartheta_i/_2\right); b_i = \sqrt{r_i}\tau \sin\left(\vartheta_i/_2\right) \quad (1\text{-}27)$$

with:

$$r_i = \frac{1}{D}\sqrt{\frac{C_T^4}{16D^2} + {\omega_i}^2}; \;\; \vartheta_i = arctg\left(\frac{4\omega_i D}{C_T^2}\right) \quad (1\text{-}28)$$

In modeling temperature effects on water quality along the Lower Deadwood River, the pertinent temperature oscillations were at the same period of fluctuation of the in-stream water (1 day). Therefore, Equation (1-26) can be further simplified considering that for τ>>1 day it results in $F_1 \rightarrow 1$, $G_1 \rightarrow 0$, $F_2 \rightarrow -1$ and $G_2 \rightarrow 0$:

$$T(\tau,t) = \frac{T_0 - T_{GW}}{2}\left[exp\left(\frac{C_T}{D}\tau\right) erfc\left(\frac{\tau + C_T t}{2\sqrt{Dt}}\right) + erfc\left(\frac{\tau - C_T t}{2\sqrt{Dt}}\right)\right] + \sum_{i=1}^{NT} T_{A,i1}\, exp\left(\frac{C_T\tau}{2D} - a_i\right)\sin(\omega_i t - b_i) - \sum_{i=1}^{NT} T_{A,i2}\, exp\left(\frac{C_T\tau}{2D} - a_i\right)\cos(\omega_i t - b_i) + T_{GW} \quad (1\text{-}29)$$

This simplified solutions was used for predicting the hyporheic water temperature at the probe locations at the study site (Reach 15).The analysis showed that the first six harmonics suffice to represent the temperature fluctuations with the Fourier series; therefore in the simulations NT = 5. On the other hand, for analyzing the effects of small and large scales on the hyporheic thermal response along the whole course of the Lower Deadwood River, it was assumed that in any reach *Ts(t)* can be represented as the sum of a constant component T_0 and a diel sinusoidal component given by the following equation:

$$T_S(t) = T_0 + T_A \sin\left(\frac{2\pi}{t_d}t\right) \quad (1\text{-}30)$$

where T_A is the daily temperature amplitude, and t_d is the fluctuation period (1 day). In this case, the solution of Equation (1-21), with the other two boundaries conditions (1-23) remaining unaltered, is:

$$T_A(\tau,t) = \frac{T_0 - T_{GW}}{2}\left[exp\left(\frac{C_T}{D}\tau\right) erfc\left(\frac{\tau + C_T t}{2\sqrt{Dt}}\right) + erfc\left(\frac{\tau - C_T t}{2\sqrt{Dt}}\right)\right] + T_{GW} + T_A exp\left(\frac{C_T}{D}\tau - a\right)\sin(\omega t - b) \quad (1\text{-}31)$$

In order to quantify the role of the hyporheic zone on in-stream water temperature, the following parameter Δ_{amp} was introduced to represent the ratio between the mean amplitude of upwelling temperature over 30 m ($T_{A,30}$) and the amplitude of the in-stream water temperature (T_A):

$$\Delta_{amp}(x) = \frac{T_{A,30}}{T_A} \cong 0 \div 1 \quad (1\text{-}32)$$

Values of Δ_{amp} close to 0 represents zones where the mean amplitude of upwelling temperature is much lower than the amplitude of the in-stream water temperature.

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APPENDIX D
BENTHIC MACROINVERTEBRATE TABLES

Table 1. Similarity percent (SIMPER) results of benthic macroinvertebrate abundance (# individuals / m^2). Orders with a high percent contribution are "discriminating" orders which most strongly associate with differences in community assemblage between the two groups being compared. Sites were sorted into groups based on ANOSIM pairwise comparisons. Scale of average abundance is the transformed value (square-root) rather than raw abundance.

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
2010						
DEA101 vs. DEA113	43.49	Ephemeroptera	15.71	55.2	27	27
		Diptera-Chironomidae	63.6	55.92	23	50
		Oligochaeta (class)	33.26	27.2	12	62
		Plecoptera	8.94	22.23	10	72
		Nematoda (phylum)	6.75	2.97	5	77
		Trombidiformes	4.53	6.08	5	82
		Trichoptera	2.06	7.69	4	86
		Diptera	2.56	7.37	4	90
		Coleoptera	0.47	5.71	4	94
DEA101 vs. DEA112, DEA108	50.3	Ephemeroptera	15.71	55.74	23	23
		Diptera-Chironomidae	63.6	32.13	22	44
		Oligochaeta (class)	33.26	23.55	14	58
		Trichoptera	2.06	18.02	9	67
		Plecoptera	8.94	21.62	8	76
		Diptera	2.56	14.71	7	83
		Trombidiformes	4.53	9.91	6	89
		Nematoda (phylum)	6.75	6.15	5	94
DEA101 vs. Upper Dwd	50.07	Diptera-Chironomidae	63.6	43.99	15	15
		Coleoptera	0.47	29.56	15	30
		Trichoptera	2.06	27.56	13	42
		Ephemeroptera	15.71	32.68	10	53
		Oligochaeta (class)	33.26	30.45	9	62
		Diptera	2.56	18.02	8	70
		Trombidiformes	4.53	17.11	8	77
		Sarcoptiformes	0	13.65	6	84
		Plecoptera	8.94	19.51	6	90
		Nematoda (phylum)	6.75	9.84	5	95
DEA101 vs. Clear Creek	51.04	Diptera-Chironomidae	63.6	34.06	20	20
		Coleoptera	0.47	32.61	18	38
		Ephemeroptera	15.71	37.12	13	50
		Oligochaeta (class)	33.26	30.26	12	62
		Trombidiformes	4.53	20.07	10	72
		Trichoptera	2.06	16.46	7	79
		Diptera	2.56	15.51	7	86
		Plecoptera	8.94	16.27	5	91
DEA101 vs. SF Payette	51.06	Diptera-Chironomidae	63.6	26.85	27	27

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
		Ephemeroptera	15.71	41.7	15	42
		Oligochaeta (class)	33.26	24.68	14	57
		Diptera	2.56	15.83	8	64
		Trombidiformes	4.53	13.47	7	72
		Coleoptera	0.47	12.34	7	79
		Trichoptera	2.06	14.01	7	86
		Plecoptera	8.94	16.58	6	92
DEA113 vs. DEA112, DEA108	34.08	Diptera-Chironomidae	55.92	32.13	22	22
		Ephemeroptera	55.2	55.74	18	41
		Oligochaeta (class)	27.2	23.55	13	54
		Plecoptera	22.23	21.62	9	62
		Trichoptera	7.69	18.02	9	71
		Diptera	7.37	14.71	7	78
		Trombidiformes	6.08	9.91	5	83
		Nematoda (phylum)	2.97	6.15	5	88
		Coleoptera	5.71	4.9	3	91
DEA113 vs. Upper Dwd	40.22	Ephemeroptera	55.2	32.68	15	15
		Diptera-Chironomidae	55.92	43.99	15	29
		Coleoptera	5.71	29.56	13	42
		Trichoptera	7.69	27.56	11	53
		Oligochaeta (class)	27.2	30.45	7	61
		Sarcoptiformes	0	13.65	7	68
		Trombidiformes	6.08	17.11	7	74
		Diptera	7.37	18.02	7	81
		Plecoptera	22.23	19.51	5	86
		Nematoda (phylum)	2.97	9.84	5	91
DEA113 vs. Clear Creek	40.68	Ephemeroptera	55.2	37.12	18	18
		Diptera-Chironomidae	55.92	34.06	17	35
		Coleoptera	5.71	32.61	16	51
		Oligochaeta (class)	27.2	30.26	9	60
		Trombidiformes	6.08	20.07	8	69
		Plecoptera	22.23	16.27	7	76
		Trichoptera	7.69	16.46	6	82
		Diptera	7.37	15.51	6	87
		Nematoda (phylum)	2.97	7.03	4	
DEA113 vs. SF Payette	39.61	Diptera-Chironomidae	55.92	26.85	24	24
		Ephemeroptera	55.2	41.7	22	45
		Oligochaeta (class)	27.2	24.68	11	56
		Plecoptera	22.23	16.58	9	65
		Diptera	7.37	15.83	7	71
		Trichoptera	7.69	14.01	6	77
		Trombidiformes	6.08	13.47	6	83
		Coleoptera	5.71	12.34	5	87

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
		Nematoda (phylum)	2.97	7.03	4	92
DEA112, DEA108 vs. Upper Dwd	38.48	Ephemeroptera	55.74	32.68	16	16
		Coleoptera	4.9	29.56	14	30
		Oligochaeta (class)	23.55	30.45	11	42
		Trichoptera	18.02	27.56	10	52
		Diptera-Chironomidae	32.13	43.99	9	61
		Sarcoptiformes	0	13.65	8	69
		Plecoptera	21.62	19.51	7	75
		Trombidiformes	9.91	17.11	6	82
		Nematoda (phylum)	6.15	9.84	6	87
		Diptera	14.71	18.02	5	93
DEA112, DEA108 vs. Clear Creek	38.62	Ephemeroptera	55.74	37.12	19	19
		Coleoptera	4.9	32.61	18	37
		Oligochaeta (class)	23.55	30.26	13	50
		Diptera-Chironomidae	32.13	34.06	9	59
		Trichoptera	18.02	16.46	8	67
		Trombidiformes	9.91	20.07	8	75
		Plecoptera	21.62	16.27	8	83
		Diptera	14.71	15.51	5	88
		Nematoda (phylum)	6.15	7.03	5	93
DEA112, DEA108 vs. SF Payette	36.65	Ephemeroptera	55.74	41.7	24	24
		Oligochaeta (class)	23.55	24.68	14	37
		Diptera-Chironomidae	32.13	26.85	13	50
		Plecoptera	21.62	16.58	10	60
		Trichoptera	18.02	14.01	10	70
		Diptera	14.71	15.83	6	76
		Trombidiformes	9.91	13.47	6	83
		Nematoda (phylum)	6.15	7.03	6	88
		Coleoptera	4.9	12.34	6	94
Upper Dwd vs. Clear Creek	31.75	Ephemeroptera	32.68	37.12	14	14
		Oligochaeta (class)	30.45	30.26	12	26
		Trichoptera	27.56	16.46	11	37
		Diptera-Chironomidae	43.99	34.06	11	48
		Coleoptera	29.56	32.61	9	57
		Sarcoptiformes	13.65	2.6	9	66
		Trombidiformes	17.11	20.07	7	73
		Diptera	18.02	15.51	7	80
		Plecoptera	19.51	16.27	7	86
		Nematoda (phylum)	9.84	7.03	6	93

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
Upper Dwd vs. SF Payette	39.05	Diptera-Chironomidae	43.99	26.85	14	14
		Ephemeroptera	32.68	41.7	13	27
		Trichoptera	27.56	14.01	12	39
		Coleoptera	29.56	12.34	12	50
		Oligochaeta (class)	30.45	24.68	11	61
		Sarcoptiformes	13.65	0	8	69
		Plecoptera	19.51	16.58	7	75
		Trombidiformes	17.11	13.47	6	82
		Diptera	18.02	15.83	6	88
		Nematoda (phylum)	9.84	7.03	6	94
Clear Creek vs. SF Payette	36.74	Ephemeroptera	37.12	41.7	17	17
		Coleoptera	32.61	12.34	16	33
		Oligochaeta (class)	30.26	24.68	13	46
		Diptera-Chironomidae	34.06	26.85	12	58
		Trichoptera	16.46	14.01	8	67
		Trombidiformes	20.07	13.47	8	75
		Plecoptera	16.27	16.58	7	81
		Diptera	15.51	15.83	6	87
2011						
DEA101 vs. DEA113	38.25	Diptera-Chironomidae	77.21	54.04	24	24
		Ephemeroptera	16.95	44.3	22	46
		Plecoptera	7.75	22.7	12	58
		Oligochaeta (class)	19.34	24.33	10	68
		Trichoptera	2.95	10.53	6	74
		Diptera	2.12	9.57	6	80
		Nematoda (phylum)	1.33	5.66	4	85
		Coleoptera	1.5	4.26	4	88
		Trombidiformes	0.57	3.91	3	92
DEA101 vs. DEA112, DEA108 & SFP	50.93	Diptera-Chironomidae	77.21	24.82	38	38
		Ephemeroptera	16.95	40.11	16	54
		Diptera	2.12	13.15	8	62
		Oligochaeta (class)	19.34	15.52	8	70
		Trichoptera	2.95	12.02	7	77
		Plecoptera	7.75	15.8	6	83
		Trombidiformes	0.57	8.75	6	89
		Coleoptera	1.5	6.26	4	93
DEA101 vs. Upper Dwd, Clear Ck	50.26	Diptera-Chironomidae	77.21	43.81	21	21
		Coleoptera	1.5	27.25	14	35
		Trichoptera	2.95	28.08	13	47
		Ephemeroptera	16.95	39.91	13	60
		Diptera	2.12	21.07	10	70
		Trombidiformes	0.57	13.87	7	77

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
		Oligochaeta (class)	19.34	22.96	7	84
		Plecoptera	7.75	19.14	6	90
DEA113 vs. DEA112, DEA108 & SFP	32.87	Diptera-Chironomidae	54.04	24.82	28	28
		Ephemeroptera	44.3	40.11	14	43
		Oligochaeta (class)	24.33	15.52	12	54
		Plecoptera	22.7	15.8	8	63
		Diptera	9.57	13.15	6	69
		Trombidiformes	3.91	8.75	6	74
		Trichoptera	10.53	12.02	5	80
		Nematoda (phylum)	5.66	4.89	5	84
		Coleoptera	4.26	6.26	4	89
		Veneroida	2.9	0.46	3	91
DEA113 vs. Upper Dwd & Clear Ck	33.98	Coleoptera	4.26	27.25	15	15
		Diptera-Chironomidae	54.04	43.81	15	31
		Trichoptera	10.53	28.08	12	42
		Ephemeroptera	44.3	39.91	10	53
		Oligochaeta (class)	24.33	22.96	9	62
		Diptera	9.57	21.07	8	70
		Trombidiformes	3.91	13.87	7	77
		Plecoptera	22.7	19.14	6	83
		Nematoda (phylum)	5.66	9.15	5	89
		Turbellaria (class)	0.33	4.8	3	92
DEA112, DEA108 & SFP vs. Upper Dwd & Clear Ck	35.17	Diptera-Chironomidae	24.82	43.81	17	17
		Coleoptera	6.26	27.25	15	33
		Trichoptera	12.02	28.08	12	45
		Ephemeroptera	40.11	39.91	12	56
		Oligochaeta (class)	15.52	22.96	10	66
		Diptera	13.15	21.07	9	75
		Trombidiformes	8.75	13.87	6	81
		Plecoptera	15.8	19.14	6	87
		Nematoda (phylum)	4.89	9.15	5	92

Table 2. Similarity percent (SIMPER) results of benthic macroinvertebrate biomass (mg / m2). Orders with a high percent contribution are "discriminating" orders which most strongly associate with differences in community assemblage between the two groups being compared. Sites were sorted into groups determined from ANOSIM pairwise comparisons. Scale of average biomass is the transformed value (square-root) of biomass, rather than raw biomass.

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
2010						
DEA101 vs. DEA113	43.91	Ephemeroptera	11.6	26.49	22	22
		Plecoptera	11.56	25.1	22	44
		Diptera-Chironomidae	25.35	20.28	21	65
		Oligochaeta (class)	25.99	17.57	19	85
		Trichoptera	4.94	10.16	12	96
DEA101 vs. DEA112, DEA108	48.85	Oligochaeta (class)	25.99	14.25	24	24
		Diptera-Chironomidae	25.35	8.74	21	45
		Ephemeroptera	11.6	22.65	17	62
		Plecoptera	11.56	16.24	16	78
		Trichoptera	4.94	12.97	14	91
DEA101 vs. Upper Dwd	49.92	Oligochaeta (class)	25.99	15.75	19	19
		Diptera-Chironomidae	25.35	17.78	19	38
		Trichoptera	4.94	19.58	18	56
		Plecoptera	11.56	13.3	13	69
		Coleoptera	0.09	11.48	13	82
		Ephemeroptera	11.6	14.06	11	93
DEA101 vs. Clear Creek	52.02	Oligochaeta (class)	25.99	16.16	21	21
		Diptera-Chironomidae	25.35	9.32	20	41
		Coleoptera	0.09	14.08	17	58
		Ephemeroptera	11.6	13.37	13	71
		Trichoptera	4.94	12.7	13	83
		Plecoptera	11.56	9.52	12	95
DEA101 vs. SF Payette	53.69	Oligochaeta (class)	25.99	13.51	25	25
		Diptera-Chironomidae	25.35	7.46	24	49
		Ephemeroptera	11.6	13.71	14	63
		Plecoptera	11.56	12.33	14	78

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
		Trichoptera	4.94	9.63	11	89
		Coleoptera	0.09	5.04	6	95
DEA113 vs. DEA112, DEA108	38.71	Plecoptera	25.1	16.24	24	24
		Diptera-Chironomidae	20.28	8.74	18	42
		Ephemeroptera	26.49	22.65	18	59
		Trichoptera	10.16	12.97	16	75
		Oligochaeta (class)	17.57	14.25	15	91
DEA113 vs. Upper Dwd	43.81	Plecoptera	25.1	13.3	20	20
		Ephemeroptera	26.49	14.06	18	38
		Trichoptera	10.16	19.58	17	55
		Diptera-Chironomidae	20.28	17.78	17	72
		Coleoptera	1.94	11.48	11	83
		Oligochaeta (class)	17.57	15.75	10	93
DEA113 vs. Clear Creek	45.56	Plecoptera	25.1	9.52	20	20
		Ephemeroptera	26.49	13.37	20	40
		Diptera-Chironomidae	20.28	9.32	15	55
		Coleoptera	1.94	14.08	15	70
		Trichoptera	10.16	12.7	13	84
		Oligochaeta (class)	17.57	16.16	12	95
DEA113 vs. SF Payette	45.66	Ephemeroptera	26.49	13.71	23	23
		Plecoptera	25.1	12.33	22	45
		Diptera-Chironomidae	20.28	7.46	18	64
		Oligochaeta (class)	17.57	13.51	14	78
		Trichoptera	10.16	9.63	13	91
DEA112, DEA108 vs. Upper Dwd	40.73	Trichoptera	12.97	19.58	21	21
		Plecoptera	16.24	13.3	18	39
		Oligochaeta (class)	14.25	15.75	15	54
		Ephemeroptera	22.65	14.06	15	68
		Coleoptera	2.22	11.48	13	82
		Diptera-Chironomidae	8.74	17.78	13	94

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
DEA112, DEA108 vs. Clear Creek	41.51	Coleoptera	2.22	14.08	18	18
		Ephemeroptera	22.65	13.37	18	36
		Plecoptera	16.24	9.52	18	54
		Oligochaeta (class)	14.25	16.16	17	71
		Trichoptera	12.97	12.7	17	88
		Diptera-Chironomidae	8.74	9.32	7	95
DEA112, DEA108 vs. SF Payette	40.41	Ephemeroptera	22.65	13.71	22	22
		Plecoptera	16.24	12.33	21	43
		Oligochaeta (class)	14.25	13.51	19	62
		Trichoptera	12.97	9.63	17	79
		Diptera-Chironomidae	8.74	7.46	9	88
		Diptera	4.9	4.62	6	94
Upper Dwd vs. Clear Creek	35.33	Trichoptera	19.58	12.7	22	22
		Oligochaeta (class)	15.75	16.16	17	39
		Plecoptera	13.3	9.52	17	56
		Diptera-Chironomidae	17.78	9.32	15	70
		Ephemeroptera	14.06	13.37	13	83
		Coleoptera	11.48	14.08	10	93
Upper Dwd vs. SF Payette	42.18	Trichoptera	19.58	9.63	21	21
		Plecoptera	13.3	12.33	17	38
		Diptera-Chironomidae	17.78	7.46	16	54
		Oligochaeta (class)	15.75	13.51	16	70
		Ephemeroptera	14.06	13.71	12	82
		Coleoptera	11.48	5.04	11	93
Clear Creek vs. SF Payette	39.97	Oligochaeta (class)	16.16	13.51	19	19
		Plecoptera	9.52	12.33	17	36
		Coleoptera	14.08	5.04	17	53
		Trichoptera	12.7	9.63	17	70
		Ephemeroptera	13.37	13.71	14	85
		Diptera-Chironomidae	9.32	7.46	9	94
2011						

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
DEA101 vs. DEA113	40.63	Diptera-Chironomidae	37.36	19.98	31	31
		Ephemeroptera	11.51	21.3	20	51
		Trichoptera	3.37	10.63	16	67
		Oligochaeta (class)	14.26	11.77	14	81
		Plecoptera	4.27	12.05	13	95
DEA101 vs. DEA112, DEA108	56.45	Diptera-Chironomidae	37.36	6.95	41	41
		Ephemeroptera	11.51	17.84	13	54
		Plecoptera	4.27	14.57	13	67
		Oligochaeta (class)	14.26	6.05	13	80
		Trichoptera	3.37	9.51	11	91
DEA101 vs. Upper Dwd	53.29	Trichoptera	3.37	35.44	31	31
		Diptera-Chironomidae	37.36	18.48	22	53
		Ephemeroptera	11.51	19.24	11	64
		Coleoptera	0.43	10.8	10	74
		Oligochaeta (class)	14.26	8.77	10	84
		Plecoptera	4.27	11.75	8	92
DEA101 vs. Clear Creek	58.43	Diptera-Chironomidae	37.36	10.45	28	28
		Trichoptera	3.37	27.76	24	52
		Coleoptera	0.43	14.54	13	65
		Ephemeroptera	11.51	19.04	11	76
		Oligochaeta (class)	14.26	8.61	9	85
		Plecoptera	4.27	13.35	8	93
DEA101 vs. GAR108	59.95	Diptera-Chironomidae	37.36	7.6	34	34
		Trichoptera	3.37	18.91	20	54
		Oligochaeta (class)	14.26	4.41	12	67
		Plecoptera	4.27	12.72	12	78
		Ephemeroptera	11.51	16.05	11	89
		Diptera	0.48	6.25	7	95
DEA101 vs. GAR109	56.58	Diptera-Chironomidae	37.36	8.7	41	41
		Trichoptera	3.37	14.04	16	57
		Oligochaeta (class)	14.26	5.71	13	70

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
		Plecoptera	4.27	13.13	13	83
		Ephemeroptera	11.51	13.71	11	94
DEA113 vs. DEA112, DEA108	37.44	Diptera-Chironomidae	19.98	6.95	26	26
		Plecoptera	12.05	14.57	18	44
		Trichoptera	10.63	9.51	17	61
		Ephemeroptera	21.3	17.84	15	76
		Oligochaeta (class)	11.77	6.05	13	89
		Diptera	1.88	5.11	7	96
DEA113 vs. Upper Dwd	37.42	Trichoptera	10.63	35.44	33	33
		Diptera-Chironomidae	19.98	18.48	13	47
		Plecoptera	12.05	11.75	13	59
		Coleoptera	1.84	10.8	12	71
		Ephemeroptera	21.3	19.24	10	81
		Oligochaeta (class)	11.77	8.77	10	91
DEA113 vs. Clear Creek	39.37	Trichoptera	10.63	27.76	26	26
		Coleoptera	1.84	14.54	17	43
		Diptera-Chironomidae	19.98	10.45	16	60
		Plecoptera	12.05	13.35	13	73
		Ephemeroptera	21.3	19.04	10	83
		Oligochaeta (class)	11.77	8.61	9	92
DEA113 vs. GAR108	40.19	Trichoptera	10.63	18.91	23	23
		Diptera-Chironomidae	19.98	7.6	21	44
		Plecoptera	12.05	12.72	17	61
		Oligochaeta (class)	11.77	4.41	13	74
		Ephemeroptera	21.3	16.05	13	87
		Diptera	1.88	6.25	8	95
DEA113 vs. GAR109	41.71	Diptera-Chironomidae	19.98	8.7	26	26
		Trichoptera	10.63	14.04	19	45
		Plecoptera	12.05	13.13	18	64
		Ephemeroptera	21.3	13.71	17	81
		Oligochaeta (class)	11.77	5.71	12	93

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
DEA112, DEA108 vs. Upper Dwd	42.8	Trichoptera	9.51	35.44	34	34
		Diptera-Chironomidae	6.95	18.48	15	49
		Plecoptera	14.57	11.75	14	64
		Coleoptera	1.99	10.8	12	75
		Ephemeroptera	17.84	19.24	10	85
		Oligochaeta (class)	6.05	8.77	8	93
DEA112, DEA108 vs. Clear Creek	40.87	Trichoptera	9.51	27.76	30	30
		Coleoptera	1.99	14.54	18	48
		Plecoptera	14.57	13.35	16	64
		Ephemeroptera	17.84	19.04	11	76
		Diptera-Chironomidae	6.95	10.45	9	85
		Oligochaeta (class)	6.05	8.61	8	92
DEA112, DEA108 vs. GAR108	36.63	Trichoptera	9.51	18.91	29	29
		Plecoptera	14.57	12.72	24	54
		Ephemeroptera	17.84	16.05	14	68
		Diptera-Chironomidae	6.95	7.6	9	77
		Diptera	5.11	6.25	8	86
		Oligochaeta (class)	6.05	4.41	8	94
DEA112, DEA108 vs. GAR109	38.72	Plecoptera	14.57	13.13	25	25
		Trichoptera	9.51	14.04	23	49
		Ephemeroptera	17.84	13.71	17	66
		Diptera-Chironomidae	6.95	8.7	14	80
		Oligochaeta (class)	6.05	5.71	8	88
		Diptera	5.11	3.01	8	96
Upper Dwd vs. Clear Creek	32.31	Trichoptera	35.44	27.76	32	32
		Plecoptera	11.75	13.35	15	47
		Diptera-Chironomidae	18.48	10.45	14	60
		Coleoptera	10.8	14.54	12	72

Groups compared	Avg. Dissim	Order	Group 1 Avg. Abund	Group 2 Avg. Abund	% Contrib	Cum %
		Ephemeroptera	19.24	19.04	10	82
		Oligochaeta (class)	8.77	8.61	9	91
Upper Dwd vs. GAR108	37.57	Trichoptera	35.44	18.91	32	32
		Plecoptera	11.75	12.72	16	48
		Diptera-Chironomidae	18.48	7.6	15	63
		Ephemeroptera	19.24	16.05	11	74
		Coleoptera	10.8	4.07	9	83
		Oligochaeta (class)	8.77	4.41	9	92
Upper Dwd vs. GAR109	44.51	Trichoptera	35.44	14.04	31	31
		Diptera-Chironomidae	18.48	8.7	17	48
		Plecoptera	11.75	13.13	15	63
		Ephemeroptera	19.24	13.71	11	74
		Coleoptera	10.8	2.88	10	85
		Diptera	8.45	3.01	8	92
Clear Creek vs. GAR108	37.04	Trichoptera	27.76	18.91	29	29
		Plecoptera	13.35	12.72	19	48
		Coleoptera	14.54	4.07	15	63
		Ephemeroptera	19.04	16.05	12	75
		Oligochaeta (class)	8.61	4.41	9	84
		Diptera-Chironomidae	10.45	7.6	8	92
Clear Creek vs. GAR109	43.08	Trichoptera	27.76	14.04	27	27
		Plecoptera	13.35	13.13	17	44
		Coleoptera	14.54	2.88	16	61
		Ephemeroptera	19.04	13.71	13	73
		Diptera-Chironomidae	10.45	8.7	11	85
		Diptera	7.16	3.01	8	92
GAR108 vs. GAR109	39	Trichoptera	18.91	14.04	29	29
		Plecoptera	12.72	13.13	24	53
		Ephemeroptera	16.05	13.71	14	66
		Diptera-Chironomidae	7.6	8.7	13	79
		Diptera	6.25	3.01	9	88
		Oligochaeta (class)	4.41	5.71	8	95

Table 3. Similarity percent (SIMPER) results of benthic macroinvertebrate biomass (mg / m2). Orders with a high percent contribution are "discriminating" orders which most strongly associate with differences in community assemblage between the two groups being compared. Sites were sorted into groups determined from ANOSIM pairwise comparisons. Scale of average biomass is the transformed value (square-root) of biomass, rather than raw biomass.

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA101	6/28/2010	28	Chironomidae	2	132.351	189.188
DEA101	6/28/2010	28	Oligochaete (class A)	1	128.378	232.014
DEA101	6/28/2010	28	Caudatella edmundsi	1	95.927	113.396
DEA101	6/28/2010	28	Caudatella heterocaudata	1	70.911	79.424
DEA101	6/28/2010	28	Hesperoperla pacifica	3	60.445	117.398
DEA101	6/28/2010	28	Rhyacophila alberta gr.	1	43.594	75.649
DEA101	6/28/2010	28	Oligochaete (class C)	1	23.254	33.835
DEA101	6/28/2010	28	Serratella tibialis	1	20.457	19.346
DEA101	6/28/2010	28	Malenka sp.	1	16.470	24.650
DEA101	6/28/2010	28	Drunella coloradensis/flavilinea	1	14.200	22.196
DEA101	6/28/2010	28	Baetis tricaudatus	1	10.233	16.311
DEA101	6/28/2010	28	Ephemerella dorothea/excrucians	1	8.323	14.637
DEA101	6/28/2010	28	Arctopsyche grandis	1	6.632	12.135
DEA101	6/28/2010	28	Epeorus longimanus	1	5.262	7.683
DEA101	6/28/2010	28	Dicranota sp.	1	4.134	7.129
DEA101	6/28/2010	28	Rhyacophila verrula	1	3.832	7.069
DEA101	6/28/2010	28	Oligochaete (class B)	1	2.148	3.112
DEA101	6/28/2010	28	Epeorus sp.	1	0.212	0.290
DEA101	6/28/2010	28	Hydroptila sp.	1	0.170	0.263
DEA101	6/28/2010	28	Rhyacophila sp.	1	0.047	0.066
DEA101	6/28/2010	28	Limnephilidae	1	0.034	0.046
DEA101	6/28/2010	28	Neoplasta sp.	1	0.024	0.033
DEA101	6/28/2010	28	Sweltsa sp.	1	0.018	0.024
DEA101	7/26/2010	21	Chironomidae	2	429.955	671.574
DEA101	7/26/2010	21	Oligochaete (class C)	1	74.811	121.850
DEA101	7/26/2010	21	Caudatella edmundsi	1	63.112	117.033
DEA101	7/26/2010	21	Drunella coloradensis/flavilinea	1	57.892	103.052
DEA101	7/26/2010	21	Caudatella heterocaudata	1	44.231	80.336
DEA101	7/26/2010	21	Oligochaete (class A)	1	39.898	77.095
DEA101	7/26/2010	21	Serratella tibialis	2	36.607	60.862
DEA101	7/26/2010	21	Rhyacophila alberta gr.	1	28.415	59.494
DEA101	7/26/2010	21	Malenka sp.	1	21.936	37.565
DEA101	7/26/2010	21	Oligochaete (class B)	1	15.028	22.626
DEA101	7/26/2010	21	Baetis tricaudatus	2	14.252	23.031

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA101	7/26/2010	21	Ephemerella dorothea/excrucians	1	4.680	8.894
DEA101	7/26/2010	21	Epeorus longimanus	1	3.767	6.150
DEA101	7/26/2010	21	Dicranota sp.	1	2.153	3.918
DEA101	7/26/2010	21	Empididae	1	1.217	2.136
DEA101	7/26/2010	21	Rhithrogena sp.	1	0.096	0.148
DEA101	7/26/2010	21	Baetidae	1	0.021	0.028
DEA101	7/26/2010	21	Perlidae	1	0.020	0.029
DEA101	8/16/2010	50	Chironomidae	2	1597.278	772.083
DEA101	8/16/2010	50	Oligochaete (class C)	1	1040.381	516.057
DEA101	8/16/2010	50	Oligochaete (class B)	1	707.283	353.530
DEA101	8/16/2010	50	Hesperoperla pacifica	1	165.393	107.829
DEA101	8/16/2010	50	Drunella coloradensis/flavilinea	1	147.416	82.790
DEA101	8/16/2010	50	Caudatella edmundsi	1	97.536	54.376
DEA101	8/16/2010	50	Serratella tibialis	1	87.683	46.290
DEA101	8/16/2010	50	Oligochaete (class A)	1	62.289	34.669
DEA101	8/16/2010	50	Caudatella heterocaudata	1	57.024	31.470
DEA101	8/16/2010	50	Tipula sp.	1	55.921	33.267
DEA101	8/16/2010	50	Malenka sp.	1	52.855	27.924
DEA101	8/16/2010	50	Baetis tricaudatus	1	18.652	8.461
DEA101	8/16/2010	50	Epeorus longimanus	1	0.146	0.062
DEA101	10/5/2010	15	Oligochaete (class B)	1	542.619	1085.532
DEA101	10/5/2010	15	Oligochaete (class C)	1	220.880	424.512
DEA101	10/5/2010	15	Chironomidae	2	183.651	325.336
DEA101	10/5/2010	15	Hesperoperla pacifica	2	97.720	225.883
DEA101	10/5/2010	15	Arctopsyche grandis	1	8.166	17.564
DEA101	10/5/2010	15	Sweltsa sp.	1	4.332	8.119
DEA101	10/5/2010	15	Chloroperlidae	1	2.440	4.622
DEA101	10/5/2010	15	Pteronarcys sp.	1	1.073	2.018
DEA101	10/5/2010	15	Optioservus sp.	1	0.166	0.281
DEA101	10/5/2010	15	Ephydridae	1	0.110	0.182
DEA101	10/5/2010	15	Rhithrogena sp.	1	0.025	0.040
DEA101	10/20/2010	259	Oligochaete (class B)	1	3488.115	794.465
DEA101	10/20/2010	259	Chironomidae	2	1746.380	341.953
DEA101	10/20/2010	259	Oligochaete (class A)	1	573.707	152.346
DEA101	10/20/2010	259	Oligochaete (class C)	1	221.373	48.309
DEA101	10/20/2010	259	Baetis tricaudatus	1	167.631	31.604
DEA101	10/20/2010	259	Hesperoperla pacifica	1	149.293	39.525
DEA101	10/20/2010	259	Sweltsa sp.	1	34.362	7.468
DEA101	10/20/2010	259	Baetis sp.	1	19.592	3.758
DEA101	10/20/2010	259	Zapada cinctipes	1	2.333	0.495

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA101	10/20/2010	259	Perlodidae	1	1.435	0.308
DEA101	10/20/2010	259	Ephydridae	1	1.027	0.198
DEA101	10/20/2010	259	Forcipomyia sp.	1	0.413	0.081
DEA101	10/20/2010	259	Capniidae	1	0.395	0.079
DEA101	10/20/2010	259	Arctopsychinae	1	0.265	0.051
DEA101	7/6/2011	27	Chironomidae	2	470.604	643.898
DEA101	7/6/2011	27	Oligochaete (class A)	1	262.758	455.755
DEA101	7/6/2011	27	Caudatella edmundsi	1	84.105	132.536
DEA101	7/6/2011	27	Oligochaete (class C)	1	54.748	74.139
DEA101	7/6/2011	27	Oligochaete (class B)	1	40.411	57.912
DEA101	7/6/2011	27	Rhyacophila verrula gr.	1	39.768	67.774
DEA101	7/6/2011	27	Serratella tibialis	1	37.517	22.305
DEA101	7/6/2011	27	Baetis tricaudatus	1	25.336	37.363
DEA101	7/6/2011	27	Malenka sp.	1	17.378	24.773
DEA101	7/6/2011	27	Rhyacophila alberta gr.	1	11.954	20.256
DEA101	7/6/2011	27	Drunella coloradensis/flavilinea	1	10.898	15.762
DEA101	7/6/2011	27	Caudatella heterocaudata	1	10.412	15.703
DEA101	7/6/2011	27	Ephemerella dorothea/excrucians	1	6.133	10.012
DEA101	7/6/2011	27	Epeorus longimanus	1	4.638	6.243
DEA101	7/6/2011	27	Baetis sp.	1	2.310	3.466
DEA101	8/2/2011	35	Chironomidae	2	1235.889	978.791
DEA101	8/2/2011	35	Oligochaete (class A)	1	367.970	377.153
DEA101	8/2/2011	35	Drunella coloradensis/flavilinea	1	49.375	35.362
DEA101	8/2/2011	35	Oligochaete (class C)	1	47.550	39.727
DEA101	8/2/2011	35	Baetis tricaudatus	2	41.503	33.289
DEA101	8/2/2011	35	Caudatella edmundsi	1	30.234	28.061
DEA101	8/2/2011	35	Oligochaete (class B)	1	28.055	24.016
DEA101	8/2/2011	35	Malenka sp.	1	26.196	22.758
DEA101	8/2/2011	35	Serratella tibialis	1	26.132	23.133
DEA101	8/2/2011	35	Dicranota sp.	1	7.793	7.237
DEA101	8/2/2011	35	Epeorus longimanus	1	6.085	5.195
DEA101	8/2/2011	35	Lepidostoma sp.	1	5.411	5.182
DEA101	8/2/2011	35	Limnephilidae	1	2.267	1.850
DEA101	8/2/2011	35	Optioservus sp.	1	1.605	1.258
DEA101	8/2/2011	35	Hesperoperla pacifica	1	0.696	0.517
DEA101	8/2/2011	35	Epeorus sp.	1	0.690	0.589
DEA101	8/2/2011	35	Simulium sp.	1	0.241	0.172
DEA101	8/2/2011	35	Muscidae	1	0.090	0.067
DEA101	9/6/2011	21	Chironomidae	2	1014.365	914.215
DEA101	9/6/2011	21	Baetis tricaudatus	1	33.878	30.203

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA101	9/6/2011	21	Oligochaete (class B)	1	28.688	25.631
DEA101	9/6/2011	21	Caudatella heterocaudata	1	24.895	25.784
DEA101	9/6/2011	21	Oligochaete (class A)	1	23.363	25.063
DEA101	9/6/2011	21	Drunella coloradensis/flavilinea	1	19.876	21.421
DEA101	9/6/2011	21	Oligochaete (class C)	1	13.490	11.825
DEA101	9/6/2011	21	Malenka sp.	1	12.818	12.506
DEA101	9/6/2011	21	Serratella tibialis	1	4.222	4.279
DEA101	9/6/2011	21	Optioservus sp.	1	1.648	1.501
DEA101	9/6/2011	21	Simulium sp.	1	0.839	0.712
DEA101	9/6/2011	21	Hesperoperla pacifica	1	0.498	0.412
DEA101	9/6/2011	21	Caudatella hystrix	1	0.498	0.437
DEA101	9/27/2011	NA	Antocha sp.	1	0.000	4.198
DEA101	9/27/2011	NA	Baetis sp.	1	0.000	0.369
DEA101	9/27/2011	NA	Baetis tricaudatus	1	0.000	3.339
DEA101	9/27/2011	NA	Capniidae	1	0.000	0.117
DEA101	9/27/2011	NA	Caudatella sp.	1	0.000	0.045
DEA101	9/27/2011	NA	Chironomidae	2	0.000	299.631
DEA101	9/27/2011	NA	Ephemerella dorothea/excrucians	1	0.000	3.075
DEA101	9/27/2011	NA	Oligochaete (class B)	1	0.000	17.285
DEA101	9/27/2011	NA	Oligochaete (class C)	1	0.000	4.624
DEA101	9/27/2011	NA	Optioservus sp.	1	0.000	0.360
DEA101	9/27/2011	NA	Rhyacophila coloradensis gr.	1	0.000	2.671
DEA101	9/27/2011	NA	Rhyacophila hyalinata gr.	1	0.000	0.902
DEA101	9/27/2011	NA	Rhyacophila narvae	1	0.000	0.223
DEA101	9/27/2011	NA	Simulium sp.	1	0.000	0.560
DEA101	9/27/2011	NA	Sweltsa sp.	1	0.000	8.703
DEA101	9/27/2011	NA	Zapada cinctipes	1	0.000	1.613
DEA102	6/30/2010	28	Brachycentrus americanus	1	360.937	218.262
DEA102	6/30/2010	28	Chironomidae	2	299.140	164.100
DEA102	6/30/2010	28	Oligochaete (class C)	1	289.756	167.244
DEA102	6/30/2010	28	Apataniidae	1	100.069	63.943
DEA102	6/30/2010	28	Optioservus sp.	2	89.044	51.656
DEA102	6/30/2010	28	Hydropsyche sp.	3	78.558	51.914
DEA102	6/30/2010	28	Drunella doddsii	2	63.121	48.007
DEA102	6/30/2010	28	Drunella coloradensis/flavilinea	1	29.371	18.282
DEA102	6/30/2010	28	Claassenia sabulosa	1	24.644	16.417
DEA102	6/30/2010	28	Glutops sp.	3	24.070	15.974
DEA102	6/30/2010	28	Glossosomatidae	1	20.482	13.258
DEA102	6/30/2010	28	Rhithrogena sp.	1	18.186	12.795
DEA102	6/30/2010	28	Rhyacophila angelita gr.	1	13.761	9.168

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	6/30/2010	28	Baetis tricaudatus	1	12.564	7.119
DEA102	6/30/2010	28	Chloroperlidae	1	8.670	5.042
DEA102	6/30/2010	28	Rhyacophila narvae	1	8.628	4.735
DEA102	6/30/2010	28	Narpus sp.	1	7.850	4.977
DEA102	6/30/2010	28	Caudatella edmundsi	1	7.508	4.835
DEA102	6/30/2010	28	Glossosoma sp.	2	6.963	4.410
DEA102	6/30/2010	28	Tipulidae	1	6.582	4.474
DEA102	6/30/2010	28	Rhyacophila pellisa/valuma	2	6.569	4.368
DEA102	6/30/2010	28	Cinygmula sp.	1	6.366	4.063
DEA102	6/30/2010	28	Hexatoma sp.	1	5.986	3.950
DEA102	6/30/2010	28	Antocha sp.	1	4.587	3.056
DEA102	6/30/2010	28	Zaitzevia sp.	2	4.158	2.399
DEA102	6/30/2010	28	Ephemerella dorothea/excrucians	1	4.013	2.569
DEA102	6/30/2010	28	Neoplasta sp.	1	3.951	2.058
DEA102	6/30/2010	28	Sweltsa sp.	1	3.906	2.063
DEA102	6/30/2010	28	Epeorus longimanus	1	2.896	1.741
DEA102	6/30/2010	28	Heterlimnius sp.	1	1.959	1.096
DEA102	6/30/2010	28	Cleptelmis addenda	1	0.871	0.529
DEA102	6/30/2010	28	Epeorus sp.	1	0.400	0.227
DEA102	6/30/2010	28	Diphetor hageni	1	0.290	0.156
DEA102	6/30/2010	28	Lepidostoma sp.	1	0.260	0.144
DEA102	6/30/2010	28	Rhyacophila arnaudi	1	0.186	0.104
DEA102	6/30/2010	28	Perlidae	1	0.183	0.100
DEA102	6/30/2010	28	Acentrella sp.	1	0.150	0.079
DEA102	6/30/2010	28	Micrasema sp.	1	0.047	0.024
DEA102	7/28/2010	21	Brachycentrus americanus	3	656.620	519.331
DEA102	7/28/2010	21	Oligochaete (class C)	1	644.763	445.061
DEA102	7/28/2010	21	Chironomidae	2	340.812	230.256
DEA102	7/28/2010	21	Optioservus sp.	2	267.104	175.219
DEA102	7/28/2010	21	Hydropsyche sp.	2	93.203	72.966
DEA102	7/28/2010	21	Rhyacophila brunnea gr.	1	40.310	31.112
DEA102	7/28/2010	21	Claassenia sabulosa	2	25.157	19.661
DEA102	7/28/2010	21	Sweltsa sp.	1	22.570	14.403
DEA102	7/28/2010	21	Zaitzevia sp.	2	13.491	9.137
DEA102	7/28/2010	21	Rhyacophila narvae	1	10.898	7.174
DEA102	7/28/2010	21	Acentrella insignificans	1	10.710	7.063
DEA102	7/28/2010	21	Heterlimnius sp.	1	9.944	6.731
DEA102	7/28/2010	21	Drunella coloradensis/flavilinea	1	8.879	6.831
DEA102	7/28/2010	21	Ochrotrichia sp.	1	7.333	4.531
DEA102	7/28/2010	21	Paraperla sp.	1	6.926	5.463

