Report on Red River Valley Water Supply Project Needs and Options

Aquatic Needs Assessment **Final Report**

Instream Flows for Aquatic Life and Riparian Maintenance

U.S. Department of the Interior
Bureau of Reclamation
Dakotas Area Office

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EXECUTIVE SUMMARY

The U.S. Department of the Interior, Bureau of Reclamation conducted a study to determine aquatic flow needs of the Red River Valley in North Dakota. This report is part of a needs assessment for the Red River Valley Water Supply Project. The purpose of the Red River Project is to evaluate alternatives to meet the water needs of the Red River Valley. According to the project's authorizing legislation (the Dakota Water Resources Act of 2000), those needs include municipal, rural, and industrial water; water quality; aquatic needs; recreation; and water conservation measures.

This study focused on hydrologic and geomorphologic aspects of aquatic needs in the Sheyenne River from Harvey, North Dakota, to the confluence with the Red River of the North just downstream of Fargo, North Dakota, and the Red River from Wahpeton, North Dakota to the International gaging station at Emerson, Manitoba, Canada.

The *Physical Habitat Simulation System* (PHABSIM) part of the *Instream Flow Incremental Methodology* (IFIM) was chosen to assess quantity of fish habitat as a consequence of stream discharge in these waterways. Reclamation selected six reference sites in the Sheyenne and Red Rivers to represent general ecoregion boundaries for North Dakota.

Representative fish species for six specific guilds (shallow pool, medium pool, deep pool, raceway, slow riffle, and fast riffle) were used to assess aquatic life maintenance flow needs. An optimization technique was used to choose the flow for a particular time of the year that caused the least detrimental effect on different aquatic organisms without imposing liabilities on other water users. Application of the technique to maintenance and spawning periods required maximizing the quantity of habitat for the species and life stage with the least habitat. Table ES-1 summarizes results of this analysis.

In the Sheyenne and Red Rivers, the recommended aquatic needs flow regime was intended to balance the needs of the aquatic community. This information will be useful for comparing effects of various flow alternatives on the aquatic resources.

Also, Reclamation estimated bankfull and floodplain flows using the hydraulic outputs from PHABSIM at the six sites (Table ES-2). Periodic bankfull flows in March to May would help to maintain the channel stability and habitat diversity of the rivers.

The recommended aquatic needs hydrologic and bankfull flows would provide a means to protect the basic needs of aquatic life in the Sheyenne and Red Rivers and would maintain the existing floodplain forest community in its present status.

Table ES-1. Recommended Aquatic Needs Flows at Sheyenne and Red River Reference Sites (cfs).

Time Period	***Sheyenne River***				***Red River***	
	Warwick	Lisbon	Pigeon Point	Norman	Moorhead	Frog Point
January	4	11	24	12	161	316
February	4	13	29	10	145	323
March	31	37	116	90	210	638
April	62	134	742	190	329	1139
May 1-15	49	100	144	104	204	755
May 16-31	21	148	234	104	516	2103
June	6	129	120	64	320	1573
July	9	26	104	89	191	732
August	7	25	66	66	148	632
September	6	21	41	16	174	609
October	7	23	45	19	129	529
November	8	25	48	17	158	501
December	5	15	33	11	137	405

Table ES-2. Estimated Bankfull and Floodplain Flows at Instream Flow Reference Sites, 2002.

Reference Site	Bankfull flow (cfs)	Floodplain flow (cfs)
Sheyenne River:		
Warwick	300	>300
Lisbon	1,000	>1,000
Pigeon Point	1,000	>1,000
Norman	1,200	>10,000
Red River:		
Moorhead	2,500	>3,000
Frog Point	4,000	21,000

INTRODUCTION: Chapter 1

The Dakota Water Resources Act of 2000 (DWRA) requires the U.S. Department of the Interior, Bureau of Reclamation to study water quality and quantity needs of the Red River Valley in eastern North Dakota. This report is part of a needs assessment for the Red River Valley Water Supply Project. The purpose of this Red River Project is to evaluate alternatives to meet the water needs of the Red River Valley. According to the Red River Project's authorizing legislation (DWRA), those needs include municipal, rural, and industrial water; water quality; aquatic needs; recreation; and water conservation measures.

This report assesses aquatic needs of the Sheyenne River and Red River of the North corridors within the United States portion of the Red River Basin (Figure 1). The purpose of the report is to identify hydrologic and geomorphologic conditions that would maintain ecological function for both the short- (the present) and long-term (within the next 50 years), given the existing anthropogenic influences (e.g., Baldhill Dam).

The Sheyenne River corridor extends from the U.S. Geological Survey (USGS) gauging station at Harvey, North Dakota, (USGS gage 05054500), downstream to the confluence with the Red River just downstream of Fargo, North Dakota. The Red River corridor extends from the Wahpeton, North Dakota, gauging station (USGS gage 05051500) downstream to the International gauging station at Emerson, Manitoba, Canada (05102500). The primary Red River reach of interest extends from Fargo, North Dakota, to the confluence with the Buffalo River (Halstad, Minnesota USGS gage 05064500).

Objectives and background are discussed below. In the chapters to follow, study methods are discussed (Chapter 2), results explained (Chapter 3), and conclusions of the study drawn (Chapter 4). The results and conclusions of this study will be used in the environmental impact statement on water quality and quantity proposals for the Red River Valley.

STUDY OBJECTIVES

This study focuses on hydrologic and geomorphologic aspects of aquatic need. The water quality of the aquatic environment will be assessed in a separate report. The hydrologic factor is defined as the magnitude, timing and duration of river flows necessary to maintain ecological conditions in the aquatic system. The geomorphic factor is defined as the occurrence, magnitude and distribution of erosion, sediment transport, and sediment deposition affecting characteristics of the stream corridor and aquatic habitat.

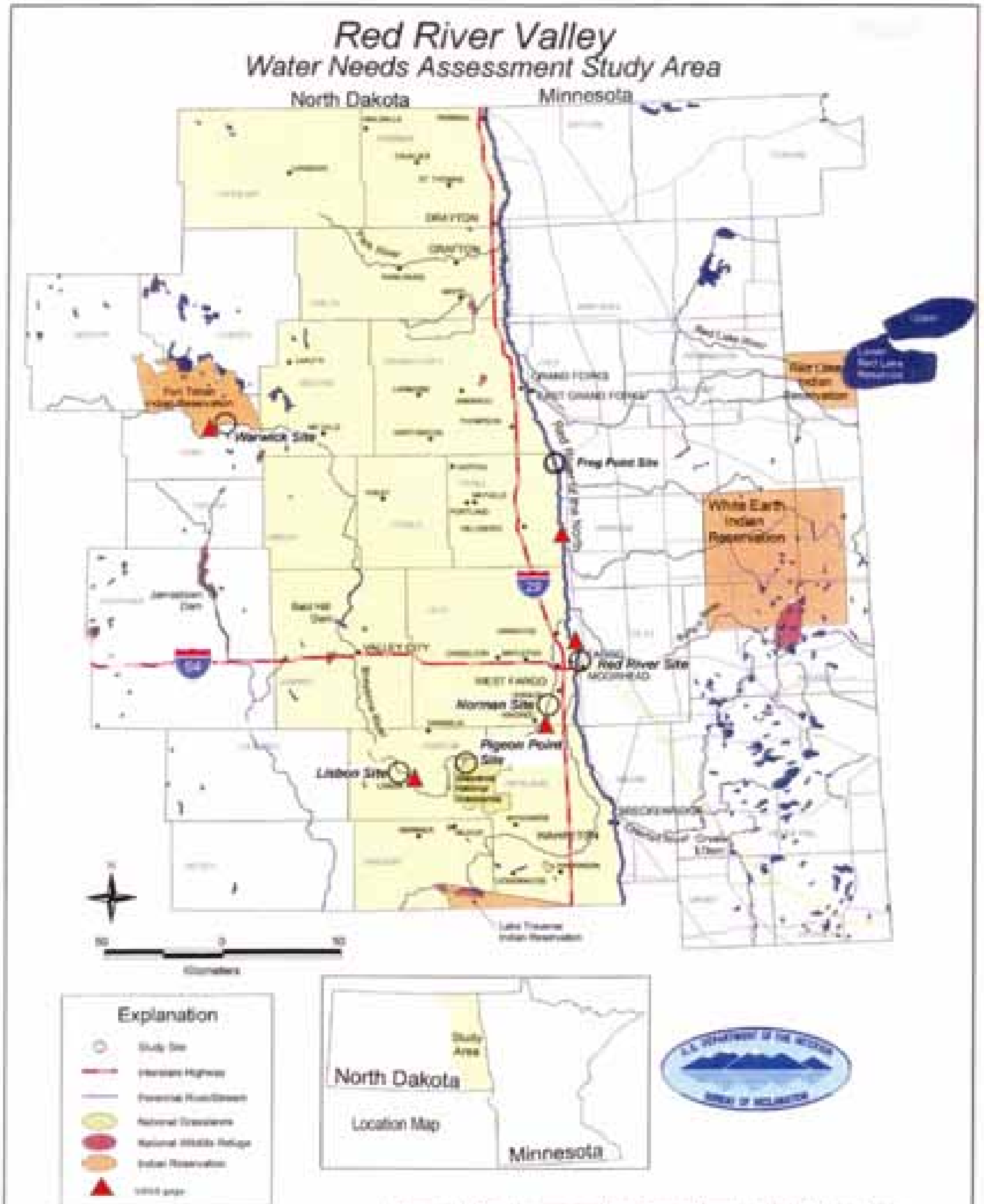


Figure 1. Study area and instream flow study site locations.

Specific objectives of the study are to:

Determine the hydrologic factor of aquatic need:

- Quantify the habitat available for aquatic life at various flows in terms of space and season.

- Determine desired river flows to maintain a diverse aquatic community by establishing target flows for each reach of the river and for each season.

Determine the geomorphological factor of aquatic need:

- Identify the desired flow regime to provide the necessary hydrologic interaction between the riparian area and the watercourse.

- Identify the desired flow regime to provide the necessary hydrologic interaction between the river valley and the watercourse.

BACKGROUND

Reclamation released the *Red River Valley Water Needs Assessment Phase I, Part A*, *Municipal, Rural, and Industrial (MR&I) Appraisal Report* in April, 1998 (Bureau of Reclamation 1998). During review, the North Dakota Congressional Delegation and others became concerned that the report did not address instream flow in regard to aquatic life and water quality, thus underestimating total water need in the Red River Valley. In response to these concerns, Reclamation conducted an appraisal-level instream flow needs assessment for the Sheyenne River and parts of the Red River.

That report, *Red River Valley Water Needs Assessment, Final Appraisal Report Phase I Part B, Instream Flow Needs Assessment,* was completed in August 1999 (Bureau of Reclamation 1999).

This study utilizes the work completed for the August 1999 report and expands upon that study. Additional field measurements were made at high, medium, and low flows to refine estimates of fish habitat and the resultant flow recommendations.

METHODS: Chapter 2

This chapter describes the computer programs used in the study, how reference sites were chosen, how transects in these sites were selected and measured, how habitat was modeled, how instream flows were determined, and how geomorphology influenced the study.

DESCRIPTION OF INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM), PHYSICAL HABITAT SIMULATION SYSTEM (PHABSIM), AND RIVER 2D MODEL

Reclamation used the *Physical Habitat Simulation System* (PHABSIM) part of the *Instream Flow Incremental Methodology* (IFIM) to quantify fish habitat from stream discharge in the Sheyenne and Red Rivers. The reason for using IFIM is that it quantifies environmental impacts to habitat for stream-dwelling organisms under alternative management treatments (Stalnaker et al. 1995). Impacts to habitat are the most direct and are quantifiable.

PHABSIM is the habitat-modeling part of IFIM. It uses one-dimensional hydrodynamic simulation tools to characterize the physical structure of a stream, and relate the biological needs of selected species at various life stages to the flow-dependent characteristics of habitat. Thus, PHABSIM has two major analytical components:

- stream hydraulics
- life stage-specific habitat requirements.

Target species and life stages are described later in this chapter. End products of the habitat modeling are habitat in comparison to stream discharge for each target species and life stage.