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	7/28/2010	21	Baetis flavistriga	1	5.894	3.819
DEA102	7/28/2010	21	Serratella tibialis	1	5.736	4.143
DEA102	7/28/2010	21	Epeorus albertae	1	4.866	3.620
DEA102	7/28/2010	21	Hesperoperla pacifica	1	4.228	2.979
DEA102	7/28/2010	21	Suwallia sp.	1	4.182	3.040
DEA102	7/28/2010	21	Acentrella turbida	1	3.768	2.590
DEA102	7/28/2010	21	Hydropsychidae	1	3.719	2.729
DEA102	7/28/2010	21	Neoplasta sp.	2	3.489	2.140
DEA102	7/28/2010	21	Rhithrogena sp.	1	3.171	1.824
DEA102	7/28/2010	21	Narpus sp.	1	2.993	2.253
DEA102	7/28/2010	21	Cleptelmis addenda	1	2.974	1.984
DEA102	7/28/2010	21	Perlodidae	1	2.907	1.809
DEA102	7/28/2010	21	Drunella doddsii	1	2.532	1.176
DEA102	7/28/2010	21	Simulium sp.	1	2.427	1.499
DEA102	7/28/2010	21	Baetis tricaudatus	1	2.366	1.531
DEA102	7/28/2010	21	Chloroperlidae	1	2.163	1.505
DEA102	7/28/2010	21	Oligochaete (class B)	1	1.833	1.224
DEA102	7/28/2010	21	Paraleptophlebia sp.	1	1.434	0.916
DEA102	7/28/2010	21	Ephemerellidae	1	1.402	0.801
DEA102	7/28/2010	21	Baetis alius	1	0.822	0.575
DEA102	7/28/2010	21	Arctopsychinae	1	0.591	0.367
DEA102	7/28/2010	21	Brachycentrus sp.	1	0.258	0.134
DEA102	7/28/2010	21	Neophylax sp.	1	0.209	0.113
DEA102	7/28/2010	21	Glossosomatidae	1	0.125	0.073
DEA102	7/28/2010	21	Drunella spinifera	1	0.115	0.069
DEA102	8/18/2010	48	Antocha sp.	1	1070.659	630.477
DEA102	8/18/2010	48	Oligochaete (class C)	1	838.040	447.625
DEA102	8/18/2010	48	Brachycentrus americanus	1	528.462	321.483
DEA102	8/18/2010	48	Optioservus sp.	2	408.651	208.565
DEA102	8/18/2010	48	Hydropsyche sp.	3	281.323	168.589
DEA102	8/18/2010	48	Chironomidae	2	261.543	127.578
DEA102	8/18/2010	48	Ephemerella dorothea/excrucians	1	77.955	36.027
DEA102	8/18/2010	48	Timpanoga hecuba	1	70.971	44.414
DEA102	8/18/2010	48	Sweltsa sp.	1	69.369	34.898
DEA102	8/18/2010	48	Hexatoma sp.	1	60.578	37.618
DEA102	8/18/2010	48	Rhyacophila brunnea gr.	2	47.913	26.867
DEA102	8/18/2010	48	Glossosoma sp.	2	46.471	24.254
DEA102	8/18/2010	48	Arctopsyche grandis	1	43.507	23.310
DEA102	8/18/2010	48	Rhyacophila narvae	1	28.874	15.395
DEA102	8/18/2010	48	Rhithrogena sp.	1	23.448	11.102

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	8/18/2010	48	Oligophlebodes sp.	1	16.164	7.353
DEA102	8/18/2010	48	Claassenia sabulosa	2	14.427	8.219
DEA102	8/18/2010	48	Zaitzevia sp.	2	13.836	7.269
DEA102	8/18/2010	48	Heterlimnius sp.	1	13.046	6.921
DEA102	8/18/2010	48	Ochrotrichia sp.	2	11.398	6.056
DEA102	8/18/2010	48	Perlodidae	1	10.717	5.244
DEA102	8/18/2010	48	Drunella doddsii	1	9.631	6.343
DEA102	8/18/2010	48	Oreodytes sp.	2	9.362	5.212
DEA102	8/18/2010	48	Capniidae	1	9.176	4.118
DEA102	8/18/2010	48	Micrasema sp.	1	8.481	4.446
DEA102	8/18/2010	48	Acentrella insignificans	1	7.567	4.008
DEA102	8/18/2010	48	Bezzia/Palpomyia sp.	1	7.208	3.675
DEA102	8/18/2010	48	Cleptelmis addenda	1	6.797	3.417
DEA102	8/18/2010	48	Rhyacophila pellisa/valuma	1	5.608	2.546
DEA102	8/18/2010	48	Apatania sp.	1	5.389	2.809
DEA102	8/18/2010	48	Attenella margarita	1	5.261	2.748
DEA102	8/18/2010	48	Zapada cinctipes	1	4.647	2.218
DEA102	8/18/2010	48	Perlidae	1	4.229	2.075
DEA102	8/18/2010	48	Baetis tricaudatus	1	3.435	1.568
DEA102	8/18/2010	48	Lepidostoma sp.	1	3.352	1.583
DEA102	8/18/2010	48	Rhyacophila angelita gr.	1	3.174	1.670
DEA102	8/18/2010	48	Acentrella turbida	1	2.606	1.164
DEA102	8/18/2010	48	Paraleptophlebia sp.	1	2.602	1.309
DEA102	8/18/2010	48	Lepidostomatidae	1	2.519	1.308
DEA102	8/18/2010	48	Hesperoperla pacifica	1	2.356	1.097
DEA102	8/18/2010	48	Simulium sp.	1	2.073	1.025
DEA102	8/18/2010	48	Glutops sp.	2	2.035	1.044
DEA102	8/18/2010	48	Hydroptilidae	1	1.727	0.878
DEA102	8/18/2010	48	Neoplasta sp.	1	1.724	0.857
DEA102	8/18/2010	48	Ephemerellidae	1	1.541	0.705
DEA102	8/18/2010	48	Parapsyche sp.	1	1.473	0.706
DEA102	8/18/2010	48	Arctopsychinae	1	0.460	0.209
DEA102	8/18/2010	48	Brachycentrus sp.	1	0.280	0.124
DEA102	8/18/2010	48	Neophylax sp.	1	0.211	0.095
DEA102	8/18/2010	48	Philopotamidae	1	0.182	0.085
DEA102	10/5/2010	274	Antocha sp.	2	2296.014	795.588
DEA102	10/5/2010	274	Oligochaete (class C)	1	618.043	193.161
DEA102	10/5/2010	274	Brachycentrus americanus	1	533.452	188.185
DEA102	10/5/2010	274	Hydropsyche sp.	2	402.170	138.992
DEA102	10/5/2010	274	Chironomidae	2	312.082	87.009
DEA102	10/5/2010	274	Optioservus sp.	2	275.889	81.985

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	10/5/2010	274	Hexatoma sp.	2	243.516	85.095
DEA102	10/5/2010	274	Ephemerella dorothea/excrucians	1	168.091	47.587
DEA102	10/5/2010	274	Glossosoma sp.	2	81.946	24.600
DEA102	10/5/2010	274	Sweltsa sp.	1	72.350	21.738
DEA102	10/5/2010	274	Cinygmula sp.	1	63.338	17.395
DEA102	10/5/2010	274	Arctopsyche grandis	1	60.378	20.997
DEA102	10/5/2010	274	Dicranota sp.	1	43.849	14.480
DEA102	10/5/2010	274	Rhyacophila narvae	2	40.452	13.762
DEA102	10/5/2010	274	Claassenia sabulosa	2	40.209	13.533
DEA102	10/5/2010	274	Rhithrogena sp.	1	31.411	9.644
DEA102	10/5/2010	274	Drunella doddsii	1	16.886	5.495
DEA102	10/5/2010	274	Oligophlebodes sp.	1	16.077	4.523
DEA102	10/5/2010	274	Capniidae	1	13.478	3.704
DEA102	10/5/2010	274	Perlodidae	1	12.273	3.556
DEA102	10/5/2010	274	Rhyacophila sp.	1	11.478	3.403
DEA102	10/5/2010	274	Drunella grandis	1	11.013	3.563
DEA102	10/5/2010	274	Acentrella insignificans	1	10.621	3.076
DEA102	10/5/2010	274	Rhyacophila brunnea gr.	1	10.370	2.976
DEA102	10/5/2010	274	Chloroperlidae	1	9.074	2.683
DEA102	10/5/2010	274	Cleptelmis addenda	1	8.838	2.708
DEA102	10/5/2010	274	Oligochaete (class B)	1	8.387	2.621
DEA102	10/5/2010	274	Rhyacophila pellisa/valuma	1	8.165	2.443
DEA102	10/5/2010	274	Zapada cinctipes	1	6.537	1.957
DEA102	10/5/2010	274	Paraperla sp.	1	6.327	1.964
DEA102	10/5/2010	274	Bezzia/Palpomyia sp.	1	6.071	1.827
DEA102	10/5/2010	274	Baetis sp.	1	5.585	1.521
DEA102	10/5/2010	274	Lepidostoma sp.	1	5.007	1.477
DEA102	10/5/2010	274	Caudatella hystrix	1	4.988	1.485
DEA102	10/5/2010	274	Perlidae	1	4.793	1.294
DEA102	10/5/2010	274	Micrasema sp.	1	4.296	1.319
DEA102	10/5/2010	274	Baetis tricaudatus	1	4.257	1.175
DEA102	10/5/2010	274	Attenella margarita	1	3.988	1.288
DEA102	10/5/2010	274	Heterlimnius sp.	1	3.638	1.087
DEA102	10/5/2010	274	Acentrella turbida	1	3.627	1.015
DEA102	10/5/2010	274	Hydroptila sp.	1	3.071	0.925
DEA102	10/5/2010	274	Hesperoperla pacifica	2	3.061	0.872
DEA102	10/5/2010	274	Empididae	1	2.501	0.664
DEA102	10/5/2010	274	Paraleptophlebia sp.	1	2.018	0.590
DEA102	10/5/2010	274	Dolophilodes sp.	1	1.975	0.613
DEA102	10/5/2010	274	Zaitzevia sp.	1	1.829	0.565

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	10/5/2010	274	Epeorus sp.	1	0.851	0.221
DEA102	10/5/2010	274	Leptophlebiidae	1	0.175	0.045
DEA102	7/6/2011	28	Chironomidae	2	246.673	167.161
DEA102	7/6/2011	28	Brachycentrus americanus	2	246.467	202.566
DEA102	7/6/2011	28	Oligochaete (class C)	1	154.825	108.908
DEA102	7/6/2011	28	Epeorus longimanus	2	129.205	96.515
DEA102	7/6/2011	28	Drunella doddsii	2	110.165	98.362
DEA102	7/6/2011	28	Antocha sp.	3	71.531	60.972
DEA102	7/6/2011	28	Optioservus sp.	2	70.516	49.005
DEA102	7/6/2011	28	Narpus sp.	1	65.410	49.209
DEA102	7/6/2011	28	Hesperoperla pacifica	2	53.722	49.306
DEA102	7/6/2011	28	Simulium sp.	1	50.221	33.117
DEA102	7/6/2011	28	Rhyacophila angelita gr.	3	49.854	39.921
DEA102	7/6/2011	28	Drunella coloradensis/flavilinea	1	45.068	34.277
DEA102	7/6/2011	28	Neophylax sp.	2	33.191	25.905
DEA102	7/6/2011	28	Baetis tricaudatus	1	31.784	22.572
DEA102	7/6/2011	28	Neophylax rickeri	2	28.711	22.471
DEA102	7/6/2011	28	Rhithrogena sp.	1	26.689	22.693
DEA102	7/6/2011	28	Hydropsyche sp.	1	25.489	19.751
DEA102	7/6/2011	28	Ephemerella dorothea/excrucians	2	14.745	11.852
DEA102	7/6/2011	28	Drunella spinifera	1	13.722	12.059
DEA102	7/6/2011	28	Claassenia sabulosa	2	13.221	11.233
DEA102	7/6/2011	28	Cinygmula sp.	1	11.237	8.425
DEA102	7/6/2011	28	Glutops sp.	1	11.215	8.568
DEA102	7/6/2011	28	Rhyacophila pellisa/valuma	3	10.998	8.568
DEA102	7/6/2011	28	Serratella tibialis	1	10.615	6.978
DEA102	7/6/2011	28	Oligochaete (class A)	1	9.578	8.063
DEA102	7/6/2011	28	Rhyacophila brunnea gr.	1	9.078	7.498
DEA102	7/6/2011	28	Ephemerellidae	1	8.648	6.021
DEA102	7/6/2011	28	Glossosoma sp.	1	7.069	5.759
DEA102	7/6/2011	28	Chloroperlidae	1	5.673	3.838
DEA102	7/6/2011	28	Sweltsa sp.	1	5.065	3.250
DEA102	7/6/2011	28	Hexatoma sp.	1	4.722	3.910
DEA102	7/6/2011	28	Caudatella heterocaudata	1	4.715	3.541
DEA102	7/6/2011	28	Micrasema sp.	1	4.149	2.786
DEA102	7/6/2011	28	Rhyacophila narvae	1	3.765	2.562
DEA102	7/6/2011	28	Glossosomatidae	1	3.322	2.594
DEA102	7/6/2011	28	Limnophila sp.	1	2.723	2.186
DEA102	7/6/2011	28	Hesperoconopa sp.	1	2.721	2.036
DEA102	7/6/2011	28	Diphetor hageni	1	2.300	1.608

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	7/6/2011	28	Rhabdomastix fascigera gr.	1	2.288	1.749
DEA102	7/6/2011	28	Oligochaete (class B)	1	1.758	1.226
DEA102	7/6/2011	28	Neoplasta sp.	1	1.124	0.720
DEA102	7/6/2011	28	Oligophlebodes sp.	1	0.973	0.738
DEA102	7/6/2011	28	Rhyacophila sp.	1	0.947	0.655
DEA102	7/6/2011	28	Rhyacophila coloradensis gr.	1	0.800	0.600
DEA102	7/6/2011	28	Lepidostoma sp.	1	0.784	0.486
DEA102	7/6/2011	28	Perlidae	1	0.675	0.429
DEA102	7/6/2011	28	Paraperla sp.	1	0.449	0.326
DEA102	7/6/2011	28	Paraleptophlebia sp.	1	0.354	0.230
DEA102	7/6/2011	28	Trichoclinocera sp.	1	0.298	0.201
DEA102	7/6/2011	28	Zaitzevia sp.	1	0.251	0.173
DEA102	7/6/2011	28	Clinocera sp.	1	0.123	0.081
DEA102	7/6/2011	28	Ameletus sp.	1	0.106	0.071
DEA102	7/6/2011	28	Acentrella sp.	1	0.050	0.031
DEA102	8/3/2011	22	Brachycentrus americanus	2	640.950	622.766
DEA102	8/3/2011	22	Chironomidae	2	220.612	164.169
DEA102	8/3/2011	22	Arctopsyche grandis	1	168.530	166.245
DEA102	8/3/2011	22	Claassenia sabulosa	2	131.471	135.188
DEA102	8/3/2011	22	Optioservus sp.	2	111.723	87.526
DEA102	8/3/2011	22	Oligochaete (class C)	1	91.531	72.028
DEA102	8/3/2011	22	Epeorus longimanus	2	62.963	54.555
DEA102	8/3/2011	22	Rhyacophila angelita gr.	3	45.744	41.106
DEA102	8/3/2011	22	Simulium sp.	1	43.864	33.816
DEA102	8/3/2011	22	Antocha sp.	1	34.984	33.641
DEA102	8/3/2011	22	Narpus sp.	1	31.963	27.222
DEA102	8/3/2011	22	Serratella tibialis	1	31.312	22.878
DEA102	8/3/2011	22	Acentrella insignificans	1	27.558	21.196
DEA102	8/3/2011	22	Sweltsa sp.	1	25.720	19.528
DEA102	8/3/2011	22	Drunella doddsii	1	17.878	13.117
DEA102	8/3/2011	22	Glossosoma sp.	1	17.770	12.971
DEA102	8/3/2011	22	Baetis tricaudatus	1	17.010	12.803
DEA102	8/3/2011	22	Hydropsyche sp.	1	16.557	15.270
DEA102	8/3/2011	22	Rhyacophila narvae	1	12.692	9.637
DEA102	8/3/2011	22	Acentrella turbida	1	12.184	9.091
DEA102	8/3/2011	22	Rhithrogena sp.	1	10.433	7.434
DEA102	8/3/2011	22	Micrasema sp.	1	7.844	5.956
DEA102	8/3/2011	22	Baetis flavistriga	1	7.227	3.768
DEA102	8/3/2011	22	Ephemerellidae	2	6.581	5.796
DEA102	8/3/2011	22	Drunella coloradensis/flavilinea	1	4.926	4.314
DEA102	8/3/2011	22	Caudatella heterocaudata	2	4.195	3.478

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	8/3/2011	22	Chloroperlidae	1	3.300	2.542
DEA102	8/3/2011	22	Zaitzevia sp.	2	3.105	2.432
DEA102	8/3/2011	22	Cleptelmis addenda	1	2.938	2.460
DEA102	8/3/2011	22	Drunella grandis	1	2.741	1.971
DEA102	8/3/2011	22	Chelifera/Metachela sp.	2	2.720	2.046
DEA102	8/3/2011	22	Heterlimnius sp.	1	2.499	1.867
DEA102	8/3/2011	22	Neoplasta sp.	1	2.064	1.522
DEA102	8/3/2011	22	Caudatella sp.	1	2.028	1.430
DEA102	8/3/2011	22	Lepidostoma sp.	1	1.925	1.498
DEA102	8/3/2011	22	Rhyacophila pellisa/valuma	1	1.854	1.509
DEA102	8/3/2011	22	Perlodidae	1	1.464	1.125
DEA102	8/3/2011	22	Hesperoperla pacifica	1	1.344	0.565
DEA102	8/3/2011	22	Perlidae	1	1.322	1.007
DEA102	8/3/2011	22	Hydroptilidae	1	0.929	0.653
DEA102	8/3/2011	22	Arctopsychinae	1	0.359	0.253
DEA102	8/3/2011	22	Paraleptophlebia sp.	1	0.202	0.148
DEA102	8/3/2011	22	Epeorus sp.	1	0.127	0.089
DEA102	8/25/2011	33	Antocha sp.	1	1246.823	1138.354
DEA102	8/25/2011	33	Brachycentrus americanus	1	349.324	361.263
DEA102	8/25/2011	33	Chironomidae	2	296.696	244.851
DEA102	8/25/2011	33	Optioservus sp.	3	264.607	228.042
DEA102	8/25/2011	33	Oligochaete (class C)	1	213.486	181.834
DEA102	8/25/2011	33	Hydropsyche sp.	2	198.193	183.821
DEA102	8/25/2011	33	Arctopsyche grandis	2	150.307	152.715
DEA102	8/25/2011	33	Drunella doddsii	1	124.236	106.008
DEA102	8/25/2011	33	Glossosoma sp.	2	109.830	96.233
DEA102	8/25/2011	33	Drunella grandis	1	70.620	60.149
DEA102	8/25/2011	33	Micrasema sp.	1	58.369	50.755
DEA102	8/25/2011	33	Sweltsa sp.	1	56.742	47.510
DEA102	8/25/2011	33	Rhithrogena sp.	1	32.180	26.979
DEA102	8/25/2011	33	Baetis tricaudatus	1	31.510	25.652
DEA102	8/25/2011	33	Glutops sp.	1	31.081	28.993
DEA102	8/25/2011	33	Hexatoma sp.	3	25.068	25.210
DEA102	8/25/2011	33	Oligophlebodes sp.	1	24.481	19.292
DEA102	8/25/2011	33	Rhyacophila narvae	1	24.037	21.618
DEA102	8/25/2011	33	Narpus sp.	1	22.977	20.966
DEA102	8/25/2011	33	Lepidostoma sp.	1	19.191	16.191
DEA102	8/25/2011	33	Serratella tibialis	1	17.063	15.949
DEA102	8/25/2011	33	Rhyacophila pellisa/valuma	1	16.058	13.050
DEA102	8/25/2011	33	Rhyacophila brunnea gr.	1	13.683	13.481
DEA102	8/25/2011	33	Ameletus sp.	1	11.978	11.176

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	8/25/2011	33	Claassenia sabulosa	1	11.153	9.456
DEA102	8/25/2011	33	Acentrella insignificans	1	10.083	8.594
DEA102	8/25/2011	33	Cleptelmis addenda	1	9.149	8.085
DEA102	8/25/2011	33	Zaitzevia sp.	2	8.430	7.326
DEA102	8/25/2011	33	Perlodidae	1	8.233	6.767
DEA102	8/25/2011	33	Caudatella hystrix	1	7.239	6.930
DEA102	8/25/2011	33	Acentrella turbida	1	6.839	5.709
DEA102	8/25/2011	33	Neophylax rickeri	1	4.829	4.897
DEA102	8/25/2011	33	Leptophlebiidae	1	4.687	3.859
DEA102	8/25/2011	33	Rhyacophila angelita gr.	2	4.643	4.566
DEA102	8/25/2011	33	Heterlimnius sp.	1	3.492	3.009
DEA102	8/25/2011	33	Limnophila sp.	1	3.236	3.209
DEA102	8/25/2011	33	Baetis flavistriga	1	2.351	2.075
DEA102	8/25/2011	33	Neoplasta sp.	1	2.161	1.743
DEA102	8/25/2011	33	Perlidae	1	0.983	0.811
DEA102	8/25/2011	33	Simulium sp.	1	0.881	0.752
DEA102	8/25/2011	33	Ochrotrichia sp.	1	0.861	0.739
DEA102	8/25/2011	33	Hydroptilidae	2	0.848	0.729
DEA102	8/25/2011	33	Ephemerella sp.	1	0.813	0.636
DEA102	8/25/2011	33	Apatania sp.	1	0.626	0.549
DEA102	8/25/2011	33	Hesperoperla pacifica	1	0.527	0.472
DEA102	8/25/2011	33	Parapsyche elsis	1	0.522	0.453
DEA102	8/25/2011	33	Neophylax sp.	1	0.306	0.243
DEA102	8/25/2011	33	Clinocera sp.	1	0.150	0.116
DEA102	8/25/2011	33	Drunella spinifera	1	0.103	0.082
DEA102	8/25/2011	33	Bezzia/Palpomyia sp.	1	0.063	0.048
DEA102	9/27/2011	NA	Acentrella sp.	1	0.000	0.257
DEA102	9/27/2011	NA	Acentrella turbida	1	0.000	2.402
DEA102	9/27/2011	NA	Ameletus sp.	1	0.000	9.397
DEA102	9/27/2011	NA	Antocha sp.	1	0.000	1108.969
DEA102	9/27/2011	NA	Arctopsyche grandis	1	0.000	25.253
DEA102	9/27/2011	NA	Baetis tricaudatus	1	0.000	19.991
DEA102	9/27/2011	NA	Brachycentrus americanus	2	0.000	322.986
DEA102	9/27/2011	NA	Capniidae	1	0.000	5.254
DEA102	9/27/2011	NA	Caudatella edmundsi	1	0.000	4.012
DEA102	9/27/2011	NA	Caudatella hystrix	1	0.000	4.202
DEA102	9/27/2011	NA	Chelifera/Metachela sp.	1	0.000	3.662
DEA102	9/27/2011	NA	Chironomidae	2	0.000	187.853
DEA102	9/27/2011	NA	Cinygmula sp.	1	0.000	2.932
DEA102	9/27/2011	NA	Claassenia sabulosa	1	0.000	7.696
DEA102	9/27/2011	NA	Cleptelmis addenda	1	0.000	7.084

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA102	9/27/2011	NA	Diphetor hageni	1	0.000	0.086
DEA102	9/27/2011	NA	Dolophilodes sp.	1	0.000	70.410
DEA102	9/27/2011	NA	Drunella doddsii	1	0.000	95.070
DEA102	9/27/2011	NA	Drunella grandis	1	0.000	58.455
DEA102	9/27/2011	NA	Ephemerella dorothea/excrucians	1	0.000	84.022
DEA102	9/27/2011	NA	Eucapnopsis brevicauda	1	0.000	0.673
DEA102	9/27/2011	NA	Glossosoma sp.	2	0.000	93.478
DEA102	9/27/2011	NA	Glutops sp.	2	0.000	26.805
DEA102	9/27/2011	NA	Hesperoperla pacifica	1	0.000	1.622
DEA102	9/27/2011	NA	Heterlimnius sp.	1	0.000	1.428
DEA102	9/27/2011	NA	Hydropsyche sp.	2	0.000	168.955
DEA102	9/27/2011	NA	Lepidostoma sp.	1	0.000	15.155
DEA102	9/27/2011	NA	Leptophlebiidae	1	0.000	3.428
DEA102	9/27/2011	NA	Micrasema sp.	1	0.000	47.510
DEA102	9/27/2011	NA	Narpus sp.	2	0.000	18.867
DEA102	9/27/2011	NA	Neophylax sp.	1	0.000	20.819
DEA102	9/27/2011	NA	Neoplasta sp.	1	0.000	0.389
DEA102	9/27/2011	NA	Oligochaete (class B)	1	0.000	3.171
DEA102	9/27/2011	NA	Oligochaete (class C)	1	0.000	175.467
DEA102	9/27/2011	NA	Oligophlebodes sp.	1	0.000	19.219
DEA102	9/27/2011	NA	Optioservus sp.	2	0.000	181.481
DEA102	9/27/2011	NA	Paraleptophlebia sp.	1	0.000	0.103
DEA102	9/27/2011	NA	Perlidae	1	0.000	0.115
DEA102	9/27/2011	NA	Perlodidae	1	0.000	6.011
DEA102	9/27/2011	NA	Rhithrogena sp.	1	0.000	20.536
DEA102	9/27/2011	NA	Rhyacophila coloradensis gr.	1	0.000	26.073
DEA102	9/27/2011	NA	Rhyacophila narvae	2	0.000	14.418
DEA102	9/27/2011	NA	Rhyacophila pellisa/valuma	1	0.000	12.975
DEA102	9/27/2011	NA	Rhyacophila sp.	1	0.000	1.415
DEA102	9/27/2011	NA	Sweltsa sp.	1	0.000	30.596
DEA102	9/27/2011	NA	Wiedemannia sp.	1	0.000	0.111
DEA102	9/27/2011	NA	Zaitzevia sp.	2	0.000	6.191
DEA102	9/27/2011	NA	Zapada cinctipes	1	0.000	2.615
DEA108	7/6/2010	28	Oligochaete (class C)	1	78.520	66.459
DEA108	7/6/2010	28	Chironomidae	2	46.152	37.714
DEA108	7/6/2010	28	Brachycentrus americanus	2	40.313	41.627
DEA108	7/6/2010	28	Drunella coloradensis/flavilinea	1	35.372	32.251
DEA108	7/6/2010	28	Serratella tibialis	1	32.811	25.707
DEA108	7/6/2010	28	Epeorus longimanus	1	26.261	22.309
DEA108	7/6/2010	28	Antocha sp.	1	22.470	23.272

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	7/6/2010	28	Baetis tricaudatus	1	15.247	56.041
DEA108	7/6/2010	28	Hexatoma sp.	1	14.654	14.561
DEA108	7/6/2010	28	Hesperoperla pacifica	2	12.510	12.110
DEA108	7/6/2010	28	Atherix sp.	2	11.748	10.592
DEA108	7/6/2010	28	Caudatella edmundsi	1	10.428	9.859
DEA108	7/6/2010	28	Pteronarcys princeps	1	9.985	9.886
DEA108	7/6/2010	28	Simulium sp.	1	9.158	8.126
DEA108	7/6/2010	28	Suwallia sp.	1	6.220	5.588
DEA108	7/6/2010	28	Caudatella heterocaudata	1	5.587	4.962
DEA108	7/6/2010	28	Rhithrogena sp.	2	5.543	5.107
DEA108	7/6/2010	28	Ameletus sp.	2	3.981	3.998
DEA108	7/6/2010	28	Cinygmula sp.	2	3.074	2.882
DEA108	7/6/2010	28	Rhyacophila coloradensis gr.	2	2.678	2.543
DEA108	7/6/2010	28	Optioservus sp.	1	1.173	0.935
DEA108	7/6/2010	28	Neophylax rickeri	1	1.041	0.994
DEA108	7/6/2010	28	Rhyacophila angelita gr.	1	1.031	0.944
DEA108	7/6/2010	28	Epeorus sp.	1	0.977	0.788
DEA108	7/6/2010	28	Neoplasta sp.	1	0.866	0.746
DEA108	7/6/2010	28	Rhyacophila sp.	2	0.676	0.597
DEA108	7/6/2010	28	Diphetor hageni	1	0.575	0.816
DEA108	7/6/2010	28	Chloroperlidae	1	0.471	0.431
DEA108	7/6/2010	28	Deuterophlebia sp.	1	0.464	0.395
DEA108	7/6/2010	28	Empididae	1	0.357	0.300
DEA108	7/6/2010	28	Drunella doddsii	1	0.328	0.248
DEA108	7/6/2010	28	Acentrella sp.	1	0.303	0.221
DEA108	7/6/2010	28	Caudatella sp.	1	0.273	0.223
DEA108	7/6/2010	28	Trichoclinocera sp.	1	0.100	0.081
DEA108	7/6/2010	28	Paraleptophlebia sp.	1	0.066	0.053
DEA108	8/3/2010	16	Oligochaete (class C)	1	82.013	119.416
DEA108	8/3/2010	16	Baetis tricaudatus	1	77.602	108.374
DEA108	8/3/2010	16	Antocha sp.	2	74.655	125.697
DEA108	8/3/2010	16	Hexatoma sp.	2	64.398	108.572
DEA108	8/3/2010	16	Chironomidae	2	51.366	68.615
DEA108	8/3/2010	16	Serratella tibialis	1	47.677	71.171
DEA108	8/3/2010	16	Epeorus longimanus	1	38.914	26.355
DEA108	8/3/2010	16	Brachycentrus occidentalis	1	30.970	37.915
DEA108	8/3/2010	16	Oligochaete (class A)	1	28.059	45.264
DEA108	8/3/2010	16	Drunella coloradensis/flavilinea	1	17.213	26.708
DEA108	8/3/2010	16	Simulium sp.	1	15.407	21.579
DEA108	8/3/2010	16	Oligochaete (class B)	1	14.043	20.916
DEA108	8/3/2010	16	Hesperoperla pacifica	2	13.372	17.843

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	8/3/2010	16	Dicranota sp.	1	12.718	20.886
DEA108	8/3/2010	16	Ameletus sp.	2	8.152	12.306
DEA108	8/3/2010	16	Optioservus sp.	2	5.173	7.782
DEA108	8/3/2010	16	Atherix sp.	1	5.085	7.488
DEA108	8/3/2010	16	Pteronarcys sp.	1	4.181	6.142
DEA108	8/3/2010	16	Rhithrogena sp.	1	3.663	4.690
DEA108	8/3/2010	16	Sweltsa sp.	1	3.300	4.446
DEA108	8/3/2010	16	Suwallia sp.	1	2.377	3.575
DEA108	8/3/2010	16	Caudatella edmundsi	1	2.348	3.506
DEA108	8/3/2010	16	Perlodidae	1	2.270	1.783
DEA108	8/3/2010	16	Lepidostomatidae	1	2.113	3.410
DEA108	8/3/2010	16	Lara sp.	1	1.780	2.909
DEA108	8/3/2010	16	Caudatella heterocaudata	1	1.306	1.950
DEA108	8/3/2010	16	Diphetor hageni	1	0.750	0.977
DEA108	8/3/2010	16	Caudatella sp.	1	0.692	0.932
DEA108	8/3/2010	16	Drunella grandis	1	0.632	0.795
DEA108	8/3/2010	16	Leptophlebiidae	1	0.603	0.835
DEA108	8/3/2010	16	Drunella doddsii	1	0.578	0.716
DEA108	8/3/2010	16	Glossosoma sp.	1	0.453	0.601
DEA108	8/3/2010	16	Zapada cinctipes	1	0.350	0.446
DEA108	8/3/2010	16	Neoplasta sp.	1	0.313	0.433
DEA108	8/3/2010	16	Acentrella sp.	1	0.285	0.355
DEA108	8/3/2010	16	Clinocera sp.	1	0.282	0.318
DEA108	8/3/2010	16	Paraleptophlebia sp.	1	0.147	0.179
DEA108	8/3/2010	16	Deuterophlebia sp.	1	0.122	0.160
DEA108	8/3/2010	16	Trichoclinocera sp.	1	0.106	0.127
DEA108	8/3/2010	16	Ephemerellidae	1	0.095	0.114
DEA108	8/3/2010	16	Epeorus sp.	1	0.069	0.093
DEA108	8/3/2010	16	Glossosomatidae	1	0.016	0.019
DEA108	8/19/2010	54	Brachycentrus occidentalis	1	2366.914	877.454
DEA108	8/19/2010	54	Oligochaete (class C)	1	1270.205	505.085
DEA108	8/19/2010	54	Hexatoma sp.	1	815.688	373.801
DEA108	8/19/2010	54	Pteronarcys californica	1	774.222	294.731
DEA108	8/19/2010	54	Antocha sp.	1	555.979	246.425
DEA108	8/19/2010	54	Baetis tricaudatus	1	404.855	148.885
DEA108	8/19/2010	54	Chironomidae	2	226.012	81.760
DEA108	8/19/2010	54	Drunella doddsii	1	201.860	70.213
DEA108	8/19/2010	54	Serratella tibialis	1	130.729	53.913
DEA108	8/19/2010	54	Glossosoma sp.	1	112.667	37.473
DEA108	8/19/2010	54	Sweltsa sp.	1	103.174	38.088
DEA108	8/19/2010	54	Dicranota sp.	1	99.195	43.492

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	8/19/2010	54	Oligochaete (class A)	1	88.057	40.221
DEA108	8/19/2010	54	Oligochaete (class B)	1	61.215	23.585
DEA108	8/19/2010	54	Simulium sp.	2	53.145	20.803
DEA108	8/19/2010	54	Drunella grandis	1	49.734	17.729
DEA108	8/19/2010	54	Hesperoperla pacifica	2	42.392	17.481
DEA108	8/19/2010	54	Epeorus longimanus	1	40.798	16.613
DEA108	8/19/2010	54	Drunella coloradensis/flavilinea	1	28.465	11.902
DEA108	8/19/2010	54	Ameletus sp.	2	27.886	11.733
DEA108	8/19/2010	54	Atherix sp.	1	27.661	10.374
DEA108	8/19/2010	54	Brachycentrus americanus	1	23.881	10.988
DEA108	8/19/2010	54	Rhithrogena sp.	1	19.115	6.915
DEA108	8/19/2010	54	Optioservus sp.	2	14.062	5.500
DEA108	8/19/2010	54	Epeorus albertae	1	12.571	5.195
DEA108	8/19/2010	54	Pteronarcys sp.	1	11.408	4.406
DEA108	8/19/2010	54	Hydropsyche sp.	1	11.066	4.268
DEA108	8/19/2010	54	Rhyacophila coloradensis gr.	1	8.145	3.142
DEA108	8/19/2010	54	Paraleptophlebia sp.	1	7.459	2.674
DEA108	8/19/2010	54	Acentrella insignificans	1	6.779	2.542
DEA108	8/19/2010	54	Caudatella edmundsi	1	3.041	1.168
DEA108	8/19/2010	54	Perlodidae	1	2.991	2.355
DEA108	8/19/2010	54	Suwallia sp.	1	2.795	1.141
DEA108	8/19/2010	54	Caudatella sp.	1	2.131	0.766
DEA108	8/19/2010	54	Acentrella turbida	1	2.034	0.785
DEA108	8/19/2010	54	Diphetor hageni	1	1.429	0.562
DEA108	8/19/2010	54	Ochrotrichia sp.	1	0.939	0.351
DEA108	8/19/2010	54	Clinocera sp.	1	0.914	0.314
DEA108	8/19/2010	54	Arctopsychinae	1	0.814	0.302
DEA108	8/19/2010	54	Leptophlebiidae	1	0.732	0.277
DEA108	8/19/2010	54	Zapada cinctipes	1	0.644	0.222
DEA108	8/19/2010	54	Zapada columbiana	1	0.485	0.175
DEA108	8/19/2010	54	Acentrella sp.	1	0.391	0.139
DEA108	8/19/2010	54	Trichoclinocera sp.	1	0.292	0.102
DEA108	8/19/2010	54	Ephemerellidae	1	0.210	0.067
DEA108	8/19/2010	54	Bezzia/Palpomyia sp.	1	0.106	0.035
DEA108	10/12/2010	272	Brachycentrus occidentalis	1	2891.101	842.293
DEA108	10/12/2010	272	Oligochaete (class C)	1	1723.025	458.067
DEA108	10/12/2010	272	Hexatoma sp.	1	1040.365	311.443
DEA108	10/12/2010	272	Pteronarcys californica	1	802.548	293.752
DEA108	10/12/2010	272	Antocha sp.	1	711.954	194.663
DEA108	10/12/2010	272	Ephemerella dorothea/excrucians	1	515.126	124.794

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	10/12/2010	272	Chironomidae	2	309.461	74.455
DEA108	10/12/2010	272	Baetis tricaudatus	1	299.611	70.090
DEA108	10/12/2010	272	Cinygmula sp.	1	288.026	71.415
DEA108	10/12/2010	272	Glossosoma sp.	2	282.838	74.213
DEA108	10/12/2010	272	Drunella doddsii	1	256.387	69.613
DEA108	10/12/2010	272	Rhyacophila pellisa/valuma	2	149.461	42.652
DEA108	10/12/2010	272	Sweltsa sp.	1	137.705	35.073
DEA108	10/12/2010	272	Dicranota sp.	1	90.593	25.811
DEA108	10/12/2010	272	Atherix sp.	2	71.937	17.859
DEA108	10/12/2010	272	Oligochaete (class B)	1	65.604	17.441
DEA108	10/12/2010	272	Drunella grandis	1	60.854	17.057
DEA108	10/12/2010	272	Arctopsyche grandis	1	48.394	14.239
DEA108	10/12/2010	272	Capniidae	1	33.027	7.953
DEA108	10/12/2010	272	Caudatella edmundsi	1	30.636	10.831
DEA108	10/12/2010	272	Rhithrogena sp.	1	15.745	3.903
DEA108	10/12/2010	272	Epeorus grandis/permagnus	1	14.250	3.707
DEA108	10/12/2010	272	Hydropsyche sp.	1	13.020	3.642
DEA108	10/12/2010	272	Epeorus sp.	1	12.991	2.916
DEA108	10/12/2010	272	Paraleptophlebia sp.	1	9.725	2.517
DEA108	10/12/2010	272	Pteronarcys sp.	1	9.412	2.393
DEA108	10/12/2010	272	Brachycentrus americanus	1	7.897	1.988
DEA108	10/12/2010	272	Caudatella hystrix	1	7.461	1.872
DEA108	10/12/2010	272	Optioservus sp.	1	5.540	1.336
DEA108	10/12/2010	272	Ameletus sp.	1	5.285	1.266
DEA108	10/12/2010	272	Hesperoperla pacifica	1	4.812	1.154
DEA108	10/12/2010	272	Perlodidae	1	4.506	1.188
DEA108	10/12/2010	272	Claassenia sabulosa	1	3.473	0.938
DEA108	10/12/2010	272	Empididae	1	0.031	0.006
DEA108	7/11/2011	29	Pteronarcys californica	2	268.297	244.577
DEA108	7/11/2011	29	Brachycentrus americanus	1	149.988	129.500
DEA108	7/11/2011	29	Baetis tricaudatus	1	137.802	97.895
DEA108	7/11/2011	29	Hexatoma sp.	2	128.250	106.810
DEA108	7/11/2011	29	Epeorus longimanus	1	84.057	58.635
DEA108	7/11/2011	29	Serratella tibialis	1	73.303	52.376
DEA108	7/11/2011	29	Ephemerella dorothea/excrucians	1	70.725	57.318
DEA108	7/11/2011	29	Chironomidae	2	67.582	46.695
DEA108	7/11/2011	29	Drunella coloradensis/flavilinea	1	47.779	35.155
DEA108	7/11/2011	29	Antocha sp.	1	47.306	38.494
DEA108	7/11/2011	29	Drunella doddsii	2	44.412	40.067
DEA108	7/11/2011	29	Atherix sp.	2	26.937	20.729

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	7/11/2011	29	Oligochaete (class C)	1	23.832	16.657
DEA108	7/11/2011	29	Hesperoperla pacifica	3	19.234	15.978
DEA108	7/11/2011	29	Suwallia sp.	1	17.993	12.905
DEA108	7/11/2011	29	Cinygmula sp.	1	13.028	9.957
DEA108	7/11/2011	29	Caudatella edmundsi	1	11.622	9.094
DEA108	7/11/2011	29	Caudatella heterocaudata	1	8.468	7.881
DEA108	7/11/2011	29	Sweltsa sp.	1	6.406	4.312
DEA108	7/11/2011	29	Simulium sp.	1	5.163	3.426
DEA108	7/11/2011	29	Optioservus sp.	2	4.874	3.621
DEA108	7/11/2011	29	Chloroperlidae	1	4.475	3.284
DEA108	7/11/2011	29	Rhyacophila angelita gr.	1	4.170	3.031
DEA108	7/11/2011	29	Diphetor hageni	1	3.744	2.555
DEA108	7/11/2011	29	Zaitzevia sp.	1	2.352	1.757
DEA108	7/11/2011	29	Deuterophlebia sp.	1	2.064	1.382
DEA108	7/11/2011	29	Rhithrogena sp.	1	1.750	1.064
DEA108	7/11/2011	29	Lepidostoma sp.	1	0.592	0.408
DEA108	7/11/2011	29	Rhyacophila pellisa/valuma	1	0.377	0.351
DEA108	7/11/2011	29	Neoplasta sp.	1	0.322	0.224
DEA108	7/11/2011	29	Trichoclinocera sp.	1	0.274	0.184
DEA108	7/11/2011	29	Leptophlebiidae	1	0.203	0.132
DEA108	7/11/2011	29	Perlidae	1	0.168	0.112
DEA108	7/11/2011	29	Epeorus grandis/permagnus	1	0.095	0.062
DEA108	7/11/2011	29	Rhyacophila sp.	1	0.056	0.036
DEA108	8/9/2011	28	Hexatoma sp.	2	155.021	134.055
DEA108	8/9/2011	28	Baetis tricaudatus	1	96.305	68.565
DEA108	8/9/2011	28	Epeorus longimanus	1	56.558	42.738
DEA108	8/9/2011	28	Chironomidae	2	51.242	35.306
DEA108	8/9/2011	28	Brachycentrus americanus	1	49.126	45.424
DEA108	8/9/2011	28	Simulium sp.	2	47.667	35.099
DEA108	8/9/2011	28	Antocha sp.	2	44.052	37.531
DEA108	8/9/2011	28	Hesperoperla pacifica	2	34.991	30.562
DEA108	8/9/2011	28	Serratella tibialis	1	23.699	15.703
DEA108	8/9/2011	28	Oligochaete (class C)	1	21.919	15.663
DEA108	8/9/2011	28	Atherix sp.	2	20.924	16.862
DEA108	8/9/2011	28	Rhithrogena sp.	1	20.636	14.197
DEA108	8/9/2011	28	Drunella coloradensis/flavilinea	1	19.526	15.370
DEA108	8/9/2011	28	Drunella doddsii	1	12.494	8.388
DEA108	8/9/2011	28	Arctopsyche grandis	1	11.436	8.223
DEA108	8/9/2011	28	Suwallia sp.	1	10.308	7.965
DEA108	8/9/2011	28	Sweltsa sp.	1	8.990	6.368
DEA108	8/9/2011	28	Brachycentrus occidentalis	1	7.052	4.846

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	8/9/2011	28	Caudatella heterocaudata	2	6.494	5.198
DEA108	8/9/2011	28	Optioservus sp.	2	5.445	3.968
DEA108	8/9/2011	28	Rhyacophila pellisa/valuma	2	3.271	2.640
DEA108	8/9/2011	28	Oligochaete (class B)	1	2.501	1.893
DEA108	8/9/2011	28	Pteronarcys sp.	1	2.110	1.565
DEA108	8/9/2011	28	Epeorus albertae	1	2.107	1.728
DEA108	8/9/2011	28	Deuterophlebia sp.	2	1.941	1.340
DEA108	8/9/2011	28	Heterlimnius sp.	1	1.376	0.972
DEA108	8/9/2011	28	Acentrella turbida	1	0.964	0.702
DEA108	8/9/2011	28	Arctopsychinae	1	0.787	0.542
DEA108	8/9/2011	28	Neoplasta sp.	1	0.613	0.416
DEA108	8/9/2011	28	Diphetor hageni	1	0.326	0.245
DEA108	8/9/2011	28	Ameletus sp.	1	0.259	0.182
DEA108	8/9/2011	28	Perlodidae	1	0.212	0.147
DEA108	8/9/2011	28	Muscidae	1	0.151	0.108
DEA108	8/9/2011	28	Trichoclinocera sp.	1	0.136	0.090
DEA108	8/9/2011	28	Drunella grandis	1	0.048	0.032
DEA108	8/9/2011	28	Paraleptophlebia sp.	1	0.036	0.024
DEA108	8/9/2011	28	Yoraperla sp.	1	0.034	0.023
DEA108	8/9/2011	28	Glossosomatidae	1	0.024	0.015
DEA108	9/6/2011	28	Baetis tricaudatus	1	182.231	113.883
DEA108	9/6/2011	28	Hexatoma sp.	2	176.341	134.390
DEA108	9/6/2011	28	Pteronarcys californica	2	168.245	141.186
DEA108	9/6/2011	28	Brachycentrus americanus	1	160.049	130.104
DEA108	9/6/2011	28	Arctopsyche grandis	1	127.434	55.665
DEA108	9/6/2011	28	Claassenia sabulosa	1	93.070	82.562
DEA108	9/6/2011	28	Rhithrogena sp.	1	85.842	53.802
DEA108	9/6/2011	28	Oligochaete (class C)	1	55.264	34.633
DEA108	9/6/2011	28	Drunella doddsii	1	51.353	36.864
DEA108	9/6/2011	28	Simulium sp.	3	47.257	31.843
DEA108	9/6/2011	28	Dicranota sp.	1	42.033	29.155
DEA108	9/6/2011	28	Chironomidae	2	40.355	25.183
DEA108	9/6/2011	28	Hesperoperla pacifica	2	31.184	24.497
DEA108	9/6/2011	28	Antocha sp.	1	27.980	19.482
DEA108	9/6/2011	28	Glossosoma sp.	2	26.312	16.790
DEA108	9/6/2011	28	Sweltsa sp.	1	25.762	16.159
DEA108	9/6/2011	28	Epeorus longimanus	1	25.316	17.696
DEA108	9/6/2011	28	Atherix sp.	1	22.815	14.924
DEA108	9/6/2011	28	Serratella tibialis	1	14.031	9.996
DEA108	9/6/2011	28	Oligochaete (class B)	1	11.429	7.149
DEA108	9/6/2011	28	Leuctridae	1	11.061	6.572

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	9/6/2011	28	Ephemerella sp.	1	11.010	6.479
DEA108	9/6/2011	28	Epeorus grandis/permagnus	1	9.041	5.389
DEA108	9/6/2011	28	Caudatella hystrix	1	8.077	5.550
DEA108	9/6/2011	28	Drunella coloradensis/flavilinea	1	7.850	5.640
DEA108	9/6/2011	28	Brachycentrus occidentalis	1	6.769	4.633
DEA108	9/6/2011	28	Optioservus sp.	2	6.019	3.845
DEA108	9/6/2011	28	Rhyacophila coloradensis gr.	1	5.078	3.328
DEA108	9/6/2011	28	Narpus sp.	1	4.669	3.257
DEA108	9/6/2011	28	Hesperoconopa sp.	1	4.242	2.893
DEA108	9/6/2011	28	Taeniopterygidae	1	4.211	2.438
DEA108	9/6/2011	28	Zaitzevia sp.	1	4.175	2.806
DEA108	9/6/2011	28	Leptophlebiidae	1	2.909	1.810
DEA108	9/6/2011	28	Rhyacophila pellisa/valuma	1	2.358	1.476
DEA108	9/6/2011	28	Baetis alius	1	1.912	1.270
DEA108	9/6/2011	28	Cinygmula sp.	1	1.740	1.196
DEA108	9/6/2011	28	Capniidae	1	1.541	0.892
DEA108	9/6/2011	28	Heterlimnius sp.	1	1.525	1.030
DEA108	9/6/2011	28	Pteronarcys sp.	1	1.413	0.922
DEA108	9/6/2011	28	Deuterophlebia sp.	2	1.128	0.669
DEA108	9/6/2011	28	Neoplasta sp.	2	0.817	0.494
DEA108	9/6/2011	28	Acentrella insignificans	1	0.614	0.385
DEA108	9/6/2011	28	Acentrella turbida	1	0.543	0.312
DEA108	9/6/2011	28	Arctopsychinae	1	0.501	0.295
DEA108	9/6/2011	28	Skwala sp.	1	0.466	0.286
DEA108	9/6/2011	28	Epeorus sp.	1	0.169	0.099
DEA108	10/4/2011	NA	Acentrella insignificans	1	0.000	0.169
DEA108	10/4/2011	NA	Acentrella sp.	1	0.000	0.082
DEA108	10/4/2011	NA	Acentrella turbida	1	0.000	0.249
DEA108	10/4/2011	NA	Antocha sp.	1	0.000	7.711
DEA108	10/4/2011	NA	Arctopsyche grandis	2	0.000	48.877
DEA108	10/4/2011	NA	Atherix sp.	1	0.000	5.754
DEA108	10/4/2011	NA	Baetis tricaudatus	1	0.000	60.828
DEA108	10/4/2011	NA	Bezzia/Palpomyia sp.	1	0.000	0.375
DEA108	10/4/2011	NA	Brachycentrus americanus	1	0.000	101.270
DEA108	10/4/2011	NA	Capniidae	1	0.000	0.866
DEA108	10/4/2011	NA	Caudatella edmundsi	1	0.000	0.610
DEA108	10/4/2011	NA	Caudatella hystrix	1	0.000	2.914
DEA108	10/4/2011	NA	Chelifera/Metachela sp.	1	0.000	0.097
DEA108	10/4/2011	NA	Chironomidae	2	0.000	3.515
DEA108	10/4/2011	NA	Cinygmula sp.	1	0.000	3.001
DEA108	10/4/2011	NA	Dicranota sp.	1	0.000	20.342

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA108	10/4/2011	NA	Drunella doddsii	1	0.000	29.501
DEA108	10/4/2011	NA	Empididae	1	0.000	0.062
DEA108	10/4/2011	NA	Epeorus grandis/permagnus	1	0.000	4.645
DEA108	10/4/2011	NA	Epeorus longimanus	2	0.000	3.485
DEA108	10/4/2011	NA	Ephemerella dorothea/excrucians	1	0.000	5.518
DEA108	10/4/2011	NA	Ephemerella sp.	1	0.000	4.491
DEA108	10/4/2011	NA	Glossosoma sp.	3	0.000	18.269
DEA108	10/4/2011	NA	Heptageniidae	1	0.000	2.279
DEA108	10/4/2011	NA	Hesperoconopa sp.	1	0.000	1.744
DEA108	10/4/2011	NA	Hesperoperla pacifica	1	0.000	0.727
DEA108	10/4/2011	NA	Heterlimnius sp.	1	0.000	0.153
DEA108	10/4/2011	NA	Hexatoma sp.	2	0.000	61.416
DEA108	10/4/2011	NA	Hydropsyche sp.	1	0.000	3.340
DEA108	10/4/2011	NA	Leptophlebiidae	1	0.000	1.061
DEA108	10/4/2011	NA	Leuctridae	1	0.000	6.530
DEA108	10/4/2011	NA	Oligochaete (class B)	1	0.000	6.738
DEA108	10/4/2011	NA	Oligochaete (class C)	1	0.000	28.927
DEA108	10/4/2011	NA	Optioservus sp.	1	0.000	0.583
DEA108	10/4/2011	NA	Paraleuctra sp.	1	0.000	1.882
DEA108	10/4/2011	NA	Perlodidae	1	0.000	1.403
DEA108	10/4/2011	NA	Pteronarcys californica	1	0.000	26.344
DEA108	10/4/2011	NA	Rhithrogena sp.	1	0.000	40.596
DEA108	10/4/2011	NA	Rhyacophila coloradensis gr.	1	0.000	0.853
DEA108	10/4/2011	NA	Rhyacophila hyalinata gr.	1	0.000	4.162
DEA108	10/4/2011	NA	Rhyacophila pellisa/valuma	1	0.000	1.269
DEA108	10/4/2011	NA	Simulium sp.	2	0.000	1.345
DEA108	10/4/2011	NA	Sweltsa sp.	1	0.000	13.326
DEA108	10/4/2011	NA	Taenionema sp.	1	0.000	0.326
DEA108	10/4/2011	NA	Taeniopterygidae	1	0.000	2.386
DEA108	10/4/2011	NA	Zaitzevia sp.	1	0.000	1.208
DEA108	10/4/2011	NA	Zapada cinctipes	1	0.000	0.773
DEA112	6/23/2010	42	Serratella tibialis	1	137.847	93.137
DEA112	6/23/2010	42	Epeorus longimanus	1	117.064	86.631
DEA112	6/23/2010	42	Chironomidae	2	106.085	70.374
DEA112	6/23/2010	42	Baetis tricaudatus	1	86.645	62.285
DEA112	6/23/2010	42	Tipulidae	1	46.959	38.469
DEA112	6/23/2010	42	Hesperoperla pacifica	2	45.103	40.562
DEA112	6/23/2010	42	Rhithrogena sp.	1	36.117	29.227
DEA112	6/23/2010	42	Oligochaete (class A)	1	31.987	25.633
DEA112	6/23/2010	42	Drunella coloradensis/flavilinea	1	27.520	15.202

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	6/23/2010	42	Suwallia sp.	1	26.747	18.775
DEA112	6/23/2010	42	Oligochaete (class B)	1	24.296	17.866
DEA112	6/23/2010	42	Ephemerella dorothea/excrucians	1	22.568	18.446
DEA112	6/23/2010	42	Sweltsa sp.	1	21.330	13.857
DEA112	6/23/2010	42	Caudatella hystrix	1	17.606	15.021
DEA112	6/23/2010	42	Chloroperlidae	1	17.125	11.945
DEA112	6/23/2010	42	Oligochaete (class C)	1	14.068	10.208
DEA112	6/23/2010	42	Simulium sp.	1	13.812	8.856
DEA112	6/23/2010	42	Cinygmula sp.	1	11.330	8.612
DEA112	6/23/2010	42	Rhyacophila angelita gr.	1	9.911	7.581
DEA112	6/23/2010	42	Lara sp.	1	7.752	5.479
DEA112	6/23/2010	42	Atherix sp.	1	7.498	5.599
DEA112	6/23/2010	42	Drunella doddsii	2	6.548	3.978
DEA112	6/23/2010	42	Rhyacophila pellisa/valuma	2	5.802	4.633
DEA112	6/23/2010	42	Trichoclinocera sp.	1	5.270	3.500
DEA112	6/23/2010	42	Dicranota sp.	2	4.399	3.521
DEA112	6/23/2010	42	Caudatella heterocaudata	1	4.021	3.375
DEA112	6/23/2010	42	Optioservus sp.	1	3.596	2.754
DEA112	6/23/2010	42	Micrasema sp.	1	2.955	2.330
DEA112	6/23/2010	42	Pteronarcys sp.	1	1.259	0.857
DEA112	6/23/2010	42	Rhyacophila coloradensis gr.	1	1.000	0.776
DEA112	6/23/2010	42	Caudatella edmundsi	1	0.707	0.515
DEA112	6/23/2010	42	Wiedemannia sp.	2	0.687	0.470
DEA112	6/23/2010	42	Hesperoconopa sp.	1	0.579	0.436
DEA112	6/23/2010	42	Rhyacophila sp.	1	0.388	0.274
DEA112	6/23/2010	42	Rhyacophila narvae	1	0.364	0.259
DEA112	6/23/2010	42	Zapada columbiana	1	0.081	0.055
DEA112	6/23/2010	42	Heterlimnius sp.	1	0.068	0.038
DEA112	8/4/2010	19	Baetis tricaudatus	1	119.997	154.632
DEA112	8/4/2010	19	Serratella tibialis	1	114.570	177.767
DEA112	8/4/2010	19	Hesperoperla pacifica	2	106.726	173.431
DEA112	8/4/2010	19	Epeorus longimanus	1	88.452	144.345
DEA112	8/4/2010	19	Chironomidae	2	59.836	76.273
DEA112	8/4/2010	19	Oligochaete (class C)	1	53.416	70.507
DEA112	8/4/2010	19	Drunella coloradensis/flavilinea	1	43.990	39.138
DEA112	8/4/2010	19	Sweltsa sp.	1	35.951	45.527
DEA112	8/4/2010	19	Oligochaete (class A)	1	31.700	47.941
DEA112	8/4/2010	19	Suwallia sp.	1	16.145	22.586
DEA112	8/4/2010	19	Brachycentrus americanus	1	14.756	14.151
DEA112	8/4/2010	19	Hexatoma sp.	1	14.238	22.816

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	8/4/2010	19	Oligochaete (class B)	1	10.691	15.111
DEA112	8/4/2010	19	Antocha sp.	1	10.254	16.132
DEA112	8/4/2010	19	Rhyacophila angelita gr.	1	10.239	15.282
DEA112	8/4/2010	19	Caudatella heterocaudata	1	7.559	10.643
DEA112	8/4/2010	19	Simulium sp.	2	6.950	9.335
DEA112	8/4/2010	19	Rhithrogena sp.	1	6.735	7.971
DEA112	8/4/2010	19	Drunella doddsii	1	5.923	7.099
DEA112	8/4/2010	19	Chloroperlidae	1	3.630	4.903
DEA112	8/4/2010	19	Lara sp.	1	3.508	5.346
DEA112	8/4/2010	19	Trichoclinocera sp.	1	2.369	3.185
DEA112	8/4/2010	19	Zaitzevia sp.	1	2.277	3.148
DEA112	8/4/2010	19	Optioservus sp.	1	2.160	3.067
DEA112	8/4/2010	19	Ameletus sp.	1	1.905	2.602
DEA112	8/4/2010	19	Cinygmula sp.	1	1.846	2.592
DEA112	8/4/2010	19	Paraleptophlebia sp.	1	1.321	1.644
DEA112	8/4/2010	19	Atherix sp.	1	1.088	1.424
DEA112	8/4/2010	19	Heterlimnius sp.	1	0.658	0.789
DEA112	8/4/2010	19	Brachycentrus occidentalis	1	0.600	0.650
DEA112	8/4/2010	19	Epeorus sp.	1	0.403	0.509
DEA112	8/4/2010	19	Bezzia/Palpomyia sp.	1	0.391	0.513
DEA112	8/4/2010	19	Deuterophlebia sp.	1	0.351	0.413
DEA112	8/4/2010	19	Pteronarcys sp.	1	0.330	0.424
DEA112	8/4/2010	19	Sericostriata surdickae	1	0.320	0.438
DEA112	8/4/2010	19	Helicopsyche sp.	1	0.231	0.310
DEA112	8/4/2010	19	Epeorus grandis/permagnus	1	0.221	0.273
DEA112	8/4/2010	19	Caudatella sp.	1	0.216	0.246
DEA112	8/4/2010	19	Rhyacophila hyalinata gr.	1	0.196	0.245
DEA112	8/4/2010	19	Perlodidae	1	0.193	0.223
DEA112	8/4/2010	19	Zapada cinctipes	1	0.111	0.132
DEA112	8/4/2010	19	Clinocera sp.	1	0.108	0.113
DEA112	8/4/2010	19	Rhyacophila narvae	1	0.084	0.104
DEA112	8/4/2010	19	Acentrella sp.	1	0.076	0.087
DEA112	8/4/2010	19	Glossosomatidae	1	0.039	0.046
DEA112	8/4/2010	19	Drunella grandis	1	0.025	0.030
DEA112	8/23/2010	52	Oligochaete (class C)	1	1016.819	494.782
DEA112	8/23/2010	52	Hesperoperla pacifica	3	917.282	552.270
DEA112	8/23/2010	52	Baetis tricaudatus	1	525.522	247.494
DEA112	8/23/2010	52	Sweltsa sp.	1	360.450	167.264
DEA112	8/23/2010	52	Brachycentrus occidentalis	1	322.260	145.011
DEA112	8/23/2010	52	Rhithrogena sp.	2	321.778	143.530
DEA112	8/23/2010	52	Pteronarcys californica	1	318.961	210.185

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	8/23/2010	52	Serratella tibialis	1	172.313	89.880
DEA112	8/23/2010	52	Epeorus longimanus	1	163.714	81.761
DEA112	8/23/2010	52	Brachycentrus americanus	1	145.003	81.092
DEA112	8/23/2010	52	Drunella doddsii	1	135.320	58.345
DEA112	8/23/2010	52	Chironomidae	2	101.740	44.951
DEA112	8/23/2010	52	Paraleptophlebia sp.	1	87.075	38.272
DEA112	8/23/2010	52	Dicranota sp.	2	61.131	32.791
DEA112	8/23/2010	52	Oligochaete (class B)	1	60.478	29.429
DEA112	8/23/2010	52	Oligochaete (class A)	1	54.973	29.453
DEA112	8/23/2010	52	Drunella coloradensis/flavilinea	1	48.380	26.165
DEA112	8/23/2010	52	Glossosoma sp.	1	43.354	18.251
DEA112	8/23/2010	52	Rhyacophila pellisa/valuma	1	37.464	17.968
DEA112	8/23/2010	52	Capniidae	1	24.646	10.680
DEA112	8/23/2010	52	Rhyacophila angelita gr.	1	23.776	13.033
DEA112	8/23/2010	52	Caudatella heterocaudata	1	15.901	8.247
DEA112	8/23/2010	52	Atherix sp.	1	15.749	7.087
DEA112	8/23/2010	52	Suwallia sp.	1	14.368	7.437
DEA112	8/23/2010	52	Optioservus sp.	2	10.471	4.995
DEA112	8/23/2010	52	Ameletus sp.	1	5.093	2.617
DEA112	8/23/2010	52	Zaitzevia sp.	2	4.735	2.310
DEA112	8/23/2010	52	Heterlimnius sp.	1	4.263	2.108
DEA112	8/23/2010	52	Epeorus grandis/permagnus	1	3.455	1.563
DEA112	8/23/2010	52	Clinocera sp.	2	2.711	1.284
DEA112	8/23/2010	52	Epeorus sp.	1	2.677	1.211
DEA112	8/23/2010	52	Narpus sp.	1	1.543	0.764
DEA112	8/23/2010	52	Diphetor hageni	1	1.534	0.750
DEA112	8/23/2010	52	Arctopsychinae	1	0.996	0.442
DEA112	8/23/2010	52	Parapsyche sp.	1	0.987	0.448
DEA112	8/23/2010	52	Deuterophlebia sp.	1	0.759	0.320
DEA112	8/23/2010	52	Epeorus deceptivus/hesperus	1	0.665	0.314
DEA112	8/23/2010	52	Ephemerellidae	1	0.623	0.259
DEA112	8/23/2010	52	Ephemerella sp.	1	0.545	0.225
DEA112	8/23/2010	52	Perlodidae	1	0.456	0.194
DEA112	8/23/2010	52	Perlidae	1	0.400	0.180
DEA112	8/23/2010	52	Dolophilodes sp.	1	0.372	0.168
DEA112	8/23/2010	52	Caudatella sp.	1	0.318	0.135
DEA112	8/23/2010	52	Simulium sp.	1	0.241	0.106
DEA112	8/23/2010	52	Neophylax sp.	1	0.160	0.070
DEA112	8/23/2010	52	Zapada cinctipes	1	0.074	0.031
DEA112	8/23/2010	52	Taeniopterygidae	1	0.025	0.010
DEA112	10/14/2010	271	Oligochaete (class C)	1	1607.189	436.283

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	10/14/2010	271	Hesperoperla pacifica	2	837.565	276.938
DEA112	10/14/2010	271	Baetis tricaudatus	1	532.340	129.638
DEA112	10/14/2010	271	Sweltsa sp.	1	519.982	135.534
DEA112	10/14/2010	271	Brachycentrus occidentalis	2	491.709	144.398
DEA112	10/14/2010	271	Rhithrogena sp.	1	470.726	123.415
DEA112	10/14/2010	271	Cinygmula sp.	1	405.751	102.222
DEA112	10/14/2010	271	Chironomidae	2	284.818	68.173
DEA112	10/14/2010	271	Brachycentrus americanus	1	244.771	73.410
DEA112	10/14/2010	271	Drunella doddsii	1	207.082	55.047
DEA112	10/14/2010	271	Ephemerella dorothea/excrucians	1	202.365	49.417
DEA112	10/14/2010	271	Paraleptophlebia sp.	1	142.082	37.053
DEA112	10/14/2010	271	Oligochaete (class B)	1	77.882	21.430
DEA112	10/14/2010	271	Hexatoma sp.	1	69.859	20.771
DEA112	10/14/2010	271	Glossosoma sp.	1	61.156	16.974
DEA112	10/14/2010	271	Rhyacophila pellisa/valuma	1	59.103	15.266
DEA112	10/14/2010	271	Hesperoconopa sp.	1	56.514	15.547
DEA112	10/14/2010	271	Capniidae	1	41.683	10.192
DEA112	10/14/2010	271	Arctopsyche grandis	1	30.759	8.877
DEA112	10/14/2010	271	Atherix sp.	1	30.260	7.759
DEA112	10/14/2010	271	Caudatella hystrix	1	26.849	6.816
DEA112	10/14/2010	271	Antocha sp.	1	21.123	5.802
DEA112	10/14/2010	271	Dicranota sp.	1	16.471	4.696
DEA112	10/14/2010	271	Optioservus sp.	1	10.680	2.733
DEA112	10/14/2010	271	Epeorus grandis/permagnus	1	5.767	1.391
DEA112	10/14/2010	271	Heterlimnius sp.	1	5.187	1.355
DEA112	10/14/2010	271	Lepidostoma sp.	1	5.079	1.356
DEA112	10/14/2010	271	Epeorus sp.	1	4.429	1.005
DEA112	10/14/2010	271	Taenionema sp.	1	4.185	1.016
DEA112	10/14/2010	271	Ameletus sp.	1	4.127	1.005
DEA112	10/14/2010	271	Leuctridae	1	3.042	0.742
DEA112	10/14/2010	271	Bezzia/Palpomyia sp.	1	0.622	0.139
DEA112	7/12/2011	27	Baetis tricaudatus	1	76.037	67.129
DEA112	7/12/2011	27	Chironomidae	2	72.406	62.785
DEA112	7/12/2011	27	Epeorus longimanus	2	51.398	59.880
DEA112	7/12/2011	27	Oligochaete (class C)	1	30.896	27.316
DEA112	7/12/2011	27	Rhithrogena sp.	2	25.265	25.043
DEA112	7/12/2011	27	Drunella coloradensis/flavilinea	1	23.159	12.433
DEA112	7/12/2011	27	Ephemerella dorothea/excrucians	1	21.612	22.475
DEA112	7/12/2011	27	Rhyacophila pellisa/valuma	2	19.540	19.869
DEA112	7/12/2011	27	Hesperoperla pacifica	3	18.850	20.623

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	7/12/2011	27	Brachycentrus americanus	1	17.298	19.841
DEA112	7/12/2011	27	Drunella doddsii	2	14.676	16.248
DEA112	7/12/2011	27	Suwallia sp.	1	11.788	10.947
DEA112	7/12/2011	27	Sweltsa sp.	1	11.509	9.535
DEA112	7/12/2011	27	Caudatella heterocaudata	1	11.088	10.294
DEA112	7/12/2011	27	Oligochaete (class B)	1	10.472	9.481
DEA112	7/12/2011	27	Chloroperlidae	1	10.038	9.270
DEA112	7/12/2011	27	Serratella tibialis	1	9.911	8.678
DEA112	7/12/2011	27	Rhyacophila angelita gr.	2	3.725	3.665
DEA112	7/12/2011	27	Cinygmula sp.	1	3.690	3.499
DEA112	7/12/2011	27	Paraperla sp.	1	2.975	3.061
DEA112	7/12/2011	27	Hesperoconopa sp.	1	2.315	2.203
DEA112	7/12/2011	27	Trichoclinocera sp.	1	2.053	1.831
DEA112	7/12/2011	27	Atherix sp.	2	1.804	1.695
DEA112	7/12/2011	27	Ameletus sp.	1	1.634	1.393
DEA112	7/12/2011	27	Neophylax rickeri	1	1.256	1.197
DEA112	7/12/2011	27	Simulium sp.	1	1.234	1.168
DEA112	7/12/2011	27	Optioservus sp.	1	1.159	1.099
DEA112	7/12/2011	27	Empididae	1	0.499	0.231
DEA112	7/12/2011	27	Epeorus sp.	1	0.316	0.254
DEA112	7/12/2011	27	Epeorus grandis/permagnus	1	0.232	0.189
DEA112	7/12/2011	27	Pteronarcys sp.	1	0.175	0.153
DEA112	7/12/2011	27	Rhyacophila hyalinata gr.	1	0.174	0.149
DEA112	7/12/2011	27	Leptophlebiidae	1	0.026	0.021
DEA112	7/12/2011	27	Perlodidae	1	0.021	0.016
DEA112	7/12/2011	27	Rhyacophila sp.	1	0.012	0.009
DEA112	8/8/2011	31	Epeorus longimanus	1	66.667	49.564
DEA112	8/8/2011	31	Baetis tricaudatus	1	60.615	43.502
DEA112	8/8/2011	31	Oligochaete (class C)	1	54.683	40.135
DEA112	8/8/2011	31	Chironomidae	2	47.145	33.805
DEA112	8/8/2011	31	Sweltsa sp.	1	37.285	26.333
DEA112	8/8/2011	31	Simulium sp.	1	27.500	18.595
DEA112	8/8/2011	31	Rhithrogena sp.	2	23.522	18.043
DEA112	8/8/2011	31	Oligochaete (class B)	1	22.301	17.440
DEA112	8/8/2011	31	Rhyacophila angelita gr.	3	17.788	14.996
DEA112	8/8/2011	31	Dicranota sp.	1	16.700	13.328
DEA112	8/8/2011	31	Epeorus grandis/permagnus	1	14.422	9.725
DEA112	8/8/2011	31	Pteronarcys dorsata	1	14.003	13.095
DEA112	8/8/2011	31	Suwallia sp.	2	10.656	8.184
DEA112	8/8/2011	31	Caudatella heterocaudata	1	9.483	7.589
DEA112	8/8/2011	31	Drunella coloradensis/flavilinea	1	9.275	7.497

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	8/8/2011	31	Drunella doddsii	1	5.280	3.541
DEA112	8/8/2011	31	Serratella tibialis	1	4.213	3.206
DEA112	8/8/2011	31	Antocha sp.	1	3.612	2.960
DEA112	8/8/2011	31	Hesperoconopa sp.	2	2.814	2.203
DEA112	8/8/2011	31	Deuterophlebia sp.	2	1.818	1.225
DEA112	8/8/2011	31	Zaitzevia sp.	1	1.612	1.234
DEA112	8/8/2011	31	Ameletus sp.	1	1.609	1.245
DEA112	8/8/2011	31	Trichoclinocera sp.	3	1.573	1.162
DEA112	8/8/2011	31	Hesperoperla pacifica	1	0.943	0.729
DEA112	8/8/2011	31	Acentrella sp.	1	0.730	0.544
DEA112	8/8/2011	31	Narpus sp.	1	0.490	0.366
DEA112	8/8/2011	31	Empididae	1	0.303	0.229
DEA112	8/8/2011	31	Epeorus sp.	1	0.229	0.158
DEA112	8/8/2011	31	Dolophilodes sp.	1	0.143	0.099
DEA112	8/8/2011	31	Neophylax sp.	1	0.069	0.048
DEA112	9/8/2011	28	Hesperoperla pacifica	1	183.596	172.642
DEA112	9/8/2011	28	Baetis tricaudatus	1	139.006	104.368
DEA112	9/8/2011	28	Rhithrogena sp.	1	97.691	71.792
DEA112	9/8/2011	28	Oligochaete (class C)	1	90.931	69.431
DEA112	9/8/2011	28	Sweltsa sp.	1	62.891	47.574
DEA112	9/8/2011	28	Chironomidae	2	36.115	25.758
DEA112	9/8/2011	28	Hexatoma sp.	2	34.918	31.455
DEA112	9/8/2011	28	Rhyacophila pellisa/valuma	2	27.136	21.248
DEA112	9/8/2011	28	Simulium sp.	2	25.438	20.113
DEA112	9/8/2011	28	Epeorus longimanus	1	24.960	20.734
DEA112	9/8/2011	28	Drunella doddsii	1	24.275	17.884
DEA112	9/8/2011	28	Antocha sp.	1	18.960	15.305
DEA112	9/8/2011	28	Dicranota sp.	1	18.805	15.540
DEA112	9/8/2011	28	Epeorus grandis/permagnus	1	17.251	13.501
DEA112	9/8/2011	28	Oligochaete (class B)	1	11.910	9.752
DEA112	9/8/2011	28	Atherix sp.	2	10.961	8.961
DEA112	9/8/2011	28	Caudatella hystrix	1	10.862	7.841
DEA112	9/8/2011	28	Glossosoma sp.	2	6.533	5.076
DEA112	9/8/2011	28	Zaitzevia sp.	1	4.664	3.719
DEA112	9/8/2011	28	Capniidae	1	3.892	2.704
DEA112	9/8/2011	28	Rhyacophila coloradensis gr.	1	2.757	2.215
DEA112	9/8/2011	28	Paraleuctra sp.	1	2.259	1.780
DEA112	9/8/2011	28	Bezzia/Palpomyia sp.	1	1.797	1.425
DEA112	9/8/2011	28	Deuterophlebia sp.	2	1.669	1.187
DEA112	9/8/2011	28	Hesperoconopa sp.	1	1.614	1.308
DEA112	9/8/2011	28	Taeniopterygidae	1	1.366	0.926

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	9/8/2011	28	Leptophlebiidae	1	1.001	0.739
DEA112	9/8/2011	28	Rhyacophila narvae	1	0.833	0.651
DEA112	9/8/2011	28	Optioservus sp.	1	0.804	0.591
DEA112	9/8/2011	28	Ephemerella sp.	1	0.671	0.467
DEA112	9/8/2011	28	Arctopsychinae	1	0.426	0.328
DEA112	9/8/2011	28	Ameletus sp.	1	0.416	0.318
DEA112	9/8/2011	28	Zapada cinctipes	1	0.175	0.128
DEA112	9/8/2011	28	Clinocera sp.	1	0.041	0.029
DEA112	10/6/2011	NA	Acentrella turbida	1	0.000	4.106
DEA112	10/6/2011	NA	Ameletus sp.	1	0.000	0.171
DEA112	10/6/2011	NA	Antocha sp.	1	0.000	14.501
DEA112	10/6/2011	NA	Arctopsyche grandis	1	0.000	1.460
DEA112	10/6/2011	NA	Atherix sp.	1	0.000	2.567
DEA112	10/6/2011	NA	Attenella margarita	1	0.000	1.523
DEA112	10/6/2011	NA	Baetis tricaudatus	1	0.000	87.997
DEA112	10/6/2011	NA	Brachycentrus americanus	2	0.000	32.651
DEA112	10/6/2011	NA	Capniidae	1	0.000	2.562
DEA112	10/6/2011	NA	Caudatella hystrix	1	0.000	7.160
DEA112	10/6/2011	NA	Chironomidae	2	0.000	2.673
DEA112	10/6/2011	NA	Cinygmula sp.	1	0.000	3.691
DEA112	10/6/2011	NA	Deuterophlebia sp.	1	0.000	0.094
DEA112	10/6/2011	NA	Dicranota sp.	1	0.000	6.144
DEA112	10/6/2011	NA	Drunella doddsii	1	0.000	14.882
DEA112	10/6/2011	NA	Drunella grandis	1	0.000	2.674
DEA112	10/6/2011	NA	Epeorus grandis/permagnus	1	0.000	3.858
DEA112	10/6/2011	NA	Ephemerella dorothea/excrucians	1	0.000	5.010
DEA112	10/6/2011	NA	Eucapnopsis brevicauda	1	0.000	2.252
DEA112	10/6/2011	NA	Glossosoma sp.	1	0.000	2.105
DEA112	10/6/2011	NA	Glossosomatidae	1	0.000	0.576
DEA112	10/6/2011	NA	Hesperoperla pacifica	1	0.000	107.863
DEA112	10/6/2011	NA	Heterlimnius sp.	1	0.000	0.733
DEA112	10/6/2011	NA	Hexatoma sp.	2	0.000	10.907
DEA112	10/6/2011	NA	Leuctridae	1	0.000	0.425
DEA112	10/6/2011	NA	Narpus sp.	1	0.000	3.766
DEA112	10/6/2011	NA	Nemouridae	1	0.000	0.034
DEA112	10/6/2011	NA	Oligochaete (class B)	1	0.000	0.793
DEA112	10/6/2011	NA	Oligochaete (class C)	1	0.000	50.024
DEA112	10/6/2011	NA	Optioservus sp.	2	0.000	0.927
DEA112	10/6/2011	NA	Paraleptophlebia sp.	1	0.000	2.036
DEA112	10/6/2011	NA	Perlidae	1	0.000	0.188

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA112	10/6/2011	NA	Pteronarcys californica	1	0.000	250.832
DEA112	10/6/2011	NA	Rhithrogena sp.	1	0.000	65.173
DEA112	10/6/2011	NA	Rhyacophila pellisa/valuma	1	0.000	12.642
DEA112	10/6/2011	NA	Simuliidae	1	0.000	0.438
DEA112	10/6/2011	NA	Sweltsa sp.	1	0.000	27.422
DEA112	10/6/2011	NA	Taeniopterygidae	1	0.000	0.821
DEA112	10/6/2011	NA	Zaitzevia sp.	1	0.000	3.080
DEA113	6/29/2010	28	Hesperoperla pacifica	4	905.033	1640.864
DEA113	6/29/2010	28	Chironomidae	2	164.759	226.962
DEA113	6/29/2010	28	Epeorus longimanus	2	110.707	171.123
DEA113	6/29/2010	28	Baetis tricaudatus	1	78.082	112.510
DEA113	6/29/2010	28	Oligochaete (class C)	1	68.046	98.890
DEA113	6/29/2010	28	Arctopsyche grandis	2	60.384	104.532
DEA113	6/29/2010	28	Oligochaete (class A)	1	55.944	92.910
DEA113	6/29/2010	28	Onocosmoecus sp.	1	52.800	102.715
DEA113	6/29/2010	28	Ephemerella dorothea/excrucians	2	50.332	86.155
DEA113	6/29/2010	28	Caudatella edmundsi	1	46.738	73.631
DEA113	6/29/2010	28	Serratella tibialis	1	41.330	56.829
DEA113	6/29/2010	28	Rhithrogena sp.	1	39.789	66.680
DEA113	6/29/2010	28	Caudatella hystrix	2	25.735	44.287
DEA113	6/29/2010	28	Drunella coloradensis/flavilinea	1	22.825	29.882
DEA113	6/29/2010	28	Oligochaete (class B)	1	22.614	32.568
DEA113	6/29/2010	28	Cinygmula sp.	1	15.293	21.451
DEA113	6/29/2010	28	Rhyacophila hyalinata gr.	1	11.406	16.867
DEA113	6/29/2010	28	Ameletus sp.	1	11.008	19.573
DEA113	6/29/2010	28	Malenka sp.	1	10.778	14.984
DEA113	6/29/2010	28	Chloroperlidae	1	4.969	2.960
DEA113	6/29/2010	28	Tipulidae	1	4.439	7.519
DEA113	6/29/2010	28	Dicranota sp.	1	4.254	6.671
DEA113	6/29/2010	28	Rhyacophila brunnea gr.	1	3.202	5.026
DEA113	6/29/2010	28	Micrasema sp.	1	3.040	4.879
DEA113	6/29/2010	28	Epeorus sp.	1	2.926	3.900
DEA113	6/29/2010	28	Hesperoconopa sp.	1	2.804	4.310
DEA113	6/29/2010	28	Polycentropus sp.	1	2.499	4.094
DEA113	6/29/2010	28	Sweltsa sp.	2	2.264	3.070
DEA113	6/29/2010	28	Optioservus sp.	2	2.097	3.092
DEA113	6/29/2010	28	Diphetor hageni	1	1.587	2.260
DEA113	6/29/2010	28	Rhyacophila alberta gr.	1	1.228	1.859
DEA113	6/29/2010	28	Heterlimnius sp.	1	1.071	1.274
DEA113	6/29/2010	28	Cleptelmis addenda	1	0.798	1.180

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA113	6/29/2010	28	Rhyacophila narvae	1	0.690	0.949
DEA113	6/29/2010	28	Pteronarcys sp.	1	0.357	0.488
DEA113	6/29/2010	28	Bezzia/Palpomyia sp.	1	0.136	0.182
DEA113	6/29/2010	28	Caudatella heterocaudata	1	0.130	0.183
DEA113	6/29/2010	28	Neophylax sp.	1	0.112	0.157
DEA113	7/27/2010	21	Chironomidae	2	313.146	478.339
DEA113	7/27/2010	21	Baetis tricaudatus	1	211.084	327.223
DEA113	7/27/2010	21	Hesperoperla pacifica	4	196.597	384.672
DEA113	7/27/2010	21	Oligochaete (class C)	1	134.284	214.099
DEA113	7/27/2010	21	Epeorus longimanus	2	70.257	120.119
DEA113	7/27/2010	21	Oligochaete (class A)	1	65.729	119.620
DEA113	7/27/2010	21	Drunella coloradensis/flavilinea	2	60.824	73.638
DEA113	7/27/2010	21	Serratella tibialis	1	53.800	88.558
DEA113	7/27/2010	21	Caudatella edmundsi	1	34.838	60.426
DEA113	7/27/2010	21	Arctopsyche grandis	1	30.512	55.056
DEA113	7/27/2010	21	Rhithrogena sp.	2	30.457	57.210
DEA113	7/27/2010	21	Oligochaete (class B)	1	21.102	34.292
DEA113	7/27/2010	21	Cinygmula sp.	1	14.421	23.840
DEA113	7/27/2010	21	Caudatella hystrix	1	12.380	23.250
DEA113	7/27/2010	21	Malenka sp.	1	9.111	14.724
DEA113	7/27/2010	21	Rhyacophila hyalinata gr.	1	8.905	16.419
DEA113	7/27/2010	21	Ameletus sp.	1	6.531	10.122
DEA113	7/27/2010	21	Sweltsa sp.	1	5.721	8.459
DEA113	7/27/2010	21	Rhyacophila narvae	1	4.825	7.831
DEA113	7/27/2010	21	Dicranota sp.	1	2.773	4.921
DEA113	7/27/2010	21	Epeorus albertae	1	1.320	2.015
DEA113	7/27/2010	21	Chloroperlidae	1	1.314	2.178
DEA113	7/27/2010	21	Caudatella sp.	1	1.104	1.460
DEA113	7/27/2010	21	Optioservus sp.	2	0.921	1.461
DEA113	7/27/2010	21	Heterlimnius sp.	1	0.785	1.264
DEA113	7/27/2010	21	Diphetor hageni	1	0.682	1.124
DEA113	7/27/2010	21	Clinocera sp.	1	0.612	0.749
DEA113	7/27/2010	21	Epeorus sp.	1	0.338	0.515
DEA113	7/27/2010	21	Leptophlebiidae	1	0.282	0.618
DEA113	7/27/2010	21	Pteronarcys sp.	1	0.230	0.357
DEA113	7/27/2010	21	Amiocentrus aspilus	1	0.188	0.279
DEA113	7/27/2010	21	Paraleptophlebia sp.	1	0.152	0.224
DEA113	7/27/2010	21	Empididae	2	0.088	0.129
DEA113	7/27/2010	21	Zapada cinctipes	1	0.084	0.123
DEA113	7/27/2010	21	Epeorus grandis/permagnus	1	0.076	0.110
DEA113	8/17/2010	50	Baetis tricaudatus	1	734.498	314.650

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA113	8/17/2010	50	Chironomidae	2	731.847	299.849
DEA113	8/17/2010	50	Oligochaete (class C)	1	566.796	253.836
DEA113	8/17/2010	50	Hesperoperla pacifica	2	331.993	171.497
DEA113	8/17/2010	50	Oligochaete (class A)	1	186.157	95.764
DEA113	8/17/2010	50	Oligochaete (class B)	1	146.581	63.980
DEA113	8/17/2010	50	Sweltsa sp.	1	117.701	48.620
DEA113	8/17/2010	50	Caudatella edmundsi	2	103.890	48.394
DEA113	8/17/2010	50	Serratella tibialis	1	87.765	38.381
DEA113	8/17/2010	50	Drunella coloradensis/flavilinea	1	83.314	39.155
DEA113	8/17/2010	50	Arctopsyche grandis	1	54.708	27.043
DEA113	8/17/2010	50	Antocha sp.	1	47.609	23.154
DEA113	8/17/2010	50	Hydropsyche sp.	1	44.588	21.790
DEA113	8/17/2010	50	Epeorus longimanus	2	27.121	11.650
DEA113	8/17/2010	50	Ameletus sp.	1	19.687	9.773
DEA113	8/17/2010	50	Rhyacophila narvae	1	18.607	8.254
DEA113	8/17/2010	50	Capniidae	1	15.963	5.934
DEA113	8/17/2010	50	Cinygmula sp.	1	12.977	5.825
DEA113	8/17/2010	50	Malenka sp.	1	5.844	2.711
DEA113	8/17/2010	50	Caudatella sp.	1	4.049	1.491
DEA113	8/17/2010	50	Cleptelmis addenda	1	2.735	1.108
DEA113	8/17/2010	50	Optioservus sp.	1	2.174	0.818
DEA113	8/17/2010	50	Clinocera sp.	1	1.969	0.721
DEA113	8/17/2010	50	Micrasema sp.	1	1.746	0.712
DEA113	8/17/2010	50	Drunella grandis	1	1.678	0.667
DEA113	8/17/2010	50	Leptophlebiidae	1	1.513	1.082
DEA113	8/17/2010	50	Ephemerellidae	1	0.926	0.341
DEA113	8/17/2010	50	Simulium sp.	1	0.912	0.364
DEA113	8/17/2010	50	Epeorus sp.	1	0.905	0.371
DEA113	8/17/2010	50	Rhyacophila sp.	1	0.884	0.369
DEA113	8/17/2010	50	Perlodidae	1	0.619	0.243
DEA113	8/17/2010	50	Drunella doddsii	1	0.460	0.171
DEA113	8/17/2010	50	Drunella spinifera	1	0.312	0.117
DEA113	8/17/2010	50	Glossosoma sp.	1	0.099	0.036
DEA113	10/6/2010	274	Oligochaete (class C)	1	446.199	98.711
DEA113	10/6/2010	274	Chironomidae	2	403.861	80.495
DEA113	10/6/2010	274	Oligochaete (class B)	1	318.930	73.290
DEA113	10/6/2010	274	Hesperoperla pacifica	2	312.511	78.022
DEA113	10/6/2010	274	Sweltsa sp.	1	195.482	41.650
DEA113	10/6/2010	274	Baetis tricaudatus	1	147.930	28.836
DEA113	10/6/2010	274	Cinygmula sp.	1	119.311	24.042
DEA113	10/6/2010	274	Antocha sp.	1	88.517	19.813

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA113	10/6/2010	274	Ephemerella dorothea/excrucians	1	76.613	15.534
DEA113	10/6/2010	274	Paraleptophlebia sp.	1	58.320	12.199
DEA113	10/6/2010	274	Capniidae	1	29.587	5.769
DEA113	10/6/2010	274	Optioservus sp.	2	18.178	3.938
DEA113	10/6/2010	274	Arctopsyche grandis	2	10.003	2.299
DEA113	10/6/2010	274	Lepidostoma sp.	1	9.250	1.770
DEA113	10/6/2010	274	Epeorus sp.	1	8.923	1.586
DEA113	10/6/2010	274	Leuctridae	1	6.414	1.420
DEA113	10/6/2010	274	Rhyacophila narvae	1	5.650	1.258
DEA113	10/6/2010	274	Leptophlebiidae	1	3.392	0.702
DEA113	10/6/2010	274	Zapada cinctipes	1	2.206	0.445
DEA113	10/6/2010	274	Heterlimnius sp.	1	1.866	0.386
DEA113	10/6/2010	274	Caudatella sp.	1	0.355	0.068
DEA113	10/6/2010	274	Brachycentrus americanus	1	0.355	0.069
DEA113	7/7/2011	26	Hesperoperla pacifica	3	157.932	250.165
DEA113	7/7/2011	26	Chironomidae	2	124.584	151.540
DEA113	7/7/2011	26	Baetis tricaudatus	1	108.647	93.711
DEA113	7/7/2011	26	Epeorus longimanus	2	102.663	141.256
DEA113	7/7/2011	26	Oligochaete (class C)	1	91.357	113.949
DEA113	7/7/2011	26	Drunella coloradensis/flavilinea	1	88.012	57.761
DEA113	7/7/2011	26	Serratella tibialis	1	55.071	67.376
DEA113	7/7/2011	26	Arctopsyche grandis	1	45.186	69.682
DEA113	7/7/2011	26	Dicranota sp.	2	37.415	53.321
DEA113	7/7/2011	26	Ephemerella dorothea/excrucians	1	36.790	54.910
DEA113	7/7/2011	26	Oligochaete (class B)	1	24.719	31.684
DEA113	7/7/2011	26	Rhyacophila alberta gr.	1	21.826	30.827
DEA113	7/7/2011	26	Antocha sp.	1	15.274	21.879
DEA113	7/7/2011	26	Oligochaete (class A)	1	14.005	20.259
DEA113	7/7/2011	26	Hexatoma sp.	1	11.300	17.499
DEA113	7/7/2011	26	Rhyacophila verrula gr.	1	10.165	15.959
DEA113	7/7/2011	26	Chloroperlidae	1	10.131	12.313
DEA113	7/7/2011	26	Cinygmula sp.	1	9.066	11.755
DEA113	7/7/2011	26	Malenka sp.	1	8.553	10.525
DEA113	7/7/2011	26	Sweltsa sp.	2	5.882	7.490
DEA113	7/7/2011	26	Caudatella edmundsi	1	4.110	5.409
DEA113	7/7/2011	26	Diphetor hageni	1	3.193	3.858
DEA113	7/7/2011	26	Optioservus sp.	1	2.586	3.442
DEA113	7/7/2011	26	Rhyacophila brunnea gr.	1	2.416	1.939
DEA113	7/7/2011	26	Caudatella heterocaudata	1	2.328	3.144
DEA113	7/7/2011	26	Cleptelmis addenda	1	1.631	2.085