River2D, a two-dimensional, depth-averaged, finite-element hydrodynamic model, was used to visualize and interpret PHABSIM-type analyses. Developed by the University of Alberta, it was customized for fish habitat evaluations (Steffler and Blackburn 2002). Two-dimensional models are more useful in describing complex hydrodynamics of streamflow than one-dimensional models. Such things as eddies, split channels, and secondary channels associated with islands and flow reversals, for example, are more accurately described with two-dimensional models (Waddle et al. 2000). For this study, two-dimensional modeling was conducted at the most hydrodynamically complex site (Frog Point) to compare with one-dimensional PHABSIM results from the same site.

SELECTION OF REFERENCE SITES

Process

Reference sites or *study sites* are the location or reach selected to establish reference (least impacted) condition. These sites represent some larger homogenous region (such as a subwatershed) within the study area. Potential sites were recommended after defining homogenous hydrologic regions for the study area (Figure 1). This information was retrieved from Reclamation's Geographic Information System (GIS) database in Bismarck, North Dakota.

To establish need along lotic systems, the study area was limited to the 100-year floodplain or part of it. The selection process required review of past studies and data, such as Reclamation (1999), Houston Engineering, Inc. (1997), North Dakota State Water Commission (1997), USGS water-resources investigation reports and topographic maps, and Reclamation's GIS database. Reclamation also contacted other resource agencies with management responsibility or expertise within the study area. In addition, an on-the-ground reconnaissance was done to select potential representative sites in the Sheyenne and Red Rivers. Data collected for each site included location, site name, homogeneous region, physical setting, a written description, photographs, and reasons the site should be considered as a reference site. All data were made available to Reclamation's Dakota Area Office's GIS Group for their use.

A multidisciplinary team helped choose study sites. The basin was stratified by applying several criteria: the first level was by ecoregion or physiographic area, the second by land use or dominant cropping pattern within each ecoregion, and the third by basin size and hydrologic contribution. Efforts were made to choose sites at USGS stream gages and sites that had been used in previous studies; this enabled the data to be integrated more easily (Figures 1 and 2).

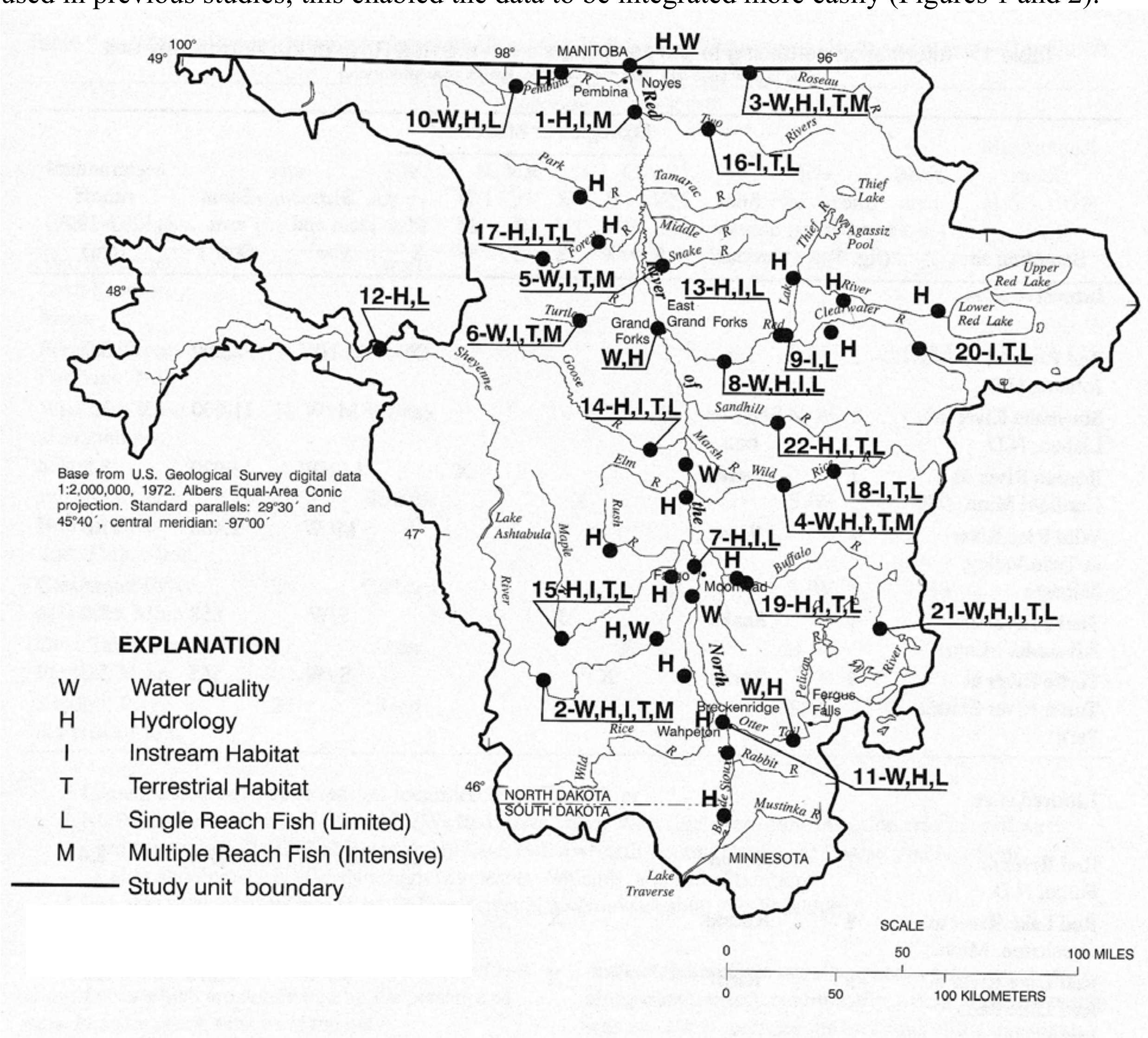


Figure 2. Locations of previous USGS studies within Red River Basin (USGS 1996).

Reclamation's (1999) instream flow study site at Warwick, North Dakota, on the Sheyenne River, for instance, overlapped a North Dakota IBI reference site. It was also located near a USGS stream gage.

The selection process comprised three steps, the first of which was examining maps for sites based on ecoregion, gaging stations, and roadway access. The second step was a field reconnaissance of potential sites. Reclamation's Technical Service Center (TSC) conducted the reconnaissance from April 3 to 6, 2002. Objectives were to:

(1) select sites representative of parts of the Sheyenne and Red Rivers,

(2) meet with other resource agencies and with contractors to coordinate activities and discuss the selection process, and

(3) place transects within the sites for later surveys to measure stream geometry and to obtain stage-discharge relationships for the instream flow study.

At each potential site, Reclamation determined site accessibility, general aquatic habitat conditions, proximity of natural or human-caused sources of degradation, equipment needs and sampling methods, and ability of the site to represent conditions compared to other sites. All sites were documented by photos. The degree of disturbance of each site was assessed during the reconnaissance selection process based on a qualitative index derived from road density, number of physical obstructions (like dams), location and magnitude of water withdrawals and return flows, proximity to cities and towns, and the like. The third step of the process required evaluating the sites visited during step two and choosing the best for further investigation. Specific sites were chosen by characterizing physical, chemical, and biological conditions which define aquatic need.

River Reaches

The Sheyenne River from Harvey to above Lake Ashtabula constituted *Sheyenne River Reach 1*. This reach was uncontrolled, with flows primarily the result of surface runoff events.

Sheyenne River Reach 2, intended to represent the drift prairie physiographic region was comprised of the Sheyenne River from below Lake Ashtabula (Baldhill Dam) to the sandhills area near Kindred. This river reach was subsequently subdivided into two reaches (from Baldhill Dam to Lisbon and Lisbon to the sandhills area upstream of Kindred).

The Sheyenne River through the sandhills constituted *Sheyenne River Reach 3*. It was represented by the reach from upstream of Kindred.

The Red River Valley Lake Plain physiographic region, represented by *Sheyenne River Reach 4*, was the Sheyenne River from downstream of the sandhills area near Kindred to the confluence with the Red River.

The Red River Reach 1 consisted of the Red River at Fargo, North Dakota. It was considered representative of the reach from Fargo to the confluence with the Buffalo River near Halstad, Minnesota.

Red River Reach 2 consisted of the Red River from the confluence with the Buffalo River downstream to Emerson, Manitoba, Canada.

Reference Sites

The selection process suggested four reference sites for the Sheyenne River and two sites for the Red River to represent general ecoregion boundaries in North Dakota. All sites were located at existing instream flow study sites used in previous reports by Reclamation (1999) and Houston Engineering, Inc. (1997) except for the site on the Red River near Grand Forks (Frog Point). The Frog Point site, which included an island when flows are less than 4,000 cfs, was selected to compare River2D with PHABSIM. The reference sites below are listed by priority. They are shown in Figure 1, with written descriptions in Appendix A.

Warwick Site – Sheyenne River above Lake Ashtabula (near Warwick, Eddy County, T150N, R63W, NW1/4NW1/4 of Section 22). This site overlaps a North Dakota IBI reference site.

Norman Site – Sheyenne River through the Agassiz Lake Plain (near Norman, Cass County, T137N, R50W, SW1/4SW1/4 of Section 24).

Lisbon Site – Sheyenne River below Lake Ashtabula (near Lisbon, Ransom County, T135N, R57W, SW1/4SE1/4 of Section 12).

Pigeon Point Site – Sheyenne River through the Sandhills (at Pigeon Point Wildlife Area, Ransom County, T135N, R53W, NW1/4NE1/4 of Section 18).

Moorhead Site – Red River near Moorhead, Minnesota (at Fargo, North Dakota, Clay County, Minnesota and Cass County, North Dakota, T140N, R48W, Section 28/29). This site is not influenced by a low-head dam.

Grand Forks Site (Frog Point) – Red River near Grand Forks, North Dakota, Traill County, North Dakota, and Polk County, Minnesota, T148N, R49W, Section 23.

TRANSECT SELECTION

PHABSIM required strategically-placed transects within each reference site to describe the longitudinal distribution of different habitat types within the stream. Transects were selected at each reference site based on presence of stable channels and hydraulic controls (e.g., channel constriction, riffle). Sites with hydraulic controls were needed to help calibrate the hydraulic models. Calibration data included three water surface elevation (WSL) – discharge data pairs and one set of calibration velocities at each site. This practice agreed with the approach recommended by Bovee et al. (1998) for a PHABSIM analysis.

Transects, benchmarks, and headpins were established and measured using differential leveling techniques. For future reference, headpin coordinates (x, y, z) were locally referenced to an arbitrary, fixed benchmark at each site using a Global Positioning System survey grade instrument (base station and rover). Transects were placed to attempt to capture habitat variability of the stream. They were positioned perpendicular to flow across each major habitat type (pools, riffles) and hydraulic controls. The number varied for each site, with the distance between transects measured along the stream channel.

TRANSECT MEASUREMENTS

WSL and Channel Cross Sections

Field data were collected according to Bovee (1997) using standard surveying equipment above the water surface and depth measured from a wading rod for wet areas. Reclamation conducted the surveys at low, medium, and high discharges. WSLs were measured to the nearest 0.01 ft near the water's edge along each transect at all discharges. Channel cross sections were measured (vertically and horizontally) to the nearest 0.1 ft between headpins at each transect during low discharge. Discharge measurements at one transect were taken at the three discharges. Additional x, y, z coordinates were measured at the Frog Point site to describe bed topography for input into the River2D model.

Depth, Velocity, Substrate and Cover

Depths, mean velocities, substrates and cover were measured at various points along each transect during low flow in August. Stationing across transects was oriented with 0.0 on the left bank looking upstream for modeling purposes. Depths were measured using a top setting wading rod. Streambed elevations and water depths were measured to the nearest 0.1 ft. Mean column water velocity (0.6 of depth in water less than 3.0 ft deep, 0.2 and 0.8 of depth in water 3.0 ft and deeper) was measured to the nearest 0.1 ft/sec using a Marsh McBirney Flo-Mate 2000 velocity meter attached to the wading rod.