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA113	7/7/2011	26	Rhithrogena sp.	1	1.619	2.293
DEA113	7/7/2011	26	Glossosoma sp.	1	1.611	2.282
DEA113	7/7/2011	26	Ameletus sp.	1	1.252	1.702
DEA113	7/7/2011	26	Epeorus sp.	1	1.243	1.473
DEA113	7/7/2011	26	Lepidostoma sp.	1	1.228	1.680
DEA113	7/7/2011	26	Hesperoconopa sp.	1	1.119	1.507
DEA113	7/7/2011	26	Micrasema sp.	1	0.846	1.043
DEA113	7/7/2011	26	Rhyacophila narvae	1	0.626	0.814
DEA113	7/7/2011	26	Empididae	1	0.408	0.518
DEA113	7/7/2011	26	Heterlimnius sp.	1	0.346	0.416
DEA113	7/7/2011	26	Zapada columbiana	1	0.195	0.241
DEA113	7/7/2011	26	Leptophlebiidae	1	0.160	0.188
DEA113	7/7/2011	26	Amiocentrus aspilus	1	0.083	0.096
DEA113	7/7/2011	26	Zapada cinctipes	1	0.079	0.093
DEA113	7/7/2011	26	Perlidae	1	0.061	0.070
DEA113	7/7/2011	26	Philopotamidae	1	0.029	0.032
DEA113	7/7/2011	26	Bezzia/Palpomyia sp.	1	0.019	0.021
DEA113	8/2/2011	36	Chironomidae	2	524.544	377.035
DEA113	8/2/2011	36	Hesperoperla pacifica	3	215.503	203.286
DEA113	8/2/2011	36	Oligochaete (class C)	1	142.631	109.266
DEA113	8/2/2011	36	Baetis tricaudatus	1	140.838	109.401
DEA113	8/2/2011	36	Serratella tibialis	1	98.411	80.883
DEA113	8/2/2011	36	Arctopsyche grandis	1	95.539	87.494
DEA113	8/2/2011	36	Epeorus longimanus	2	88.579	74.340
DEA113	8/2/2011	36	Drunella coloradensis/flavilinea	1	62.277	52.310
DEA113	8/2/2011	36	Brachycentrus americanus	1	53.096	52.458
DEA113	8/2/2011	36	Oligochaete (class B)	1	44.529	36.739
DEA113	8/2/2011	36	Rhyacophila brunnea gr.	2	31.964	29.675
DEA113	8/2/2011	36	Rhyacophila alberta gr.	1	30.795	27.756
DEA113	8/2/2011	36	Dicranota sp.	1	21.136	17.767
DEA113	8/2/2011	36	Paraperla sp.	1	17.637	15.763
DEA113	8/2/2011	36	Sweltsa sp.	1	15.672	11.555
DEA113	8/2/2011	36	Chloroperlidae	1	14.822	11.236
DEA113	8/2/2011	36	Helicopsyche sp.	1	14.334	13.137
DEA113	8/2/2011	36	Malenka sp.	1	14.072	10.807
DEA113	8/2/2011	36	Rhyacophila sp.	2	12.548	11.143
DEA113	8/2/2011	36	Cinygmula sp.	1	10.825	8.517
DEA113	8/2/2011	36	Cleptelmis addenda	1	7.549	5.622
DEA113	8/2/2011	36	Antocha sp.	1	4.631	3.962
DEA113	8/2/2011	36	Heterlimnius sp.	1	4.497	3.106
DEA113	8/2/2011	36	Suwallia sp.	1	4.373	3.219

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA113	8/2/2011	36	Diphetor hageni	1	4.224	3.278
DEA113	8/2/2011	36	Caudatella edmundsi	2	3.380	2.703
DEA113	8/2/2011	36	Drunella grandis	1	3.137	2.222
DEA113	8/2/2011	36	Optioservus sp.	2	2.794	2.166
DEA113	8/2/2011	36	Leuctridae	1	2.456	1.966
DEA113	8/2/2011	36	Rhyacophila narvae	1	0.496	0.363
DEA113	8/2/2011	36	Micrasema sp.	1	0.480	0.365
DEA113	8/2/2011	36	Acentrella sp.	1	0.420	0.287
DEA113	8/2/2011	36	Ameletus sp.	1	0.279	0.206
DEA113	8/2/2011	36	Simulium sp.	1	0.186	0.134
DEA113	8/2/2011	36	Empididae	1	0.157	0.099
DEA113	8/2/2011	36	Caudatella sp.	1	0.099	0.064
DEA113	8/2/2011	36	Hydropsyche sp.	1	0.062	0.042
DEA113	9/7/2011	21	Chironomidae	2	463.767	416.229
DEA113	9/7/2011	21	Baetis tricaudatus	1	244.448	216.224
DEA113	9/7/2011	21	Sweltsa sp.	1	73.667	63.817
DEA113	9/7/2011	21	Oligochaete (class B)	1	72.372	67.335
DEA113	9/7/2011	21	Oligochaete (class C)	1	52.972	47.318
DEA113	9/7/2011	21	Antocha sp.	2	28.470	27.890
DEA113	9/7/2011	21	Serratella tibialis	1	20.703	21.018
DEA113	9/7/2011	21	Dicranota sp.	2	13.061	13.276
DEA113	9/7/2011	21	Drunella coloradensis/flavilinea	1	12.789	13.269
DEA113	9/7/2011	21	Caudatella hystrix	1	8.967	13.278
DEA113	9/7/2011	21	Hexatoma sp.	1	7.872	8.539
DEA113	9/7/2011	21	Capniidae	1	7.865	6.295
DEA113	9/7/2011	21	Arctopsyche grandis	1	7.443	5.986
DEA113	9/7/2011	21	Cleptelmis addenda	1	5.501	5.120
DEA113	9/7/2011	21	Epeorus longimanus	1	5.157	5.256
DEA113	9/7/2011	21	Malenka sp.	1	4.193	4.075
DEA113	9/7/2011	21	Hesperoconopa sp.	1	4.016	3.853
DEA113	9/7/2011	21	Cinygmula sp.	1	3.614	3.543
DEA113	9/7/2011	21	Zapada cinctipes	1	3.389	2.833
DEA113	9/7/2011	21	Heterlimnius sp.	1	3.173	3.046
DEA113	9/7/2011	21	Hesperoperla pacifica	1	2.967	2.769
DEA113	9/7/2011	21	Drunella grandis	1	2.341	2.125
DEA113	9/7/2011	21	Rhithrogena sp.	1	2.121	1.863
DEA113	9/7/2011	21	Clinocera sp.	1	1.834	1.499
DEA113	9/7/2011	21	Ephemerella sp.	1	1.484	1.206
DEA113	9/7/2011	21	Epeorus albertae	1	1.390	1.267
DEA113	9/7/2011	21	Arctopsychinae	1	1.239	1.053
DEA113	9/7/2011	21	Drunella spinifera	1	1.033	0.931

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA113	9/7/2011	21	Helicopsyche sp.	1	0.497	0.462
DEA113	9/7/2011	21	Leptophlebiidae	1	0.161	0.134
DEA113	9/7/2011	21	Perlodidae	1	0.059	0.049
DEA113	9/28/2011	NA	Acentrella insignificans	1	0.000	0.244
DEA113	9/28/2011	NA	Acentrella sp.	1	0.000	0.109
DEA113	9/28/2011	NA	Antocha sp.	1	0.000	18.218
DEA113	9/28/2011	NA	Arctopsyche grandis	1	0.000	5.776
DEA113	9/28/2011	NA	Arctopsychinae	1	0.000	0.601
DEA113	9/28/2011	NA	Attenella margarita	1	0.000	1.301
DEA113	9/28/2011	NA	Baetis tricaudatus	1	0.000	175.313
DEA113	9/28/2011	NA	Capniidae	1	0.000	5.973
DEA113	9/28/2011	NA	Caudatella edmundsi	1	0.000	0.228
DEA113	9/28/2011	NA	Caudatella hystrix	1	0.000	7.261
DEA113	9/28/2011	NA	Chironomidae	2	0.000	126.041
DEA113	9/28/2011	NA	Cinygmula sp.	1	0.000	0.732
DEA113	9/28/2011	NA	Drunella doddsii	1	0.000	0.674
DEA113	9/28/2011	NA	Epeorus sp.	1	0.000	0.158
DEA113	9/28/2011	NA	Ephemerella dorothea/excrucians	1	0.000	9.451
DEA113	9/28/2011	NA	Glossosoma sp.	1	0.000	0.385
DEA113	9/28/2011	NA	Hesperoperla pacifica	1	0.000	1.668
DEA113	9/28/2011	NA	Leptophlebiidae	1	0.000	0.078
DEA113	9/28/2011	NA	Oligochaete (class B)	1	0.000	44.514
DEA113	9/28/2011	NA	Oligochaete (class C)	1	0.000	31.354
DEA113	9/28/2011	NA	Optioservus sp.	1	0.000	0.039
DEA113	9/28/2011	NA	Paraleptophlebia sp.	1	0.000	2.032
DEA113	9/28/2011	NA	Rhithrogena sp.	1	0.000	1.103
DEA113	9/28/2011	NA	Rhyacophila hyalinata gr.	1	0.000	7.087
DEA113	9/28/2011	NA	Simulium sp.	1	0.000	0.660
DEA113	9/28/2011	NA	Sweltsa sp.	1	0.000	55.581
DEA113	9/28/2011	NA	Zapada cinctipes	1	0.000	2.224
DEA114	6/30/2010	28	Claassenia sabulosa	1	1270.388	1040.522
DEA114	6/30/2010	28	Oligochaete (class C)	1	217.388	140.081
DEA114	6/30/2010	28	Chironomidae	2	191.305	117.599
DEA114	6/30/2010	28	Glutops sp.	2	100.589	70.531
DEA114	6/30/2010	28	Brachycentrus americanus	1	94.939	62.627
DEA114	6/30/2010	28	Epeorus longimanus	2	86.682	61.367
DEA114	6/30/2010	28	Hydropsyche sp.	2	68.867	49.157
DEA114	6/30/2010	28	Optioservus sp.	2	54.452	34.518
DEA114	6/30/2010	28	Serratella tibialis	1	44.505	26.389
DEA114	6/30/2010	28	Rhithrogena sp.	1	43.123	32.316

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	6/30/2010	28	Baetis tricaudatus	1	39.199	24.457
DEA114	6/30/2010	28	Ecclisomyia sp.	1	35.134	28.474
DEA114	6/30/2010	28	Drunella coloradensis/flavilinea	1	33.063	22.379
DEA114	6/30/2010	28	Rhyacophila angelita gr.	2	32.968	23.720
DEA114	6/30/2010	28	Drunella doddsii	2	29.513	24.025
DEA114	6/30/2010	28	Hesperoperla pacifica	1	27.960	22.506
DEA114	6/30/2010	28	Ameletus sp.	1	22.916	17.631
DEA114	6/30/2010	28	Glossosoma sp.	2	18.497	12.726
DEA114	6/30/2010	28	Cinygmula sp.	1	14.263	9.660
DEA114	6/30/2010	28	Caudatella edmundsi	1	13.067	9.799
DEA114	6/30/2010	28	Antocha sp.	1	11.285	8.031
DEA114	6/30/2010	28	Blephariceridae	1	10.551	7.818
DEA114	6/30/2010	28	Paraleptophlebia sp.	1	10.487	5.958
DEA114	6/30/2010	28	Sweltsa sp.	1	9.993	5.803
DEA114	6/30/2010	28	Rhabdomastix fascigera gr.	1	8.586	5.989
DEA114	6/30/2010	28	Rhyacophila pellisa/valuma	2	8.553	5.951
DEA114	6/30/2010	28	Caudatella heterocaudata	1	7.714	5.282
DEA114	6/30/2010	28	Rhyacophila brunnea gr.	1	6.985	4.608
DEA114	6/30/2010	28	Oligochaete (class B)	1	6.782	4.321
DEA114	6/30/2010	28	Chloroperlidae	1	6.689	4.194
DEA114	6/30/2010	28	Dicranota sp.	1	4.547	3.287
DEA114	6/30/2010	28	Simulium sp.	1	4.518	2.853
DEA114	6/30/2010	28	Suwallia sp.	1	4.293	2.812
DEA114	6/30/2010	28	Arctopsyche grandis	1	4.023	2.906
DEA114	6/30/2010	28	Hexatoma sp.	1	3.991	2.881
DEA114	6/30/2010	28	Narpus sp.	1	3.124	2.076
DEA114	6/30/2010	28	Neoplasta sp.	1	2.638	1.558
DEA114	6/30/2010	28	Paraperla sp.	1	2.587	1.705
DEA114	6/30/2010	28	Rhyacophila narvae	1	2.510	2.750
DEA114	6/30/2010	28	Diphetor hageni	1	2.006	1.181
DEA114	6/30/2010	28	Micrasema sp.	1	1.556	0.872
DEA114	6/30/2010	28	Apataniidae	1	1.532	1.049
DEA114	6/30/2010	28	Heterlimnius sp.	1	1.388	0.857
DEA114	6/30/2010	28	Bezzia/Palpomyia sp.	1	1.160	0.719
DEA114	6/30/2010	28	Zaitzevia sp.	1	0.458	0.261
DEA114	6/30/2010	28	Caudatella sp.	1	0.379	0.200
DEA114	6/30/2010	28	Acentrella sp.	1	0.161	0.088
DEA114	6/30/2010	28	Epeorus sp.	1	0.109	0.064
DEA114	6/30/2010	28	Chelifera/Metachela sp.	1	0.104	0.059
DEA114	7/28/2010	21	Claassenia sabulosa	1	948.081	1005.750
DEA114	7/28/2010	21	Oligochaete (class C)	1	371.844	275.187

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	7/28/2010	21	Chironomidae	2	173.578	121.285
DEA114	7/28/2010	21	Optioservus sp.	2	126.802	92.165
DEA114	7/28/2010	21	Brachycentrus americanus	2	78.953	67.600
DEA114	7/28/2010	21	Serratella tibialis	1	54.830	43.124
DEA114	7/28/2010	21	Baetis tricaudatus	1	49.704	34.579
DEA114	7/28/2010	21	Glutops sp.	2	47.150	39.420
DEA114	7/28/2010	21	Micrasema sp.	1	36.602	27.577
DEA114	7/28/2010	21	Rhyacophila brunnea gr.	2	25.576	21.149
DEA114	7/28/2010	21	Sweltsa sp.	1	22.187	15.481
DEA114	7/28/2010	21	Rhithrogena sp.	1	17.747	12.033
DEA114	7/28/2010	21	Acentrella insignificans	1	16.595	12.099
DEA114	7/28/2010	21	Epeorus albertae	1	15.208	12.320
DEA114	7/28/2010	21	Hydropsyche sp.	2	14.824	12.450
DEA114	7/28/2010	21	Baetis flavistriga	1	13.525	9.556
DEA114	7/28/2010	21	Cleptelmis addenda	1	13.206	10.034
DEA114	7/28/2010	21	Acentrella turbida	1	12.651	9.188
DEA114	7/28/2010	21	Ephemerella dorothea/excrucians	2	11.816	10.188
DEA114	7/28/2010	21	Rhyacophila narvae	1	9.887	7.432
DEA114	7/28/2010	21	Ameletus sp.	1	9.495	8.049
DEA114	7/28/2010	21	Paraleptophlebia sp.	1	9.031	6.499
DEA114	7/28/2010	21	Epeorus longimanus	1	8.542	7.273
DEA114	7/28/2010	21	Arctopsychinae	1	8.009	5.344
DEA114	7/28/2010	21	Simulium sp.	1	5.937	4.162
DEA114	7/28/2010	21	Narpus sp.	1	5.598	4.207
DEA114	7/28/2010	21	Rhabdomastix fascigera gr.	1	5.431	4.489
DEA114	7/28/2010	21	Drunella doddsii	1	4.055	2.690
DEA114	7/28/2010	21	Neoplasta sp.	1	2.973	2.060
DEA114	7/28/2010	21	Zaitzevia sp.	2	2.730	2.073
DEA114	7/28/2010	21	Perlodidae	1	2.627	1.732
DEA114	7/28/2010	21	Suwallia sp.	1	2.274	1.790
DEA114	7/28/2010	21	Drunella grandis	1	1.918	1.241
DEA114	7/28/2010	21	Heterlimnius sp.	1	1.308	0.891
DEA114	7/28/2010	21	Ephemerellidae	1	1.164	0.695
DEA114	7/28/2010	21	Hesperoperla pacifica	1	1.131	0.793
DEA114	7/28/2010	21	Diphetor hageni	1	1.041	0.785
DEA114	7/28/2010	21	Baetis alius	1	0.970	0.688
DEA114	7/28/2010	21	Rhyacophila pellisa/valuma	1	0.674	0.485
DEA114	7/28/2010	21	Centroptilum sp.	1	0.442	0.317
DEA114	7/28/2010	21	Nemouridae	1	0.307	0.195
DEA114	7/28/2010	21	Caudatella sp.	1	0.296	0.192

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	7/28/2010	21	Drunella spinifera	1	0.158	0.103
DEA114	7/28/2010	21	Capniidae	1	0.064	0.041
DEA114	7/28/2010	21	Hydroptilidae	1	0.056	0.037
DEA114	7/28/2010	21	Attenella sp.	1	0.031	0.020
DEA114	8/18/2010	47	Antocha sp.	1	1514.538	921.408
DEA114	8/18/2010	47	Oligochaete (class C)	1	587.317	343.433
DEA114	8/18/2010	47	Optioservus sp.	2	247.770	137.990
DEA114	8/18/2010	47	Arctopsyche grandis	2	246.426	150.173
DEA114	8/18/2010	47	Chironomidae	2	221.249	118.111
DEA114	8/18/2010	47	Brachycentrus americanus	1	197.160	125.193
DEA114	8/18/2010	47	Micrasema sp.	1	134.992	74.712
DEA114	8/18/2010	47	Doroneuria sp.	1	131.331	96.071
DEA114	8/18/2010	47	Baetis tricaudatus	1	103.401	56.584
DEA114	8/18/2010	47	Drunella grandis	1	88.560	43.278
DEA114	8/18/2010	47	Dolophilodes sp.	1	85.046	49.391
DEA114	8/18/2010	47	Rhithrogena sp.	1	76.283	40.645
DEA114	8/18/2010	47	Glossosoma sp.	1	74.694	38.481
DEA114	8/18/2010	47	Sweltsa sp.	1	68.496	36.438
DEA114	8/18/2010	47	Drunella doddsii	1	62.603	27.759
DEA114	8/18/2010	47	Caudatella hystrix	1	47.133	25.164
DEA114	8/18/2010	47	Glutops sp.	2	46.493	27.232
DEA114	8/18/2010	47	Oligophlebodes sp.	1	44.256	21.646
DEA114	8/18/2010	47	Rhyacophila brunnea gr.	1	42.928	27.592
DEA114	8/18/2010	47	Cleptelmis addenda	1	31.059	17.443
DEA114	8/18/2010	47	Serratella tibialis	1	28.281	17.494
DEA114	8/18/2010	47	Oligochaete (class B)	1	27.239	15.928
DEA114	8/18/2010	47	Rhyacophila angelita gr.	1	25.923	16.661
DEA114	8/18/2010	47	Perlodidae	1	25.189	13.126
DEA114	8/18/2010	47	Narpus sp.	1	11.910	7.078
DEA114	8/18/2010	47	Epeorus longimanus	1	9.498	5.772
DEA114	8/18/2010	47	Rhyacophila narvae	1	9.312	5.438
DEA114	8/18/2010	47	Heterlimnius sp.	1	9.237	4.962
DEA114	8/18/2010	47	Ochrotrichia sp.	2	8.083	4.620
DEA114	8/18/2010	47	Hydropsychidae	1	6.831	4.237
DEA114	8/18/2010	47	Rhyacophila pellisa/valuma	1	4.849	2.487
DEA114	8/18/2010	47	Zapada cinctipes	1	4.782	2.459
DEA114	8/18/2010	47	Simulium sp.	1	4.729	2.558
DEA114	8/18/2010	47	Acentrella turbida	1	4.670	2.592
DEA114	8/18/2010	47	Chelifera/Metachela sp.	1	3.471	1.864
DEA114	8/18/2010	47	Rhyacophila sp.	1	3.009	1.390
DEA114	8/18/2010	47	Paraleptophlebia sp.	1	2.562	1.325

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	8/18/2010	47	Baetis flavistriga	1	1.944	1.124
DEA114	8/18/2010	47	Neoplasta sp.	1	1.855	0.990
DEA114	8/18/2010	47	Perlidae	1	1.626	0.916
DEA114	8/18/2010	47	Ephemerellidae	1	1.391	0.656
DEA114	8/18/2010	47	Hydroptilidae	1	0.798	0.439
DEA114	8/18/2010	47	Zaitzevia sp.	1	0.269	0.133
DEA114	8/18/2010	47	Bezzia/Palpomyia sp.	1	0.072	0.035
DEA114	8/18/2010	47	Clinocera sp.	1	0.055	0.026
DEA114	8/18/2010	47	Hesperoperla pacifica	1	0.000	0.000
DEA114	10/4/2010	274	Antocha sp.	1	2534.773	865.256
DEA114	10/4/2010	274	Brachycentrus americanus	3	600.389	219.126
DEA114	10/4/2010	274	Arctopsyche grandis	3	538.261	186.922
DEA114	10/4/2010	274	Oligochaete (class C)	1	527.459	166.114
DEA114	10/4/2010	274	Claassenia sabulosa	1	347.572	104.255
DEA114	10/4/2010	274	Chironomidae	2	344.613	98.270
DEA114	10/4/2010	274	Optioservus sp.	2	246.741	75.308
DEA114	10/4/2010	274	Micrasema sp.	1	181.132	54.940
DEA114	10/4/2010	274	Glossosoma sp.	2	179.009	55.948
DEA114	10/4/2010	274	Hydropsyche sp.	2	151.061	50.470
DEA114	10/4/2010	274	Glutops sp.	2	139.193	44.518
DEA114	10/4/2010	274	Dolophilodes sp.	1	127.240	48.165
DEA114	10/4/2010	274	Drunella grandis	1	119.759	42.125
DEA114	10/4/2010	274	Ephemerella dorothea/excrucians	1	110.531	31.864
DEA114	10/4/2010	274	Rhithrogena sp.	1	97.266	30.378
DEA114	10/4/2010	274	Baetis tricaudatus	1	96.540	27.900
DEA114	10/4/2010	274	Sweltsa sp.	1	81.678	24.160
DEA114	10/4/2010	274	Drunella doddsii	1	77.582	25.390
DEA114	10/4/2010	274	Cultus sp.	1	72.004	23.614
DEA114	10/4/2010	274	Oligophlebodes sp.	1	69.463	19.721
DEA114	10/4/2010	274	Caudatella hystrix	1	65.685	20.331
DEA114	10/4/2010	274	Oligochaete (class B)	1	53.080	15.434
DEA114	10/4/2010	274	Rhyacophila brunnea gr.	2	50.598	17.555
DEA114	10/4/2010	274	Cleptelmis addenda	2	47.138	14.608
DEA114	10/4/2010	274	Cinygmula sp.	1	43.717	12.062
DEA114	10/4/2010	274	Perlodidae	1	37.935	11.492
DEA114	10/4/2010	274	Caudatella edmundsi	1	34.291	10.022
DEA114	10/4/2010	274	Hesperoperla pacifica	2	16.095	5.023
DEA114	10/4/2010	274	Drunella spinifera	1	15.714	4.934
DEA114	10/4/2010	274	Heterlimnius sp.	1	14.810	4.681
DEA114	10/4/2010	274	Narpus sp.	2	12.413	4.030

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	10/4/2010	274	Rhyacophila coloradensis gr.	1	11.752	3.746
DEA114	10/4/2010	274	Dicranota sp.	1	11.374	3.762
DEA114	10/4/2010	274	Simulium sp.	1	8.131	2.508
DEA114	10/4/2010	274	Rhyacophila pellisa/valuma	1	7.781	2.370
DEA114	10/4/2010	274	Zapada cinctipes	1	7.451	2.213
DEA114	10/4/2010	274	Lepidostoma sp.	1	5.016	1.453
DEA114	10/4/2010	274	Leptophlebiidae	1	4.935	1.480
DEA114	10/4/2010	274	Rhyacophila sp.	1	4.487	1.309
DEA114	10/4/2010	274	Paraleuctra sp.	1	3.790	1.120
DEA114	10/4/2010	274	Capniidae	1	3.058	0.846
DEA114	10/4/2010	274	Paraleptophlebia sp.	1	2.407	0.733
DEA114	10/4/2010	274	Chelifera/Metachela sp.	1	2.213	0.656
DEA114	10/4/2010	274	Baetis sp.	1	2.076	0.562
DEA114	10/4/2010	274	Ameletus sp.	1	1.257	0.355
DEA114	10/4/2010	274	Taenionema sp.	1	1.153	0.336
DEA114	10/4/2010	274	Epeorus sp.	1	0.328	0.086
DEA114	10/4/2010	274	Ceratopogoninae	1	0.031	0.007
DEA114	7/5/2011	27	Arctopsyche grandis	2	330.581	313.015
DEA114	7/5/2011	27	Brachycentrus americanus	2	169.066	154.170
DEA114	7/5/2011	27	Chironomidae	2	165.734	125.706
DEA114	7/5/2011	27	Epeorus longimanus	2	120.831	103.945
DEA114	7/5/2011	27	Claassenia sabulosa	1	95.050	102.772
DEA114	7/5/2011	27	Simulium sp.	1	84.110	62.331
DEA114	7/5/2011	27	Baetis tricaudatus	1	81.291	65.588
DEA114	7/5/2011	27	Neophylax rickeri	2	62.908	54.894
DEA114	7/5/2011	27	Glutops sp.	1	57.136	51.067
DEA114	7/5/2011	27	Drunella grandis	2	48.261	50.341
DEA114	7/5/2011	27	Serratella tibialis	1	41.482	31.297
DEA114	7/5/2011	27	Antocha sp.	1	40.687	36.156
DEA114	7/5/2011	27	Oligochaete (class C)	1	38.791	30.544
DEA114	7/5/2011	27	Drunella coloradensis/flavilinea	1	29.592	26.320
DEA114	7/5/2011	27	Micrasema sp.	3	26.282	21.115
DEA114	7/5/2011	27	Drunella doddsii	2	25.792	24.129
DEA114	7/5/2011	27	Hesperoperla pacifica	2	24.985	24.557
DEA114	7/5/2011	27	Rhabdomastix fascigera gr.	3	23.272	21.141
DEA114	7/5/2011	27	Oligochaete (class A)	1	20.880	20.952
DEA114	7/5/2011	27	Cultus sp.	1	17.494	17.208
DEA114	7/5/2011	27	Narpus sp.	1	15.282	12.689
DEA114	7/5/2011	27	Drunella spinifera	1	13.214	12.925
DEA114	7/5/2011	27	Optioservus sp.	2	12.379	9.614
DEA114	7/5/2011	27	Rhyacophila angelita gr.	1	12.316	10.901

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	7/5/2011	27	Rhithrogena sp.	1	12.160	11.306
DEA114	7/5/2011	27	Hydropsyche sp.	1	10.268	8.012
DEA114	7/5/2011	27	Paraperla sp.	1	9.840	8.585
DEA114	7/5/2011	27	Cinygmula sp.	1	9.677	8.241
DEA114	7/5/2011	27	Rhyacophila pellisa/valuma	2	9.470	8.587
DEA114	7/5/2011	27	Rhyacophila coloradensis gr.	1	8.964	8.007
DEA114	7/5/2011	27	Glossosomatidae	1	8.787	7.884
DEA114	7/5/2011	27	Isoperla sp.	1	8.353	7.884
DEA114	7/5/2011	27	Caudatella hystrix	1	7.926	7.459
DEA114	7/5/2011	27	Sweltsa sp.	2	7.199	5.196
DEA114	7/5/2011	27	Oligochaete (class B)	1	6.518	5.552
DEA114	7/5/2011	27	Hydropsychidae	1	6.201	5.961
DEA114	7/5/2011	27	Ephemerella dorothea/excrucians	1	5.843	5.225
DEA114	7/5/2011	27	Hexatoma sp.	1	5.029	4.779
DEA114	7/5/2011	27	Epeorus sp.	1	4.338	3.260
DEA114	7/5/2011	27	Caudatella heterocaudata	1	4.059	3.483
DEA114	7/5/2011	27	Hesperoconopa sp.	1	3.784	3.187
DEA114	7/5/2011	27	Chloroperlidae	1	3.231	2.550
DEA114	7/5/2011	27	Caudatella edmundsi	1	2.907	4.304
DEA114	7/5/2011	27	Limnophila sp.	1	2.254	1.997
DEA114	7/5/2011	27	Diphetor hageni	1	2.187	1.623
DEA114	7/5/2011	27	Rhabdomastix setigera gr.	1	1.793	1.568
DEA114	7/5/2011	27	Chelifera/Metachela sp.	1	1.383	1.071
DEA114	7/5/2011	27	Rhyacophila brunnea gr.	1	1.119	0.927
DEA114	7/5/2011	27	Neophylax sp.	1	0.635	0.506
DEA114	7/5/2011	27	Neophylax splendens	1	0.436	0.352
DEA114	7/5/2011	27	Ameletus sp.	1	0.385	0.287
DEA114	7/5/2011	27	Perlidae	1	0.204	0.138
DEA114	7/5/2011	27	Paraleptophlebia sp.	1	0.043	0.030
DEA114	7/5/2011	27	Bezzia/Palpomyia sp.	1	0.030	0.020
DEA114	8/1/2011	23	Arctopsyche grandis	3	1045.146	992.496
DEA114	8/1/2011	23	Brachycentrus americanus	2	685.386	633.274
DEA114	8/1/2011	23	Chironomidae	2	539.835	405.518
DEA114	8/1/2011	23	Optioservus sp.	3	120.218	93.340
DEA114	8/1/2011	23	Micrasema sp.	1	117.254	92.338
DEA114	8/1/2011	23	Baetis tricaudatus	1	95.391	76.240
DEA114	8/1/2011	23	Antocha sp.	2	95.143	89.395
DEA114	8/1/2011	23	Simulium sp.	2	91.872	70.875
DEA114	8/1/2011	23	Serratella tibialis	1	87.038	91.916
DEA114	8/1/2011	23	Epeorus longimanus	2	72.414	62.854

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	8/1/2011	23	Acentrella insignificans	1	68.821	53.634
DEA114	8/1/2011	23	Glutops sp.	2	49.391	44.219
DEA114	8/1/2011	23	Rhyacophila angelita gr.	2	47.394	39.464
DEA114	8/1/2011	23	Hydropsyche sp.	2	41.600	35.022
DEA114	8/1/2011	23	Cleptelmis addenda	1	22.815	18.343
DEA114	8/1/2011	23	Narpus sp.	1	21.367	18.049
DEA114	8/1/2011	23	Sweltsa sp.	1	21.031	15.857
DEA114	8/1/2011	23	Oligochaete (class C)	1	20.712	16.231
DEA114	8/1/2011	23	Rhyacophila alberta gr.	1	19.874	19.029
DEA114	8/1/2011	23	Rhyacophila sp.	1	16.186	14.787
DEA114	8/1/2011	23	Drunella coloradensis/flavilinea	1	16.166	14.420
DEA114	8/1/2011	23	Drunella grandis	1	14.859	11.016
DEA114	8/1/2011	23	Drunella doddsii	1	13.189	9.679
DEA114	8/1/2011	23	Acentrella turbida	1	11.405	8.889
DEA114	8/1/2011	23	Rhithrogena sp.	1	9.780	7.218
DEA114	8/1/2011	23	Suwallia sp.	1	9.032	7.097
DEA114	8/1/2011	23	Hesperoperla pacifica	1	7.619	5.357
DEA114	8/1/2011	23	Rhyacophila coloradensis gr.	1	7.205	6.519
DEA114	8/1/2011	23	Epeorus albertae	1	5.070	8.766
DEA114	8/1/2011	23	Caudatella edmundsi	2	4.449	3.654
DEA114	8/1/2011	23	Heterlimnius sp.	1	3.692	2.771
DEA114	8/1/2011	23	Baetis flavistriga	1	3.468	2.269
DEA114	8/1/2011	23	Epeorus sp.	1	3.392	2.942
DEA114	8/1/2011	23	Chelifera/Metachela sp.	2	3.151	2.405
DEA114	8/1/2011	23	Ephemerella dorothea/excrucians	1	2.730	2.385
DEA114	8/1/2011	23	Zaitzevia sp.	1	2.556	2.069
DEA114	8/1/2011	23	Leptophlebiidae	1	2.393	1.802
DEA114	8/1/2011	23	Diphetor hageni	1	1.784	1.386
DEA114	8/1/2011	23	Hesperoconopa sp.	1	1.384	1.164
DEA114	8/1/2011	23	Heptageniidae	1	0.730	0.539
DEA114	8/1/2011	23	Perlidae	1	0.623	0.465
DEA114	8/1/2011	23	Caudatella sp.	1	0.586	0.415
DEA114	8/1/2011	23	Ameletus sp.	1	0.314	0.238
DEA114	8/24/2011	33	Brachycentrus americanus	1	918.258	773.863
DEA114	8/24/2011	33	Chironomidae	2	658.085	458.783
DEA114	8/24/2011	33	Antocha sp.	1	568.991	469.453
DEA114	8/24/2011	33	Arctopsyche grandis	3	545.528	445.399
DEA114	8/24/2011	33	Hesperoperla pacifica	2	178.164	156.888
DEA114	8/24/2011	33	Optioservus sp.	2	133.906	95.362
DEA114	8/24/2011	33	Glutops sp.	2	132.375	110.544

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	8/24/2011	33	Micrasema sp.	1	128.189	91.676
DEA114	8/24/2011	33	Serratella tibialis	1	99.581	77.642
DEA114	8/24/2011	33	Glossosoma sp.	1	88.866	60.807
DEA114	8/24/2011	33	Oligochaete (class C)	1	88.421	61.346
DEA114	8/24/2011	33	Hydropsyche sp.	1	82.354	64.506
DEA114	8/24/2011	33	Baetis tricaudatus	1	70.871	47.708
DEA114	8/24/2011	33	Oligophlebodes sp.	1	66.658	42.466
DEA114	8/24/2011	33	Rhyacophila brunnea gr.	2	65.916	53.736
DEA114	8/24/2011	33	Sweltsa sp.	1	48.118	32.792
DEA114	8/24/2011	33	Caudatella hystrix	1	47.824	36.303
DEA114	8/24/2011	33	Drunella doddsii	1	47.660	33.562
DEA114	8/24/2011	33	Rhyacophila angelita gr.	1	35.567	30.146
DEA114	8/24/2011	33	Cleptelmis addenda	1	27.993	20.430
DEA114	8/24/2011	33	Rhithrogena sp.	1	26.216	17.868
DEA114	8/24/2011	33	Drunella grandis	1	23.382	16.399
DEA114	8/24/2011	33	Lepidostoma sp.	1	22.873	17.066
DEA114	8/24/2011	33	Rhabdomastix fascigera gr.	1	21.968	16.774
DEA114	8/24/2011	33	Narpus sp.	1	21.591	16.266
DEA114	8/24/2011	33	Tipulidae	1	10.984	8.387
DEA114	8/24/2011	33	Neophylax sp.	2	9.577	7.370
DEA114	8/24/2011	33	Acentrella insignificans	1	9.116	6.463
DEA114	8/24/2011	33	Simulium sp.	1	8.651	6.130
DEA114	8/24/2011	33	Heterlimnius sp.	1	8.231	5.526
DEA114	8/24/2011	33	Rhyacophila pellisa/valuma	2	7.851	6.332
DEA114	8/24/2011	33	Epeorus albertae	1	6.955	5.650
DEA114	8/24/2011	33	Hexatoma sp.	1	5.346	4.280
DEA114	8/24/2011	33	Zapada cinctipes	1	4.854	3.213
DEA114	8/24/2011	33	Leptophlebiidae	1	4.373	2.704
DEA114	8/24/2011	33	Baetis alius	1	4.361	3.129
DEA114	8/24/2011	33	Ephemerella sp.	1	4.232	2.673
DEA114	8/24/2011	33	Perlodidae	1	3.926	3.599
DEA114	8/24/2011	33	Acentrella turbida	1	2.824	1.881
DEA114	8/24/2011	33	Rhyacophila sp.	1	2.440	1.525
DEA114	8/24/2011	33	Caudatella edmundsi	1	2.311	1.465
DEA114	8/24/2011	33	Baetis flavistriga	1	2.055	1.500
DEA114	8/24/2011	33	Drunella spinifera	1	2.015	1.347
DEA114	8/24/2011	33	Chelifera/Metachela sp.	1	1.730	1.191
DEA114	8/24/2011	33	Perlidae	1	0.768	0.477
DEA114	8/24/2011	33	Rhyacophila narvae	1	0.629	0.447
DEA114	8/24/2011	33	Neoplasta sp.	1	0.453	0.297
DEA114	8/24/2011	33	Simuliidae	1	0.187	0.124

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA114	9/26/2011	NA	Antocha sp.	1	0.000	433.208
DEA114	9/26/2011	NA	Arctopsyche grandis	3	0.000	339.826
DEA114	9/26/2011	NA	Baetis tricaudatus	1	0.000	19.870
DEA114	9/26/2011	NA	Bezzia/Palpomyia sp.	1	0.000	3.188
DEA114	9/26/2011	NA	Brachycentrus americanus	2	0.000	354.087
DEA114	9/26/2011	NA	Capniidae	1	0.000	1.460
DEA114	9/26/2011	NA	Caudatella edmundsi	1	0.000	1.216
DEA114	9/26/2011	NA	Caudatella hystrix	1	0.000	19.696
DEA114	9/26/2011	NA	Chironomidae	2	0.000	126.501
DEA114	9/26/2011	NA	Cinygmula sp.	1	0.000	1.952
DEA114	9/26/2011	NA	Cleptelmis addenda	1	0.000	2.585
DEA114	9/26/2011	NA	Dicranota sp.	1	0.000	1.672
DEA114	9/26/2011	NA	Drunella doddsii	1	0.000	27.807
DEA114	9/26/2011	NA	Drunella grandis	1	0.000	5.599
DEA114	9/26/2011	NA	Epeorus sp.	1	0.000	0.390
DEA114	9/26/2011	NA	Ephemerella dorothea/excrucians	1	0.000	33.490
DEA114	9/26/2011	NA	Glossosoma sp.	1	0.000	34.463
DEA114	9/26/2011	NA	Glutops sp.	2	0.000	36.187
DEA114	9/26/2011	NA	Hesperoperla pacifica	1	0.000	49.629
DEA114	9/26/2011	NA	Heterlimnius sp.	1	0.000	3.161
DEA114	9/26/2011	NA	Hydropsyche sp.	2	0.000	46.895
DEA114	9/26/2011	NA	Lepidostoma sp.	1	0.000	10.518
DEA114	9/26/2011	NA	Leptophlebiidae	1	0.000	1.429
DEA114	9/26/2011	NA	Micrasema sp.	1	0.000	10.901
DEA114	9/26/2011	NA	Narpus sp.	1	0.000	0.759
DEA114	9/26/2011	NA	Neophylax sp.	1	0.000	0.110
DEA114	9/26/2011	NA	Oligochaete (class C)	1	0.000	48.826
DEA114	9/26/2011	NA	Oligophlebodes sp.	1	0.000	41.553
DEA114	9/26/2011	NA	Optioservus sp.	2	0.000	20.842
DEA114	9/26/2011	NA	Paraleptophlebia sp.	1	0.000	2.082
DEA114	9/26/2011	NA	Perlidae	1	0.000	0.137
DEA114	9/26/2011	NA	Perlodidae	1	0.000	2.197
DEA114	9/26/2011	NA	Rhithrogena sp.	1	0.000	11.659
DEA114	9/26/2011	NA	Rhyacophila sp.	1	0.000	1.430
DEA114	9/26/2011	NA	Serratella tibialis	1	0.000	16.443
DEA114	9/26/2011	NA	Sweltsa sp.	1	0.000	21.096
DEA114	9/26/2011	NA	Zaitzevia sp.	1	0.000	3.726
DEA114	9/26/2011	NA	Zapada cinctipes	1	0.000	2.931
DEA115	7/7/2010	22	Brachycentrus americanus	1	227.373	151.590
DEA115	7/7/2010	22	Optioservus sp.	2	174.483	114.978

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	7/7/2010	22	Oligochaete (class C)	1	139.273	92.789
DEA115	7/7/2010	22	Epeorus longimanus	2	133.208	95.185
DEA115	7/7/2010	22	Chironomidae	2	72.713	45.355
DEA115	7/7/2010	22	Antocha sp.	1	71.347	53.874
DEA115	7/7/2010	22	Baetis tricaudatus	1	56.070	36.431
DEA115	7/7/2010	22	Caudatella heterocaudata	1	50.437	34.731
DEA115	7/7/2010	22	Hydropsyche sp.	2	48.594	34.893
DEA115	7/7/2010	22	Ephemerella dorothea/excrucians	2	26.391	19.481
DEA115	7/7/2010	22	Narpus sp.	1	24.561	16.933
DEA115	7/7/2010	22	Rhyacophila verrula	1	23.722	20.062
DEA115	7/7/2010	22	Tabanidae	1	17.679	14.429
DEA115	7/7/2010	22	Epeorus albertae	1	12.937	5.169
DEA115	7/7/2010	22	Arctopsyche grandis	2	9.953	7.503
DEA115	7/7/2010	22	Serratella tibialis	1	9.918	7.022
DEA115	7/7/2010	22	Rhithrogena sp.	1	9.434	7.013
DEA115	7/7/2010	22	Zaitzevia sp.	2	7.533	4.888
DEA115	7/7/2010	22	Sweltsa sp.	1	7.424	4.618
DEA115	7/7/2010	22	Kogotus sp.	1	6.786	5.352
DEA115	7/7/2010	22	Drunella coloradensis/flavilinea	1	6.044	15.757
DEA115	7/7/2010	22	Suwallia sp.	1	5.920	3.858
DEA115	7/7/2010	22	Ameletus sp.	1	3.784	2.384
DEA115	7/7/2010	22	Rhyacophila angelita gr.	1	3.679	1.980
DEA115	7/7/2010	22	Chloroperlidae	1	3.374	2.164
DEA115	7/7/2010	22	Cinygmula sp.	1	2.880	2.083
DEA115	7/7/2010	22	Bezzia/Palpomyia sp.	1	2.639	1.728
DEA115	7/7/2010	22	Hexatoma sp.	1	2.520	1.880
DEA115	7/7/2010	22	Diphetor hageni	1	2.124	2.096
DEA115	7/7/2010	22	Heterlimnius sp.	1	1.921	1.318
DEA115	7/7/2010	22	Leptophlebiidae	1	1.598	1.140
DEA115	7/7/2010	22	Epeorus sp.	1	1.550	0.971
DEA115	7/7/2010	22	Dolophilodes sp.	1	1.326	0.815
DEA115	7/7/2010	22	Perlidae	1	1.169	0.724
DEA115	7/7/2010	22	Atherix sp.	1	1.071	0.501
DEA115	7/7/2010	22	Perlodidae	1	0.842	0.507
DEA115	7/7/2010	22	Paraperla sp.	1	0.836	0.587
DEA115	7/7/2010	22	Oligochaete (class B)	1	0.777	0.440
DEA115	7/7/2010	22	Simulium sp.	1	0.566	0.355
DEA115	7/7/2010	22	Paraleptophlebia sp.	1	0.460	0.272
DEA115	7/7/2010	22	Claassenia sabulosa	1	0.361	0.237
DEA115	7/7/2010	22	Neoplasta sp.	1	0.207	0.133

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	7/7/2010	22	Pteronarcys sp.	1	0.155	0.095
DEA115	7/7/2010	22	Hydroporinae	1	0.092	0.056
DEA115	7/7/2010	22	Rhyacophila sp.	1	0.089	0.055
DEA115	7/7/2010	22	Deuterophlebia sp.	1	0.071	0.042
DEA115	7/7/2010	22	Limnephilidae	1	0.010	0.005
DEA115	7/29/2010	34	Oligochaete (class C)	1	327.724	143.303
DEA115	7/29/2010	34	Brachycentrus americanus	2	324.074	156.183
DEA115	7/29/2010	34	Optioservus sp.	2	297.178	128.667
DEA115	7/29/2010	34	Antocha sp.	2	261.074	138.340
DEA115	7/29/2010	34	Chironomidae	2	152.894	62.660
DEA115	7/29/2010	34	Pteronarcys californica	1	92.636	52.108
DEA115	7/29/2010	34	Hydropsyche sp.	1	63.404	31.246
DEA115	7/29/2010	34	Hesperoperla pacifica	2	56.977	30.367
DEA115	7/29/2010	34	Baetis tricaudatus	1	50.732	21.189
DEA115	7/29/2010	34	Sweltsa sp.	1	20.833	8.768
DEA115	7/29/2010	34	Narpus sp.	2	19.200	9.334
DEA115	7/29/2010	34	Drunella coloradensis/flavilinea	1	18.715	8.942
DEA115	7/29/2010	34	Epeorus longimanus	1	15.702	7.695
DEA115	7/29/2010	34	Limnophila sp.	1	11.772	5.901
DEA115	7/29/2010	34	Serratella tibialis	1	9.959	4.533
DEA115	7/29/2010	34	Epeorus albertae	1	8.701	4.358
DEA115	7/29/2010	34	Zaitzevia sp.	1	8.361	3.415
DEA115	7/29/2010	34	Glutops sp.	1	8.043	3.947
DEA115	7/29/2010	34	Oligochaete (class B)	1	7.809	3.460
DEA115	7/29/2010	34	Bezzia/Palpomyia sp.	1	5.637	2.348
DEA115	7/29/2010	34	Arctopsyche grandis	1	5.441	2.034
DEA115	7/29/2010	34	Acentrella turbida	1	5.113	2.229
DEA115	7/29/2010	34	Dolophilodes sp.	1	4.909	2.065
DEA115	7/29/2010	34	Paraleptophlebia sp.	1	4.439	1.729
DEA115	7/29/2010	34	Ameletus sp.	1	4.098	1.791
DEA115	7/29/2010	34	Chloroperlidae	1	3.770	1.733
DEA115	7/29/2010	34	Rhyacophila angelita gr.	1	3.744	1.760
DEA115	7/29/2010	34	Rhithrogena sp.	1	3.640	1.406
DEA115	7/29/2010	34	Diphetor hageni	1	2.622	1.148
DEA115	7/29/2010	34	Heterlimnius sp.	1	2.141	0.886
DEA115	7/29/2010	34	Caudatella heterocaudata	1	1.941	0.894
DEA115	7/29/2010	34	Glossosoma sp.	1	1.666	0.642
DEA115	7/29/2010	34	Perlodidae	1	1.483	1.621
DEA115	7/29/2010	34	Ochrotrichia sp.	1	1.482	0.605
DEA115	7/29/2010	34	Perlidae	1	1.430	0.614
DEA115	7/29/2010	34	Epeorus sp.	1	1.399	0.559