Substrate and cover for PHABSIM were visually assessed using a system developed by the Minnesota Department of Natural Resources and converted to a three-digit channel index code to allow coding of substrate and cover classes (Table 1). The first number was the dominant substrate, the second the dominant cover and the third number was always 0. For example, a code of 3.30 referred to a cell with dominant sand (code 3) and dominant vegetation cover (code 3). A temporary staff gage was installed at each site so fluctuations in WSL could be monitored.

COMPUTER MODELING

Data Input and Checking

Field data were entered into Excel spreadsheets and checked for errors. Input files for PHABSIM were then created from the spreadsheets. Input files for River2D programs were also created by converting PHABSIM field data into locally referenced x, y, z coordinates at the Frog Point site.

Hydraulic Model Calibration

Hydraulic modeling approximated depth and mean velocity distribution of each site using the PHABSIM submodels. Reclamation used the Water Surface Profile (WSP) submodel and defined Manning's n-values for overbank and main channel areas only. This submodel was considered appropriate because of the backwater effect created by hydraulic controls at each site;

Table 1. Red River Instream Substrate and Cover Coding System.[1]

CODE	SUBSTRATE	DIAMETER (in)	DIAMETER (mm)
1	Detritus	organic matter	
2	Silt	<0.0024	0-0.0.62
3	Sand	0.0024 - 0.125	0.062-3.2
4	Gravel	0.125 - 2.5	3.2-64
5	Cobble	2.5 – 5	64-128
6	Rubble	5-10	128-256
7	Small Boulder	10-20	256-508
8	Large Boulder	20-40	508-1016
9	Bedrock	>40	>1016
	COVER		
1	None		
2	Undercut	undercut bank	
3	Veg	Rooted or unrooted plants	
4	Wood	Woody matter at least 1 1/2" (4 cm) in diameter	
5	Boulder	boulders >4" (10 cm) above streambed	
6	Flotsam	thick foam on water surface	
7	Canopy	canopy or overhead structure	
8	Edge	a break from high to low velocities	

[1] Source: Aadland (1993)

WSP was designed specifically for backwater applications (Bovee et al. 1998). The WSP submodel calculates the WSL at a transect on the basis of the WSL of the next transect downstream.

WSLs measured at each site were used to calibrate and/or check calibration of the model. Calibration of the data consisted of manipulating Manning's n values until simulated WSLs were within 0.1 ft of measured WSLs. It should be noted that the most accurate simulated WSLs were for those flows closest to the calibration flow within each data set. After the data banks were calibrated and simulated, WSLs using WSP over a range of flows were transferred to an input data deck (IFG4), which was then imported into the Windows version of PHABSIM (USGS 2001). A single calibration simulation was then run on each file to simulate depths and velocities over a range of flows representing the unregulated hydrologic regime.

For the Frog Point site, a mesh file was created from the bed topography file using 2-meter node distancing. The final mesh file was used as the input file for the River2D program for velocity, depth, and habitat modeling at various river flows. Simulated velocities at the measured low-flow of 1,500 cfs were compared with measured velocities taken along each transect to determine if the model was performing reasonably.

Habitat Modeling

Weighted usable area (WUA), an index of habitat availability or quantity for selected guild representatives, was calculated at each site for each simulated flow. WUA was computed by multiplying depth, velocity, substrate, and cover Habitat Suitability Criteria (HSC) values for a life stage at predicted hydraulic conditions and cell surface area in the HABTAE model of the PHABSIM Windows version (USGS 2001). Output from the HABTAE simulation equaled habitat area expressed as WUA (ft^2/1000 ft of stream).

WUA was predicted for a range of discharges at the six reference sites. The habitat-modeling part of River 2D was also used to compute WUA at the Frog Point site. To compare PHABSIM with River2D habitat analyses at the Frog Point site, WUAs were normalized as a percentage of maximum habitat.

Selection of Guild Representatives and Species Periodicity

Aadland et al. (1991) identified representative fish species for six specific guilds: (1) shallow pool, (2) medium pool, (3) deep pool, (4) raceway, (5) slow riffle, and (6) fast riffle. Representative species from these guilds were used to estimate aquatic life maintenance flow needs. Peterka (1978), Owen et al. (1981), and Niemela et al. (1997) were used to ensure that guild representatives occurred within the study area. Data on fish species in the Sheyenne and Red Rivers were compared to existing preference curves developed by Aadland et al. (1991) to ensure availability of habitat preference information.

Fish species/life stages selected as guild representatives and their monthly periodicities are shown in Tables 2 and 3, respectively. Aadland agreed that this list was acceptable for our purposes (personal communication September 30, 2002). Several selected species came from both slow and fast riffle guilds. Use of riffle guild species to evaluate instream flow needs serves to protect species using other types of habitat since riffles are generally the first areas to become dewatered as depths decline. Thus, species representing riffle guilds are most sensitive to changes in flow. A riffle representative, the longnose dace, was used for all seasons. Longnose dace adults also served as a surrogate species for macroinvertebrates, as recommended by Aadland (personal communication September 30, 2002).

Selection of Discharges to Compute Fisheries Habitat

Stream discharges were needed for each site to determine an aquatic needs flow regime based on available water supply. Monthly flow duration curves were established using exceedance probabilities ranging from 10 to 90 percent. The 90 percent exceedance flow was the flow equaled or exceeded 90 percent of the time, for

Table 2. Habitat-preference Guild Representatives Modeled for the Sheyenne and Red Rivers by Season.

SEASON	SHALLOW POOL	MEDIUM POOL	DEEP POOL	RACEWAY	SLOW RIFFLE	FAST RIFFLE
April 1 – May 15 - Riffle spawning				Logperch spawning	Longnose dace spawning	Shorthead redhorse spawning
				Walleye spawning	Sand shiner spawning	Longnose dace adult
May 16 – June 30 - Pool spawning	Hornyhead chub spawning	Orangespotted sunfish spawning				
		Smallmouth bass spawning				Longnose dace adult
July 1 – March 31 - Maintenance	Sand shiner adult	Walleye young and juvenile	Walleye adult	Smallmouth bass adult	White sucker juvenile	Longnose dace adult
	Longnose dace young	Channel catfish juvenile	Channel catfish adult	Shorthead redhorse juvenile and adult	Smallmouth bass juvenile	
		White sucker adult		Channel catfish young	Sand shiner young	

Table 3. Periodicities of Guild Representatives Modeled for the Sheyenne River and Red River.

Species/life stage	Jan	Feb	Mar	Apr	May 1-15	May 16-31	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Logperch													
Spawning													
Longnose dace													
Spawning													
Young													
Adult													
Shorthead redhorse													
Spawning													
Juvenile													
Adult													
Walleye													
Spawning													
Young													
Juvenile													
Adult													
Sand shiner													
Spawning													
Young													
Adult													
Hornyhead chub													
Spawning													
Orangespotted sunfish													
Spawning													
Smallmouth bass													
Spawning													
Juvenile													
Adult													
White sucker													
Juvenile													
Adult													
Channel catfish													
Young													
Juvenile													
Adult													

example. These gaging stations were used to compute unregulated flow duration curves for each site based on period of record 1931-1999:

Sheyenne River
Warwick site – Warwick gage No. 05056000
Norman site – Kindred gage No. 05059000
Pigeon Point site – Kindred gage No. 05059000
Lisbon site – Lisbon gage 05058700

Red River
Moorhead – Fargo gage No. 05054000
Frog Point – Halstad gage No. 05064500

Stream discharge data were also useful for determining the range of flows used in the hydraulic modeling to calculate stream cross-sectional velocity and depth distributions. A range of unregulated discharges was selected for each stream reach and site that represented some specific flow regime. This information was used to develop the relationship between habitat and discharge for a particular fish species and life stage.

Habitat Suitability Criteria

HSC are required by PHABSIM to relate observed fish use of depth, velocity, substrate, and cover to predicted channel hydraulic values of depth, velocity, and substrate. Observed values of depth, velocity, substrate, and cover where fish occur should reflect the microhabitat conditions that a given life stage will freely select. Reclamation used HSCs developed by the Minnesota Department of Natural Resources Stream Habitat Program. The PHABSIM habitat analysis used the English measuring system for HSCs, while for River2D at Frog Point, the metric system was used.

SELECTION OF AQUATIC LIFE SEASONAL INSTREAM FLOW REGIME

As stated previously, we performed the following steps for the PHABSIM analysis:

- selecting reference sites and establishing and collecting representative cross-sectional data,
- performing hydraulic modeling using WSP and IFG4 models to approximate velocity and depth distribution for site-specific data collected, and
- using HSCs for fish species, developed for similar watersheds in Minnesota from a variety of guilds as developed by Aadland et al. (1991), to calculate WUA for each reference site.

The optimization technique discussed by Bovee (1982) was used to develop a recommended seasonal (monthly) instream flow regime. Optimization techniques are used to determine the best conditions to yield benefits or to minimize negative effects (Bovee 1982). For instream flow studies, this requires choosing the flow for a particular time (such as a month) of the year with the least detrimental effect on different aquatic organisms without imposing liabilities on other water users. Exceedance probabilities for instream flow studies typically range from 90 to 95 percent to 50 percent (Bovee 1982).

Application of the optimization technique for maintenance and spawning periods required determining the minimum amount of habitat for all species for each selected discharge. This method consisted of optimizing the WUA for each species/life stage by the maximum WUA value. The technique was applied to each month by arraying flows across the top of the table and guild representatives down the side to reflect water supply and species use of the stream segment over time (Table 7 for an example). The recommended flow is the flow that maximizes the habitat in least supply. The final hydrograph represented the "preferred scenario" because flows recorded in the hydrograph minimized habitat losses while meeting the criterion for water availability.

WUAs were used instead of normalized values to be consistent with Bovee's (1982) example and two previous Red River instream flow reports (Bureau of Reclamation 1999; Houston Engineering, Inc. 1997). Two assumptions are inherent in this optimization technique: first, the habitat requirements for each time were assumed independent of all other times, second, all life stages and species were assumed to have the same relative requirements for space. This second assumption could be avoided by weighting total habitat area for each life stage according to its relative space requirements or for each species according to its priority from a management perspective (Bovee 1982). Since this information was unavailable, Reclamation assumed equal weighting for each life stage and species.

GEOMORPHOLOGY

Geomorphological characteristics of natural channels are formed and maintained largely by bankfull flows (Dunne and Leopold 1978; Leopold 1994; Biedenharn et al. 2000). Bankfull flows move the most sediment over time, forming bars, bends, and meanders. Morphological characteristics include a river's dimension (width/depth ratio, entrenchment ratio, wetted perimeter), pattern (sinuosity, meander wavelength and radius of curvature), and profile (water surface slope, riffle/pool spacing).

Bankfull flows are important for maintaining stability of stream channels and diversity of habitats found in river systems. For this reason, Reclamation determined bankfull flows using hydraulic outputs from PHABSIM at the six reference sites. Using modeled water surface elevations at various flows and cross sectional profiles, flows that resulted in the stage at which the river started to flow out of its banks were considered bankfull flows.

WEST Consultants, Inc. (2001) conducted a thorough investigation of the geomorphology of the Sheyenne River Basin and predictions of the future behavior of the river geomorphology under different hydrologic and project assumptions. Their study included estimates of bankfull flows using three methods: (1) field observations and using the hydraulic model SAM at various cross sections, (2) effective discharge using flow duration curves at each cross section, and (3) frequency analysis (annual flood that occurs on average 66.7 percent of the years). Reclamation compared our bankfull estimate results with WEST Consultants, Inc. (2001).

Periodic flooding of floodplain habitat plays a vital role in maintaining the health of riverine ecosystems (Hynes 1975; Welcomme 1979; Sparks 1992; Stanford and Ward 1979). Floods transfer sediments, nutrients, and organisms between a river's channel and its floodplain, helping to maintain stream productivity. Most of the riverine animal biomass derives from production within the floodplain (Junk et al. 1989). Many aquatic and terrestrial plants and animals have key critical life stages to take advantage of the *flood pulse*, a natural, predictable, and ecologically critical feature of the annual hydrograph of floodplain rivers (Junk et al. 1989; Sparks 1992).

Reclamation attempted to estimate floodplain flows at each site using PHABSIM hydraulic analysis by locating headpins such that at least one headpin on each transect approximated the elevation corresponding to floodplain flow. Headpin elevations at the downstream-most transects were used to determine flows that resulted in water surface elevations exceeding headpin elevations.

The riparian vegetation communities in the Sheyenne River Basin include high prairie, mid prairie, disturbed mid and low prairie, low prairie, meadow, marsh, prairie thicket, river bottom forest, prairie forest, and shelterbelts. Maintenance of riparian vegetation focused on the river bottom forest community because it includes riparian species most directly affected by floodplain flows.

RESULTS and DISCUSSION: Chapter 3

A flow regime to meet aquatic needs was developed from data collected at the six study sites in the Sheyenne and Red Rivers. Bankfull and floodplain flows were estimated and resultant effects on representative species were projected.

AQUATIC LIFE FLOW NEEDS

Exceedances of monthly unregulated flows are summarized in Tables 4 and 5 for each stream gage in this study on the Sheyenne and Red Rivers .

Table 4. Unregulated Average Daily Flows (cfs) for Stream Gages on the Sheyenne River.

					Month							
Warwick												
% Exceedance	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**Dec.**
90	1	1	5	32	21	6	3	2	2	1	3	2
80	2	2	12	43	23	14	6	3	2	3	4	3
70	3	3	16	62	30	19	9	4	3	4	5	4
60	3	3	24	104	37	26	14	5	3	4	8	5
50	4	4	31	180	49	32	22	7	6	7	9	5
40	4	4	55	262	66	44	24	12	8	9	11	7
30	5	6	98	330	85	59	34	18	12	12	13	8
20	7	8	209	471	107	73	53	28	17	18	15	9
10	9	14	329	687	292	110	108	49	30	32	22	15
Lisbon												
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**Dec.**
90	0	0	37	134	68	33	16	6	2	4	6	1
80	5	3	71	159	86	63	26	10	7	8	13	8
70	7	6	96	199	100	81	38	15	11	13	17	9
60	10	10	103	348	112	96	57	21	17	19	25	13
50	11	13	184	665	148	129	74	25	21	23	31	15
40	15	17	271	827	221	189	103	44	27	28	33	19
30	17	24	359	1048	285	242	163	55	39	42	42	29
20	23	41	540	1234	393	272	196	85	53	59	54	33
10	47	59	776	2301	894	408	305	162	105	102	81	59
Kindred												
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**Dec.**
90	8	4	39	190	104	64	30	19	16	19	17	11
80	12	10	90	221	125	91	58	25	21	25	28	13
70	16	15	116	282	144	120	89	38	32	32	33	19
60	19	20	148	464	185	158	104	47	38	37	39	24
50	24	29	186	742	234	208	125	66	41	45	48	33
40	27	31	251	959	316	244	144	81	53	62	56	38
30	32	45	391	1164	463	305	197	112	76	71	64	46
20	42	50	551	1369	533	362	276	146	109	83	84	56
10	70	72	879	2374	1130	564	463	235	137	143	111	75

Table 5. Unregulated Average Daily Flows (cfs) for Stream Gages along the Red River.

	Month											
Fargo												
% Exceedence	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
90	20	36	210	329	204	156	96	20	14	23	25	19
80	92	102	309	532	421	320	191	148	122	129	116	86
70	117	145	389	691	516	481	394	242	174	175	158	100
0	161	175	497	885	708	743	514	294	238	235	206	137
50	195	241	593	1109	910	875	691	353	283	299	265	210
40	252	306	765	1686	1077	1154	776	421	344	358	333	258
30	292	343	881	2527	1253	1355	1063	532	456	452	418	354
20	424	422	1379	4225	1675	1898	1395	734	561	549	524	443
10	541	545	2679	6728	2347	2404	1845	939	741	815	712	566
Halstad												
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
90	39	67	241	1139	755	354	207	49	78	92	106	61
80	141	170	472	1530	1036	745	330	254	265	236	269	153
70	186	209	638	2043	1229	1051	732	397	368	309	327	219
60	228	271	867	2890	1569	1573	1100	520	457	417	423	264
50	316	323	941	3943	2103	1734	1440	632	609	529	501	405
40	362	404	1213	6131	2287	2127	1577	812	658	633	593	472
30	478	510	1861	8243	2849	3132	2013	1048	854	781	710	594
20	661	582	3286	11117	4406	3653	2420	1305	923	1221	846	783
10	828	777	5736	14551	6569	4469	4233	1762	1483	1655	1312	1018

Surveys for habitat modeling were done at the discharges listed in Table 6. Appendix B contains IFG4 input data decks for each site. Hydraulic model calibration results are summarized in Appendix C. Cross-sectional profiles and longitudinal profiles are summarized in Appendix D.

The only hydraulic calibration problem occurred at the Moorhead site on the Red River. Simulated WSLs at the mid-flow measurement (798 cfs) differed from measured WSLs by as much as 0.41 ft (Appendix C, Table C-5). Closer examination of the data suggested a WSL measurement error at this site, based on comparing the difference in average measured depths at transect 1 between the low and mid flow discharge measurements with the difference in measured WSLs at transect 1. The average depth difference was 0.18 ft, compared with an average WSL difference of 0.75 ft.

HSCs developed by the Minnesota Department of Natural Resources Stream Habitat Program are presented in Appendix E. Comparison of the velocity and depth HSCs for chosen species/life stages showed “coverage” throughout the ranges in velocity and depth within the reference sites. Appendix F contains species specific WUA by discharge.

Table 7 shows how an instream flow determination was made using the optimization technique discussed in Chapter 3. In this example, the range of unregulated flows during April at the Warwick site was arrayed across the top of the matrix according to the probability of exceedance

Table 6. Discharges Measured during Field Surveys.

Reference Site	Discharge (cfs)	Survey Dates (2002)
Sheyenne River:		
Warwick	31	August 29
	89	May 24
	161	April 26
Norman	73	August 26
	169	April 30
	437	May 16
Lisbon	23	August 28
	72	April 26
	518	May 16
Pigeon Point	35	August 27
	142	April 30
	378	May 16
Red River:		
Frog Point	1,500	August 24
	2,265	April 23
	3,343	May 17
Moorhead	765	August 23
	798	April 24
	1,492	May 15

Table 7. Example of Optimization Technique to Determine Aquatic Flow Needs at Warwick Study Site.

April		% Exceedance				
		90	80	70	60	50
		Flows (cfs)				
		32	43	62	104	180
Species	Life Stage	Habitat Values (ft^2/1000 ft)				
Logperch						
	Spawning	10	35	145	687	1761
Walleye						
	Spawning	2574	3159	4359	6722	7676
Longnose Dace						
	Adult	2707	3277	3731	3854	2697
	Spawning	105	146	134	52	3
Sand Shiner						
	Spawning	8949	9861	9823	8002	4762
Shorthead Redhorse						
	Spawning	40	97	271	550	526
Minimum Habitat Value		10	35	134	52	3
Recommended flow which maximizes habitat in least supply = 62 cfs						

read from the flow duration curve for that month. The typical range of discharges is the 90 to 95 percent to 50 percent range of exceedance probabilities (Bovee 1982).

Next, life stages of each guild representative present at the Warwick site during April (spawning period) were arrayed down the left side of the matrix. Finally, referring to the habitat in comparison to discharge curves, the WUA (ft^2/1000 ft) was entered for each life stage corresponding to flows at the top of the table. To determine the optimum flow for the mix of life stages and species, each column was scanned, and the smallest WUA value was recorded at the bottom of the column.

After recording the minimum value for each column, the highest number among the minimum values was identified. This value corresponded to the flow that maximized the habitat in least supply. In this example, the flow equaled 62 cfs.

A complete set of analyses for all sites is presented in Appendix G.

Recommended Flow Regime
Based on the optimization analysis summarized in Appendix G, the seasonal instream flow regime developed to maintain aquatic life is shown in Table 8. The primary value of developing aquatic needs flows is that they provide reference points to compare effects of alternative flow regimes on fish habitat.

During the spawning period (April to May 15) aquatic flow needs were generally driven by longnose dace spawning at all sites. At the Moorhead site on the Red River, adult longnose dace determined spawning flow needs. Spawning life stages of shorthead redhorse, longnose dace, logperch, and hornyhead chub were not used at the Moorhead site because PHABSIM results showed no habitat at any flows due to lack of substrate and cover combinations. From May 16 to June 30, flow needs were always controlled by smallmouth bass spawning habitat, in short supply probably due to lack of aquatic macrophytes for spawning.

Table 8. Recommended Aquatic Needs Flows at Sheyenne and Red Rivers Reference Sites Based on Unregulated Stream Flows (in cfs).

	Sheyenne River				Red River	
	Warwick	Lisbon	Pigeon Point	Norman	Moorhead	Frog Point
January	4	11	24	12	161	316
February	4	13	29	10	145	323
March	31	37	116	90	210	638
April	62	134	742	190	329	1139
May 1-15	49	100	144	104	204	755
May 16-31	21	148	234	104	516	2103
June	6	129	120	64	320	1573
July	9	26	104	89	191	732
August	7	25	66	66	148	632
September	6	21	41	16	174	609
October	7	23	45	19	129	529
November	8	25	48	17	158	501
December	5	15	33	11	137	405

Managing the rivers to meet the aquatic life seasonal instream flow regime during the July to March maintenance period would maintain a perennial stream throughout each site. At most sites, flows were generally determined by walleye young habitat. At the Norman Site, longnose dace young generally controlled maintenance flow needs. Adult longnose dace determined maintenance flow needs at the Moorhead Site, probably due to lack of riffles.

Recommended Flow Regime Compared to Natural Hydrograph

Protecting natural hydrologic regimes is a need that is increasingly recognized in river management (Junk et al. 1989; Sparks 1992). Figures 3 and 4 compare recommended hydrologic aquatic needs at the Sheyenne and Red River sites, respectively, with natural hydrographs based on 10, 50, and 90 percent exceedance levels (1931-1999 period of record) from USGS gage records (Tables 4 and 5).

Except for March to May, flows for aquatic needs generally follow the natural hydrograph. Bankfull flows and flows required to maintain connection between the river channel and the floodplain generally follow the natural flow regime between March to May.

Although the recommended aquatic needs flow regime probably would not be ideal for all guild representatives, it was intended to provide the highest diversity of habitat suitable to balance needs of the entire riverine community. Depending on fish species, flows other than aquatic needs flows could be beneficial or detrimental. Prolonged flows greater than those recommended for aquatic needs, for instance, would benefit some fish species and harm others, depending on location and the season.

Depending on fishery management goals of state agencies, this may or may not be desirable. For example, at the Warwick site if a recommended flow of 62 cfs in April was increased to the natural hydrograph 50 percent exceedance level of 180 cfs, habitat would increase for logperch, walleye, and shorthead redhorse spawning (Table 7). However, habitat would decrease for longnose dace adult and spawning, and sand shiner spawning.

If increased flows were maintained over several years in April, the aquatic community would likely shift in favor of logperch, walleye, and shorthead redhorse at the expense of longnose dace and sand shiners. The longnose dace adults serve as a surrogate species for macroinvertebrates, which are a food supply for fish. Thus, a reduced food supply could be a greater negative impact to the system than the benefits derived from more habitat.

Tables 9 and 10 provide examples of how recommended aquatic needs flows could be used to assess effects of alternative flow regimes on fish habitat. Table 9 shows effects of increasing flows (40 percent exceedance level--Tables 4 and 5) on habitat, while Table 10 shows effects of decreasing flows (90 percent exceedance level--Tables 4 and 5). These tables show that various life stages would be affected positively (+), negatively (-), or would be unaffected (0), depending on the site and time of year.