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	7/29/2010	34	Atherix sp.	1	1.299	0.580
DEA115	7/29/2010	34	Simulium sp.	1	1.248	0.482
DEA115	7/29/2010	34	Cleptelmis addenda	1	0.987	0.796
DEA115	7/29/2010	34	Zapada cinctipes	1	0.960	0.377
DEA115	7/29/2010	34	Acentrella insignificans	1	0.780	0.329
DEA115	7/29/2010	34	Timpanoga hecuba	1	0.649	0.277
DEA115	7/29/2010	34	Wormaldia sp.	1	0.580	0.231
DEA115	7/29/2010	34	Neophylax sp.	1	0.538	0.205
DEA115	7/29/2010	34	Micrasema sp.	1	0.534	0.229
DEA115	7/29/2010	34	Agapetus sp.	1	0.385	0.153
DEA115	7/29/2010	34	Arctopsychinae	1	0.306	0.112
DEA115	7/29/2010	34	Acentrella sp.	1	0.217	0.082
DEA115	7/29/2010	34	Attenella margarita	1	0.206	0.078
DEA115	7/29/2010	34	Stilobezzia sp.	1	0.089	0.033
DEA115	7/29/2010	34	Epeorus grandis/permagnus	1	0.073	0.028
DEA115	7/29/2010	34	Neoplasta sp.	1	0.062	0.024
DEA115	7/29/2010	34	Heptageniidae	1	0.062	0.023
DEA115	9/1/2010	42	Oligochaete (class C)	1	1356.218	878.684
DEA115	9/1/2010	42	Antocha sp.	2	813.460	572.357
DEA115	9/1/2010	42	Optioservus sp.	3	582.848	370.523
DEA115	9/1/2010	42	Brachycentrus americanus	2	386.435	280.813
DEA115	9/1/2010	42	Chironomidae	2	139.343	83.618
DEA115	9/1/2010	42	Baetis tricaudatus	1	110.720	68.772
DEA115	9/1/2010	42	Hexatoma sp.	3	108.023	85.909
DEA115	9/1/2010	42	Dicranota sp.	1	98.200	67.172
DEA115	9/1/2010	42	Hesperoperla pacifica	2	96.978	76.804
DEA115	9/1/2010	42	Sweltsa sp.	1	65.650	41.585
DEA115	9/1/2010	42	Cinygmula sp.	1	37.929	22.172
DEA115	9/1/2010	42	Paraleptophlebia sp.	1	26.017	16.155
DEA115	9/1/2010	42	Atherix sp.	2	22.545	15.301
DEA115	9/1/2010	42	Bezzia/Palpomyia sp.	1	16.660	10.320
DEA115	9/1/2010	42	Glossosoma sp.	1	15.533	9.341
DEA115	9/1/2010	42	Hydropsyche sp.	1	14.432	10.921
DEA115	9/1/2010	42	Lepidostoma sp.	1	14.321	8.087
DEA115	9/1/2010	42	Zaitzevia sp.	2	12.594	7.667
DEA115	9/1/2010	42	Rhithrogena sp.	1	11.344	7.015
DEA115	9/1/2010	42	Arctopsyche grandis	1	10.279	6.711
DEA115	9/1/2010	42	Claassenia sabulosa	2	9.882	6.783
DEA115	9/1/2010	42	Narpus sp.	2	7.141	4.711
DEA115	9/1/2010	42	Epeorus sp.	1	6.352	3.642
DEA115	9/1/2010	42	Oligochaete (class B)	1	4.799	3.030

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	9/1/2010	42	Pericoma/Telmatoscopus sp.	1	4.359	2.474
DEA115	9/1/2010	42	Oligophlebodes sp.	1	3.560	2.088
DEA115	9/1/2010	42	Perlodidae	1	3.346	2.069
DEA115	9/1/2010	42	Zapada cinctipes	1	3.240	1.933
DEA115	9/1/2010	42	Dolophilodes sp.	1	2.478	1.635
DEA115	9/1/2010	42	Ameletus sp.	1	2.346	1.527
DEA115	9/1/2010	42	Acentrella turbida	1	2.111	1.282
DEA115	9/1/2010	42	Cleptelmis addenda	2	1.934	1.260
DEA115	9/1/2010	42	Lara sp.	1	1.655	1.185
DEA115	9/1/2010	42	Ephemerellidae	1	0.866	0.465
DEA115	9/1/2010	42	Heterlimnius sp.	1	0.748	0.493
DEA115	9/1/2010	42	Simulium sp.	1	0.432	0.268
DEA115	9/1/2010	42	Hydroptilidae	1	0.382	0.252
DEA115	9/1/2010	42	Oreodytes sp.	1	0.259	0.153
DEA115	9/1/2010	42	Neophylax sp.	1	0.233	0.141
DEA115	9/1/2010	42	Perlidae	1	0.101	0.058
DEA115	9/1/2010	42	Atylotus/Tabanus sp.	1	0.036	0.021
DEA115	9/1/2010	42	Wiedemannia sp.	1	0.018	0.009
DEA115	10/13/2010	273	Oligochaete (class C)	1	3045.288	859.554
DEA115	10/13/2010	273	Antocha sp.	1	1833.175	552.517
DEA115	10/13/2010	273	Optioservus sp.	2	1116.239	303.044
DEA115	10/13/2010	273	Brachycentrus americanus	2	907.371	281.408
DEA115	10/13/2010	273	Arctopsyche grandis	2	430.990	135.185
DEA115	10/13/2010	273	Chironomidae	2	299.771	73.676
DEA115	10/13/2010	273	Ephemerella dorothea/excrucians	1	243.710	61.162
DEA115	10/13/2010	273	Drunella grandis	1	220.083	65.776
DEA115	10/13/2010	273	Baetis tricaudatus	1	210.821	53.169
DEA115	10/13/2010	273	Dicranota sp.	1	209.800	63.175
DEA115	10/13/2010	273	Sweltsa sp.	1	138.446	37.314
DEA115	10/13/2010	273	Hesperoperla pacifica	1	136.404	45.605
DEA115	10/13/2010	273	Cinygmula sp.	1	96.799	24.579
DEA115	10/13/2010	273	Limnophila sp.	1	95.104	28.193
DEA115	10/13/2010	273	Capniidae	1	66.144	17.012
DEA115	10/13/2010	273	Glossosoma sp.	1	61.404	15.898
DEA115	10/13/2010	273	Paraleptophlebia sp.	1	55.599	14.676
DEA115	10/13/2010	273	Blephariceridae	1	39.469	11.579
DEA115	10/13/2010	273	Bezzia/Palpomyia sp.	1	33.969	8.864
DEA115	10/13/2010	273	Lepidostoma sp.	1	30.696	8.034
DEA115	10/13/2010	273	Zaitzevia sp.	1	26.494	6.910
DEA115	10/13/2010	273	Rhyacophila coloradensis gr.	1	23.829	6.331

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	10/13/2010	273	Rhithrogena sp.	1	20.853	5.738
DEA115	10/13/2010	273	Epeorus sp.	1	20.785	4.976
DEA115	10/13/2010	273	Atherix sp.	1	20.592	5.825
DEA115	10/13/2010	273	Hydropsyche sp.	1	19.703	4.995
DEA115	10/13/2010	273	Pericoma/Telmatoscopus sp.	1	9.464	2.445
DEA115	10/13/2010	273	Rhyacophila pellisa/valuma	1	8.487	2.285
DEA115	10/13/2010	273	Oligophlebodes sp.	1	7.927	1.999
DEA115	10/13/2010	273	Zapada cinctipes	1	6.299	1.774
DEA115	10/13/2010	273	Narpus sp.	1	5.986	1.681
DEA115	10/13/2010	273	Neophylax occidentis	1	5.308	1.411
DEA115	10/13/2010	273	Claassenia sabulosa	1	4.662	1.142
DEA115	10/13/2010	273	Leuctridae	1	4.476	1.163
DEA115	10/13/2010	273	Diphetor hageni	1	4.082	2.629
DEA115	10/13/2010	273	Ameletus sp.	1	3.821	0.947
DEA115	10/13/2010	273	Caudatella sp.	1	3.656	0.832
DEA115	10/13/2010	273	Perlodidae	1	3.344	0.909
DEA115	10/13/2010	273	Rhyacophila sp.	1	1.870	0.492
DEA115	10/13/2010	273	Brachycentrus sp.	1	1.071	0.247
DEA115	10/13/2010	273	Empididae	1	0.408	0.085
DEA115	7/13/2011	29	Optioservus sp.	2	255.030	156.036
DEA115	7/13/2011	29	Brachycentrus americanus	2	158.559	106.059
DEA115	7/13/2011	29	Oligochaete (class C)	1	148.577	91.394
DEA115	7/13/2011	29	Epeorus longimanus	2	140.222	92.489
DEA115	7/13/2011	29	Chironomidae	2	136.002	78.469
DEA115	7/13/2011	29	Baetis tricaudatus	1	132.666	78.262
DEA115	7/13/2011	29	Antocha sp.	1	83.201	57.435
DEA115	7/13/2011	29	Drunella coloradensis/flavilinea	1	63.212	41.406
DEA115	7/13/2011	29	Caudatella heterocaudata	1	58.741	37.792
DEA115	7/13/2011	29	Rhithrogena sp.	2	42.703	29.611
DEA115	7/13/2011	29	Arctopsyche grandis	2	38.178	28.507
DEA115	7/13/2011	29	Lara sp.	1	22.159	15.541
DEA115	7/13/2011	29	Hexatoma sp.	1	22.072	16.175
DEA115	7/13/2011	29	Ephemerella dorothea/excrucians	1	21.954	15.033
DEA115	7/13/2011	29	Hydropsychidae	1	21.558	15.724
DEA115	7/13/2011	29	Sweltsa sp.	1	20.139	11.336
DEA115	7/13/2011	29	Serratella tibialis	1	18.102	12.357
DEA115	7/13/2011	29	Oligochaete (class B)	1	16.690	10.491
DEA115	7/13/2011	29	Ameletus sp.	1	14.564	7.564
DEA115	7/13/2011	29	Glossosomatidae	1	14.419	9.740
DEA115	7/13/2011	29	Hydropsyche sp.	1	13.617	8.975

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	7/13/2011	29	Neophylax rickeri	1	13.547	5.688
DEA115	7/13/2011	29	Zaitzevia sp.	2	13.325	8.203
DEA115	7/13/2011	29	Narpus sp.	1	12.907	8.081
DEA115	7/13/2011	29	Rhyacophila angelita gr.	3	11.778	7.983
DEA115	7/13/2011	29	Glossosoma sp.	1	10.594	7.168
DEA115	7/13/2011	29	Chloroperlidae	1	10.352	6.462
DEA115	7/13/2011	29	Caudatella edmundsi	1	9.764	6.354
DEA115	7/13/2011	29	Paraperla sp.	1	8.071	4.815
DEA115	7/13/2011	29	Rhyacophila coloradensis gr.	1	6.125	4.089
DEA115	7/13/2011	29	Lepidostoma sp.	1	5.598	3.860
DEA115	7/13/2011	29	Diphetor hageni	1	5.390	3.170
DEA115	7/13/2011	29	Cinygmula sp.	1	5.351	3.430
DEA115	7/13/2011	29	Bezzia/Palpomyia sp.	1	4.421	2.514
DEA115	7/13/2011	29	Paraleptophlebia sp.	1	4.263	2.329
DEA115	7/13/2011	29	Simulium sp.	1	3.284	1.820
DEA115	7/13/2011	29	Rhabdomastix fascigera gr.	1	2.999	1.966
DEA115	7/13/2011	29	Heterlimnius sp.	1	2.846	1.684
DEA115	7/13/2011	29	Micrasema sp.	1	2.703	1.695
DEA115	7/13/2011	29	Epeorus sp.	1	2.483	1.410
DEA115	7/13/2011	29	Drunella doddsii	1	1.694	0.897
DEA115	7/13/2011	29	Leptophlebiidae	1	1.640	0.915
DEA115	7/13/2011	29	Perlidae	1	1.502	0.852
DEA115	7/13/2011	29	Deuterophlebia sp.	1	1.318	0.740
DEA115	7/13/2011	29	Rhyacophila pellisa/valuma	1	1.163	0.691
DEA115	7/13/2011	29	Rhyacophila sp.	1	0.868	0.516
DEA115	7/13/2011	29	Chelifera/Metachela sp.	1	0.557	0.338
DEA115	7/13/2011	29	Neophylax occidentis	1	0.366	0.213
DEA115	7/13/2011	29	Epeorus grandis/permagnus	1	0.240	0.374
DEA115	7/13/2011	29	Maruina sp.	1	0.114	0.062
DEA115	8/11/2011	19	Arctopsyche grandis	2	1113.388	1191.125
DEA115	8/11/2011	19	Brachycentrus americanus	1	456.310	443.221
DEA115	8/11/2011	19	Optioservus sp.	2	307.203	265.854
DEA115	8/11/2011	19	Chironomidae	2	189.805	153.035
DEA115	8/11/2011	19	Pteronarcys dorsata	1	136.375	151.518
DEA115	8/11/2011	19	Claassenia sabulosa	1	97.678	34.533
DEA115	8/11/2011	19	Baetis tricaudatus	1	77.531	63.767
DEA115	8/11/2011	19	Oligochaete (class C)	1	71.236	59.361
DEA115	8/11/2011	19	Brachycentrus sp.	1	65.011	69.301
DEA115	8/11/2011	19	Serratella tibialis	1	51.104	45.957
DEA115	8/11/2011	19	Antocha sp.	1	47.528	47.020
DEA115	8/11/2011	19	Sweltsa sp.	1	35.736	29.696

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	8/11/2011	19	Epeorus longimanus	1	26.119	22.948
DEA115	8/11/2011	19	Dicranota sp.	1	25.178	23.068
DEA115	8/11/2011	19	Epeorus albertae	1	20.892	19.916
DEA115	8/11/2011	19	Hydropsyche sp.	1	19.320	18.404
DEA115	8/11/2011	19	Rhithrogena sp.	2	17.458	15.399
DEA115	8/11/2011	19	Atherix sp.	1	16.624	15.486
DEA115	8/11/2011	19	Zaitzevia sp.	2	12.350	10.797
DEA115	8/11/2011	19	Acentrella turbida	1	11.909	9.750
DEA115	8/11/2011	19	Dolophilodes sp.	1	10.944	8.409
DEA115	8/11/2011	19	Bezzia/Palpomyia sp.	1	10.612	8.391
DEA115	8/11/2011	19	Oligochaete (class B)	1	10.427	8.797
DEA115	8/11/2011	19	Lara sp.	1	10.390	10.225
DEA115	8/11/2011	19	Drunella coloradensis/flavilinea	1	10.355	9.655
DEA115	8/11/2011	19	Ameletus sp.	1	8.541	7.522
DEA115	8/11/2011	19	Acentrella insignificans	1	7.758	6.298
DEA115	8/11/2011	19	Rhyacophila angelita gr.	1	7.716	6.711
DEA115	8/11/2011	19	Glossosomatidae	1	6.542	6.127
DEA115	8/11/2011	19	Simulium sp.	1	5.669	4.545
DEA115	8/11/2011	19	Suwallia sp.	1	5.615	4.831
DEA115	8/11/2011	19	Drunella doddsii	1	5.414	4.212
DEA115	8/11/2011	19	Paraperla sp.	1	4.946	4.565
DEA115	8/11/2011	19	Neophylax rickeri	1	4.377	4.239
DEA115	8/11/2011	19	Hesperoperla pacifica	1	3.054	2.696
DEA115	8/11/2011	19	Paraleptophlebia sp.	1	2.870	2.308
DEA115	8/11/2011	19	Lepidostoma sp.	1	2.463	1.919
DEA115	8/11/2011	19	Perlodidae	1	2.050	1.609
DEA115	8/11/2011	19	Leptophlebiidae	1	1.779	1.439
DEA115	8/11/2011	19	Caudatella edmundsi	1	1.765	1.625
DEA115	8/11/2011	19	Rhyacophila coloradensis gr.	1	1.516	1.310
DEA115	8/11/2011	19	Heterlimnius sp.	1	1.511	1.211
DEA115	8/11/2011	19	Arctopsychinae	1	1.159	0.934
DEA115	8/11/2011	19	Diphetor hageni	1	1.078	0.934
DEA115	8/11/2011	19	Caudatella heterocaudata	1	1.077	0.964
DEA115	8/11/2011	19	Deuterophlebia sp.	1	0.846	0.687
DEA115	8/11/2011	19	Visoka cataractae	1	0.836	0.699
DEA115	8/11/2011	19	Epeorus deceptivus/hesperus	1	0.748	0.609
DEA115	8/11/2011	19	Agapetus sp.	1	0.580	0.486
DEA115	8/11/2011	19	Epeorus grandis/permagnus	1	0.506	0.660
DEA115	8/11/2011	19	Neophylax sp.	1	0.504	0.380
DEA115	8/11/2011	19	Caudatella sp.	1	0.111	0.083
DEA115	8/11/2011	19	Stilobezzia sp.	1	0.064	0.045

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	8/30/2011	36	Arctopsyche grandis	3	2095.909	1665.956
DEA115	8/30/2011	36	Brachycentrus americanus	1	1187.785	913.156
DEA115	8/30/2011	36	Pteronarcys californica	1	491.645	444.228
DEA115	8/30/2011	36	Optioservus sp.	2	385.097	259.012
DEA115	8/30/2011	36	Chironomidae	2	181.068	113.224
DEA115	8/30/2011	36	Hexatoma sp.	2	170.564	137.872
DEA115	8/30/2011	36	Oligochaete (class C)	1	123.556	79.683
DEA115	8/30/2011	36	Antocha sp.	1	106.504	75.310
DEA115	8/30/2011	36	Baetis tricaudatus	1	80.838	50.150
DEA115	8/30/2011	36	Sweltsa sp.	1	70.947	45.385
DEA115	8/30/2011	36	Dicranota sp.	1	65.094	45.839
DEA115	8/30/2011	36	Serratella tibialis	1	47.793	35.266
DEA115	8/30/2011	36	Caudatella hystrix	1	43.950	27.073
DEA115	8/30/2011	36	Dolophilodes sp.	1	42.130	27.041
DEA115	8/30/2011	36	Claassenia sabulosa	1	34.175	26.605
DEA115	8/30/2011	36	Rhithrogena sp.	1	32.370	19.633
DEA115	8/30/2011	36	Ephemerella sp.	1	20.009	11.767
DEA115	8/30/2011	36	Zapada cinctipes	1	18.707	11.607
DEA115	8/30/2011	36	Drunella doddsii	1	17.587	8.668
DEA115	8/30/2011	36	Skwala sp.	1	17.371	11.486
DEA115	8/30/2011	36	Hydropsyche sp.	1	17.273	12.716
DEA115	8/30/2011	36	Bezzia/Palpomyia sp.	1	14.981	9.859
DEA115	8/30/2011	36	Atherix sp.	2	13.679	9.496
DEA115	8/30/2011	36	Glossosoma sp.	1	12.184	7.459
DEA115	8/30/2011	36	Rhyacophila hyalinata gr.	1	11.518	7.110
DEA115	8/30/2011	36	Epeorus longimanus	1	11.373	8.139
DEA115	8/30/2011	36	Narpus sp.	1	10.653	7.204
DEA115	8/30/2011	36	Blepharicera sp.	1	9.957	7.216
DEA115	8/30/2011	36	Zaitzevia sp.	2	9.635	6.231
DEA115	8/30/2011	36	Perlodidae	1	8.361	5.123
DEA115	8/30/2011	36	Epeorus grandis/permagnus	1	7.333	4.750
DEA115	8/30/2011	36	Leptophlebiidae	1	7.332	4.261
DEA115	8/30/2011	36	Rhyacophila angelita gr.	1	6.826	5.049
DEA115	8/30/2011	36	Acentrella turbida	1	6.726	4.115
DEA115	8/30/2011	36	Oligochaete (class B)	1	6.378	4.349
DEA115	8/30/2011	36	Rhabdomastix fascigera gr.	1	4.959	3.492
DEA115	8/30/2011	36	Simulium sp.	1	4.345	2.835
DEA115	8/30/2011	36	Epeorus sp.	1	3.833	2.319
DEA115	8/30/2011	36	Rhyacophila pellisa/valuma	1	3.790	2.605
DEA115	8/30/2011	36	Lepidostoma sp.	1	2.716	1.849
DEA115	8/30/2011	36	Glossosomatidae	1	2.324	1.618

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	8/30/2011	36	Drunella grandis	1	1.748	1.117
DEA115	8/30/2011	36	Perlidae	1	1.402	0.872
DEA115	8/30/2011	36	Attenella margarita	1	1.183	0.769
DEA115	8/30/2011	36	Deuterophlebia sp.	2	0.942	0.563
DEA115	8/30/2011	36	Cleptelmis addenda	1	0.916	0.581
DEA115	8/30/2011	36	Acentrella sp.	1	0.885	0.524
DEA115	8/30/2011	36	Rhyacophila vagrita gr.	1	0.589	0.365
DEA115	8/30/2011	36	Apatania sp.	1	0.557	0.347
DEA115	8/30/2011	36	Neophylax sp.	1	0.506	0.314
DEA115	8/30/2011	36	Blephariceridae	1	0.408	0.248
DEA115	8/30/2011	36	Leuctridae	1	0.328	0.189
DEA115	8/30/2011	36	Amiocentrus aspilus	1	0.323	0.193
DEA115	8/30/2011	36	Hesperoperla pacifica	1	0.318	0.194
DEA115	8/30/2011	36	Acentrella insignificans	1	0.256	0.151
DEA115	10/5/2011	NA	Acentrella turbida	1	0.000	2.646
DEA115	10/5/2011	NA	Amphizoa sp.	1	0.000	8.080
DEA115	10/5/2011	NA	Antocha sp.	1	0.000	34.634
DEA115	10/5/2011	NA	Arctopsyche grandis	2	0.000	364.419
DEA115	10/5/2011	NA	Atherix sp.	1	0.000	0.679
DEA115	10/5/2011	NA	Baetis tricaudatus	1	0.000	37.903
DEA115	10/5/2011	NA	Bezzia/Palpomyia sp.	1	0.000	2.797
DEA115	10/5/2011	NA	Brachycentrus americanus	3	0.000	538.234
DEA115	10/5/2011	NA	Capniidae	1	0.000	2.730
DEA115	10/5/2011	NA	Caudatella edmundsi	1	0.000	0.352
DEA115	10/5/2011	NA	Caudatella hystrix	1	0.000	26.101
DEA115	10/5/2011	NA	Chironomidae	2	0.000	17.234
DEA115	10/5/2011	NA	Cinygmula sp.	1	0.000	13.343
DEA115	10/5/2011	NA	Claassenia sabulosa	1	0.000	18.016
DEA115	10/5/2011	NA	Dicranota sp.	1	0.000	34.661
DEA115	10/5/2011	NA	Diptera	1	0.000	0.357
DEA115	10/5/2011	NA	Dolophilodes sp.	2	0.000	106.406
DEA115	10/5/2011	NA	Drunella doddsii	1	0.000	5.307
DEA115	10/5/2011	NA	Epeorus grandis/permagnus	1	0.000	4.338
DEA115	10/5/2011	NA	Epeorus sp.	1	0.000	0.498
DEA115	10/5/2011	NA	Ephemerella dorothea/excrucians	1	0.000	9.890
DEA115	10/5/2011	NA	Ephemerella sp.	1	0.000	11.164
DEA115	10/5/2011	NA	Glossosoma sp.	1	0.000	2.698
DEA115	10/5/2011	NA	Hesperoconopa sp.	1	0.000	0.999
DEA115	10/5/2011	NA	Heterlimnius sp.	2	0.000	0.485
DEA115	10/5/2011	NA	Hexatoma sp.	1	0.000	33.534

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA115	10/5/2011	NA	Hydraena sp.	1	0.000	0.510
DEA115	10/5/2011	NA	Hydropsyche sp.	1	0.000	4.343
DEA115	10/5/2011	NA	Lara sp.	1	0.000	26.989
DEA115	10/5/2011	NA	Lepidostoma sp.	1	0.000	1.495
DEA115	10/5/2011	NA	Leptophlebiidae	1	0.000	3.573
DEA115	10/5/2011	NA	Leuctridae	1	0.000	0.142
DEA115	10/5/2011	NA	Limnephilidae	1	0.000	0.291
DEA115	10/5/2011	NA	Oligochaete (class C)	1	0.000	53.865
DEA115	10/5/2011	NA	Oligophlebodes sp.	1	0.000	0.459
DEA115	10/5/2011	NA	Optioservus sp.	2	0.000	99.621
DEA115	10/5/2011	NA	Paraleptophlebia sp.	1	0.000	5.455
DEA115	10/5/2011	NA	Pericoma/Telmatoscopus sp.	1	0.000	2.276
DEA115	10/5/2011	NA	Perlidae	1	0.000	0.139
DEA115	10/5/2011	NA	Perlodidae	1	0.000	4.174
DEA115	10/5/2011	NA	Rhithrogena sp.	2	0.000	67.991
DEA115	10/5/2011	NA	Rhyacophila coloradensis gr.	1	0.000	24.624
DEA115	10/5/2011	NA	Rhyacophila pellisa/valuma	1	0.000	0.389
DEA115	10/5/2011	NA	Skwala sp.	1	0.000	10.878
DEA115	10/5/2011	NA	Sweltsa sp.	1	0.000	23.985
DEA115	10/5/2011	NA	Wiedemannia sp.	1	0.000	0.039
DEA115	10/5/2011	NA	Zaitzevia sp.	1	0.000	0.785
DEA115	10/5/2011	NA	Zapada cinctipes	1	0.000	9.325
DEA116	7/7/2010	22	Oligochaete (class C)	1	330.835	219.081
DEA116	7/7/2010	22	Optioservus sp.	2	179.438	118.288
DEA116	7/7/2010	22	Chironomidae	2	135.143	82.518
DEA116	7/7/2010	22	Baetis tricaudatus	1	56.466	36.160
DEA116	7/7/2010	22	Arctopsyche grandis	2	42.863	34.199
DEA116	7/7/2010	22	Hydropsyche sp.	2	25.551	18.952
DEA116	7/7/2010	22	Epeorus longimanus	2	21.771	14.741
DEA116	7/7/2010	22	Ephemerella dorothea/excrucians	1	20.140	14.999
DEA116	7/7/2010	22	Epeorus albertae	1	15.814	6.997
DEA116	7/7/2010	22	Drunella coloradensis/flavilinea	1	12.556	8.843
DEA116	7/7/2010	22	Narpus sp.	1	12.203	8.360
DEA116	7/7/2010	22	Serratella tibialis	1	9.529	4.487
DEA116	7/7/2010	22	Rhyacophila angelita gr.	2	8.910	6.251
DEA116	7/7/2010	22	Simulium sp.	1	7.869	4.765
DEA116	7/7/2010	22	Oligochaete (class B)	1	7.015	4.705
DEA116	7/7/2010	22	Suwallia sp.	1	6.646	4.287
DEA116	7/7/2010	22	Brachycentrus americanus	1	6.437	4.313
DEA116	7/7/2010	22	Atherix sp.	2	5.973	4.226

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	7/7/2010	22	Epeorus sp.	1	3.988	2.318
DEA116	7/7/2010	22	Glossosoma sp.	2	3.909	2.853
DEA116	7/7/2010	22	Diphetor hageni	1	3.778	2.404
DEA116	7/7/2010	22	Claassenia sabulosa	1	3.342	2.256
DEA116	7/7/2010	22	Caudatella heterocaudata	1	3.211	2.232
DEA116	7/7/2010	22	Heterlimnius sp.	1	3.084	1.988
DEA116	7/7/2010	22	Rhithrogena sp.	2	3.071	2.153
DEA116	7/7/2010	22	Chloroperlidae	1	2.884	1.819
DEA116	7/7/2010	22	Ameletus sp.	1	2.780	1.779
DEA116	7/7/2010	22	Sweltsa sp.	1	2.581	1.536
DEA116	7/7/2010	22	Bezzia/Palpomyia sp.	1	2.355	1.355
DEA116	7/7/2010	22	Cinygmula sp.	1	1.581	1.007
DEA116	7/7/2010	22	Zaitzevia sp.	1	1.529	0.951
DEA116	7/7/2010	22	Micrasema sp.	1	1.021	0.610
DEA116	7/7/2010	22	Paraleptophlebia sp.	1	0.901	0.532
DEA116	7/7/2010	22	Perlodidae	1	0.722	0.417
DEA116	7/7/2010	22	Hesperoperla pacifica	1	0.645	0.435
DEA116	7/7/2010	22	Rhyacophila pellisa/valuma	1	0.613	0.385
DEA116	7/7/2010	22	Perlidae	1	0.341	0.215
DEA116	7/7/2010	22	Rhyacophila narvae	1	0.237	0.147
DEA116	7/7/2010	22	Stilobezzia sp.	1	0.042	0.022
DEA116	7/7/2010	22	Deuterophlebia sp.	1	0.035	0.020
DEA116	7/7/2010	22	Acentrella sp.	1	0.032	0.018
DEA116	7/7/2010	22	Trichoclinocera sp.	1	0.027	0.015
DEA116	7/29/2010	34	Oligochaete (class C)	1	464.033	207.653
DEA116	7/29/2010	34	Antocha sp.	1	276.794	149.677
DEA116	7/29/2010	34	Chironomidae	2	248.000	104.106
DEA116	7/29/2010	34	Optioservus sp.	2	219.078	96.490
DEA116	7/29/2010	34	Baetis tricaudatus	1	94.576	39.143
DEA116	7/29/2010	34	Hydropsyche sp.	1	29.796	15.436
DEA116	7/29/2010	34	Rhabdomastix fascigera gr.	1	16.857	8.871
DEA116	7/29/2010	34	Drunella coloradensis/flavilinea	1	10.843	5.184
DEA116	7/29/2010	34	Epeorus albertae	1	10.765	5.132
DEA116	7/29/2010	34	Rhithrogena sp.	1	10.590	4.205
DEA116	7/29/2010	34	Simulium sp.	1	10.297	4.494
DEA116	7/29/2010	34	Sweltsa sp.	1	7.568	3.066
DEA116	7/29/2010	34	Serratella tibialis	1	7.126	3.408
DEA116	7/29/2010	34	Atherix sp.	1	6.658	3.220
DEA116	7/29/2010	34	Oligochaete (class B)	1	5.639	2.563
DEA116	7/29/2010	34	Acentrella turbida	1	5.470	2.335
DEA116	7/29/2010	34	Epeorus sp.	1	5.327	2.291

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	7/29/2010	34	Rhyacophila sp.	1	4.243	2.042
DEA116	7/29/2010	34	Hesperoconopa sp.	1	3.873	1.784
DEA116	7/29/2010	34	Chloroperlidae	2	3.753	1.753
DEA116	7/29/2010	34	Acentrella insignificans	1	3.736	1.618
DEA116	7/29/2010	34	Zaitzevia sp.	2	3.734	1.637
DEA116	7/29/2010	34	Perlodidae	1	3.606	2.036
DEA116	7/29/2010	34	Bezzia/Palpomyia sp.	1	3.220	1.275
DEA116	7/29/2010	34	Heterlimnius sp.	1	3.211	1.233
DEA116	7/29/2010	34	Epeorus grandis/permagnus	1	3.042	1.305
DEA116	7/29/2010	34	Suwallia sp.	1	2.416	1.098
DEA116	7/29/2010	34	Hesperoperla pacifica	1	2.211	0.930
DEA116	7/29/2010	34	Perlidae	1	1.591	0.594
DEA116	7/29/2010	34	Narpus sp.	1	1.567	0.689
DEA116	7/29/2010	34	Micrasema sp.	1	1.145	0.491
DEA116	7/29/2010	34	Paraleptophlebia sp.	1	1.141	0.449
DEA116	7/29/2010	34	Arctopsychinae	1	1.001	0.403
DEA116	7/29/2010	34	Epeorus longimanus	1	0.853	0.375
DEA116	7/29/2010	34	Diphetor hageni	1	0.826	0.350
DEA116	7/29/2010	34	Leptophlebiidae	1	0.748	0.308
DEA116	7/29/2010	34	Lara sp.	1	0.336	0.142
DEA116	7/29/2010	34	Drunella doddsii	1	0.311	0.125
DEA116	7/29/2010	34	Hydroptilidae	1	0.204	0.080
DEA116	7/29/2010	34	Ameletus sp.	1	0.174	0.071
DEA116	7/29/2010	34	Zapada cinctipes	1	0.173	0.067
DEA116	7/29/2010	34	Ochrotrichia sp.	1	0.107	0.042
DEA116	7/29/2010	34	Stilobezzia sp.	1	0.104	0.035
DEA116	9/1/2010	42	Oligochaete (class C)	1	533.994	363.762
DEA116	9/1/2010	42	Antocha sp.	1	477.135	348.432
DEA116	9/1/2010	42	Hesperoperla pacifica	3	170.667	137.135
DEA116	9/1/2010	42	Optioservus sp.	2	130.977	85.781
DEA116	9/1/2010	42	Baetis tricaudatus	1	108.023	68.435
DEA116	9/1/2010	42	Arctopsyche grandis	2	103.379	75.074
DEA116	9/1/2010	42	Chironomidae	2	80.618	49.944
DEA116	9/1/2010	42	Brachycentrus americanus	1	74.966	55.086
DEA116	9/1/2010	42	Rhithrogena sp.	1	45.122	30.443
DEA116	9/1/2010	42	Sweltsa sp.	1	25.044	16.035
DEA116	9/1/2010	42	Glossosoma sp.	2	23.809	15.227
DEA116	9/1/2010	42	Dicranota sp.	1	21.736	16.000
DEA116	9/1/2010	42	Narpus sp.	1	12.260	8.403
DEA116	9/1/2010	42	Paraperla sp.	1	9.695	6.509
DEA116	9/1/2010	42	Atherix sp.	1	9.416	6.428

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	9/1/2010	42	Hydropsyche sp.	1	8.835	6.264
DEA116	9/1/2010	42	Heterlimnius sp.	1	8.591	5.981
DEA116	9/1/2010	42	Epeorus deceptivus/hesperus	1	7.499	4.974
DEA116	9/1/2010	42	Zaitzevia sp.	2	6.836	4.183
DEA116	9/1/2010	42	Paraleptophlebia sp.	1	6.346	3.976
DEA116	9/1/2010	42	Bezzia/Palpomyia sp.	1	5.694	3.583
DEA116	9/1/2010	42	Micrasema sp.	1	4.173	2.680
DEA116	9/1/2010	42	Rhyacophila sp.	1	3.648	2.179
DEA116	9/1/2010	42	Perlodidae	1	2.950	1.926
DEA116	9/1/2010	42	Skwala sp.	1	2.488	1.768
DEA116	9/1/2010	42	Attenella margarita	1	1.803	1.217
DEA116	9/1/2010	42	Pericoma/Telmatoscopus sp.	1	1.487	0.962
DEA116	9/1/2010	42	Caudatella sp.	1	1.079	0.678
DEA116	9/1/2010	42	Perlidae	1	0.831	0.507
DEA116	9/1/2010	42	Paraleuctra sp.	1	0.757	0.505
DEA116	9/1/2010	42	Heptageniidae	1	0.229	0.136
DEA116	9/1/2010	42	Oreodytes sp.	1	0.206	0.134
DEA116	9/1/2010	42	Chloroperlidae	1	0.180	0.111
DEA116	9/1/2010	42	Leptophlebiidae	1	0.171	0.105
DEA116	9/1/2010	42	Uenoidae	1	0.114	0.069
DEA116	9/1/2010	42	Clinocera sp.	1	0.068	0.041
DEA116	9/1/2010	42	Limnephilidae	1	0.049	0.029
DEA116	9/1/2010	42	Stilobezzia sp.	1	0.045	0.026
DEA116	9/1/2010	42	Acentrella turbida	1	0.034	0.020
DEA116	10/13/2010	273	Oligochaete (class C)	1	1192.833	343.665
DEA116	10/13/2010	273	Antocha sp.	1	1035.931	321.148
DEA116	10/13/2010	273	Hesperoperla pacifica	2	355.508	119.967
DEA116	10/13/2010	273	Chironomidae	2	317.973	83.183
DEA116	10/13/2010	273	Arctopsyche grandis	2	244.934	75.735
DEA116	10/13/2010	273	Optioservus sp.	2	179.210	49.729
DEA116	10/13/2010	273	Brachycentrus americanus	2	158.878	51.322
DEA116	10/13/2010	273	Ephemerella dorothea/excrucians	1	139.215	36.208
DEA116	10/13/2010	273	Baetis tricaudatus	1	126.760	32.284
DEA116	10/13/2010	273	Hexatoma sp.	1	99.644	32.470
DEA116	10/13/2010	273	Rhithrogena sp.	1	90.822	26.542
DEA116	10/13/2010	273	Cultus sp.	1	90.566	26.851
DEA116	10/13/2010	273	Glossosoma sp.	1	56.906	15.266
DEA116	10/13/2010	273	Oligochaete (class B)	1	52.068	15.001
DEA116	10/13/2010	273	Narpus sp.	1	51.995	16.028
DEA116	10/13/2010	273	Sweltsa sp.	1	50.171	13.666

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	10/13/2010	273	Hydropsyche sp.	2	49.793	14.508
DEA116	10/13/2010	273	Caudatella hystrix	1	42.678	11.871
DEA116	10/13/2010	273	Dicranota sp.	1	37.269	11.277
DEA116	10/13/2010	273	Capniidae	1	35.916	9.371
DEA116	10/13/2010	273	Heterlimnius sp.	2	31.287	9.037
DEA116	10/13/2010	273	Paraperla sp.	1	20.187	5.903
DEA116	10/13/2010	273	Atherix sp.	1	17.687	5.336
DEA116	10/13/2010	273	Cinygmula sp.	1	16.410	4.239
DEA116	10/13/2010	273	Epeorus grandis/permagnus	1	15.199	4.257
DEA116	10/13/2010	273	Drunella doddsii	1	14.655	4.375
DEA116	10/13/2010	273	Paraleptophlebia sp.	1	13.141	3.617
DEA116	10/13/2010	273	Zaitzevia sp.	1	12.731	3.547
DEA116	10/13/2010	273	Bezzia/Palpomyia sp.	1	10.305	2.824
DEA116	10/13/2010	273	Micrasema sp.	1	8.857	2.418
DEA116	10/13/2010	273	Rhyacophila sp.	1	7.325	1.921
DEA116	10/13/2010	273	Simulium sp.	1	5.604	1.484
DEA116	10/13/2010	273	Rhyacophila pellisa/valuma	1	5.454	1.482
DEA116	10/13/2010	273	Pericoma/Telmatoscopus sp.	1	3.096	0.831
DEA116	10/13/2010	273	Lepidostoma sp.	1	2.304	0.620
DEA116	10/13/2010	273	Caudatella sp.	1	0.800	0.201
DEA116	10/13/2010	273	Brachycentrus sp.	1	0.649	0.163
DEA116	10/13/2010	273	Epeorus sp.	1	0.393	0.094
DEA116	10/13/2010	273	Perlodidae	1	0.321	0.081
DEA116	10/13/2010	273	Empididae	1	0.009	0.002
DEA116	7/13/2011	27	Epeorus longimanus	2	197.673	183.106
DEA116	7/13/2011	27	Chironomidae	2	168.066	112.627
DEA116	7/13/2011	27	Baetis tricaudatus	1	138.550	94.991
DEA116	7/13/2011	27	Optioservus sp.	2	112.465	79.164
DEA116	7/13/2011	27	Simulium sp.	1	92.907	61.092
DEA116	7/13/2011	27	Brachycentrus americanus	1	52.272	42.675
DEA116	7/13/2011	27	Rhyacophila angelita gr.	3	48.671	35.465
DEA116	7/13/2011	27	Oligochaete (class C)	1	45.493	30.846
DEA116	7/13/2011	27	Antocha sp.	1	35.914	27.998
DEA116	7/13/2011	27	Drunella doddsii	1	32.847	28.717
DEA116	7/13/2011	27	Drunella coloradensis/flavilinea	1	32.286	23.827
DEA116	7/13/2011	27	Glossosomatidae	1	29.001	22.680
DEA116	7/13/2011	27	Serratella tibialis	1	28.111	18.824
DEA116	7/13/2011	27	Hydropsyche sp.	1	27.283	21.330
DEA116	7/13/2011	27	Caudatella heterocaudata	1	26.402	18.917
DEA116	7/13/2011	27	Narpus sp.	1	22.337	16.476
DEA116	7/13/2011	27	Rhyacophila hyalinata gr.	1	20.669	15.882

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	7/13/2011	27	Rhithrogena sp.	2	19.915	15.747
DEA116	7/13/2011	27	Sweltsa sp.	1	16.854	11.064
DEA116	7/13/2011	27	Chloroperlidae	1	12.711	8.823
DEA116	7/13/2011	27	Hexatoma sp.	1	11.691	9.599
DEA116	7/13/2011	27	Ameletus sp.	2	9.971	7.124
DEA116	7/13/2011	27	Caudatella edmundsi	1	9.710	7.415
DEA116	7/13/2011	27	Hesperoconopa sp.	1	9.586	6.993
DEA116	7/13/2011	27	Paraleptophlebia sp.	2	6.521	4.912
DEA116	7/13/2011	27	Ephemerella dorothea/excrucians	1	5.753	4.429
DEA116	7/13/2011	27	Suwallia sp.	1	5.545	3.840
DEA116	7/13/2011	27	Lepidostoma sp.	1	5.161	4.116
DEA116	7/13/2011	27	Oligochaete (class B)	1	5.024	3.839
DEA116	7/13/2011	27	Glossosoma sp.	2	4.943	3.728
DEA116	7/13/2011	27	Epeorus grandis/permagnus	1	4.066	2.543
DEA116	7/13/2011	27	Diphetor hageni	1	3.990	3.073
DEA116	7/13/2011	27	Bezzia/Palpomyia sp.	1	3.124	2.046
DEA116	7/13/2011	27	Hesperoperla pacifica	1	3.103	2.081
DEA116	7/13/2011	27	Heterlimnius sp.	1	3.093	2.018
DEA116	7/13/2011	27	Leptophlebiidae	1	2.091	1.301
DEA116	7/13/2011	27	Perlidae	1	1.822	1.182
DEA116	7/13/2011	27	Cinygmula sp.	1	1.694	1.140
DEA116	7/13/2011	27	Rhyacophila pellisa/valuma	1	1.630	1.110
DEA116	7/13/2011	27	Gonomyia sp.	1	1.497	1.114
DEA116	7/13/2011	27	Paraleuctra sp.	1	1.294	0.916
DEA116	7/13/2011	27	Rhyacophila sp.	1	1.013	0.646
DEA116	7/13/2011	27	Lara sp.	1	0.829	0.574
DEA116	7/13/2011	27	Deuterophlebia sp.	1	0.794	0.519
DEA116	7/13/2011	27	Visoka cataractae	1	0.732	0.499
DEA116	7/13/2011	27	Micrasema sp.	1	0.602	0.384
DEA116	7/13/2011	27	Philopotamidae	1	0.576	0.372
DEA116	7/13/2011	27	Epeorus sp.	1	0.510	0.323
DEA116	7/13/2011	27	Perlodidae	1	0.355	0.222
DEA116	7/13/2011	27	Trichoclinocera sp.	1	0.276	0.184
DEA116	7/13/2011	27	Stilobezzia sp.	1	0.120	0.070
DEA116	8/9/2011	23	Arctopsyche grandis	2	332.765	287.570
DEA116	8/9/2011	23	Simulium sp.	2	257.291	188.141
DEA116	8/9/2011	23	Brachycentrus americanus	2	197.547	163.177
DEA116	8/9/2011	23	Optioservus sp.	2	166.229	125.691
DEA116	8/9/2011	23	Chironomidae	2	155.007	108.619
DEA116	8/9/2011	23	Baetis tricaudatus	1	118.903	86.049