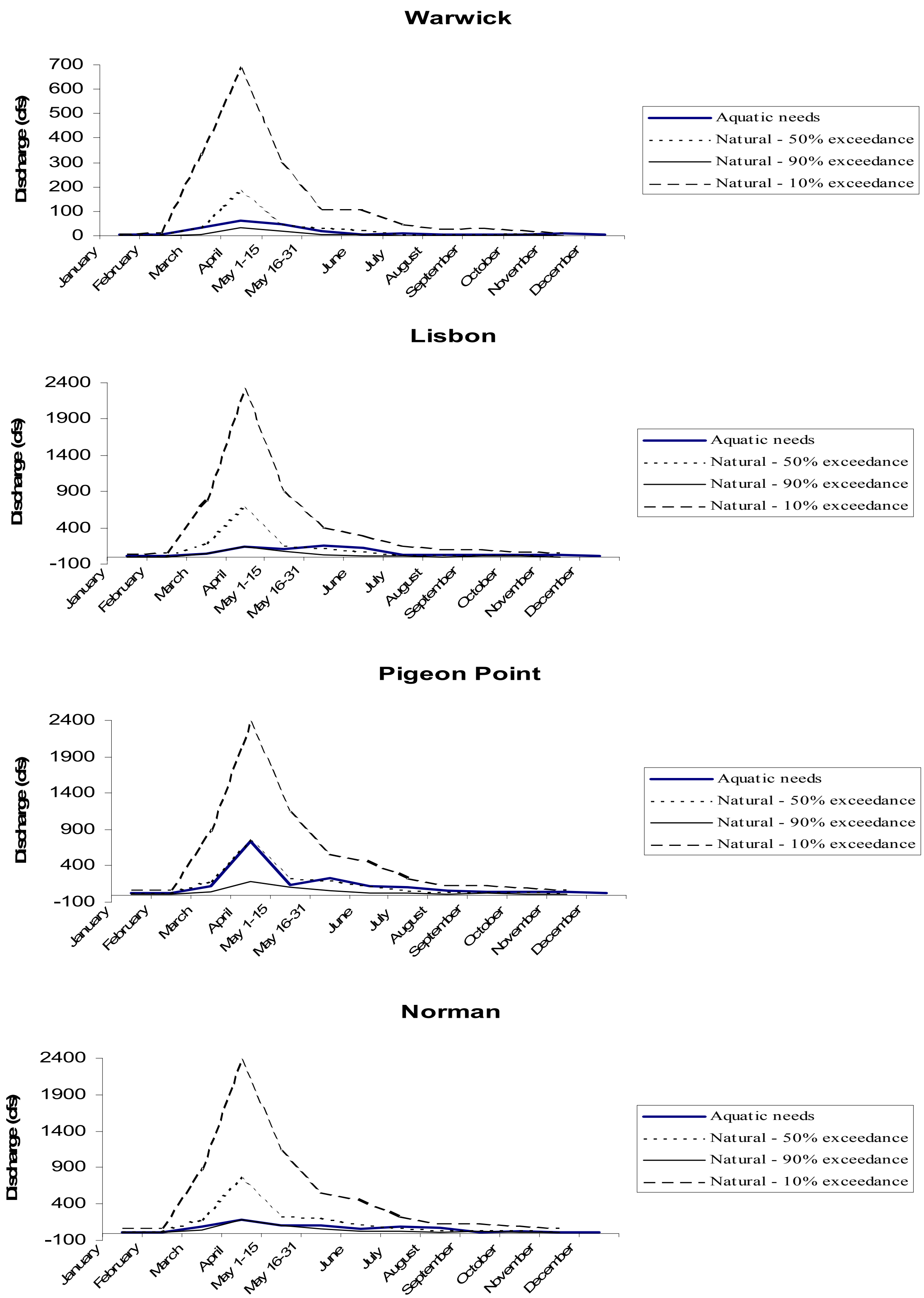
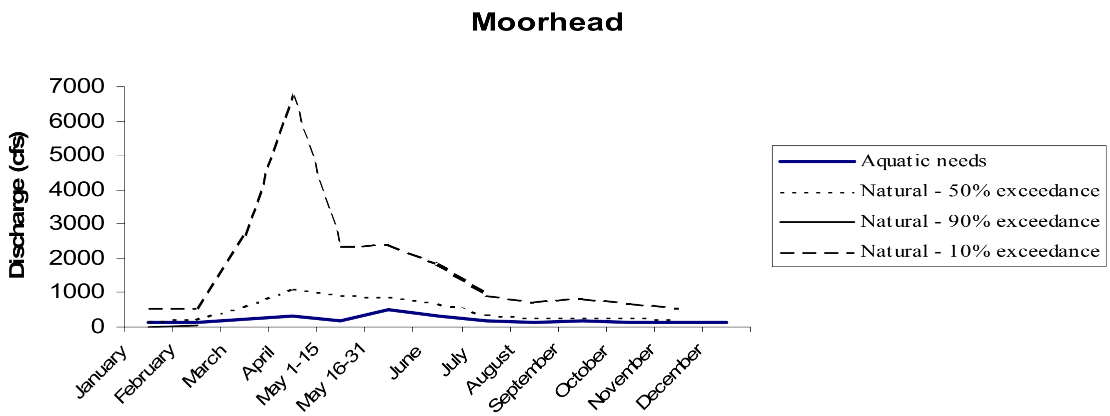


Figure 3. Natural Hydrograph of Sheyenne River Near Instream Flow Study Sites Based on 1931-1999 Period of Record, Plus Recommended Aquatic Needs Flows.



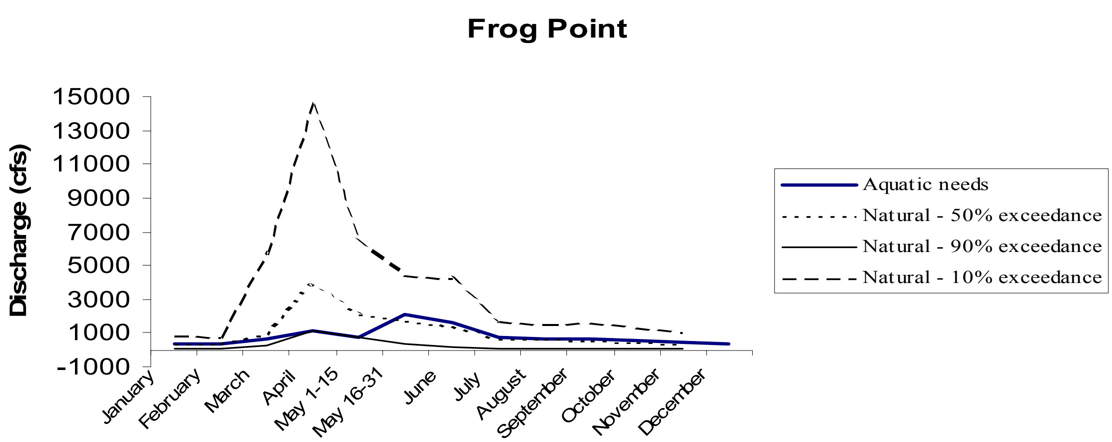


Figure 4. Natural Hydrograph of Red River Near Instream Flow Study Sites Based on 1931-1999 Period of Record, Plus Recommended Aquatic Needs Flows.

Table 9. Example of Effects of Increasing Aquatic Needs Flows to Unregulated 40 Percent Exceedance Levels on Fish Habitat in the Sheyenne River and Red River.

Species/life stage	Jan						Feb						Mar						Apr						May						Jun					
Site:[1]	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F
Logperch Spawning																			+	-	-	-	*[2]	*	+	+	-	-	*	-						
Longnose dace Spawning																			-	-	-	0[3]	*	*	-	-	-	0	*	*						
Young	0	-	+	-	-	+	0	-	+	-	-	+	-	-	-	-	+	-																		
Adult	0																		-	-	+	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-
Shorthead redhorse Spawning																			+	-	-	-	*	*	+	+	-	-	*	-						
Juvenile	0	+	+	+	+	+	0	+	+	+	+	+	+	+	-	-	-	-																		
Adult	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+																		
Walleye Spawning																			+	-	-	-	-	-	+	+	-	-	-	-						
Young	0	+	+	+	+	+	0	+	+	+	+	+	+	-	+	-	+	+																		
Juvenile	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+																		
Adult	0	+	+	+	+	+	0	+	+	+	+	+	+	-	+	+	+	+																		
Sand shiner Spawning																			-	-	-	-	-	-	-	-	-	-	-	-						
Young	0	+	+	-	-	+	0	+	+	-	-	+	-	-	-	-	+	-																		
Adult	0	-	+	+	-	+	0	-	+	+	-	+	+	-	-	-	-	-																		
Hornyhead chub Spawning																									-	-	-	-	*	-	+	-	-	-	*	-
Orangespotted sunfish Spawning																									+	-	-	-	-	-	+	-	-	-	+	-
Smallmouth bass Spawning																									-	+	+	+	+	+	-	+	+	-	+	-
Juvenile	0	+	+	+	+	+	0	+	+	+	+	+	+	+	-	+	-	-																		
Adult	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	-	+																		
White sucker Juvenile	0	+	+	+	-	+	0	+	+	+	-	+	+	-	-	-	-	-																		
Adult	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+																		
Channel catfish Young	0	+	+	+	+	+	0	+	+	+	+	+	+	-	-	-	-	-																		
Juvenile	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+																		
Adult	0	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+																		

[1] W = Warwick; L = Lisbon; P = Pigeon Point; N = Norman; M = Moorhead; F = Frog Point

[2] * - indicates no habitat

[3] 0 – indicates no change

Table 9. Continued.

Species/life stage	Jul						Aug						Sep						Oct						Nov						Dec					
Site:[1]	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F
Logperch Spawning																																				
Longnose dace Spawning																																				
Young	+	-	-	-	-	-	+	-	-	+	-	-	+	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	+	-	+	-	-	-
Adult	+	+	-	-	+	-	+	+	+	-	-	-	+	+	+	+	-	-	+	+	+	+	-	-	+	+	+	-	-	-	+	+	+	+	-	+
Shorthead redhorse Spawning																																				
Juvenile	+	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+
Adult	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Walleye Spawning																																				
Young	-	-	+	-	-	+	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	-	+	+	-	-	+	-	+	+	-	+	+	+	+	+
Juvenile	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
Adult	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sand shiner Spawning																																				
Young	+	-	-	-	-	-	+	+	-	+	-	-	+	+	-	+	-	-	+	+	-	+	-	-	+	+	-	+	-	-	+	+	+	-	-	-
Adult	+	-	+	+	-	-	+	-	+	+	-	-	+	-	+	+	-	-	+	-	+	+	-	-	+	-	+	+	-	-	+	-	+	+	-	+
Hornyhead chub Spawning																																				
Orangespotted sunfish Spawning																																				
Smallmouth bass Spawning																																				
Juvenile	+	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+
Adult	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
White sucker Juvenile	+	-	-	-	-	-	+	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+	-	+
Adult	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Channel catfish Young	+	-	-	+	-	-	+	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+
Juvenile	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
Adult	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	-	+	-	+	+	+	+	+	+	+	+

[1] W = Warwick; L = Lisbon; P = Pigeon Point; N = Norman; M = Moorhead; F = Frog Point

[2] * - indicates no habitat

[3] 0 – indicates no change

Table 10. Example of Effects of Decreasing Aquatic Needs Flows to Unregulated 90 Percent Exceedance Levels on Fish Habitat in the Sheyenne River and Red River.

Species/life stage	Jan						Feb						Mar						Apr						May						Jun					
Site:[1]	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F
Logperch Spawning																			-	0[2]	+	0	*[3]	0	-	-	-	0	*	0						
Longnose dace Spawning																			-	0	-	0	*	0	-	+	-	0	*	0						
Young	-	-	-	+	-	-	-	-	-	+	-	-	+	0	+	-	0	+																		
Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	+	0	+	-	0	+	0	0	0	-	-	+	0	+	+	0	-	-	0	-	+
Shorthead redhorse Spawning																			-	0	+	0	*	0	-	-	-	0	*	0						
Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
Adult	+	-	-	-	-	-	+	-	-	-	-	-	-	0	-	-	0	-																		
Walleye Spawning																			-	0	+	0	0	0	-	-	-	0	0	0						
Young	+	-	-	-	-	-	+	-	-	+	-	-	-	0	-	-	0	-																		
Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	+	0	-																		
Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
Sand shiner Spawning																			-	0	+	0	0	0	-	+	+	0	0	0						
Young	-	-	-	+	-	-	-	-	-	-	-	-	-	0	+	-	0	+																		
Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	+																		
Hornyhead chub Spawning																									0	+	+	0	*	+	0	+	+	0	*	+
Orangespotted sunfish Spawning																									0	+	+	0	+	+	0	-	-	0	-	+
Smallmouth bass Spawning																									0	-	-	0	-	-	0	-	-	0	-	-
Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
White sucker Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
Adult	+	-	-	-	-	-	+	-	-	-	-	-	-	0	-	-	0	-																		
Channel catfish Young	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
Juvenile	-	-	-	+	-	-	-	-	-	-	-	-	-	0	-	-	0	-																		
Adult	+	-	-	-	-	-	+	-	-	-	-	-	-	0	-	+	0	-																		

[1] W = Warwick; L = Lisbon; P = Pigeon Point; N = Norman; M = Moorhead; F = Frog Point

[2] 0 – indicates no change

[3] * - indicates no habitat

Table 10. Continued.

Species/life stage	Jul						Aug						Sep						Oct						Nov						Dec					
Site:[1]	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F	W	L	P	N	M	F
Logperch Spawning																																				
Longnose dace Spawning																																				
Young	-	+	+	-	+	+	-	+	-	-	-	+	-	-	-	0	-	+	-	-	-	0	-	+	-	-	-	0	-	-	-	0	-	0	-	-
Adult	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	0	-	+	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Shorthead redhorse Spawning																																				
Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Adult	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	+	0	-	0	-	-
Walleye Spawning																																				
Young	+	-	-	-	-	-	+	-	-	-	-	-	+	+	-	0	-	-	+	-	-	0	-	-	+	-	-	0	-	-	+	0	-	0	-	-
Juvenile	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Sand shiner Spawning																																				
Young	-	-	+	-	+	+	-	-	-	-	-	+	-	-	-	0	-	+	-	+	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Adult	-	+	-	-	-	+	-	+	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	+	-	0	-	-	-	0	-	0	-	-
Hornyhead chub Spawning																																				
Orangespotted sunfish Spawning																																				
Smallmouth bass Spawning																																				
Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
White sucker Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Adult	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	0	-	-	+	-	-	0	-	-	-	-	-	0	-	-	+	0	-	0	-	-
Channel catfish Young	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	-
Adult	+	-	-	+	-	-	+	-	-	+	-	-	+	+	-	0	-	-	+	-	-	0	-	-	+	-	-	0	-	-	+	0	-	0	-	-

[1] W = Warwick; L = Lisbon; P = Pigeon Point; N = Norman; M = Moorhead; F = Frog Point [2] 0 – indicates no change [3] * - indicates no habitat

RIVER2D RESULTS AT THE FROG POINT SITE

Figure 5 shows a frequency histogram of simulated and measured velocities at all transects surveyed at the Frog Point site at 1,500 cfs (43 cubic meters per second (cms)). Comparisons show that, in general, simulated velocities reflected measured values and that the two-dimensional hydrodynamic model was performing as expected. Figures 6 and 7 show velocity magnitude maps of the Frog Point site at various flow levels using River2D. These maps show how velocities and wetted areas changed as a function of flow.

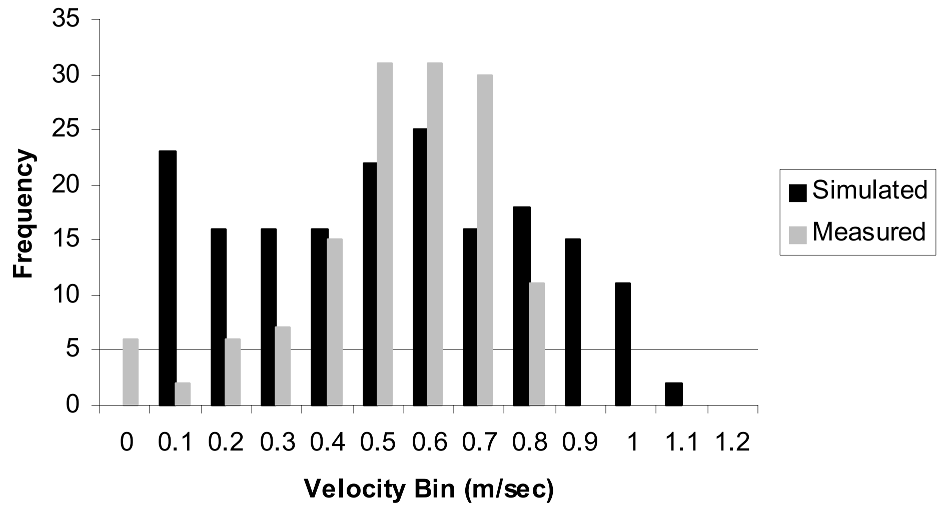


Figure 5. Comparison of Total Simulated and Measured Velocities along Seven Transects at Frog Point Site (1,500 cfs (43 cms)).

Comparison of PHABSIM with River2D

Figures 8-12 compare analysis results for selected fish species between PHABSIM (the one dimensional hydrodynamic model--"1d") and River2D (two dimensional hydrodynamic model-- "2d") at Frog Point. These figures highlight both similarities and differences resulting from different approaches to field data collection, hydraulic modeling, and computing habitat. Examination of these figures, based on percent of maximum habitat relationships over the same flow ranges, shows similar overall relationships in the habitat compared to discharge functions for most life stages. The differences between models are considered within expected variability ranges given the nature and differences in the respective approaches.

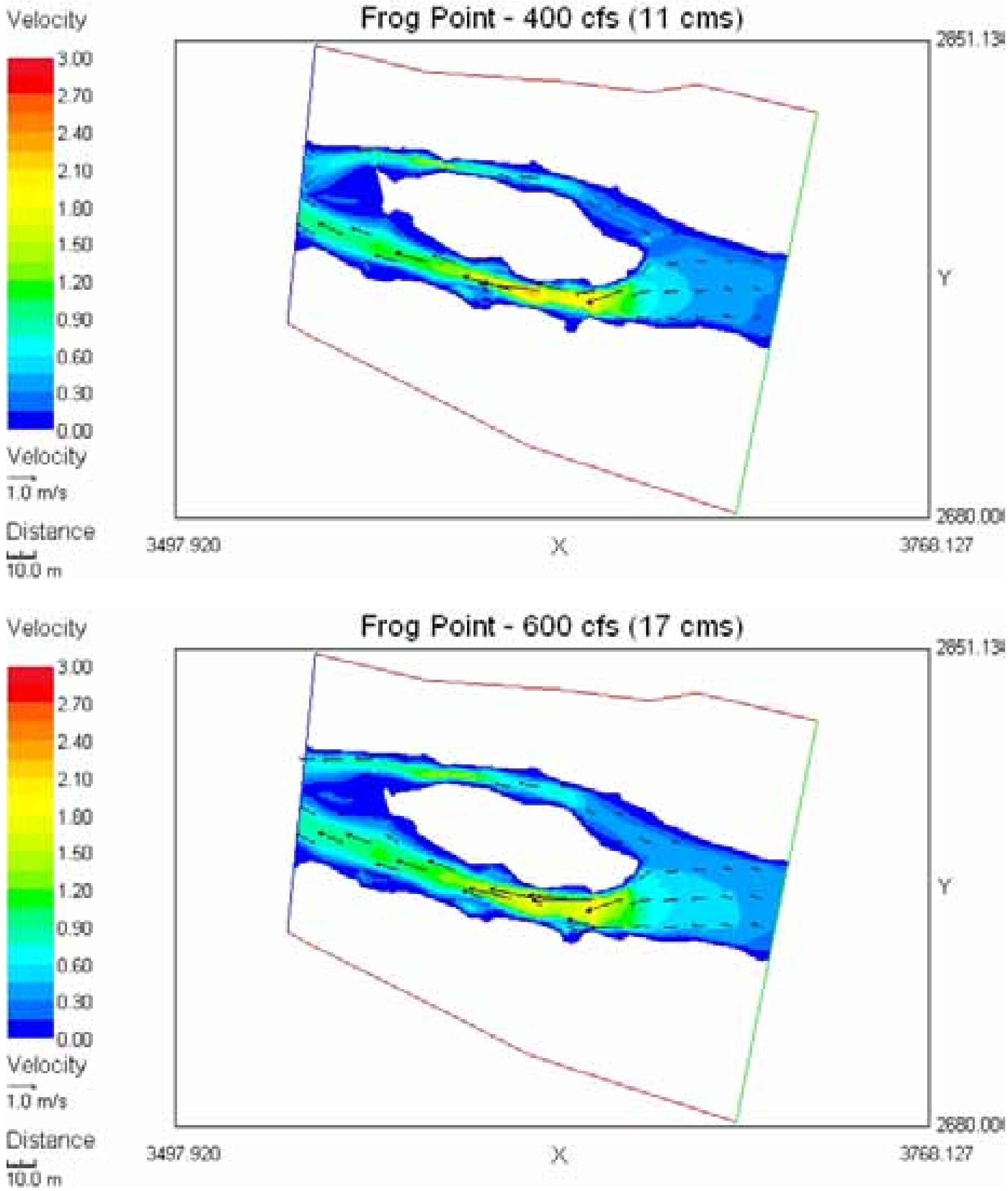


Figure 6. Velocity Magnitudes at 400 And 600 cfs at Frog Point Using River2D.

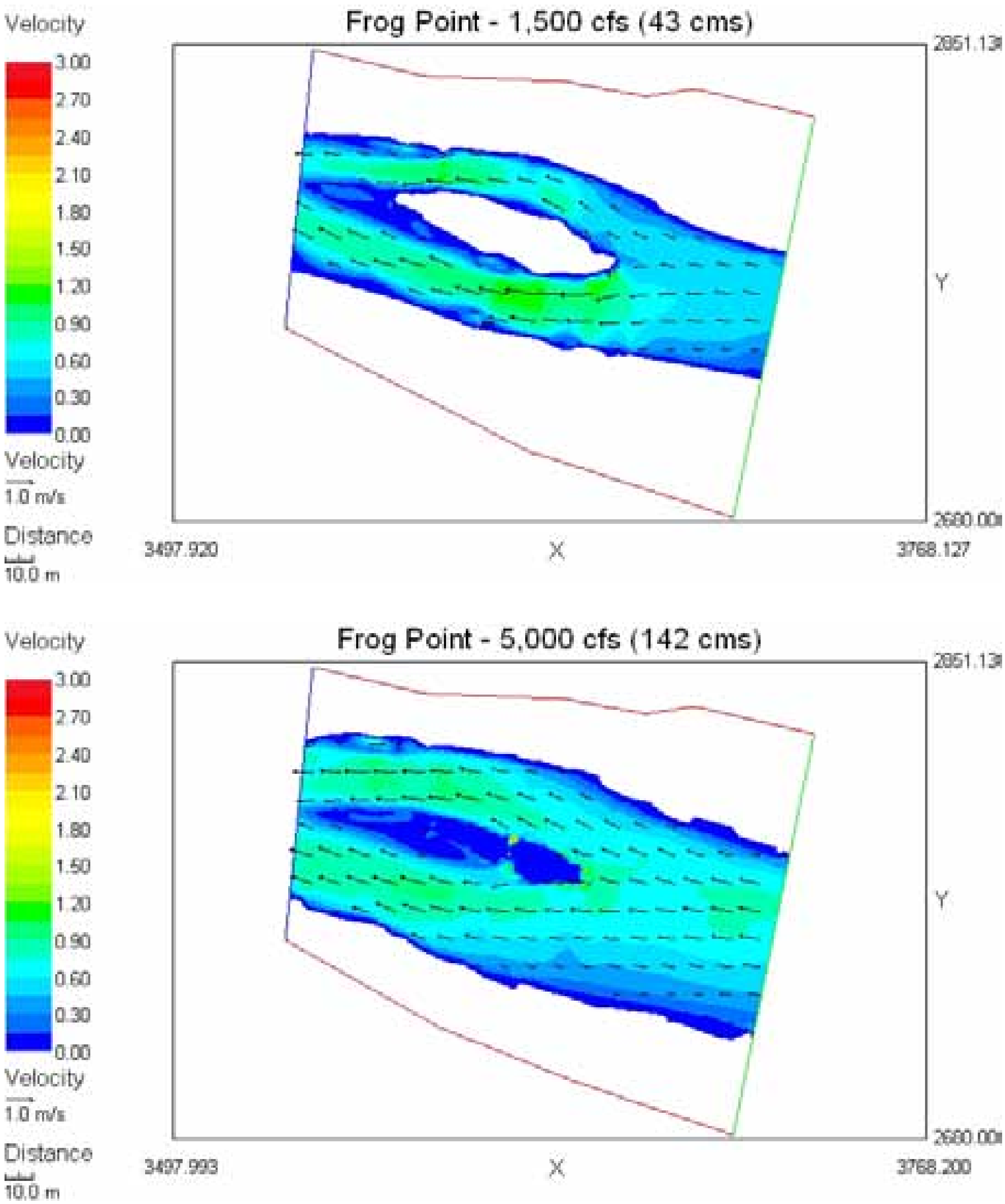


Figure 7. Velocity Magnitudes at 1,500 And 5,000 cfs at Frog Point Using River2D.