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	8/9/2011	23	Epeorus longimanus	1	104.971	81.857
DEA116	8/9/2011	23	Hesperoperla pacifica	2	61.526	56.460
DEA116	8/9/2011	23	Serratella tibialis	1	43.120	33.800
DEA116	8/9/2011	23	Oligochaete (class C)	1	40.239	29.095
DEA116	8/9/2011	23	Antocha sp.	2	36.092	31.241
DEA116	8/9/2011	23	Epeorus grandis/permagnus	1	35.422	24.667
DEA116	8/9/2011	23	Sweltsa sp.	1	31.388	21.850
DEA116	8/9/2011	23	Dicranota sp.	1	26.397	21.059
DEA116	8/9/2011	23	Rhithrogena sp.	1	23.409	16.224
DEA116	8/9/2011	23	Hydropsyche sp.	2	21.839	18.604
DEA116	8/9/2011	23	Epeorus albertae	1	21.461	16.734
DEA116	8/9/2011	23	Rhyacophila angelita gr.	1	20.223	16.911
DEA116	8/9/2011	23	Bezzia/Palpomyia sp.	1	18.324	12.789
DEA116	8/9/2011	23	Rhyacophila hyalinata gr.	1	13.554	11.621
DEA116	8/9/2011	23	Epeorus deceptivus/hesperus	1	12.191	9.094
DEA116	8/9/2011	23	Dolophilodes sp.	1	11.170	7.731
DEA116	8/9/2011	23	Narpus sp.	1	10.820	8.459
DEA116	8/9/2011	23	Claassenia sabulosa	1	9.676	7.621
DEA116	8/9/2011	23	Atherix sp.	1	8.138	6.507
DEA116	8/9/2011	23	Drunella coloradensis/flavilinea	1	8.021	6.572
DEA116	8/9/2011	23	Drunella doddsii	1	7.911	7.162
DEA116	8/9/2011	23	Caudatella heterocaudata	2	7.781	5.861
DEA116	8/9/2011	23	Ameletus sp.	2	7.151	5.588
DEA116	8/9/2011	23	Acentrella turbida	1	6.518	4.516
DEA116	8/9/2011	23	Acentrella insignificans	1	4.151	2.956
DEA116	8/9/2011	23	Rhabdomastix fascigera gr.	1	3.675	2.996
DEA116	8/9/2011	23	Leptophlebiidae	1	3.488	2.442
DEA116	8/9/2011	23	Heterlimnius sp.	1	3.027	2.174
DEA116	8/9/2011	23	Diphetor hageni	1	2.739	2.066
DEA116	8/9/2011	23	Glossosomatidae	1	2.515	2.007
DEA116	8/9/2011	23	Kathroperla sp.	1	1.788	1.369
DEA116	8/9/2011	23	Hesperoconopa sp.	1	1.652	1.288
DEA116	8/9/2011	23	Rhyacophila sp.	1	1.380	0.932
DEA116	8/9/2011	23	Deuterophlebia sp.	1	1.355	0.904
DEA116	8/9/2011	23	Rhyacophila pellisa/valuma	1	1.088	0.828
DEA116	8/9/2011	23	Perlidae	1	0.534	0.382
DEA116	8/9/2011	23	Chelifera/Metachela sp.	2	0.495	0.348
DEA116	8/9/2011	23	Micrasema sp.	1	0.439	0.323
DEA116	8/9/2011	23	Caudatella sp.	1	0.355	0.229
DEA116	8/9/2011	23	Agapetus sp.	1	0.332	0.231
DEA116	8/9/2011	23	Perlodidae	1	0.263	0.181

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	8/9/2011	23	Arctopsychinae	1	0.256	0.173
DEA116	8/9/2011	23	Lepidostoma sp.	1	0.236	0.161
DEA116	8/9/2011	23	Heptageniidae	1	0.120	0.079
DEA116	8/9/2011	23	Nemouridae	1	0.076	0.049
DEA116	8/9/2011	23	Paraleptophlebia sp.	1	0.075	0.050
DEA116	8/9/2011	23	Stilobezzia sp.	1	0.045	0.027
DEA116	9/1/2011	34	Arctopsyche grandis	2	482.626	432.364
DEA116	9/1/2011	34	Brachycentrus americanus	1	288.639	249.983
DEA116	9/1/2011	34	Oligochaete (class C)	1	185.017	130.034
DEA116	9/1/2011	34	Simulium sp.	2	179.744	135.060
DEA116	9/1/2011	34	Optioservus sp.	2	168.233	127.601
DEA116	9/1/2011	34	Chironomidae	2	103.466	73.096
DEA116	9/1/2011	34	Baetis tricaudatus	1	78.784	56.238
DEA116	9/1/2011	34	Antocha sp.	1	63.504	49.105
DEA116	9/1/2011	34	Dicranota sp.	1	51.844	40.570
DEA116	9/1/2011	34	Epeorus grandis/permagnus	1	46.752	33.882
DEA116	9/1/2011	34	Sweltsa sp.	1	36.600	26.475
DEA116	9/1/2011	34	Rhithrogena sp.	1	34.381	25.005
DEA116	9/1/2011	34	Epeorus longimanus	1	32.420	25.748
DEA116	9/1/2011	34	Drunella doddsii	1	30.933	23.535
DEA116	9/1/2011	34	Claassenia sabulosa	1	29.553	20.654
DEA116	9/1/2011	34	Neophylax sp.	1	28.396	24.479
DEA116	9/1/2011	34	Glossosoma sp.	1	27.472	18.775
DEA116	9/1/2011	34	Hesperoperla pacifica	2	20.524	17.652
DEA116	9/1/2011	34	Serratella tibialis	1	19.836	16.371
DEA116	9/1/2011	34	Caudatella hystrix	1	17.278	13.803
DEA116	9/1/2011	34	Bezzia/Palpomyia sp.	1	16.690	12.443
DEA116	9/1/2011	34	Hydropsyche sp.	1	14.458	11.145
DEA116	9/1/2011	34	Dolophilodes sp.	1	12.245	8.913
DEA116	9/1/2011	34	Epeorus deceptivus/hesperus	2	11.057	8.822
DEA116	9/1/2011	34	Heterlimnius sp.	2	10.607	7.841
DEA116	9/1/2011	34	Ephemerella sp.	1	10.009	6.570
DEA116	9/1/2011	34	Atherix sp.	1	9.842	7.707
DEA116	9/1/2011	34	Epeorus sp.	1	9.470	7.500
DEA116	9/1/2011	34	Zapada cinctipes	1	6.555	4.392
DEA116	9/1/2011	34	Acentrella turbida	1	4.306	2.993
DEA116	9/1/2011	34	Zaitzevia sp.	1	2.379	1.796
DEA116	9/1/2011	34	Leptophlebiidae	1	1.801	1.237
DEA116	9/1/2011	34	Oligophlebodes sp.	1	1.797	1.205
DEA116	9/1/2011	34	Oligochaete (class B)	1	1.573	1.127
DEA116	9/1/2011	34	Deuterophlebia sp.	1	1.197	0.803

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	9/1/2011	34	Rhyacophila hyalinata gr.	1	1.114	1.071
DEA116	9/1/2011	34	Rhyacophila sp.	1	0.930	0.634
DEA116	9/1/2011	34	Caudatella heterocaudata	1	0.854	0.644
DEA116	9/1/2011	34	Blephariceridae	1	0.613	0.433
DEA116	9/1/2011	34	Yoraperla sp.	1	0.063	0.039
DEA116	9/1/2011	34	Ephemerellidae	1	0.042	0.025
DEA116	10/5/2011	NA	Antocha sp.	1	0.000	41.782
DEA116	10/5/2011	NA	Arctopsyche grandis	2	0.000	180.047
DEA116	10/5/2011	NA	Atherix sp.	1	0.000	6.379
DEA116	10/5/2011	NA	Baetis tricaudatus	1	0.000	15.630
DEA116	10/5/2011	NA	Bezzia/Palpomyia sp.	1	0.000	1.200
DEA116	10/5/2011	NA	Brachycentrus americanus	2	0.000	120.375
DEA116	10/5/2011	NA	Capniidae	1	0.000	1.840
DEA116	10/5/2011	NA	Caudatella hystrix	1	0.000	6.913
DEA116	10/5/2011	NA	Chironomidae	2	0.000	7.936
DEA116	10/5/2011	NA	Cinygmula sp.	1	0.000	4.479
DEA116	10/5/2011	NA	Claassenia sabulosa	2	0.000	15.417
DEA116	10/5/2011	NA	Cleptelmis addenda	1	0.000	0.320
DEA116	10/5/2011	NA	Dicranota sp.	2	0.000	26.038
DEA116	10/5/2011	NA	Dolophilodes sp.	1	0.000	1.384
DEA116	10/5/2011	NA	Drunella doddsii	1	0.000	18.252
DEA116	10/5/2011	NA	Epeorus grandis/permagnus	1	0.000	11.229
DEA116	10/5/2011	NA	Ephemerella dorothea/excrucians	1	0.000	10.846
DEA116	10/5/2011	NA	Ephemerella sp.	1	0.000	5.670
DEA116	10/5/2011	NA	Ephydridae	1	0.000	1.039
DEA116	10/5/2011	NA	Eucapnopsis brevicauda	1	0.000	0.488
DEA116	10/5/2011	NA	Glossosoma sp.	1	0.000	17.631
DEA116	10/5/2011	NA	Heterlimnius sp.	2	0.000	4.274
DEA116	10/5/2011	NA	Hexatoma sp.	1	0.000	16.767
DEA116	10/5/2011	NA	Hydropsyche sp.	2	0.000	9.087
DEA116	10/5/2011	NA	Lara sp.	1	0.000	0.275
DEA116	10/5/2011	NA	Lepidostoma sp.	1	0.000	1.556
DEA116	10/5/2011	NA	Leptophlebiidae	1	0.000	0.058
DEA116	10/5/2011	NA	Leuctridae	1	0.000	1.393
DEA116	10/5/2011	NA	Micrasema sp.	1	0.000	0.011
DEA116	10/5/2011	NA	Narpus sp.	1	0.000	1.177
DEA116	10/5/2011	NA	Oligochaete (class C)	1	0.000	117.793
DEA116	10/5/2011	NA	Oligophlebodes sp.	1	0.000	1.135
DEA116	10/5/2011	NA	Optioservus sp.	2	0.000	36.103
DEA116	10/5/2011	NA	Paraleptophlebia sp.	1	0.000	1.127

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
DEA116	10/5/2011	NA	Pericoma/Telmatoscopus sp.	1	0.000	0.482
DEA116	10/5/2011	NA	Perlidae	1	0.000	0.549
DEA116	10/5/2011	NA	Perlodidae	1	0.000	0.273
DEA116	10/5/2011	NA	Rhithrogena sp.	1	0.000	10.032
DEA116	10/5/2011	NA	Rhyacophila coloradensis gr.	1	0.000	10.752
DEA116	10/5/2011	NA	Rhyacophila hyalinata gr.	1	0.000	0.814
DEA116	10/5/2011	NA	Rhyacophila pellisa/valuma	1	0.000	0.417
DEA116	10/5/2011	NA	Simulium sp.	1	0.000	7.392
DEA116	10/5/2011	NA	Sweltsa sp.	1	0.000	11.569
DEA116	10/5/2011	NA	Zaitzevia sp.	2	0.000	1.461
DEA116	10/5/2011	NA	Zapada cinctipes	1	0.000	3.814
DEA116	10/5/2011	NA	Zapada oregonensis gr.	1	0.000	0.298
GAR108	7/8/2010	28	Pteronarcys californica	1	141.371	99.169
GAR108	7/8/2010	28	Oligochaete (class C)	1	94.596	58.709
GAR108	7/8/2010	28	Antocha sp.	1	46.467	31.261
GAR108	7/8/2010	28	Chironomidae	2	37.943	21.265
GAR108	7/8/2010	28	Brachycentrus americanus	2	28.175	27.284
GAR108	7/8/2010	28	Claassenia sabulosa	2	28.013	23.229
GAR108	7/8/2010	28	Baetis tricaudatus	1	21.974	12.836
GAR108	7/8/2010	28	Epeorus longimanus	1	21.069	12.783
GAR108	7/8/2010	28	Atherix sp.	3	13.140	7.372
GAR108	7/8/2010	28	Serratella tibialis	1	12.626	7.478
GAR108	7/8/2010	28	Oligochaete (class B)	1	12.114	7.665
GAR108	7/8/2010	28	Optioservus sp.	1	5.566	3.097
GAR108	7/8/2010	28	Glossosomatidae	1	5.255	3.496
GAR108	7/8/2010	28	Drunella coloradensis/flavilinea	1	4.991	2.859
GAR108	7/8/2010	28	Rhyacophila pellisa/valuma	3	4.253	2.664
GAR108	7/8/2010	28	Cinygmula sp.	2	3.906	2.488
GAR108	7/8/2010	28	Ephemerella dorothea/excrucians	1	3.324	2.156
GAR108	7/8/2010	28	Arctopsyche grandis	1	3.221	2.254
GAR108	7/8/2010	28	Chloroperlidae	1	2.814	1.668
GAR108	7/8/2010	28	Hexatoma sp.	1	2.333	1.603
GAR108	7/8/2010	28	Epeorus sp.	1	2.107	1.109
GAR108	7/8/2010	28	Diphetor hageni	1	1.911	0.821
GAR108	7/8/2010	28	Sweltsa sp.	1	1.782	1.030
GAR108	7/8/2010	28	Bezzia/Palpomyia sp.	2	1.569	0.977
GAR108	7/8/2010	28	Narpus sp.	1	1.291	0.807
GAR108	7/8/2010	28	Drunella doddsii	1	1.186	0.623
GAR108	7/8/2010	28	Rhyacophila coloradensis gr.	1	0.742	0.460
GAR108	7/8/2010	28	Caudatella heterocaudata	1	0.695	0.446

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	7/8/2010	28	Perlidae	1	0.597	0.380
GAR108	7/8/2010	28	Wiedemannia sp.	1	0.593	0.363
GAR108	7/8/2010	28	Paraleptophlebia sp.	1	0.464	0.265
GAR108	7/8/2010	28	Deuterophlebia sp.	1	0.414	0.221
GAR108	7/8/2010	28	Neoplasta sp.	1	0.402	0.225
GAR108	7/8/2010	28	Thaumaleidae	1	0.105	0.061
GAR108	7/8/2010	28	Empididae	1	0.081	0.044
GAR108	7/8/2010	28	Ameletus sp.	1	0.078	0.044
GAR108	7/8/2010	28	Centroptilum sp.	1	0.077	0.044
GAR108	7/8/2010	28	Rhyacophila narvae	1	0.053	0.029
GAR108	7/8/2010	28	Acentrella sp.	1	0.013	0.007
GAR108	7/8/2010	28	Trichoclinocera sp.	1	0.012	0.006
GAR108	8/5/2010	26	Hexatoma sp.	1	162.191	129.677
GAR108	8/5/2010	26	Oligochaete (class C)	1	122.500	83.655
GAR108	8/5/2010	26	Chironomidae	2	119.385	75.910
GAR108	8/5/2010	26	Pteronarcys californica	1	114.426	94.421
GAR108	8/5/2010	26	Brachycentrus americanus	4	53.379	41.738
GAR108	8/5/2010	26	Optioservus sp.	2	38.177	25.352
GAR108	8/5/2010	26	Atherix sp.	2	36.103	25.378
GAR108	8/5/2010	26	Antocha sp.	1	34.618	27.821
GAR108	8/5/2010	26	Claassenia sabulosa	2	32.262	26.569
GAR108	8/5/2010	26	Serratella tibialis	1	30.669	22.581
GAR108	8/5/2010	26	Rhithrogena sp.	1	27.337	16.429
GAR108	8/5/2010	26	Baetis tricaudatus	1	19.773	12.473
GAR108	8/5/2010	26	Pteronarcys sp.	2	15.218	11.082
GAR108	8/5/2010	26	Simulium sp.	1	14.428	9.221
GAR108	8/5/2010	26	Oligochaete (class B)	1	10.120	6.978
GAR108	8/5/2010	26	Drunella doddsii	1	8.039	4.361
GAR108	8/5/2010	26	Acentrella turbida	1	7.657	4.935
GAR108	8/5/2010	26	Sweltsa sp.	1	7.599	4.698
GAR108	8/5/2010	26	Acentrella insignificans	1	7.482	5.028
GAR108	8/5/2010	26	Dicranota sp.	1	5.289	4.021
GAR108	8/5/2010	26	Epeorus longimanus	1	4.564	3.151
GAR108	8/5/2010	26	Paraleptophlebia sp.	1	4.434	2.846
GAR108	8/5/2010	26	Drunella grandis	1	4.412	2.533
GAR108	8/5/2010	26	Glossosomatidae	2	3.729	2.638
GAR108	8/5/2010	26	Suwallia sp.	1	3.474	2.438
GAR108	8/5/2010	26	Blephariceridae	1	3.135	1.615
GAR108	8/5/2010	26	Epeorus albertae	1	2.198	1.483
GAR108	8/5/2010	26	Baetis flavistriga	1	2.117	1.362
GAR108	8/5/2010	26	Uenoidae	1	2.109	1.550

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	8/5/2010	26	Drunella coloradensis/flavilinea	1	1.990	1.443
GAR108	8/5/2010	26	Bezzia/Palpomyia sp.	1	1.964	1.186
GAR108	8/5/2010	26	Epeorus sp.	1	1.682	1.098
GAR108	8/5/2010	26	Dolophilodes sp.	1	1.598	1.157
GAR108	8/5/2010	26	Deuterophlebia sp.	2	1.594	0.969
GAR108	8/5/2010	26	Rhyacophila pellisa/valuma	1	1.517	0.972
GAR108	8/5/2010	26	Neoplasta sp.	1	1.432	0.844
GAR108	8/5/2010	26	Arctopsychinae	1	1.328	0.821
GAR108	8/5/2010	26	Perlodidae	1	1.272	0.764
GAR108	8/5/2010	26	Heterlimnius sp.	1	1.237	0.720
GAR108	8/5/2010	26	Diphetor hageni	1	0.779	0.548
GAR108	8/5/2010	26	Brachycentrus occidentalis	1	0.514	0.328
GAR108	8/5/2010	26	Zapada cinctipes	1	0.431	0.248
GAR108	8/5/2010	26	Hesperoperla pacifica	2	0.255	0.157
GAR108	8/5/2010	26	Epeorus grandis/permagnus	1	0.151	0.087
GAR108	8/5/2010	26	Empididae	2	0.071	0.043
GAR108	8/5/2010	26	Ephemerellidae	1	0.023	0.013
GAR108	8/5/2010	26	Caudatella sp.	1	0.017	0.010
GAR108	8/5/2010	26	Trichoclinocera sp.	1	0.001	0.001
GAR108	8/31/2010	42	Oligochaete (class C)	1	475.569	301.023
GAR108	8/31/2010	42	Hexatoma sp.	3	267.431	188.406
GAR108	8/31/2010	42	Chironomidae	2	183.806	108.330
GAR108	8/31/2010	42	Rhithrogena sp.	1	177.318	105.775
GAR108	8/31/2010	42	Brachycentrus americanus	2	163.637	110.952
GAR108	8/31/2010	42	Baetis tricaudatus	1	117.357	66.791
GAR108	8/31/2010	42	Optioservus sp.	2	81.792	50.991
GAR108	8/31/2010	42	Drunella doddsii	1	62.809	38.379
GAR108	8/31/2010	42	Antocha sp.	1	59.881	39.170
GAR108	8/31/2010	42	Sweltsa sp.	1	46.968	28.446
GAR108	8/31/2010	42	Atherix sp.	2	40.624	26.566
GAR108	8/31/2010	42	Drunella grandis	1	38.887	23.939
GAR108	8/31/2010	42	Cinygmula sp.	1	38.854	22.007
GAR108	8/31/2010	42	Arctopsyche grandis	1	33.757	20.923
GAR108	8/31/2010	42	Dicranota sp.	1	28.479	19.338
GAR108	8/31/2010	42	Paraleptophlebia sp.	1	25.303	15.586
GAR108	8/31/2010	42	Acentrella turbida	1	23.404	13.437
GAR108	8/31/2010	42	Serratella tibialis	2	23.313	16.459
GAR108	8/31/2010	42	Claassenia sabulosa	1	12.986	9.681
GAR108	8/31/2010	42	Perlodidae	1	10.894	6.565
GAR108	8/31/2010	42	Pteronarcys sp.	2	7.000	4.775
GAR108	8/31/2010	42	Capniidae	1	6.947	3.800

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	8/31/2010	42	Zaitzevia sp.	2	5.689	3.755
GAR108	8/31/2010	42	Heterlimnius sp.	1	4.117	2.452
GAR108	8/31/2010	42	Chloroperlidae	1	2.806	1.847
GAR108	8/31/2010	42	Oligochaete (class B)	1	2.779	1.679
GAR108	8/31/2010	42	Perlidae	1	2.130	1.227
GAR108	8/31/2010	42	Chelifera/Metachela sp.	1	1.974	1.164
GAR108	8/31/2010	42	Bezzia/Palpomyia sp.	1	1.895	1.148
GAR108	8/31/2010	42	Glossosoma sp.	1	1.451	0.866
GAR108	8/31/2010	42	Epeorus grandis/permagnus	1	1.396	0.773
GAR108	8/31/2010	42	Blephariceridae	1	1.343	0.861
GAR108	8/31/2010	42	Suwallia sp.	1	1.292	0.877
GAR108	8/31/2010	42	Neoplasta sp.	1	1.126	0.652
GAR108	8/31/2010	42	Deuterophlebia sp.	1	0.980	0.556
GAR108	8/31/2010	42	Narpus sp.	1	0.731	0.464
GAR108	8/31/2010	42	Clinocera sp.	1	0.684	0.380
GAR108	8/31/2010	42	Caudatella hystrix	1	0.491	0.293
GAR108	8/31/2010	42	Ephemerella sp.	1	0.413	0.235
GAR108	8/31/2010	42	Zapada cinctipes	1	0.395	0.233
GAR108	8/31/2010	42	Simulium sp.	1	0.173	0.101
GAR108	8/31/2010	42	Oreodytes sp.	1	0.157	0.091
GAR108	8/31/2010	42	Ceratopogoninae	1	0.105	0.059
GAR108	8/31/2010	42	Taeniopterygidae	1	0.039	0.021
GAR108	8/31/2010	42	Ameletus sp.	1	0.021	0.011
GAR108	10/12/2010	287	Brachycentrus americanus	2	2231.305	623.525
GAR108	10/12/2010	287	Oligochaete (class C)	1	1216.599	272.783
GAR108	10/12/2010	287	Hexatoma sp.	1	566.735	145.215
GAR108	10/12/2010	287	Rhithrogena sp.	1	423.593	92.016
GAR108	10/12/2010	287	Chironomidae	2	394.398	80.182
GAR108	10/12/2010	287	Arctopsyche grandis	2	393.768	96.698
GAR108	10/12/2010	287	Antocha sp.	1	325.792	73.909
GAR108	10/12/2010	287	Baetis tricaudatus	1	316.472	63.046
GAR108	10/12/2010	287	Ephemerella dorothea/excrucians	1	222.438	43.753
GAR108	10/12/2010	287	Drunella doddsii	1	153.795	34.540
GAR108	10/12/2010	287	Optioservus sp.	2	137.297	29.879
GAR108	10/12/2010	287	Cinygmula sp.	1	118.374	24.710
GAR108	10/12/2010	287	Sweltsa sp.	1	116.207	24.717
GAR108	10/12/2010	287	Drunella grandis	1	91.287	21.517
GAR108	10/12/2010	287	Brachycentrus occidentalis	1	73.141	17.417
GAR108	10/12/2010	287	Dicranota sp.	1	71.518	17.681
GAR108	10/12/2010	287	Rhyacophila pellisa/valuma	1	60.742	13.290

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	10/12/2010	287	Paraleptophlebia sp.	1	58.575	12.957
GAR108	10/12/2010	287	Acentrella turbida	1	50.164	11.000
GAR108	10/12/2010	287	Hesperoperla pacifica	1	47.727	11.536
GAR108	10/12/2010	287	Atherix sp.	1	47.547	9.643
GAR108	10/12/2010	287	Perlodidae	1	28.952	5.952
GAR108	10/12/2010	287	Claassenia sabulosa	1	28.001	6.320
GAR108	10/12/2010	287	Capniidae	1	18.906	3.744
GAR108	10/12/2010	287	Hesperoconopa sp.	1	17.506	3.958
GAR108	10/12/2010	287	Lepidostoma sp.	1	13.079	2.688
GAR108	10/12/2010	287	Zaitzevia sp.	1	10.196	2.261
GAR108	10/12/2010	287	Heterlimnius sp.	1	7.988	1.747
GAR108	10/12/2010	287	Taenionema sp.	1	6.758	1.355
GAR108	10/12/2010	287	Hydropsyche sp.	1	5.314	1.068
GAR108	10/12/2010	287	Perlidae	1	4.553	0.896
GAR108	10/12/2010	287	Chelifera/Metachela sp.	1	4.339	0.863
GAR108	10/12/2010	287	Epeorus grandis/permagnus	1	3.373	0.703
GAR108	10/12/2010	287	Glossosoma sp.	1	2.899	0.577
GAR108	10/12/2010	287	Rhyacophila sp.	1	1.543	0.291
GAR108	10/12/2010	287	Nemouridae	1	0.354	0.065
GAR108	10/12/2010	287	Caudatella sp.	1	0.266	0.048
GAR108	10/12/2010	287	Stilobezzia sp.	1	0.245	0.042
GAR108	10/12/2010	287	Ceratopogoninae	1	0.035	0.006
GAR108	7/26/2011	15	Brachycentrus americanus	3	464.284	722.505
GAR108	7/26/2011	15	Hesperoperla pacifica	1	55.950	72.189
GAR108	7/26/2011	15	Antocha sp.	2	46.147	68.933
GAR108	7/26/2011	15	Simulium sp.	1	39.406	49.198
GAR108	7/26/2011	15	Baetis tricaudatus	1	32.601	41.580
GAR108	7/26/2011	15	Arctopsyche grandis	2	32.349	52.496
GAR108	7/26/2011	15	Hexatoma sp.	2	28.823	44.107
GAR108	7/26/2011	15	Chironomidae	2	27.749	35.158
GAR108	7/26/2011	15	Pteronarcys sp.	1	21.608	27.188
GAR108	7/26/2011	15	Serratella tibialis	1	21.080	27.318
GAR108	7/26/2011	15	Acentrella insignificans	1	15.783	19.463
GAR108	7/26/2011	15	Epeorus longimanus	1	13.865	17.490
GAR108	7/26/2011	15	Optioservus sp.	2	7.636	10.094
GAR108	7/26/2011	15	Atherix sp.	1	6.950	8.734
GAR108	7/26/2011	15	Oligochaete (class C)	1	5.395	6.770
GAR108	7/26/2011	15	Diphetor hageni	1	4.480	5.667
GAR108	7/26/2011	15	Oligochaete (class B)	1	3.667	4.869
GAR108	7/26/2011	15	Sweltsa sp.	1	2.968	3.602
GAR108	7/26/2011	15	Epeorus sp.	1	2.835	3.435

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	7/26/2011	15	Rhithrogena sp.	1	2.796	3.166
GAR108	7/26/2011	15	Drunella coloradensis/flavilinea	1	2.507	3.254
GAR108	7/26/2011	15	Glossosomatidae	1	2.494	3.537
GAR108	7/26/2011	15	Chloroperlidae	1	2.346	3.168
GAR108	7/26/2011	15	Narpus sp.	1	2.237	3.119
GAR108	7/26/2011	15	Cinygmula sp.	1	2.195	3.027
GAR108	7/26/2011	15	Drunella doddsii	1	2.085	2.374
GAR108	7/26/2011	15	Ephemerella dorothea/excrucians	1	1.929	2.631
GAR108	7/26/2011	15	Acentrella turbida	1	1.797	2.488
GAR108	7/26/2011	15	Ameletus sp.	1	1.687	2.256
GAR108	7/26/2011	15	Deuterophlebia sp.	2	1.664	2.006
GAR108	7/26/2011	15	Neophylax rickeri	1	1.441	1.962
GAR108	7/26/2011	15	Neothremma sp.	1	1.387	1.920
GAR108	7/26/2011	15	Heterlimnius sp.	1	1.021	1.347
GAR108	7/26/2011	15	Rhyacophila angelita gr.	1	0.826	1.142
GAR108	7/26/2011	15	Rhyacophila pellisa/valuma	1	0.728	0.999
GAR108	7/26/2011	15	Claassenia sabulosa	1	0.695	0.910
GAR108	7/26/2011	15	Dicranota sp.	1	0.677	0.950
GAR108	7/26/2011	15	Hesperoconopa sp.	1	0.508	0.698
GAR108	7/26/2011	15	Rhyacophila brunnea gr.	1	0.461	0.633
GAR108	7/26/2011	15	Drunella grandis	2	0.413	0.466
GAR108	7/26/2011	15	Neophylax occidentis	1	0.320	0.431
GAR108	7/26/2011	15	Bezzia/Palpomyia sp.	1	0.313	0.354
GAR108	7/26/2011	15	Epeorus grandis/permagnus	1	0.292	0.343
GAR108	7/26/2011	15	Zapada oregonensis gr.	1	0.237	0.305
GAR108	7/26/2011	15	Perlidae	1	0.155	0.188
GAR108	7/26/2011	15	Rhyacophila sp.	1	0.149	0.187
GAR108	7/26/2011	15	Serratella teresa	1	0.120	0.152
GAR108	7/26/2011	15	Dolophilodes sp.	1	0.099	0.125
GAR108	7/26/2011	15	Paraleptophlebia sp.	1	0.074	0.087
GAR108	7/26/2011	15	Perlodidae	1	0.045	0.054
GAR108	7/26/2011	15	Zaitzevia sp.	1	0.041	0.049
GAR108	7/26/2011	15	Caudatella sp.	1	0.030	0.033
GAR108	7/26/2011	15	Stilobezzia sp.	1	0.025	0.027
GAR108	7/26/2011	15	Clinocera sp.	1	0.007	0.008
GAR108	8/10/2011	20	Brachycentrus americanus	2	228.052	248.067
GAR108	8/10/2011	20	Hexatoma sp.	2	117.697	127.097
GAR108	8/10/2011	20	Claassenia sabulosa	2	76.639	95.476
GAR108	8/10/2011	20	Pteronarcys californica	2	63.757	75.446
GAR108	8/10/2011	20	Hesperoperla pacifica	1	59.507	71.682

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	8/10/2011	20	Simulium sp.	2	58.863	52.009
GAR108	8/10/2011	20	Oligochaete (class C)	1	44.257	38.878
GAR108	8/10/2011	20	Antocha sp.	2	33.904	36.239
GAR108	8/10/2011	20	Chironomidae	2	32.821	27.183
GAR108	8/10/2011	20	Rhithrogena sp.	1	32.131	27.018
GAR108	8/10/2011	20	Pteronarcys sp.	1	25.693	27.430
GAR108	8/10/2011	20	Serratella tibialis	1	22.554	26.261
GAR108	8/10/2011	20	Acentrella insignificans	1	21.748	18.850
GAR108	8/10/2011	20	Drunella doddsii	1	19.463	16.418
GAR108	8/10/2011	20	Atherix sp.	1	18.515	17.350
GAR108	8/10/2011	20	Epeorus longimanus	1	15.259	14.388
GAR108	8/10/2011	20	Optioservus sp.	2	14.322	12.929
GAR108	8/10/2011	20	Sweltsa sp.	1	12.132	10.241
GAR108	8/10/2011	20	Baetis tricaudatus	1	12.020	10.687
GAR108	8/10/2011	20	Tipulidae	1	5.009	5.094
GAR108	8/10/2011	20	Epeorus deceptivus/hesperus	1	4.999	4.375
GAR108	8/10/2011	20	Drunella grandis	1	4.260	3.488
GAR108	8/10/2011	20	Suwallia sp.	1	3.702	3.475
GAR108	8/10/2011	20	Epeorus albertae	1	3.098	2.993
GAR108	8/10/2011	20	Diphetor hageni	1	2.838	2.524
GAR108	8/10/2011	20	Deuterophlebia sp.	1	2.748	2.278
GAR108	8/10/2011	20	Acentrella turbida	1	2.748	2.386
GAR108	8/10/2011	20	Narpus sp.	1	1.234	1.183
GAR108	8/10/2011	20	Hydropsyche sp.	1	1.193	1.178
GAR108	8/10/2011	20	Chloroperlidae	1	1.123	0.988
GAR108	8/10/2011	20	Rhyacophila pellisa/valuma	1	1.111	0.979
GAR108	8/10/2011	20	Rhyacophila hyalinata gr.	1	1.099	1.080
GAR108	8/10/2011	20	Rhabdomastix fascigera gr.	1	1.068	1.048
GAR108	8/10/2011	20	Ameletus sp.	1	0.958	0.825
GAR108	8/10/2011	20	Baetis bicaudatus	1	0.957	0.880
GAR108	8/10/2011	20	Lepidostoma sp.	1	0.903	0.816
GAR108	8/10/2011	20	Caudatella heterocaudata	1	0.858	0.816
GAR108	8/10/2011	20	Oligochaete (class B)	1	0.812	0.706
GAR108	8/10/2011	20	Heterlimnius sp.	1	0.785	0.679
GAR108	8/10/2011	20	Glossosoma sp.	1	0.648	0.582
GAR108	8/10/2011	20	Arctopsychinae	1	0.417	0.341
GAR108	8/10/2011	20	Bezzia/Palpomyia sp.	1	0.344	0.288
GAR108	8/10/2011	20	Empididae	2	0.323	0.290
GAR108	8/10/2011	20	Simuliidae	1	0.281	0.251
GAR108	8/10/2011	20	Chelifera/Metachela sp.	2	0.143	0.117
GAR108	8/10/2011	20	Blephariceridae	1	0.131	0.109

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	8/10/2011	20	Epeorus grandis/permagnus	1	0.043	0.035
GAR108	8/10/2011	20	Caudatella sp.	1	0.019	0.014
GAR108	8/30/2011	35	Hexatoma sp.	2	188.809	154.841
GAR108	8/30/2011	35	Brachycentrus americanus	2	159.752	126.055
GAR108	8/30/2011	35	Rhithrogena sp.	1	125.294	81.963
GAR108	8/30/2011	35	Pteronarcys californica	2	119.958	107.582
GAR108	8/30/2011	35	Chironomidae	2	102.955	66.593
GAR108	8/30/2011	35	Oligochaete (class C)	1	69.167	46.385
GAR108	8/30/2011	35	Drunella doddsii	1	68.849	48.448
GAR108	8/30/2011	35	Baetis tricaudatus	1	51.734	32.771
GAR108	8/30/2011	35	Sweltsa sp.	1	26.755	17.640
GAR108	8/30/2011	35	Optioservus sp.	2	24.694	17.066
GAR108	8/30/2011	35	Arctopsyche grandis	2	22.806	25.636
GAR108	8/30/2011	35	Antocha sp.	2	22.603	17.656
GAR108	8/30/2011	35	Drunella grandis	1	21.923	11.319
GAR108	8/30/2011	35	Atherix sp.	1	21.377	15.153
GAR108	8/30/2011	35	Serratella tibialis	1	18.979	13.887
GAR108	8/30/2011	35	Dicranota sp.	1	17.598	13.148
GAR108	8/30/2011	35	Glossosoma sp.	1	16.043	10.470
GAR108	8/30/2011	35	Acentrella insignificans	1	12.265	8.624
GAR108	8/30/2011	35	Ameletus sp.	1	9.372	6.906
GAR108	8/30/2011	35	Drunella coloradensis/flavilinea	1	6.001	4.769
GAR108	8/30/2011	35	Simulium sp.	1	5.432	3.794
GAR108	8/30/2011	35	Acentrella turbida	1	4.700	3.565
GAR108	8/30/2011	35	Heterlimnius sp.	1	3.523	2.258
GAR108	8/30/2011	35	Rhyacophila pellisa/valuma	1	3.000	2.043
GAR108	8/30/2011	35	Epeorus albertae	1	2.901	2.024
GAR108	8/30/2011	35	Paraleptophlebia sp.	1	2.869	1.864
GAR108	8/30/2011	35	Baetis flavistriga	1	2.147	1.494
GAR108	8/30/2011	35	Epeorus sp.	2	1.481	1.065
GAR108	8/30/2011	35	Deuterophlebia sp.	2	1.325	0.844
GAR108	8/30/2011	35	Taeniopterygidae	1	0.951	0.563
GAR108	8/30/2011	35	Diphetor hageni	1	0.914	0.635
GAR108	8/30/2011	35	Perlidae	1	0.549	0.344
GAR108	8/30/2011	35	Pteronarcys sp.	1	0.525	0.364
GAR108	8/30/2011	35	Narpus sp.	1	0.496	0.352
GAR108	8/30/2011	35	Perlodidae	1	0.357	0.228
GAR108	8/30/2011	35	Capniidae	1	0.338	0.207
GAR108	8/30/2011	35	Neoplasta sp.	1	0.320	0.194
GAR108	8/30/2011	35	Ephemerella sp.	1	0.119	0.071
GAR108	8/30/2011	35	Ephemerellidae	1	0.106	0.063

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	8/30/2011	35	Clinocera sp.	1	0.022	0.013
GAR108	10/4/2011	NA	Acentrella insignificans	1	0.000	0.113
GAR108	10/4/2011	NA	Acentrella turbida	1	0.000	2.471
GAR108	10/4/2011	NA	Ameletus sp.	2	0.000	6.407
GAR108	10/4/2011	NA	Antocha sp.	1	0.000	6.499
GAR108	10/4/2011	NA	Apatania sp.	1	0.000	0.922
GAR108	10/4/2011	NA	Arctopsyche grandis	2	0.000	71.995
GAR108	10/4/2011	NA	Atherix sp.	1	0.000	4.856
GAR108	10/4/2011	NA	Baetis tricaudatus	1	0.000	30.312
GAR108	10/4/2011	NA	Bezzia/Palpomyia sp.	1	0.000	0.168
GAR108	10/4/2011	NA	Bibiocephala sp.	1	0.000	1.350
GAR108	10/4/2011	NA	Brachycentrus americanus	2	0.000	73.978
GAR108	10/4/2011	NA	Capniidae	1	0.000	0.150
GAR108	10/4/2011	NA	Caudatella hystrix	1	0.000	0.838
GAR108	10/4/2011	NA	Chelifera/Metachela sp.	2	0.000	0.198
GAR108	10/4/2011	NA	Chironomidae	2	0.000	44.351
GAR108	10/4/2011	NA	Cinygmula sp.	1	0.000	1.082
GAR108	10/4/2011	NA	Deuterophlebia sp.	1	0.000	0.199
GAR108	10/4/2011	NA	Dicranota sp.	1	0.000	3.366
GAR108	10/4/2011	NA	Dolophilodes sp.	1	0.000	0.782
GAR108	10/4/2011	NA	Drunella doddsii	1	0.000	34.296
GAR108	10/4/2011	NA	Drunella grandis	1	0.000	8.170
GAR108	10/4/2011	NA	Empididae	1	0.000	0.362
GAR108	10/4/2011	NA	Epeorus grandis/permagnus	1	0.000	0.778
GAR108	10/4/2011	NA	Epeorus longimanus	1	0.000	1.623
GAR108	10/4/2011	NA	Ephemerella dorothea/excrucians	1	0.000	3.279
GAR108	10/4/2011	NA	Glossosoma sp.	1	0.000	10.168
GAR108	10/4/2011	NA	Heterlimnius sp.	1	0.000	2.156
GAR108	10/4/2011	NA	Hexatoma sp.	2	0.000	56.896
GAR108	10/4/2011	NA	Lepidostoma sp.	1	0.000	0.788
GAR108	10/4/2011	NA	Neoplasta sp.	1	0.000	0.014
GAR108	10/4/2011	NA	Oligochaete (class C)	1	0.000	12.175
GAR108	10/4/2011	NA	Optioservus sp.	2	0.000	8.525
GAR108	10/4/2011	NA	Paraleptophlebia sp.	1	0.000	1.054
GAR108	10/4/2011	NA	Perlidae	1	0.000	0.186
GAR108	10/4/2011	NA	Perlodidae	1	0.000	0.151
GAR108	10/4/2011	NA	Pteronarcys californica	1	0.000	75.623
GAR108	10/4/2011	NA	Rhithrogena sp.	1	0.000	57.953
GAR108	10/4/2011	NA	Rhyacophila pellisa/valuma	1	0.000	1.623
GAR108	10/4/2011	NA	Rhyacophila sp.	1	0.000	0.183

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR108	10/4/2011	NA	Simulium sp.	2	0.000	1.135
GAR108	10/4/2011	NA	Sweltsa sp.	1	0.000	9.872
GAR108	10/4/2011	NA	Taeniopterygidae	1	0.000	0.532
GAR108	10/4/2011	NA	Wiedemannia sp.	1	0.000	0.009
GAR108	10/4/2011	NA	Zapada cinctipes	1	0.000	0.174
GAR109	7/8/2010	28	Pteronarcys californica	1	189.447	164.713
GAR109	7/8/2010	28	Oligochaete (class C)	1	177.295	124.291
GAR109	7/8/2010	28	Claassenia sabulosa	1	132.949	134.942
GAR109	7/8/2010	28	Chironomidae	2	48.696	32.661
GAR109	7/8/2010	28	Parapsyche elsis	1	38.891	32.904
GAR109	7/8/2010	28	Hexatoma sp.	2	31.746	26.507
GAR109	7/8/2010	28	Ephemerella dorothea/excrucians	2	29.702	25.229
GAR109	7/8/2010	28	Rhyacophila brunnea gr.	2	21.107	18.472
GAR109	7/8/2010	28	Rhithrogena sp.	2	19.967	14.648
GAR109	7/8/2010	28	Baetis tricaudatus	1	15.620	10.377
GAR109	7/8/2010	28	Suwallia sp.	1	13.631	10.219
GAR109	7/8/2010	28	Epeorus longimanus	1	11.587	7.732
GAR109	7/8/2010	28	Brachycentrus americanus	1	10.347	7.610
GAR109	7/8/2010	28	Optioservus sp.	2	10.330	7.212
GAR109	7/8/2010	28	Drunella coloradensis/flavilinea	1	10.099	4.219
GAR109	7/8/2010	28	Serratella tibialis	1	9.883	6.799
GAR109	7/8/2010	28	Cinygmula sp.	1	9.467	6.778
GAR109	7/8/2010	28	Sweltsa sp.	1	8.557	5.580
GAR109	7/8/2010	28	Rhyacophila betteni gr.	1	7.664	6.632
GAR109	7/8/2010	28	Rhabdomastix fascigera gr.	1	7.036	5.542
GAR109	7/8/2010	28	Doroneuria sp.	1	6.721	5.555
GAR109	7/8/2010	28	Atherix sp.	1	6.696	4.733
GAR109	7/8/2010	28	Antocha sp.	1	5.070	4.125
GAR109	7/8/2010	28	Blephariceridae	1	4.436	3.723
GAR109	7/8/2010	28	Ameletus sp.	1	4.080	2.882
GAR109	7/8/2010	28	Hesperoperla pacifica	2	3.306	2.338
GAR109	7/8/2010	28	Paraleptophlebia sp.	1	3.040	1.927
GAR109	7/8/2010	28	Epeorus sp.	1	3.017	1.875
GAR109	7/8/2010	28	Diphetor hageni	1	2.862	1.947
GAR109	7/8/2010	28	Lara sp.	1	2.820	2.308
GAR109	7/8/2010	28	Narpus sp.	1	2.469	1.886
GAR109	7/8/2010	28	Dicranota sp.	1	2.287	1.751
GAR109	7/8/2010	28	Drunella doddsii	1	1.856	1.129
GAR109	7/8/2010	28	Glossosoma sp.	1	1.819	1.366
GAR109	7/8/2010	28	Zaitzevia sp.	1	1.588	1.065

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	7/8/2010	28	Kogotus sp.	1	1.575	1.185
GAR109	7/8/2010	28	Oligophlebodes sp.	1	1.444	1.003
GAR109	7/8/2010	28	Perlidae	1	1.214	0.766
GAR109	7/8/2010	28	Zapada columbiana	1	0.946	0.644
GAR109	7/8/2010	28	Zapada oregonensis gr.	1	0.863	0.604
GAR109	7/8/2010	28	Parapsyche sp.	1	0.814	0.622
GAR109	7/8/2010	28	Rhyacophila pellisa/valuma	1	0.676	0.464
GAR109	7/8/2010	28	Chloroperlidae	1	0.588	0.408
GAR109	7/8/2010	28	Neoplasta sp.	1	0.327	0.209
GAR109	7/8/2010	28	Dolichopodidae	1	0.313	0.215
GAR109	7/8/2010	28	Glutops sp.	1	0.249	0.178
GAR109	7/8/2010	28	Simulium sp.	1	0.249	0.155
GAR109	7/8/2010	28	Caudatella heterocaudata	1	0.247	0.177
GAR109	7/8/2010	28	Rhyacophila narvae	1	0.191	0.128
GAR109	7/8/2010	28	Acentrella sp.	1	0.168	0.101
GAR109	7/8/2010	28	Neophylax sp.	1	0.161	0.112
GAR109	7/8/2010	28	Clinocera sp.	1	0.050	0.027
GAR109	7/8/2010	28	Pteronarcyidae	1	0.046	0.030
GAR109	7/8/2010	28	Epeorus grandis/permagnus	1	0.043	0.027
GAR109	7/8/2010	28	Dytiscidae	1	0.034	0.021
GAR109	7/8/2010	28	Rhyacophila sp.	1	0.025	0.016
GAR109	7/8/2010	28	Wiedemannia sp.	1	0.001	0.000
GAR109	8/5/2010	28	Oligochaete (class C)	1	270.252	196.963
GAR109	8/5/2010	28	Pteronarcys californica	1	149.701	145.141
GAR109	8/5/2010	28	Rhithrogena sp.	2	30.706	21.901
GAR109	8/5/2010	28	Chironomidae	2	26.167	17.354
GAR109	8/5/2010	28	Brachycentrus americanus	1	24.293	17.841
GAR109	8/5/2010	28	Arctopsyche grandis	2	20.739	16.555
GAR109	8/5/2010	28	Sweltsa sp.	1	17.520	11.839
GAR109	8/5/2010	28	Baetis tricaudatus	1	15.081	9.911
GAR109	8/5/2010	28	Optioservus sp.	2	14.278	9.818
GAR109	8/5/2010	28	Suwallia sp.	1	9.409	6.872
GAR109	8/5/2010	28	Acentrella insignificans	1	8.732	6.038
GAR109	8/5/2010	28	Atherix sp.	1	7.334	4.890
GAR109	8/5/2010	28	Drunella doddsii	1	6.431	3.333
GAR109	8/5/2010	28	Cinygmula sp.	1	6.412	4.768
GAR109	8/5/2010	28	Serratella tibialis	1	5.489	4.138
GAR109	8/5/2010	28	Rhabdomastix fascigera gr.	1	5.448	4.420
GAR109	8/5/2010	28	Acentrella turbida	1	4.017	2.724
GAR109	8/5/2010	28	Drunella coloradensis/flavilinea	1	3.578	2.768
GAR109	8/5/2010	28	Paraleptophlebia sp.	1	3.459	2.270