Waddle et al. (2000) reported that whether based on 1d or 2d flow models, the sensitivity of calculated habitat to errors in simulated depth and velocity ultimately depended on the sensitivity of habitat of target species suitability indices to depth and velocity. For this study, the major advantage of River2D modeling over PHABSIM was the attractive visual aids generated to display hydraulic and habitat results. However, River2D is more labor intensive and expensive.

The PHABSIM analysis was considered reasonable for purposes of this study because the river channels were not hydrodynamically complex enough (few eddies, intermittent backwaters, transverse flows and braided channels) to justify using River2D. Therefore, similar habitat-discharge relationships would be expected with either model. Waddle et al. (2000) suggested that in areas with generally straight or gradually bending single channels, the 1d approach might suffice. This generally describes most segments of the Sheyenne and Red Rivers.

GEOMORPHOLOGY

Bankfull Flows

Using PHABSIM results, approximate bankfull flows at each site are summarized in Table 11 (with bankfull flows from WEST Consultants, Inc. 2001 study included for comparison). Bankfull flow corresponds to the stage at which the river begins to flow out of its banks (hydrologic floodplain) and onto its topographic floodplain.

Table 11. Estimated Bankfull Flows at Instream Flow Study Sites, 2002.

Reference Site	Downstream Transect Estimated Bankfull Elevation (ft)	Estimated Bankfull Flow (cfs)	Adopted Bankfull Values From WEST Consultants, Inc. (2001) (cfs)
Sheyenne River:			
Warwick	89.1	300	500
Lisbon	83.7	1,000	1,100
Pigeon Point	51.3	1,000	1,100
Norman	84.8	1,200	1,200
Red River:			
Moorhead	74.6	2,500	
Frog Point	806.9	4,000	

Reclamation's estimates were similar to estimates from WEST Consultants, Inc. (2001). Unregulated average daily flows during the 1931 to 1999 period of record in the Sheyenne and Red Rivers (Tables 4 and 5), show that bankfull flows occurred about 10 percent of the time in March and May and about 30 percent of the time in April at all sites except Frog Point. At Frog Point, bankfull flows occurred less than 20, 60, and 30 percent of the time in March, April, and May, respectively.

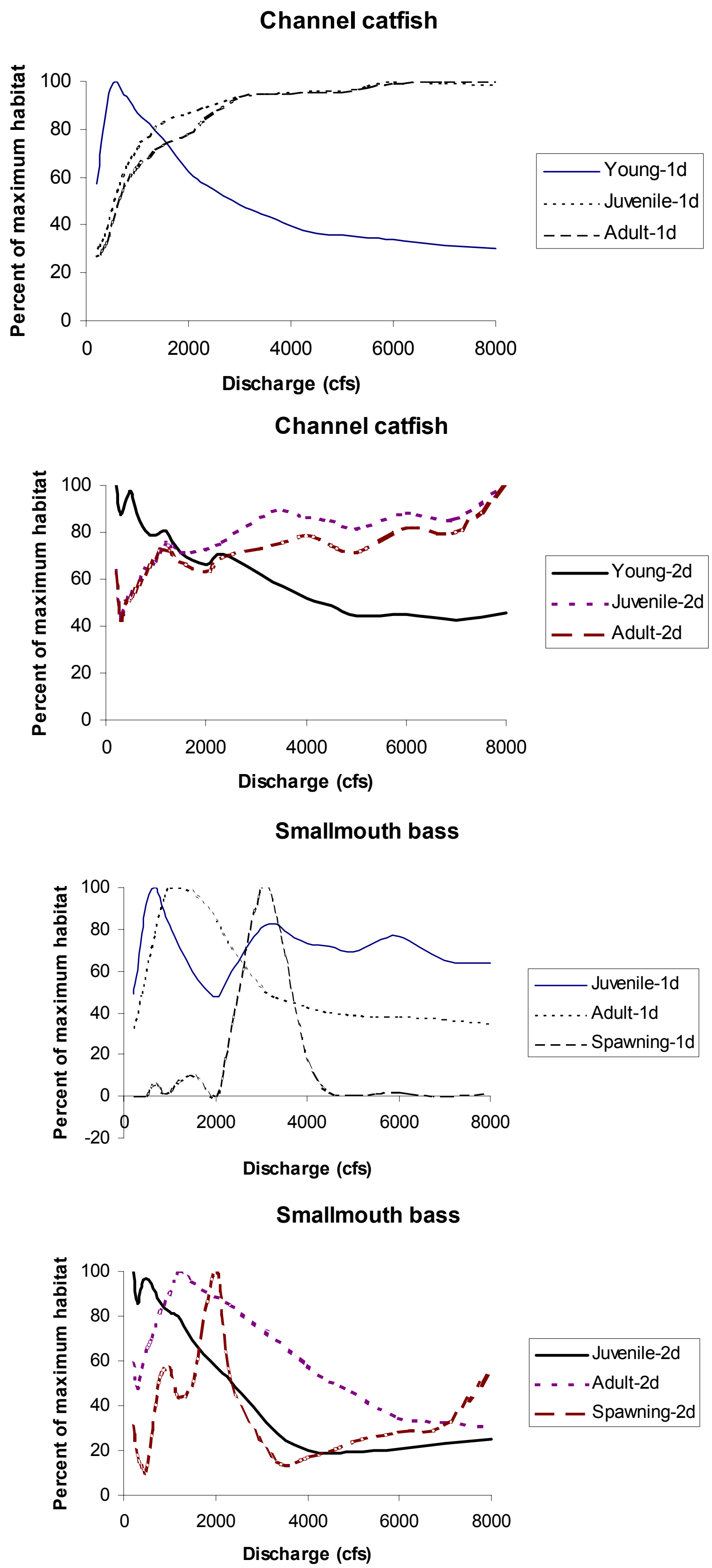


Figure 8. Comparison of Habitat Modeling Results between PHABSIM (1d) and River 2D (2d) for Channel Catfish and Smallmouth Bass at Frog Point.

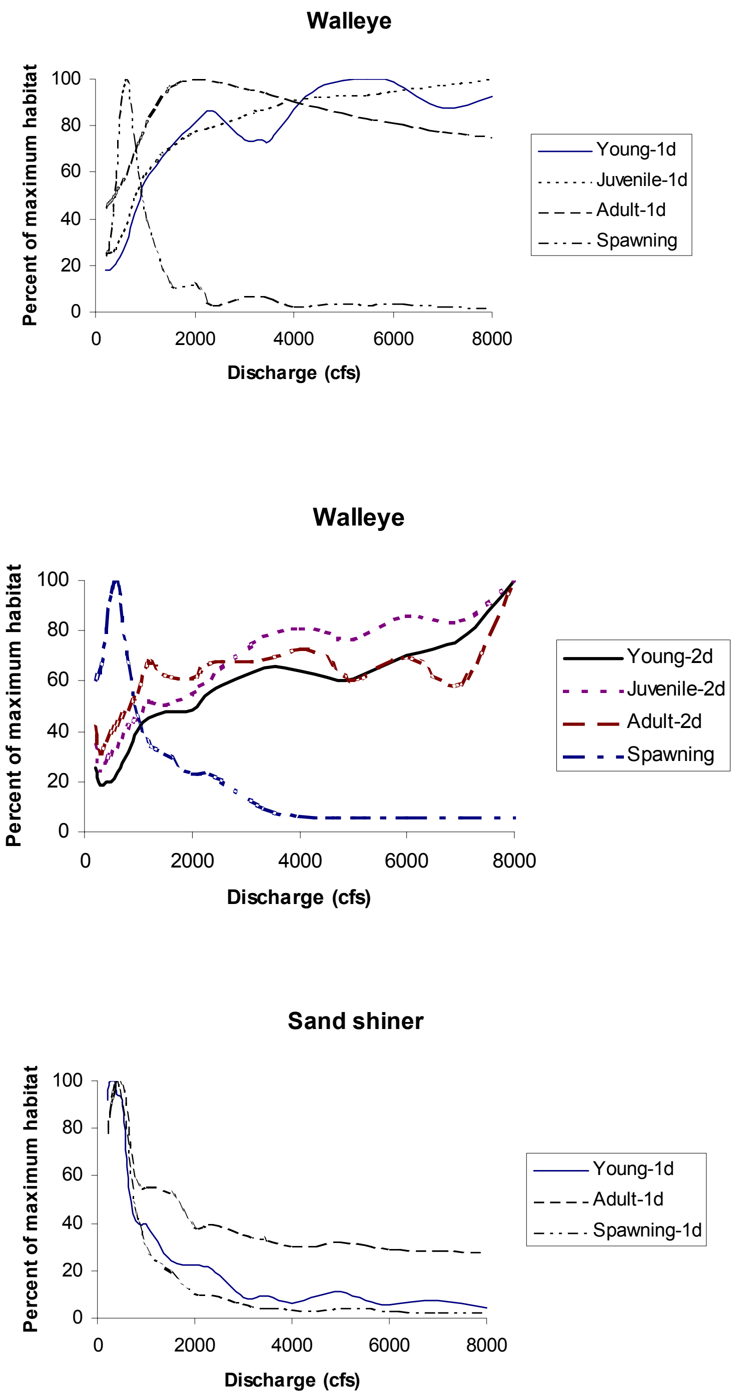


Figure 9. Comparison of Habitat Modeling Results between PHABSIM (1d) and River 2D (2d) for Walleye and Sand Shiner at Frog Point.

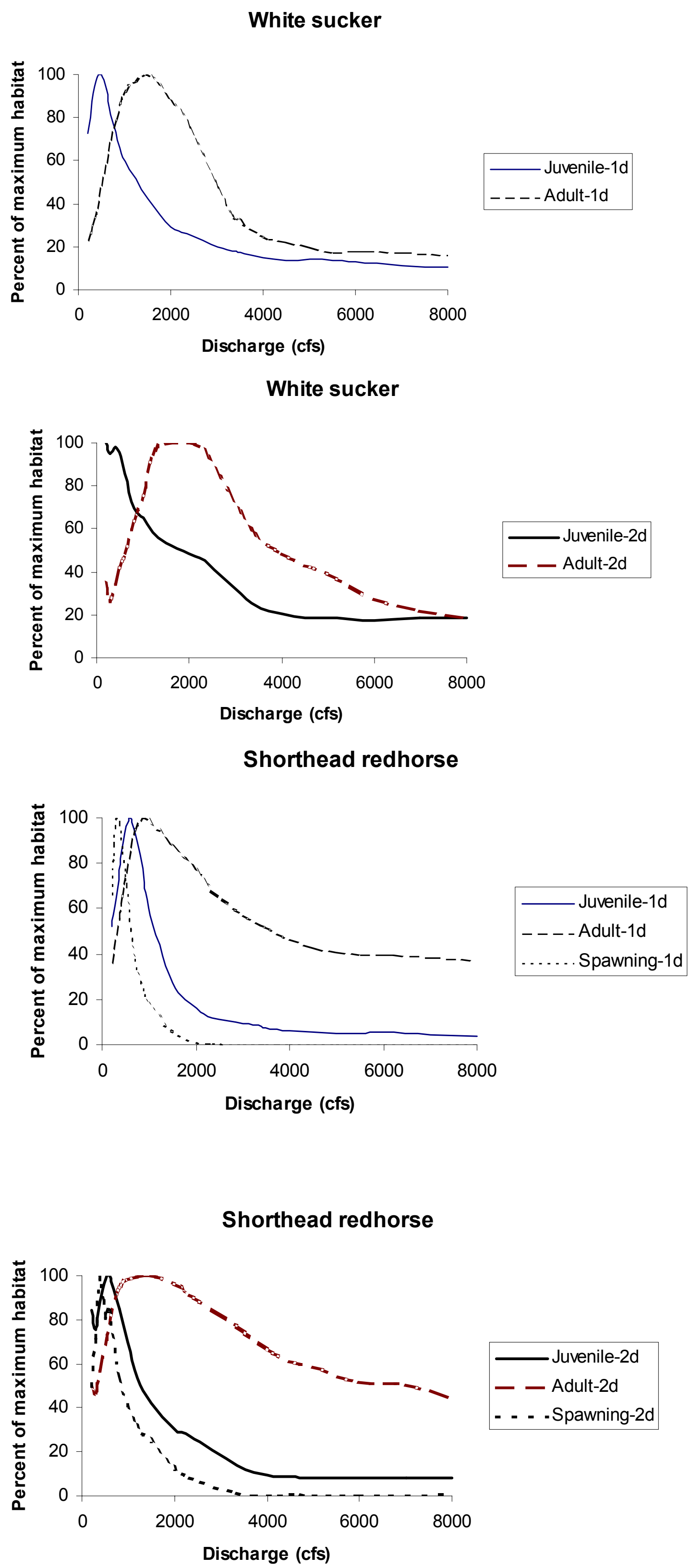


Figure 10. Comparison of Habitat Modeling Results between PHABSIM (1d) and River 2D (2d) for White Sucker and Shorthead Redhorse at Frog Point.