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	8/5/2010	28	Pteronarcys sp.	1	2.675	2.032
GAR109	8/5/2010	28	Baetis flavistriga	1	2.237	1.491
GAR109	8/5/2010	28	Rhyacophila brunnea gr.	1	2.198	1.627
GAR109	8/5/2010	28	Epeorus sp.	1	2.146	1.456
GAR109	8/5/2010	28	Epeorus longimanus	1	1.887	1.443
GAR109	8/5/2010	28	Oligochaete (class B)	1	1.881	1.305
GAR109	8/5/2010	28	Dicranota sp.	1	1.407	1.096
GAR109	8/5/2010	28	Zaitzevia sp.	1	1.260	0.904
GAR109	8/5/2010	28	Epeorus albertae	1	1.243	0.904
GAR109	8/5/2010	28	Cleptelmis addenda	1	1.176	0.861
GAR109	8/5/2010	28	Hesperoperla pacifica	2	1.122	0.786
GAR109	8/5/2010	28	Perlidae	1	1.099	0.749
GAR109	8/5/2010	28	Ameletus sp.	1	0.879	0.599
GAR109	8/5/2010	28	Trichoptera	1	0.865	0.656
GAR109	8/5/2010	28	Uenoidae	1	0.865	0.656
GAR109	8/5/2010	28	Perlodidae	1	0.736	0.486
GAR109	8/5/2010	28	Drunella grandis	1	0.619	0.389
GAR109	8/5/2010	28	Bezzia/Palpomyia sp.	1	0.250	0.151
GAR109	8/5/2010	28	Hydropsyche sp.	1	0.207	0.145
GAR109	8/5/2010	28	Diphetor hageni	1	0.199	0.139
GAR109	8/5/2010	28	Zapada cinctipes	1	0.192	0.118
GAR109	8/5/2010	28	Simulium sp.	1	0.174	0.120
GAR109	8/5/2010	28	Clinocera sp.	1	0.123	0.067
GAR109	8/5/2010	28	Drunella spinifera	1	0.111	0.069
GAR109	8/5/2010	28	Hydroptilidae	1	0.088	0.057
GAR109	8/5/2010	28	Ephemerellidae	1	0.022	0.013
GAR109	8/5/2010	28	Trichoclinocera sp.	1	0.020	0.012
GAR109	8/5/2010	28	Caudatella sp.	1	0.011	0.006
GAR109	9/2/2010	39	Oligochaete (class C)	1	1182.875	844.796
GAR109	9/2/2010	39	Brachycentrus americanus	1	305.819	242.009
GAR109	9/2/2010	39	Hexatoma sp.	3	221.720	175.854
GAR109	9/2/2010	39	Rhithrogena sp.	1	149.297	99.340
GAR109	9/2/2010	39	Sweltsa sp.	1	114.180	77.328
GAR109	9/2/2010	39	Baetis tricaudatus	1	95.212	62.701
GAR109	9/2/2010	39	Chironomidae	2	92.880	59.226
GAR109	9/2/2010	39	Ephemerella dorothea/excrucians	1	87.641	54.784
GAR109	9/2/2010	39	Optioservus sp.	2	65.439	44.836
GAR109	9/2/2010	39	Drunella doddsii	1	49.051	33.180
GAR109	9/2/2010	39	Cinygmula sp.	2	42.218	27.571
GAR109	9/2/2010	39	Atherix sp.	1	27.532	19.191

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	9/2/2010	39	Paraleptophlebia sp.	1	24.696	16.796
GAR109	9/2/2010	39	Drunella grandis	1	22.086	15.464
GAR109	9/2/2010	39	Pteronarcys californica	1	19.952	17.154
GAR109	9/2/2010	39	Arctopsyche grandis	1	11.665	10.043
GAR109	9/2/2010	39	Bezzia/Palpomyia sp.	1	9.001	5.898
GAR109	9/2/2010	39	Epeorus deceptivus/hesperus	1	7.170	5.431
GAR109	9/2/2010	39	Rhyacophila pellisa/valuma	1	7.168	4.883
GAR109	9/2/2010	39	Oligochaete (class B)	1	5.860	4.324
GAR109	9/2/2010	39	Brachycentrus occidentalis	1	3.943	2.660
GAR109	9/2/2010	39	Acentrella turbida	1	3.090	2.005
GAR109	9/2/2010	39	Perlodidae	1	1.762	1.121
GAR109	9/2/2010	39	Serratella tibialis	1	0.998	0.757
GAR109	9/2/2010	39	Arctopsychinae	1	0.405	0.263
GAR109	9/2/2010	39	Cleptelmis addenda	1	0.264	0.186
GAR109	9/2/2010	39	Zapada cinctipes	1	0.161	0.106
GAR109	9/2/2010	39	Agraylea sp.	1	0.160	0.110
GAR109	9/2/2010	39	Zaitzevia sp.	1	0.142	0.096
GAR109	9/2/2010	39	Epeorus grandis/permagnus	1	0.091	0.058
GAR109	9/2/2010	39	Clinocera sp.	1	0.074	0.046
GAR109	9/2/2010	39	Deuterophlebia sp.	1	0.074	0.048
GAR109	9/2/2010	39	Oligophlebodes sp.	1	0.042	0.025
GAR109	9/2/2010	39	Epeorus sp.	1	0.017	0.010
GAR109	9/2/2010	39	Lepidostoma sp.	1	0.012	0.007
GAR109	10/11/2010	287	Oligochaete (class C)	1	3167.245	768.068
GAR109	10/11/2010	287	Brachycentrus americanus	2	934.814	254.152
GAR109	10/11/2010	287	Chironomidae	2	905.174	201.197
GAR109	10/11/2010	287	Hexatoma sp.	1	563.997	155.376
GAR109	10/11/2010	287	Rhithrogena sp.	1	401.610	91.193
GAR109	10/11/2010	287	Sweltsa sp.	1	307.124	70.530
GAR109	10/11/2010	287	Baetis tricaudatus	1	262.150	55.227
GAR109	10/11/2010	287	Dicranota sp.	1	246.442	62.766
GAR109	10/11/2010	287	Ephemerella dorothea/excrucians	1	245.448	53.953
GAR109	10/11/2010	287	Optioservus sp.	2	172.566	39.171
GAR109	10/11/2010	287	Cinygmula sp.	1	142.758	31.367
GAR109	10/11/2010	287	Antocha sp.	1	136.309	33.445
GAR109	10/11/2010	287	Drunella doddsii	1	128.853	30.741
GAR109	10/11/2010	287	Atherix sp.	1	75.237	16.101
GAR109	10/11/2010	287	Paraleptophlebia sp.	1	70.490	15.895
GAR109	10/11/2010	287	Drunella grandis	1	62.241	15.298
GAR109	10/11/2010	287	Taenionema sp.	1	41.032	9.030

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	10/11/2010	287	Caudatella hystrix	1	35.095	7.584
GAR109	10/11/2010	287	Acentrella sp.	1	31.278	6.794
GAR109	10/11/2010	287	Rhyacophila pellisa/valuma	1	27.713	6.411
GAR109	10/11/2010	287	Bezzia/Palpomyia sp.	1	25.542	5.756
GAR109	10/11/2010	287	Arctopsyche grandis	2	25.485	6.262
GAR109	10/11/2010	287	Diphetor hageni	1	17.488	3.442
GAR109	10/11/2010	287	Perlidae	1	14.385	3.138
GAR109	10/11/2010	287	Oligochaete (class B)	1	13.267	3.371
GAR109	10/11/2010	287	Baetis sp.	1	11.806	2.484
GAR109	10/11/2010	287	Brachycentrus occidentalis	1	9.920	2.578
GAR109	10/11/2010	287	Capniidae	1	7.948	1.708
GAR109	10/11/2010	287	Hesperoperla pacifica	1	7.360	4.353
GAR109	10/11/2010	287	Hydropsyche sp.	1	7.137	1.821
GAR109	10/11/2010	287	Simulium sp.	1	4.284	0.910
GAR109	10/11/2010	287	Perlodidae	1	3.891	0.868
GAR109	10/11/2010	287	Micrasema sp.	1	3.184	0.758
GAR109	10/11/2010	287	Zaitzevia sp.	1	2.357	0.565
GAR109	10/11/2010	287	Nemouridae	1	0.164	0.033
GAR109	10/11/2010	287	Caudatella sp.	1	0.123	0.024
GAR109	10/11/2010	287	Ameletus sp.	1	0.056	0.011
GAR109	7/25/2011	16	Chironomidae	2	118.423	162.386
GAR109	7/25/2011	16	Limnephilidae	1	116.368	223.524
GAR109	7/25/2011	16	Parapsyche elsis	1	37.730	63.466
GAR109	7/25/2011	16	Serratella tibialis	1	35.423	51.157
GAR109	7/25/2011	16	Baetis bicaudatus	1	28.216	40.226
GAR109	7/25/2011	16	Antocha sp.	2	27.831	46.835
GAR109	7/25/2011	16	Oligochaete (class C)	1	24.250	33.002
GAR109	7/25/2011	16	Drunella coloradensis/flavilinea	1	23.163	35.810
GAR109	7/25/2011	16	Drunella doddsii	2	22.966	40.153
GAR109	7/25/2011	16	Rhyacophila betteni gr.	1	22.820	39.497
GAR109	7/25/2011	16	Baetis tricaudatus	1	17.618	24.771
GAR109	7/25/2011	16	Epeorus longimanus	2	16.332	24.897
GAR109	7/25/2011	16	Hydropsychidae	1	13.392	22.797
GAR109	7/25/2011	16	Rhithrogena sp.	2	13.182	21.224
GAR109	7/25/2011	16	Zapada oregonensis gr.	1	10.558	14.959
GAR109	7/25/2011	16	Brachycentrus americanus	1	9.995	15.742
GAR109	7/25/2011	16	Acentrella insignificans	1	8.072	10.837
GAR109	7/25/2011	16	Optioservus sp.	2	7.211	10.578
GAR109	7/25/2011	16	Rhyacophila vagrita gr.	2	6.874	10.340
GAR109	7/25/2011	16	Atherix sp.	2	6.105	9.263
GAR109	7/25/2011	16	Chloroperlidae	1	5.629	8.142

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	7/25/2011	16	Cinygmula sp.	1	5.507	8.111
GAR109	7/25/2011	16	Hexatoma sp.	1	4.558	7.574
GAR109	7/25/2011	16	Acentrella sp.	1	4.119	5.314
GAR109	7/25/2011	16	Acentrella turbida	1	3.514	4.451
GAR109	7/25/2011	16	Oligophlebodes sp.	1	3.482	5.055
GAR109	7/25/2011	16	Pteronarcys sp.	1	3.323	5.035
GAR109	7/25/2011	16	Sweltsa sp.	1	3.212	4.258
GAR109	7/25/2011	16	Uenoidae	1	2.815	4.392
GAR109	7/25/2011	16	Diphetor hageni	1	2.684	3.680
GAR109	7/25/2011	16	Ephemerella dorothea/excrucians	1	2.512	3.895
GAR109	7/25/2011	16	Drunella grandis	1	2.240	2.805
GAR109	7/25/2011	16	Bezzia/Palpomyia sp.	1	2.199	3.255
GAR109	7/25/2011	16	Ameletus sp.	1	2.179	3.043
GAR109	7/25/2011	16	Narpus sp.	1	1.960	2.852
GAR109	7/25/2011	16	Hesperoperla pacifica	1	1.898	2.767
GAR109	7/25/2011	16	Dicranota sp.	1	1.873	2.857
GAR109	7/25/2011	16	Rhyacophila pellisa/valuma	2	1.607	2.418
GAR109	7/25/2011	16	Rhyacophila brunnea gr.	1	1.402	2.104
GAR109	7/25/2011	16	Prosimulium sp.	1	1.330	1.991
GAR109	7/25/2011	16	Trichoclinocera sp.	1	1.260	1.874
GAR109	7/25/2011	16	Visoka cataractae	1	1.008	1.397
GAR109	7/25/2011	16	Epeorus sp.	1	0.891	1.181
GAR109	7/25/2011	16	Cleptelmis addenda	1	0.678	0.978
GAR109	7/25/2011	16	Simulium sp.	1	0.678	0.949
GAR109	7/25/2011	16	Rhyacophila sp.	1	0.669	0.893
GAR109	7/25/2011	16	Epeorus grandis/permagnus	1	0.637	0.816
GAR109	7/25/2011	16	Leptophlebiidae	1	0.512	0.699
GAR109	7/25/2011	16	Empididae	1	0.225	0.304
GAR109	7/25/2011	16	Micrasema sp.	1	0.198	0.264
GAR109	7/25/2011	16	Cryptochia sp.	1	0.173	0.249
GAR109	7/25/2011	16	Yoraperla sp.	1	0.166	0.221
GAR109	7/25/2011	16	Zapada columbiana	1	0.118	0.159
GAR109	7/25/2011	16	Clinocera sp.	1	0.108	0.128
GAR109	7/25/2011	16	Perlidae	1	0.100	0.127
GAR109	7/25/2011	16	Ephemerella sp.	1	0.082	0.100
GAR109	7/25/2011	16	Caudatella sp.	1	0.075	0.093
GAR109	8/10/2011	19	Claassenia sabulosa	1	92.658	134.732
GAR109	8/10/2011	19	Parapsyche elsis	1	37.711	53.432
GAR109	8/10/2011	19	Oligochaete (class C)	1	26.586	28.248
GAR109	8/10/2011	19	Chironomidae	2	20.363	20.340

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	8/10/2011	19	Acentrella insignificans	1	15.770	16.538
GAR109	8/10/2011	19	Baetis tricaudatus	1	14.276	14.477
GAR109	8/10/2011	19	Brachycentrus americanus	1	10.826	15.088
GAR109	8/10/2011	19	Sweltsa sp.	1	10.609	11.035
GAR109	8/10/2011	19	Psychoglypha sp.	1	9.677	12.604
GAR109	8/10/2011	19	Rhithrogena sp.	1	9.473	9.784
GAR109	8/10/2011	19	Serratella tibialis	2	7.455	8.736
GAR109	8/10/2011	19	Hexatoma sp.	1	6.913	8.687
GAR109	8/10/2011	19	Optioservus sp.	2	6.366	7.175
GAR109	8/10/2011	19	Acentrella turbida	1	6.145	6.465
GAR109	8/10/2011	19	Epeorus deceptivus/hesperus	1	4.537	2.232
GAR109	8/10/2011	19	Antocha sp.	1	4.194	5.011
GAR109	8/10/2011	19	Epeorus longimanus	1	4.086	4.521
GAR109	8/10/2011	19	Drunella doddsii	1	3.796	3.800
GAR109	8/10/2011	19	Drunella grandis	1	3.726	3.777
GAR109	8/10/2011	19	Rhyacophila vagrita gr.	2	3.605	4.315
GAR109	8/10/2011	19	Atherix sp.	1	3.342	3.663
GAR109	8/10/2011	19	Neothremma sp.	2	2.739	3.513
GAR109	8/10/2011	19	Baetis flavistriga	1	2.565	2.627
GAR109	8/10/2011	19	Cinygmula sp.	1	2.210	2.511
GAR109	8/10/2011	19	Paraleptophlebia sp.	1	2.181	2.307
GAR109	8/10/2011	19	Ameletus sp.	1	2.000	2.128
GAR109	8/10/2011	19	Baetis bicaudatus	1	1.644	1.719
GAR109	8/10/2011	19	Narpus sp.	1	1.494	1.672
GAR109	8/10/2011	19	Chloroperlidae	1	1.286	1.427
GAR109	8/10/2011	19	Rhabdomastix fascigera gr.	1	1.210	1.492
GAR109	8/10/2011	19	Drunella coloradensis/flavilinea	1	1.134	1.393
GAR109	8/10/2011	19	Simulium sp.	1	1.019	1.025
GAR109	8/10/2011	19	Zapada oregonensis gr.	1	0.920	1.061
GAR109	8/10/2011	19	Baetis sp.	1	0.836	0.840
GAR109	8/10/2011	19	Zapada sp.	1	0.753	0.818
GAR109	8/10/2011	19	Perlodidae	1	0.558	0.558
GAR109	8/10/2011	19	Suwallia sp.	1	0.554	0.629
GAR109	8/10/2011	19	Oligochaete (class B)	1	0.505	0.594
GAR109	8/10/2011	19	Hesperoperla pacifica	1	0.498	0.317
GAR109	8/10/2011	19	Diphetor hageni	2	0.351	0.506
GAR109	8/10/2011	19	Epeorus albertae	1	0.342	0.378
GAR109	8/10/2011	19	Paraleuctra sp.	1	0.174	0.192
GAR109	8/10/2011	19	Rhyacophila betteni gr.	1	0.110	0.119
GAR109	8/10/2011	19	Trichoclinocera sp.	1	0.102	0.093
GAR109	8/10/2011	19	Glossosoma sp.	1	0.076	0.080

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	8/10/2011	19	Epeorus grandis/permagnus	2	0.055	0.055
GAR109	8/10/2011	19	Caudatella sp.	1	0.050	0.046
GAR109	8/10/2011	19	Zaitzevia sp.	1	0.046	0.047
GAR109	8/10/2011	19	Taeniopterygidae	1	0.000	0.000
GAR109	8/29/2011	35	Pteronarcys californica	1	233.959	233.103
GAR109	8/29/2011	35	Arctopsyche grandis	2	100.945	80.459
GAR109	8/29/2011	35	Oligochaete (class C)	1	52.629	37.239
GAR109	8/29/2011	35	Rhithrogena sp.	1	44.229	30.567
GAR109	8/29/2011	35	Hexatoma sp.	1	33.951	28.425
GAR109	8/29/2011	35	Sweltsa sp.	1	32.918	23.117
GAR109	8/29/2011	35	Baetis tricaudatus	1	27.367	19.125
GAR109	8/29/2011	35	Chironomidae	2	27.090	18.013
GAR109	8/29/2011	35	Brachycentrus americanus	1	22.384	19.065
GAR109	8/29/2011	35	Parapsyche elsis	1	16.352	12.222
GAR109	8/29/2011	35	Serratella tibialis	2	15.034	11.879
GAR109	8/29/2011	35	Drunella doddsii	1	9.552	7.328
GAR109	8/29/2011	35	Optioservus sp.	2	9.001	6.629
GAR109	8/29/2011	35	Acentrella insignificans	1	8.874	6.246
GAR109	8/29/2011	35	Drunella grandis	1	7.893	5.042
GAR109	8/29/2011	35	Acentrella turbida	1	5.611	3.869
GAR109	8/29/2011	35	Zapada columbiana	1	5.460	3.857
GAR109	8/29/2011	35	Paraleptophlebia sp.	1	4.592	3.093
GAR109	8/29/2011	35	Epeorus longimanus	1	4.455	3.366
GAR109	8/29/2011	35	Cinygmula sp.	2	4.230	3.098
GAR109	8/29/2011	35	Antocha sp.	1	3.432	2.820
GAR109	8/29/2011	35	Atherix sp.	1	2.411	1.690
GAR109	8/29/2011	35	Sericostriata surdickae	1	2.135	1.718
GAR109	8/29/2011	35	Epeorus deceptivus/hesperus	2	2.024	1.518
GAR109	8/29/2011	35	Ameletus sp.	1	1.819	1.267
GAR109	8/29/2011	35	Baetis flavistriga	1	1.666	1.196
GAR109	8/29/2011	35	Skwala sp.	1	1.427	0.966
GAR109	8/29/2011	35	Simulium sp.	1	1.300	0.929
GAR109	8/29/2011	35	Zapada oregonensis gr.	1	0.871	0.645
GAR109	8/29/2011	35	Hesperoperla pacifica	1	0.760	0.526
GAR109	8/29/2011	35	Perlodidae	1	0.615	0.414
GAR109	8/29/2011	35	Epeorus sp.	1	0.540	0.390
GAR109	8/29/2011	35	Rhyacophila pellisa/valuma	1	0.481	0.342
GAR109	8/29/2011	35	Rhyacophila vagrita gr.	1	0.430	0.320
GAR109	8/29/2011	35	Diphetor hageni	1	0.342	0.252
GAR109	8/29/2011	35	Ephemerella sp.	1	0.280	0.180
GAR109	8/29/2011	35	Rhyacophila brunnea gr.	1	0.252	0.182

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	8/29/2011	35	Perlidae	1	0.122	0.080
GAR109	8/29/2011	35	Deuterophlebia sp.	1	0.115	0.080
GAR109	8/29/2011	35	Drunella spinifera	1	0.042	0.027
GAR109	8/29/2011	35	Clinocera sp.	1	0.020	0.012
GAR109	10/3/2011	NA	Acentrella insignificans	1	0.000	0.412
GAR109	10/3/2011	NA	Acentrella turbida	1	0.000	1.564
GAR109	10/3/2011	NA	Agraylea sp.	1	0.000	0.698
GAR109	10/3/2011	NA	Ameletus sp.	1	0.000	0.974
GAR109	10/3/2011	NA	Antocha sp.	1	0.000	0.283
GAR109	10/3/2011	NA	Arctopsyche grandis	2	0.000	69.398
GAR109	10/3/2011	NA	Atherix sp.	1	0.000	0.598
GAR109	10/3/2011	NA	Baetis tricaudatus	1	0.000	5.056
GAR109	10/3/2011	NA	Brachycentrus americanus	2	0.000	41.212
GAR109	10/3/2011	NA	Capniidae	1	0.000	0.501
GAR109	10/3/2011	NA	Chironomidae	2	0.000	14.507
GAR109	10/3/2011	NA	Cinygmula sp.	1	0.000	0.866
GAR109	10/3/2011	NA	Claassenia sabulosa	1	0.000	33.210
GAR109	10/3/2011	NA	Cleptelmis addenda	1	0.000	0.118
GAR109	10/3/2011	NA	Dicranota sp.	1	0.000	0.959
GAR109	10/3/2011	NA	Drunella doddsii	1	0.000	3.819
GAR109	10/3/2011	NA	Drunella grandis	1	0.000	3.510
GAR109	10/3/2011	NA	Empididae	1	0.000	0.062
GAR109	10/3/2011	NA	Ephemerella dorothea/excrucians	1	0.000	3.101
GAR109	10/3/2011	NA	Glossosomatidae	1	0.000	0.064
GAR109	10/3/2011	NA	Hesperoconopa sp.	1	0.000	0.580
GAR109	10/3/2011	NA	Hesperoperla pacifica	1	0.000	0.344
GAR109	10/3/2011	NA	Hexatoma sp.	2	0.000	32.313
GAR109	10/3/2011	NA	Neoplasta sp.	1	0.000	0.006
GAR109	10/3/2011	NA	Ochrotrichia sp.	1	0.000	0.175
GAR109	10/3/2011	NA	Oligochaete (class C)	1	0.000	31.552
GAR109	10/3/2011	NA	Optioservus sp.	2	0.000	4.791
GAR109	10/3/2011	NA	Paraleptophlebia sp.	1	0.000	2.351
GAR109	10/3/2011	NA	Perlidae	1	0.000	0.041
GAR109	10/3/2011	NA	Pteronarcys californica	1	0.000	136.276
GAR109	10/3/2011	NA	Rhithrogena sp.	1	0.000	23.402
GAR109	10/3/2011	NA	Rhyacophila pellisa/valuma	1	0.000	0.205
GAR109	10/3/2011	NA	Sericostriata surdickae	1	0.000	0.732
GAR109	10/3/2011	NA	Serratella tibialis	1	0.000	9.893
GAR109	10/3/2011	NA	Skwala sp.	1	0.000	0.836
GAR109	10/3/2011	NA	Sweltsa sp.	1	0.000	14.176

Site	Sampling (Interval Start) Date	Interval Length (days)	Taxon	# of Cohorts	Interval Production (mg)	Mean Biomass
GAR109	10/3/2011	NA	Taeniopterygidae	1	0.000	0.083
GAR109	10/3/2011	NA	Zapada cinctipes	1	0.000	0.378
GAR109	10/3/2011	NA	Zapada columbiana	1	0.000	3.565

APPENDIX E
GENERAL LOCATION, SPECIES, AND NUMBER CAPTURED DURING THE STUDY

Species captured by location during the study.
Tables include total counts from all years and all gear types used in the study.

Table 1. Number of fish by species captured in the tributaries upstream from Deadwood Reservoir.

Deadwood Above Dam Tributaries Electroshocking- Summary		
Species	**Total Count**	**%**
Bull Trout (*Salvelinus confluentus*)	81	9.35
Cutthroat Trout (*Oncorhynchus clarki lewisi*)	620	71.59
Rainbow Trout (*Oncorhynchus mykiss*)	41	4.73
Dace *Rhinichthys spps.*	29	3.35
Sculpin *Cottus spps.*	86	9.93
Mountain Whitefish (*Prosopium williamsoni*)	9	1.04
Total	**866**	100.00

Table 2. Number of fish by species captured in Deadwood Reservoir.

Deadwood Reservoir Total- Summary		
Species	**Total Count**	**%**
Bull Trout (*Salvelinus confluentus*)	104	2.10
Cutthroat Trout (*Oncorhynchus clarki lewisi*)	474	9.46
Cutthroat/Rainbow hybrid	35	0.70
Rainbow Trout (*Oncorhynchus mykiss*)	493	9.84
Redside Shiner (*Richardsonius balteatus)*	153	3.06
Sculpin *Cottus spps.*	46	0.92
Dace *Rhinichthys spps.*	1900	37.94
Kokanee (Oncorhynchus nerka)	247	4.93
Mountain Whitefish (*Prosopium williamsoni*)	1555	31.05
Total	**5008**	100.00

Table 3. Number of fish by species captured in the stilling basin at Deadwood Dam.

Stilling Basin Total- Summary		
Species	**Total Count**	**%**
Bull Trout (*Salvelinus confluentus*)	43	3.12
Cutthroat Trout (*Oncorhynchus clarki lewisi*)	4	0.29
Cutthroat/Rainbow hybrid	2	0.15
Rainbow Trout (*Oncorhynchus mykiss*)	519	37.66
Redside Shiner (*Richardsonius balteatus)*	15	1.09
Sculpin *Cottus spps.*	22	1.60
Dace *Rhinichthys spps.*	693	50.29
Kokanee (Oncorhynchus nerka)	13	0.94
Mountain Whitefish (*Prosopium williamsoni*)	67	4.86
Total	**1378**	100.00

Table 4. Number of fish by species captured in the mainstem Deadwood River downstream from Deadwood Dam.

Mainstem Below Dam Total- Summary		
Species	**Total Count**	**%**
Bull Trout (*Salvelinus confluentus*)	0	0.00
Cutthroat Trout (*Oncorhynchus clarki lewisi*)	0	0.00
Cutthroat/Rainbow hybrid	0	0.00
Rainbow Trout (*Oncorhynchus mykiss*)	238	36.96
Redside Shiner (*Richardsonius balteatus)*	0	0.00
Sculpin *Cottus spps.*	274	42.55
Dace *Rhinichthys spps.*	70	10.87
Kokanee (Oncorhynchus nerka)	46	7.14
Mountain Whitefish (*Prosopium williamsoni*)	16	2.48
Total	**644**	100.00

Table 5. Number of fish by species captured in tributaries to the Deadwood River downstream from Deadwood Dam.

Deadwood Below Dam Tributaries Electroshocking- Summary		
Species	**Total Count**	**%**
Bull Trout (*Salvelinus confluentus*)	177	38.23
Cutthroat Trout (*Oncorhynchus clarki lewisi*)		0.00
Rainbow Trout (*Oncorhynchus mykiss*)	279	60.26
Dace *Rhinichthys spps.*	7	1.51
Sculpin *Cottus spps.*		0.00
Mountain Whitefish (*Prosopium williamsoni*)		0.00
Total	**463**	100.00

APPENDIX F
COMPARISON OF MIKE 11 MODEL TO WATER TEMPERATURES MEASURED NOVEMBER 2013 TO SEPTEMBER 2014

Water temperatures measured during 2013/2014 are compared to the predicted water temperatures for an average water year with 2.3 cfs post-irrigation stream flow and fast ramping rate using the MIKE 11 model from this study (see Chapter 3) (Figures 3-18 to 3-31). The model was better at predicting temperatures at the upper site (downstream from the dam) than at the lower site near the mouth. Model error increased at the lower (downstream) site likely from various tributary inflows and cumulative unmeasured effects (see Chapter 3.1). Generally, the measured temperatures in 2013/2014 follow the predicted temperatures at the two locations in the Deadwood River downstream from the dam and were reasonably close (within 2 ^{o}C) to the measured data for the first half of the 2014 water year. Differences between the measured and predicted temperatures increase to $\geq$ 4 ^{o}C during the spring/summer spill (June 2014) and during September 2014. Climatic conditions and resulting operations are not identical across years and the model data were not derived to make future (out-year) predictions. Water surpluses or deficits will accumulate in the reservoir depending on variable operations and climatic conditions across the years. Therefore, differences between the predicted and the measured stream temperatures are expected to be greatest as the year progresses from a general starting reference reservoir elevation. The measured data from September 2014 are between the predicted temperatures for the average and wet climatic conditions (Figure 3-18).

Water year conditions in 2014 are average. Yet, the measured data follow predicted average conditions and then diverge to follow wet conditions based on reservoir content (Figure 1 and Figure 3). Specifically, the post-irrigation operation follows the average water year as operations during the wet water year includes wintertime spill which did not occur in 2013/2014. Spill occurred during the spring/early summer which would add warmer surface water to the river downstream. Interestingly, the September 2014 temperatures lie in between the wet and average water year due to end of season reservoir content in between the wet and average water year conditions.

The differences between the measured and predicted temperatures were within 2 ^{o}C for most of the dates examined at the upper site which would be a reasonable amount of expected error (Figure 3-19). Temperatures from late May to early July 2014 were noticeably warmer in the measured data than predicted. These higher than predicted temperatures coincide with the dates that water was being spilled over the dam which would contribute warmer surface water to the outflow from the dam. Error was also higher than expected during the fall where measured temperatures were about 4^{o}C colder than predicted. Variation in the climatic conditions and precipitation across years will create different reservoir conditions and water temperature conditions than predicted in the MIKE 11 model with the 2003 data. Specifically, the 2013 water year was 66% exceedence whereas the 2003 water year (representing average water year conditions) was 48% exceedence. The higher reservoir content in 2013 will result in different temperature profiles in the reservoir and the river downstream from the dam and this will create unmeasured differences when comparing the model predicted data for an average water year to future conditions.

The MIKE 11 model predictions are not expected to perfectly describe future measured data for several reasons. First, three water years ranging from dry (95% exceedence), average (48% exceedence) to wet (4% exceedence) conditions were characterized using this model. This approach characterizes two extremes with an average (middle) condition for the purposes of understanding the range of management and operations. Annual climatic conditions will vary from these three scenarios which will not provide identical climatic conditions during measurement in future years. Specifically, water year 2013 at 66% exceedence and 2014 at 53% exceedence were not identical to the modeled conditions. For comparison, the average water year (48% exceedence) was used as the closest to the 2013 and 2014 environmental conditions. Second, the model used 2009 as the year for model calibration. This water year was close to average (55% exceedence), so we would expect water year conditions close to average to have a better model fit than years in the more extreme climatic conditions. Additionally, the model held air temperature, relative humidity and hours of daylight constant across years to remove this variation from the measurements across the scenarios modeled in Chapter 3.1. This approach allowed the model predictions to isolate the effects of the variables of interest – streamflow and reservoir content. Because these values are held constant in the model, it is unlikely that they will exactly represent future year conditions. Therefore, considering these limitations in the model settings, a few degrees of error from measured data would be expected.

Model scenarios were developed for direct comparison of water operation options, and not for prediction of future conditions which would require running the scenario based on the actual climatic conditions from the time period when the measured data were collected (inflows, air temperatures, relative humidity, and sunshine hours). When we examined the water year operation differences, 2014 had higher amount of pre-irrigation water release which extended a longer period of time than in the modeled (average) year, 2003 (Figure 3-22). Spill is from the surface water which is warmer during the late spring and summer months due to residence time and solar warming. Therefore, in 2014 a greater amount of warmer water from spill was passed at the dam creating higher measured temperatures than predicted in the model conditions. The dates of these warmer temperatures coincide with the dates water was being spilled over the dam.

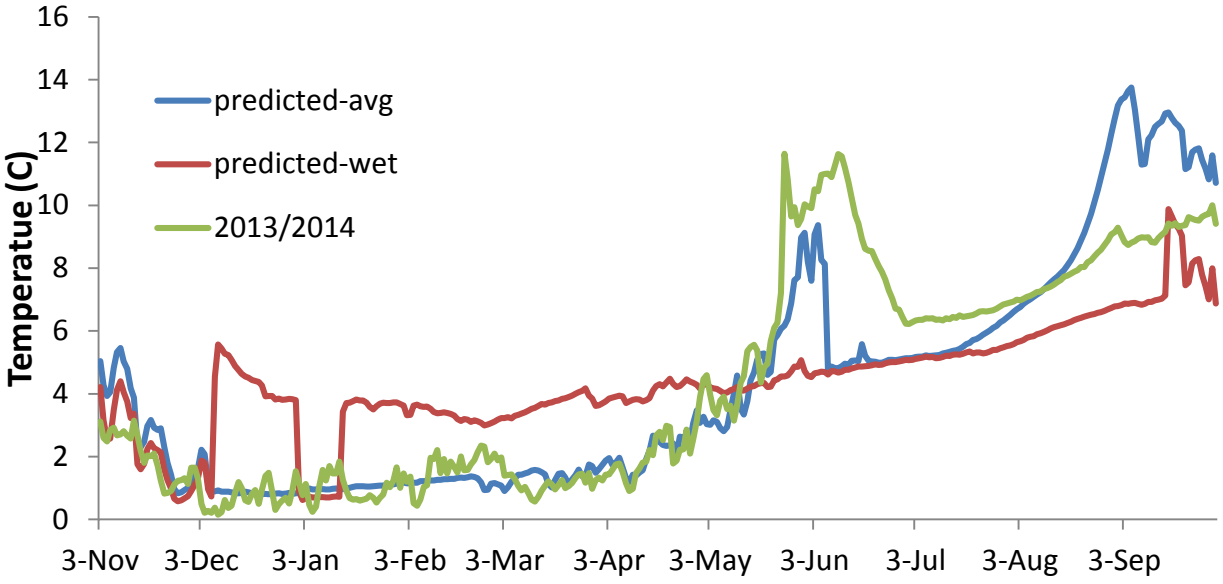


Figure 1. Comparison of water temperature data (C) collected during November 2013 to September 2014 to predicted water temperatures from the hydrologic model scenario for 2 cfs post-irrigation streamflow, average water year for the upper site, Deadwood River (below Wilson Creek).

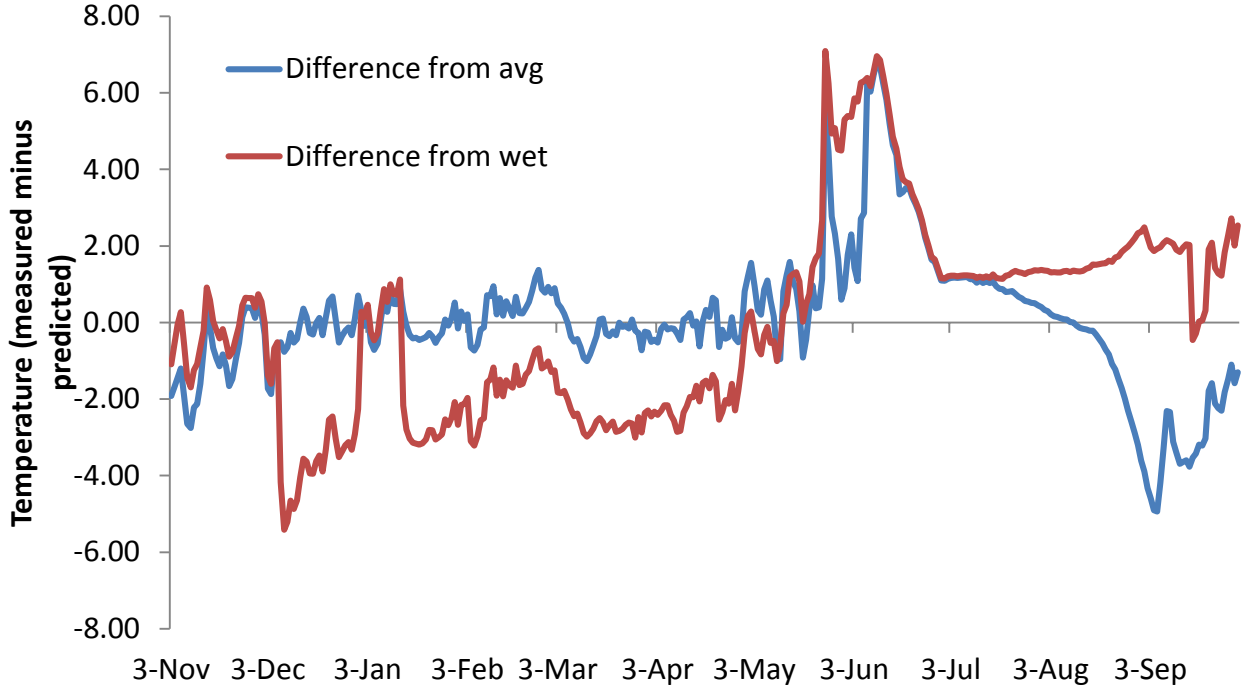


Figure 2. Difference between the measured stream temperature at the upper site in 2013/2014 (location 1) from the predicted temperature from the MIKE 11 model. Values below the x-axis are cooler than predicted by the model. Values above the x-axis are warmer than predicted by the model. Location 1 is measured downstream from Wilson Creek.

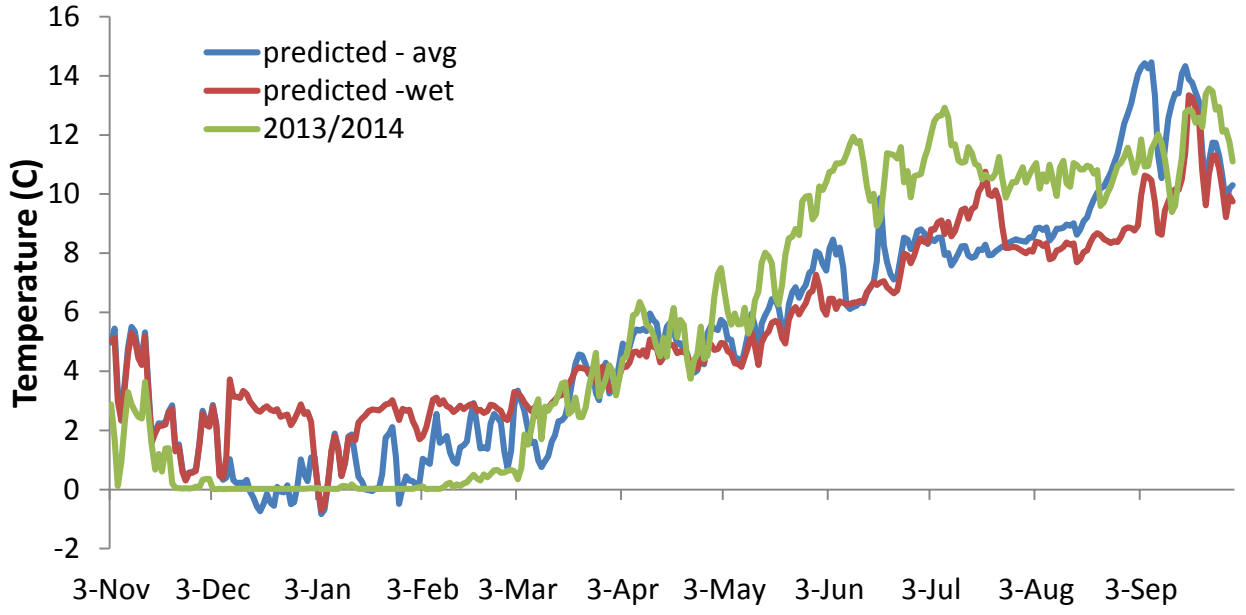


Figure 3. Comparison of water temperature data (C) collected during November 2013 to September 2014 to predicted water temperatures from the hydrologic model scenarios or 2 cfs post-irrigation streamflow, average water year for the lower site, Deadwood River (near the mouth).

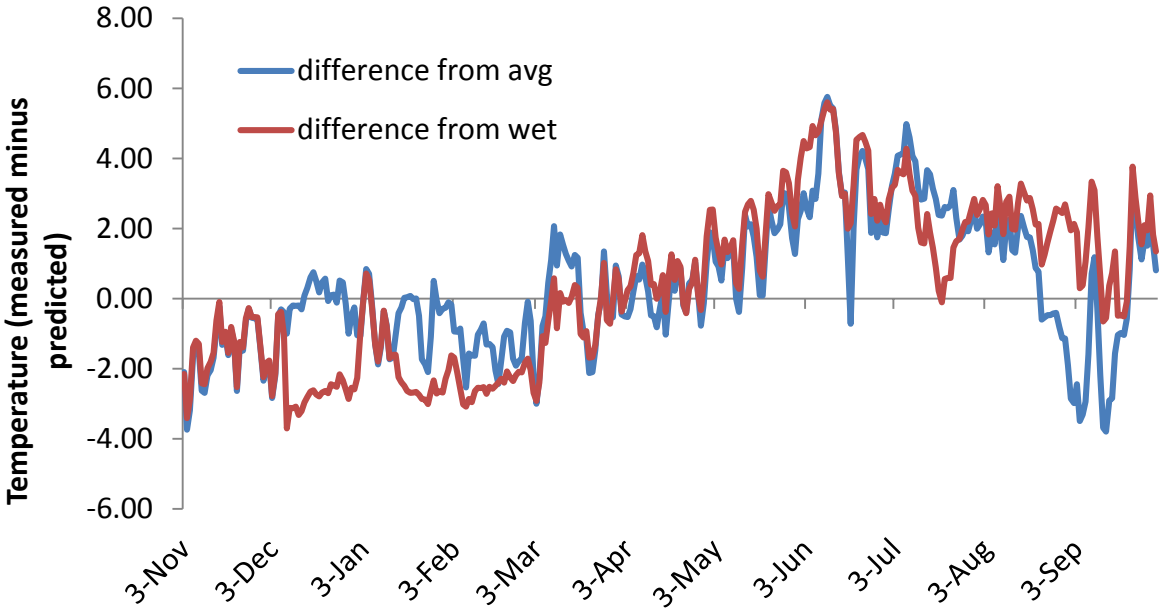


Figure 4. Difference between the measured stream temperature at the lower site (location 2) from the predicted temperature from the MIKE 11 model. Values below the x-axis are cooler than predicted by the model. Values above the x-axis are warmer than predicted by the model. Location 2 is near the mouth of the Deadwood River.

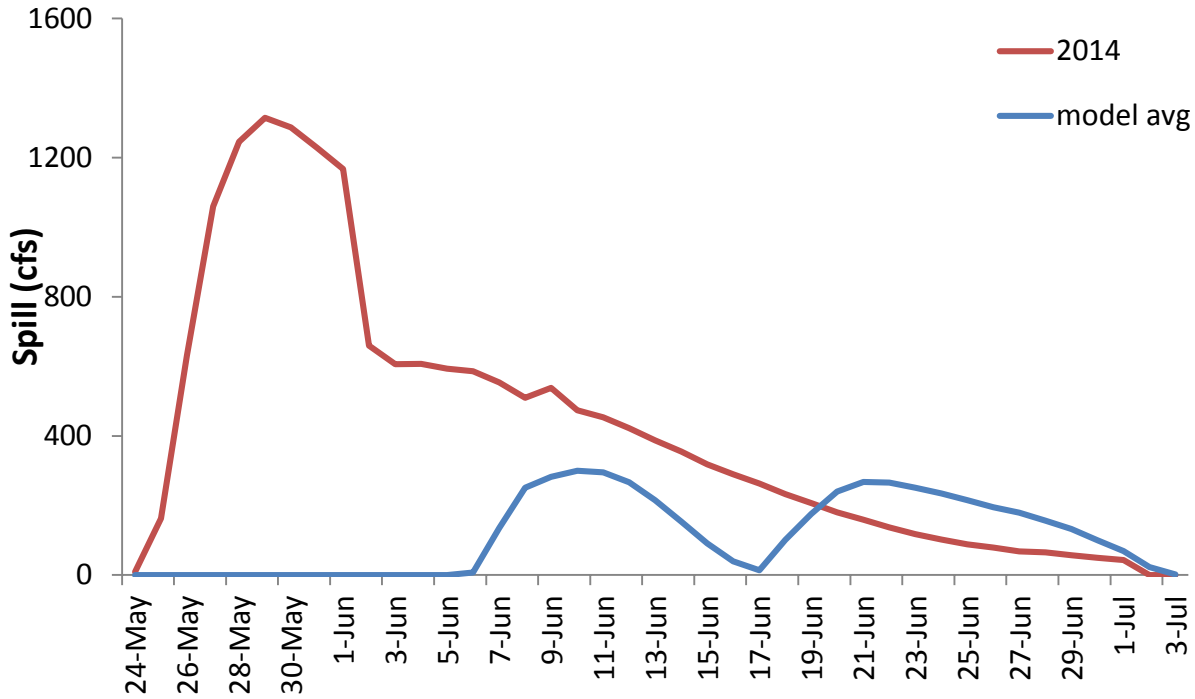


Figure 5. Daily average spill (cfs) over Deadwood Dam during the modeled (average) year (2003) and 2014.

APPENDIX G
WATER TEMPERATURE DATA,
DEADWOOD RIVER,
SEPTEMBER 2013 – AUGUST 2014

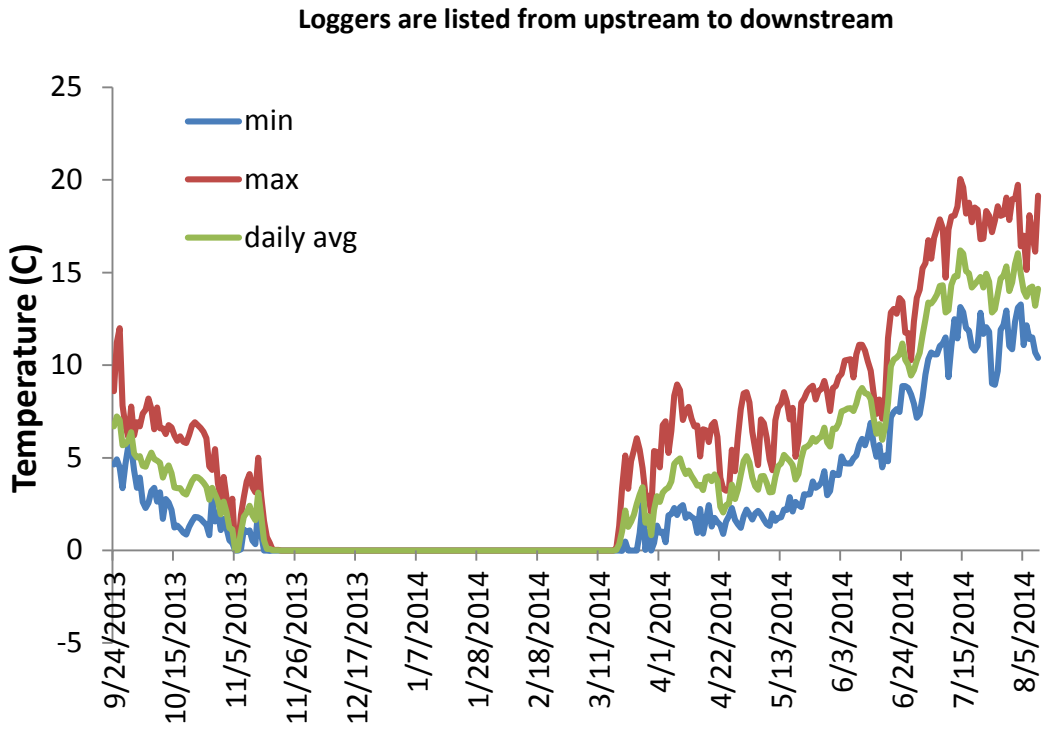


Figure 1. Deadwood River upstream from Deadwood Dam.

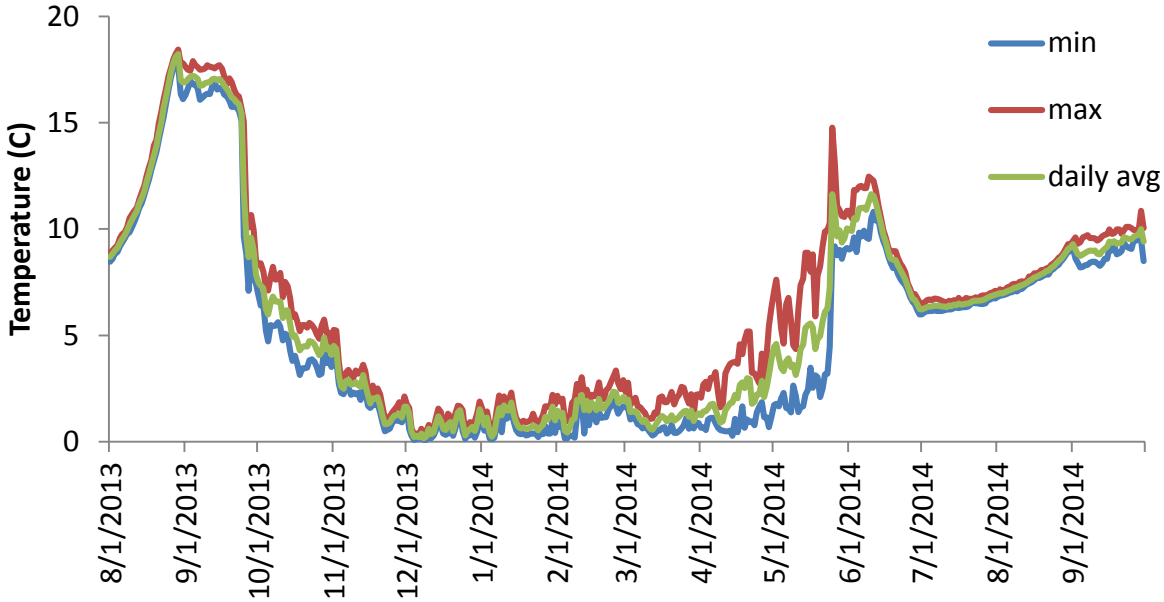


Figure 2. Deadwood River downstream from Wilson Creek.

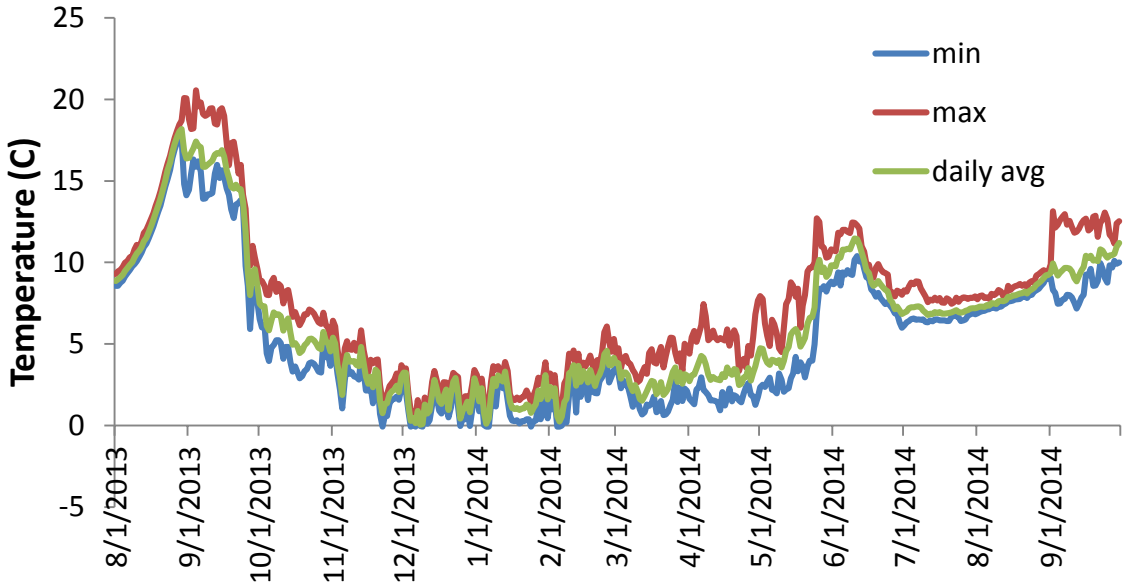


Figure 3. Deadwood River downstream from White Hawk Creek.

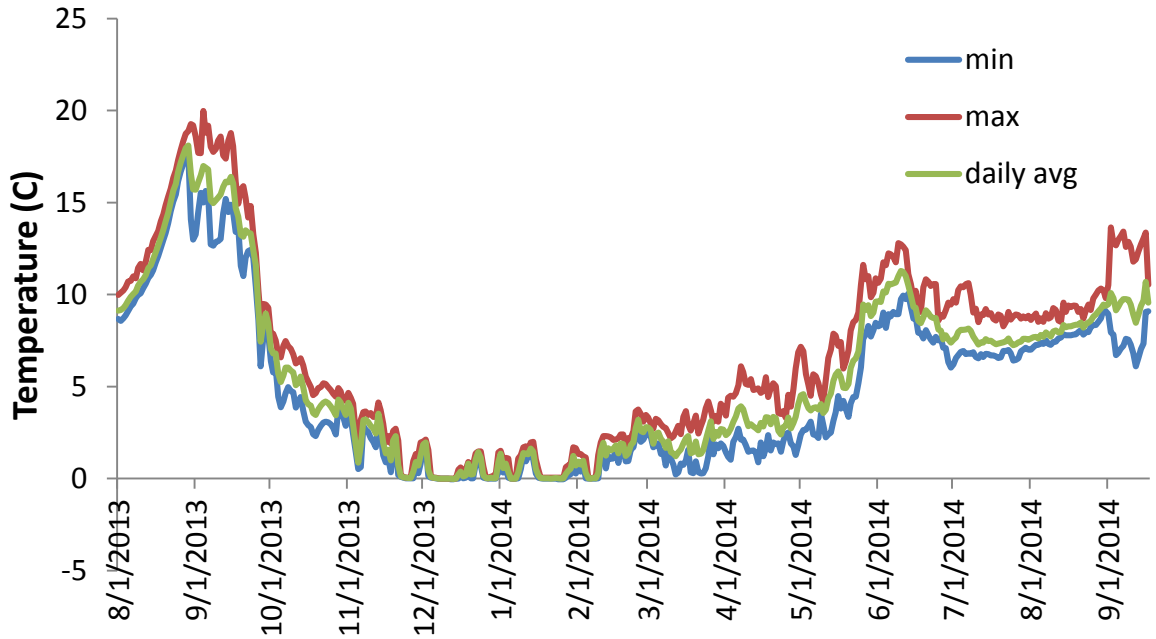


Figure 4. Deadwood River downstream of No Man Creek.

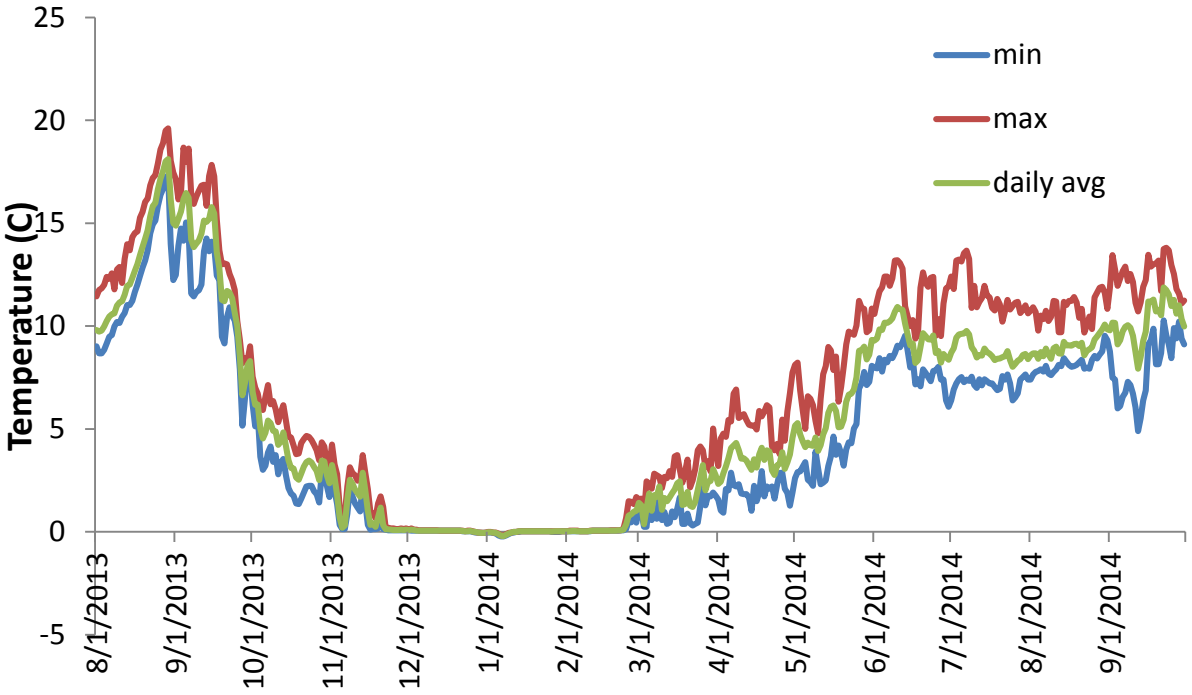


Figure 5. Deadwood River downstream from Lorenzo Creek.

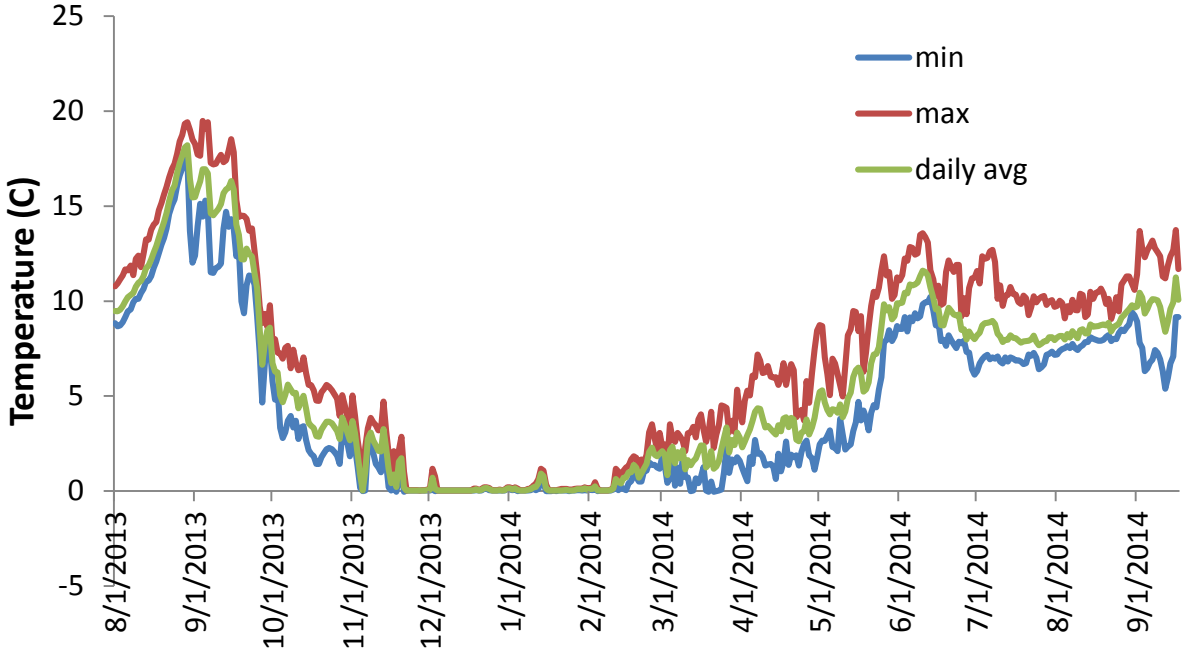


Figure 6. Deadwood River downstream from Scott Creek.

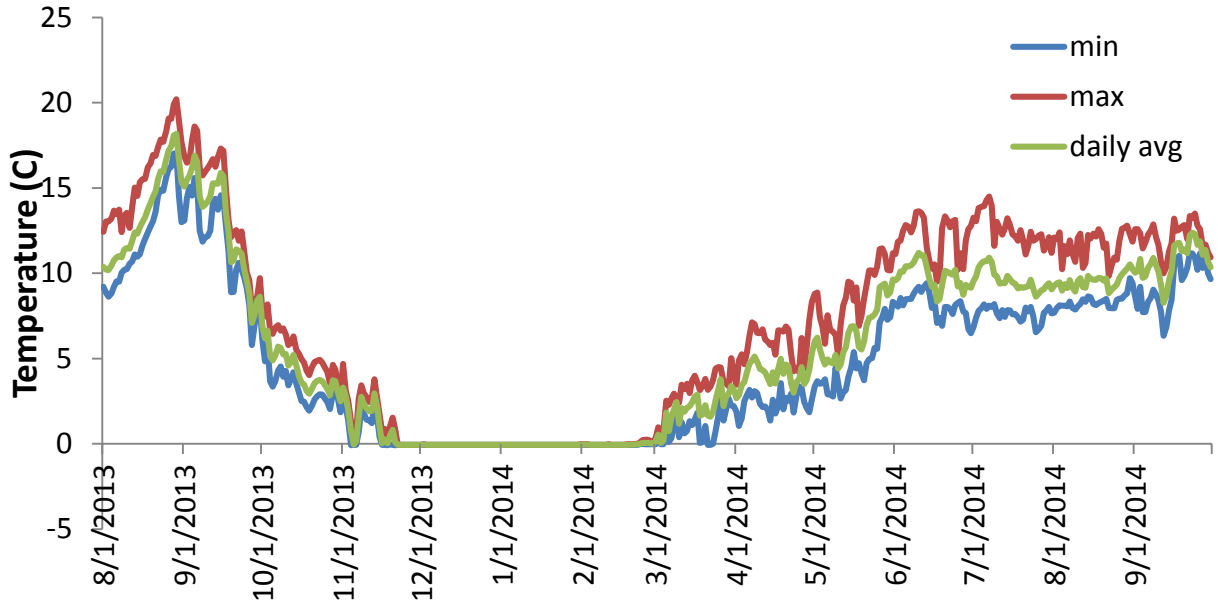


Figure 7. Deadwood River upstream from Julie Creek

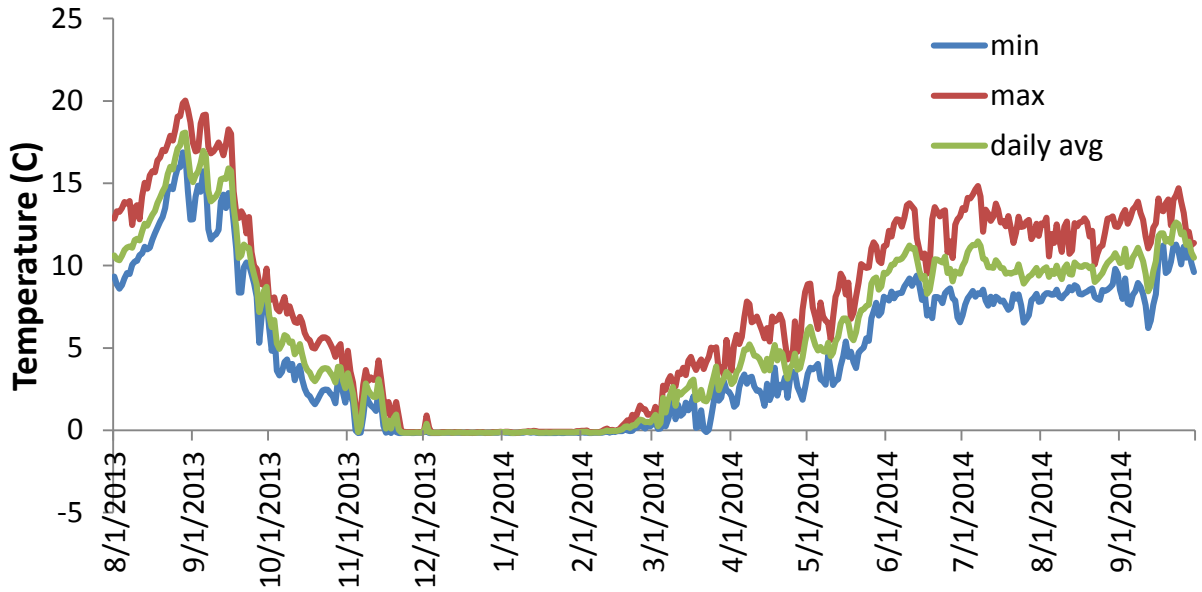


Figure 8. Deadwood River downstream from Stevens Creek.

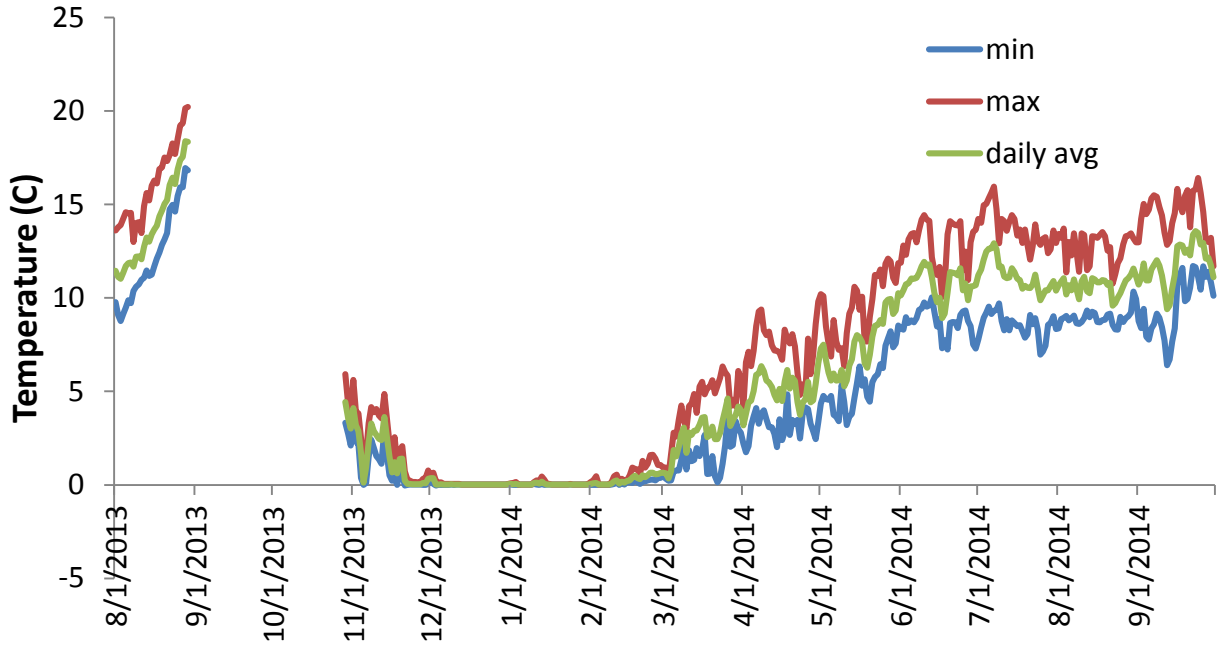


Figure 9. Deadwood River upstream from mouth.

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APPENDIX H
WATER TEMPERATURE DATA, TRIBUTARIES DEADWOOD BASIN, SEPTEMBER 2013 – AUGUST 2014

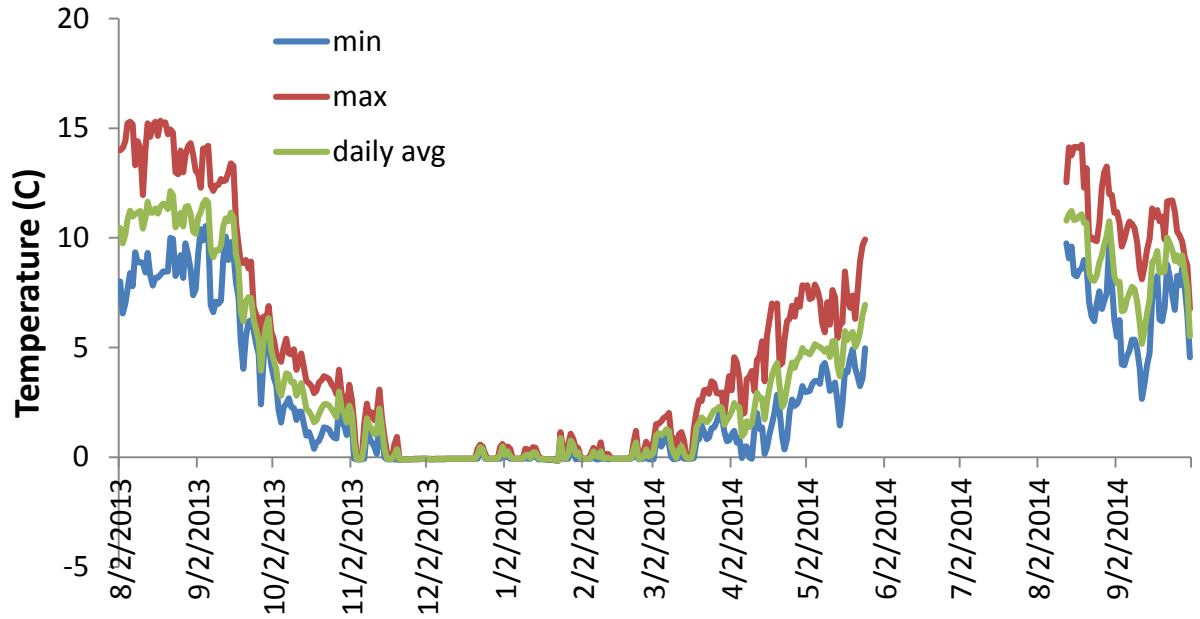


Figure 1. Trail Creek near Deadwood Reservoir.

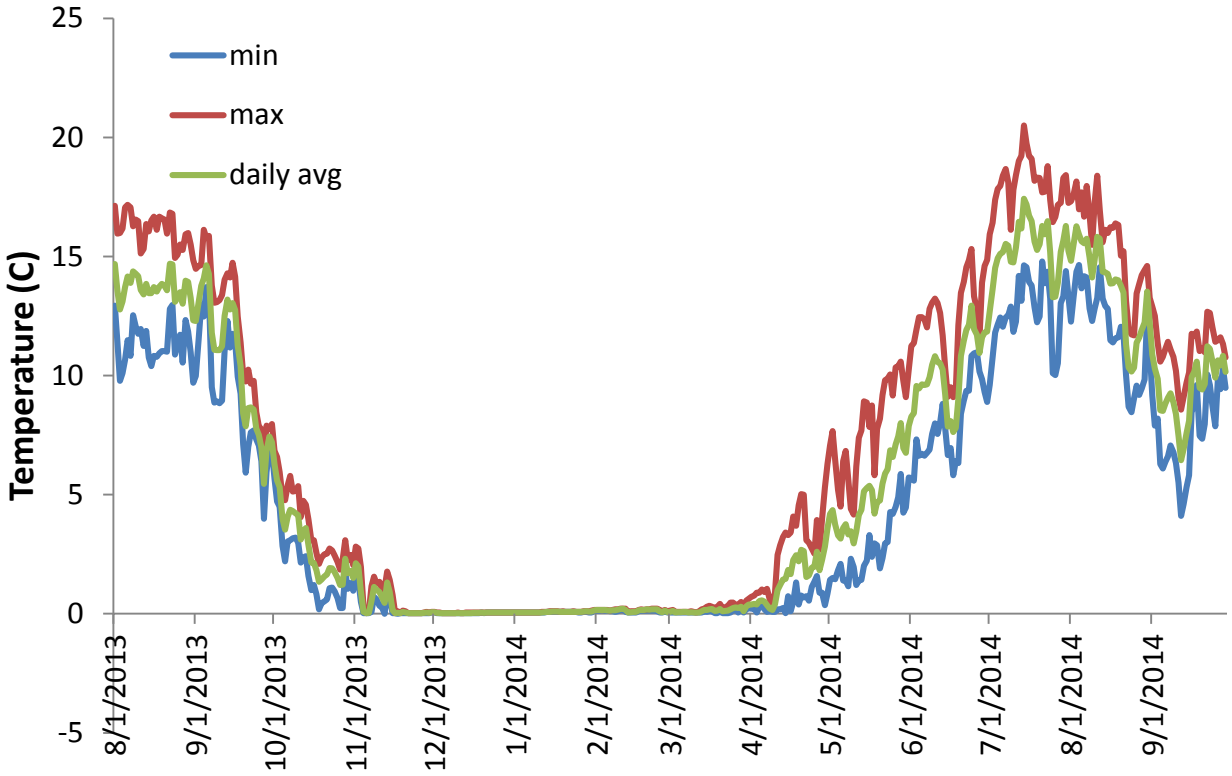


Figure 2. Wilson Creek near mouth.

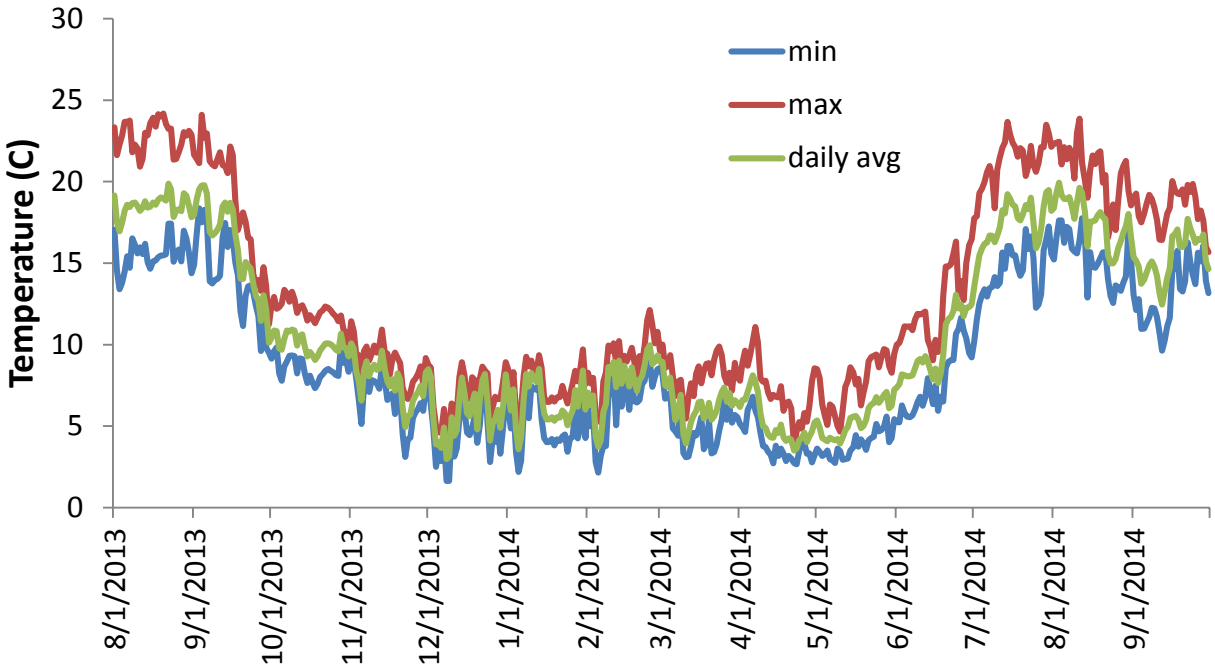


Figure 3. Warm Springs Creek near mouth.

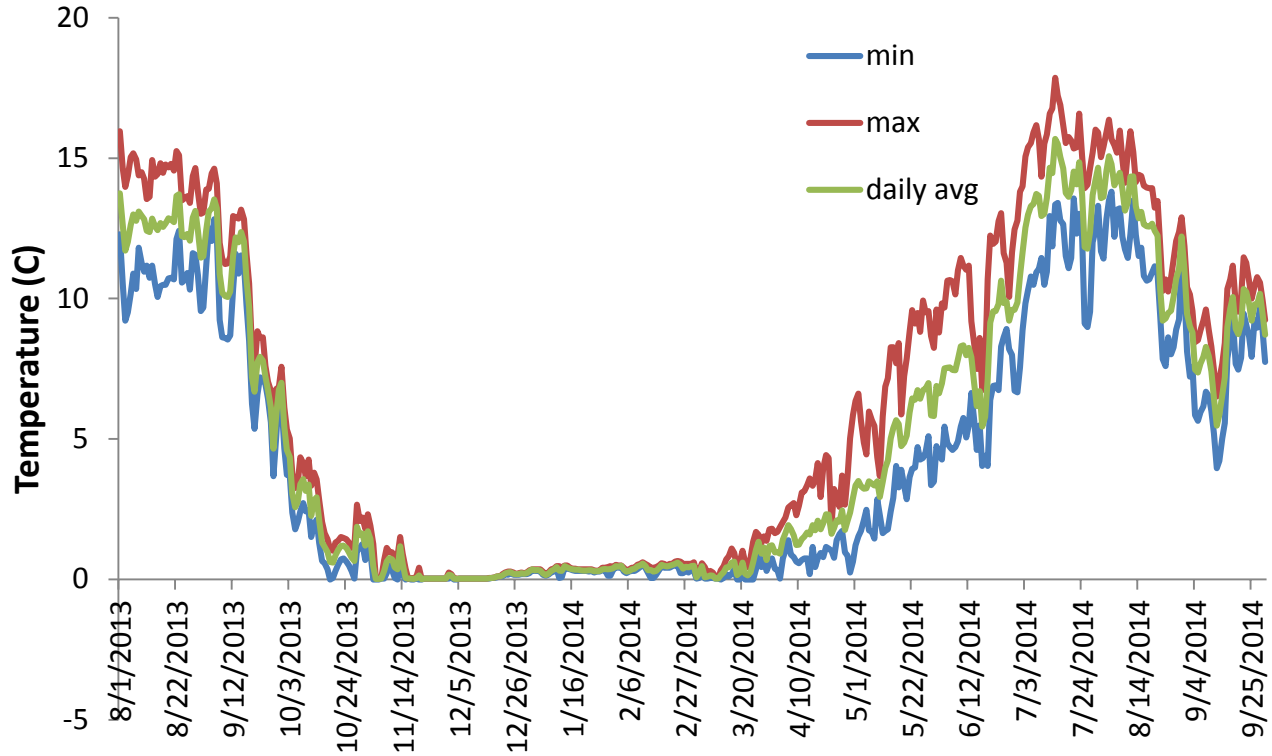


Figure 4. White Hawk Creek near mouth.

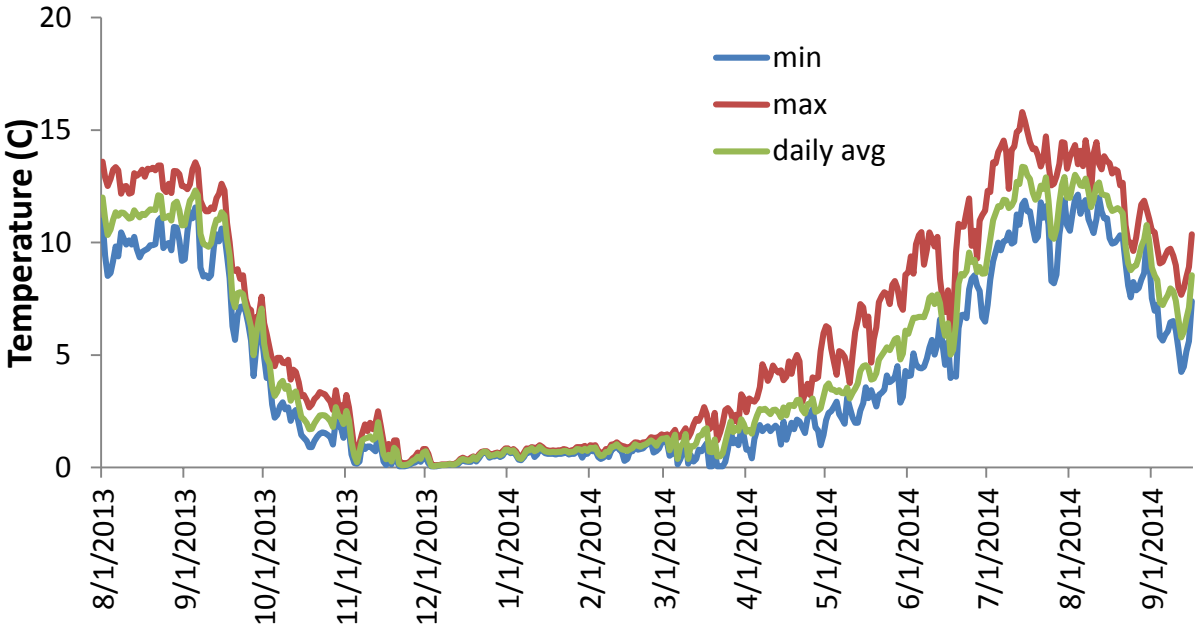


Figure 5. No Man Creek near mouth.

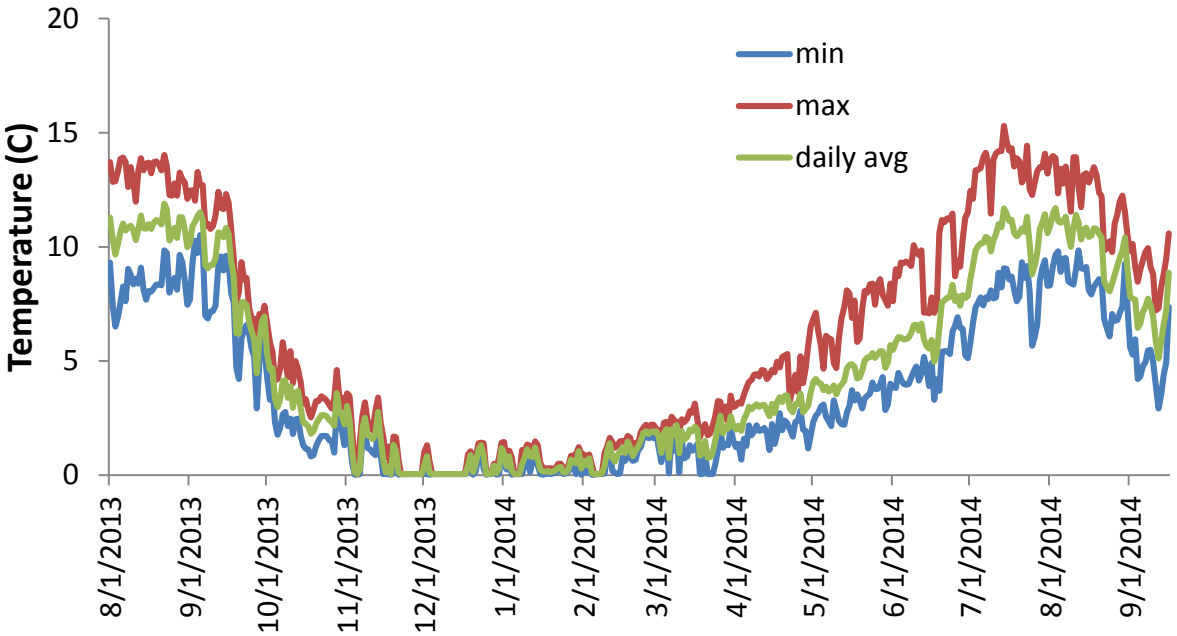


Figure 6. Scott Creek near mouth.

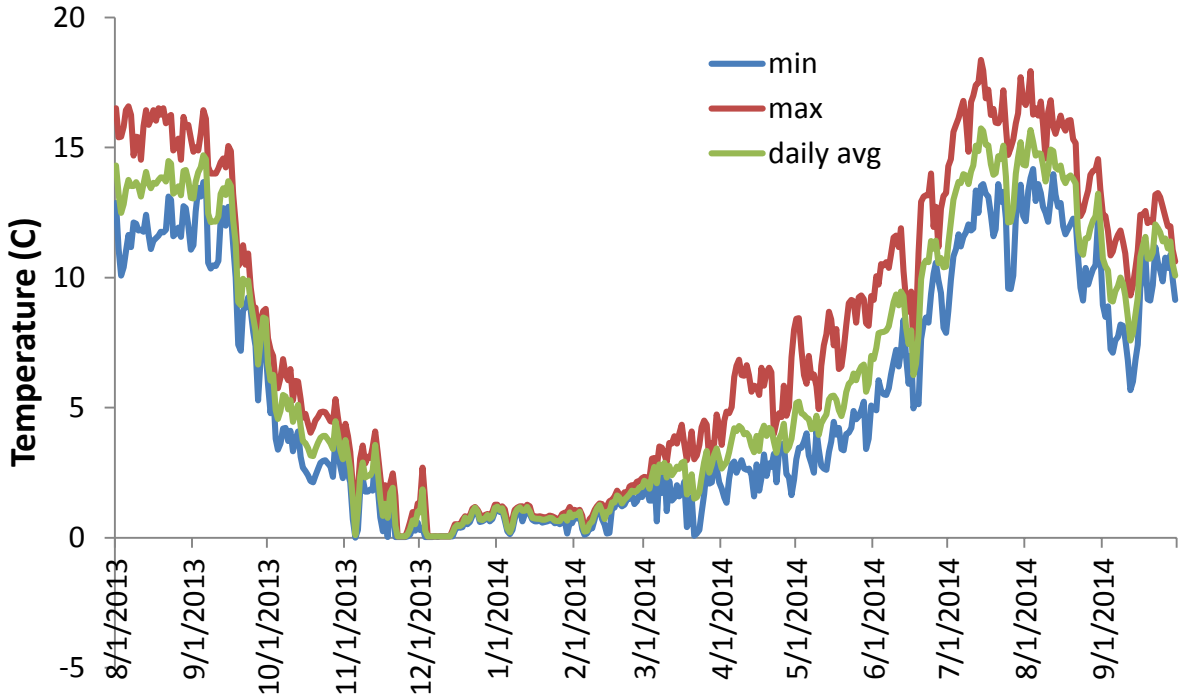


Figure 7. Stevens Creek near mouth.

APPENDIX I
WINTER ICE COVER PHOTOGRAPHS
(2013-2014)



Photograph 1. Game camera set up on the bank of the Deadwood River, October 2013.



Photograph 2. Deadwood River at the dam bridge looking downstream showing no ice cover, December 23, 2013.



Photograph 3. Deadwood River at the dam bridge looking downstream showing ice cover less than 50%, December 4, 2013.



Photograph 4. Deadwood River at the dam bridge looking downstream showing greater than 50% ice cover, December 6, 2013.



Photograph 5. Deadwood River at the Road 555 Bridge, no ice cover, January 12, 2014.



Photograph 6. Deadwood River at the Road 555 Bridge, less than 50% ice cover, December 9, 2013.



Photograph 7. Deadwood River downstream from Wilson Creek looking upstream, no ice cover, February 10, 2014.



Photograph 8. Deadwood River downstream from Wilson Creek looking upstream, less than 50% ice cover, December 13, 2013.



Photograph 9. Deadwood River downstream from Wilson Creek looking upstream, greater than 50% ice cover, December 6, 2013.



Photograph 10. Deadwood River near Lorenzo Creek looking upstream, less than 50% ice cover, February 27, 2014.



Photograph 11. Deadwood River near Lorenzo Creek looking upstream, greater than 50% ice cover, December 20, 2013.



Photograph 12. Deadwood River near Julie Creek, less than 50% ice cover, December 2, 2013. Note, the date stamp on the photo is incorrect.



Photograph 13. Deadwood River near Julie Creek, greater than 50% ice cover, December 13, 2013. Note the date stamp on the photo is incorrect.



Photograph 14. South Fork Payette near the Deadwood River, no ice cover, February 22, 2014.



Photograph 15. South Fork Payette near the Deadwood River, less than 50% ice cover, December 5, 2013.



Photograph 16. South Fork Payette near the Deadwood River, greater than 50% ice cover, January 8, 2014.



Photograph 17. Clear Creek tributary to the South Fork Payette River, less than 50% ice cover, December 3, 2013.



Photograph 18. Clear Creek tributary to the South Fork Payette River, greater than 50% ice cover, January 20, 2014.

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APPENDIX J
CONNECTIVITY SURVEY PHOTOGRAPHS

Photographs of shallow sites identified during connectivity survey are shown from upstream most to downstream.



Photograph 1. Site no. C1000 Deadwood River near Deadwood Dam looking downstream, September 2014. Maximum depth in the riffle habitat is 0.13 m with 2.3 cfs streamflow measured from dam.



Photograph 2. Site no. C0999 Deadwood River near Deadwood Dam looking downstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam.



Photograph 3. Site no. C0998 Deadwood River near Deadwood Dam looking upstream, September 2014. Maximum depth in the riffle habitat is 0.14 m with 2.3 cfs streamflow measured from dam. Deadwood Dam is visible in the background.



Photograph 4. Site no. C0997 Deadwood River near Deadwood Dam looking upstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam. Deadwood Dam is visible in the background.



Photograph 5. Site no. C0996 Deadwood River downstream from Deadwood Dam looking upstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam.



Photograph 6. Site no. C0995 Deadwood River downstream from Deadwood Dam looking downstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam. The Road 555 Bridge is visible in the background.



Photograph 7. Site no. C0994 Deadwood River downstream from Deadwood Dam looking downstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam. The Road 555 Bridge is visible in the background.



Photograph 8. Site no. C0993 Deadwood River downstream from Deadwood Dam looking upstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam.



Photograph 9. Site no. C0992 Deadwood River downstream from Deadwood Dam looking upstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam.



Photograph 10. Site no. C0902 Deadwood River downstream from Deadwood Dam between Warm Springs and White Hawk creeks looking upstream, September 2014. Maximum depth in the riffle habitat is 0.10 m with 2.3 cfs streamflow measured from dam.



Photograph 11. Site no. C0901 Deadwood River downstream from Deadwood Dam between Warm Springs and White Hawk creeks looking upstream, September 2014. Maximum depth in the riffle habitat is 0.10 m with 2.3 cfs streamflow measured from dam.



Photograph 12. Site no. C0900 Deadwood River downstream from Deadwood Dam between White Hawk and No Man creeks looking upstream, September 2014. Maximum depth in the riffle habitat is 0.15 m with 2.3 cfs streamflow measured from dam.