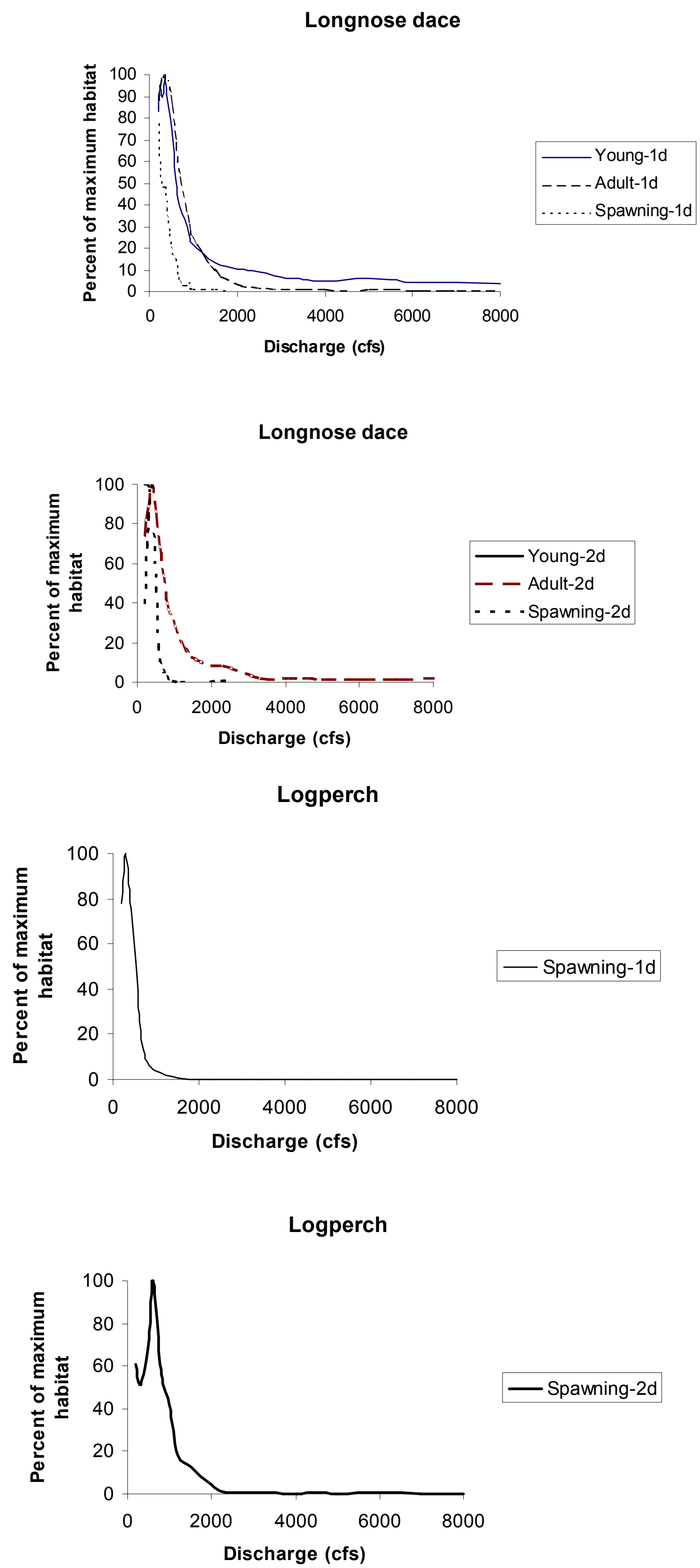


Figure 11. Comparison of Habitat Modeling Results between PHABSIM (1d) and River 2D (2d) for Longnose Dace And Logperch at Frog Point.

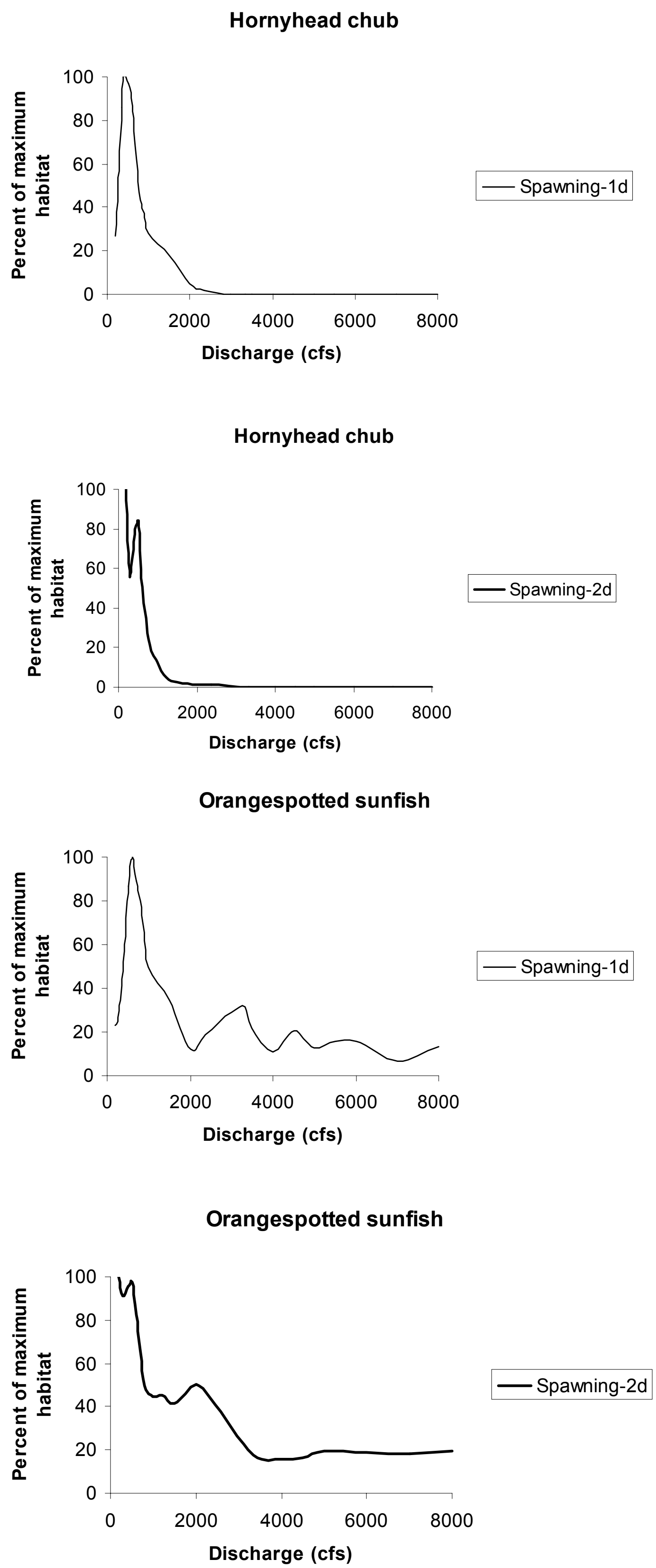


Figure 12. Comparison of Habitat Modeling Results between PHABSIM (1d) and River 2D (2d) for Hornyhead Chub and Orangespotted Sunfish at Frog Point.

Based on flood frequency analysis, annual bankfull flows occur 2 out of 3 years on average (Leopold et al. 1964; Dunne and Leopold 1978). In the Sheyenne and Red Rivers, bankfull flows occur most frequently during April. As discussed earlier, bankfull flows are important for maintaining stability of stream channels and the diversity of habitats found in river systems.

Providing high flows during the summer (after early July) beyond bankfull flows might cause excessive riparian zone physical adjustment. Therefore, high flows are not recommended during the low flow period for riverine riparian corridor improvement.

Watercourse/Floodplain Connectivity

Based on PHABSIM, floodplain flows for each site are summarized in Table 11. Floodplain flow is the flow at which the river begins to flow out of its topographic floodplain. The topographic floodplain is the area adjoining the river forming the bottom of a valley usually subject to flooding (for example, a 500-year flood event).

Between 1931 to1999, Red River flows near the Frog Point site exceeded floodplain flows twice in April--1969 and 1997 (Halstead gage). Floodplain flows were never reached during any other month. Flows exceeded 10,000 cfs twice in April (same 2 years) at the Fargo gage. The highest flow on record near the Norman site in the Sheyenne River occurred in April 1997 (4,757 cfs at the Kindred gage). The highest flow on record at the Lisbon gage was 4,982 cfs, and at the Warwick gage 1,794 cfs, both in April 1997.

Table 12. Estimated Floodplain Flows in the Sheyenne and Red Rivers.

Reference Site	Downstream transect high bank headpin elevation (ft)	Downstream transect low bank headpin elevation (ft)	Elevation difference (ft)	Estimated flood plain flow (cfs)
Sheyenne River:				
Warwick	96.2	90.2	6.0	>300[1]
Lisbon	87.0	85.5	1.5	>1,000[1]
Pigeon Point	60.9	57.5	3.4	>1,000[1]
Norman	97.8	94.2	3.6	>10,000[1]
Red River:				
Moorhead	98.1	77.8	20.3	>3,000[1]
Frog Point	829.1	838.0	8.9	21,000

[1] Flow reflects stage at bankfull, except the Norman and Moorhead sites reflect stage at low bank headpin elevation. Actual floodplain flow stage would be at high bank headpin elevation but this cannot be calculated with existing survey data.

Riparian Maintenance

The riparian corridor in the Sheyenne and Red Rivers is dominated by a variety of nonnative trees and herbaceous vegetation tolerant or very tolerant to flooding (Reclamation 1999). Pioneer species such as peachtree willow are confined to very shallow groundwater sites and require sustained flow for seedling establishment.

The recommended aquatic needs hydrology and bankfull flows would maintain the existing floodplain forest community. This flow scheme should produce adequate moist soil conditions to benefit seed germination and growth and improve the existing floodplain forest community. Large overbank flows in the Sheyenne and Red Rivers usually occur in March and early April. High flows would normally benefit riparian vegetation seedling establishment by increasing availability of required continuously moist surface soil conditions.

The timing of these flows, however, does not correspond to pioneering riparian vegetation species seed drop (late May to early July). If the goal were to improve the corridor for pioneering species seed germination and growth, flows out of channel (non-damaging channel capacity flows) should occur for a 2-week period between late May and early July, preceding cottonwood and willow seed disbursal by about a week. It should be noted that high flows in June do not follow the natural flow regime; based on historic unregulated flow records, average daily bankfull flows are rarely exceeded in June. At the Warwick and Kindred gages, for instance, bankfull flows were exceeded once between 1931 to 1999. Bankfull flows were never exceeded in June at the Lisbon gage over the period of record. At the Fargo and Halstead gages, bankfull flows were exceeded six times in June.

CONCLUSIONS: Chapter 4

Seasonal instream flow needs can be defined many ways. For this study, these flows were defined as those that maintain the existing community structure at a defined level based on the application of hydrologic, hydraulic, and habitat-based methodologies.

The seasonal instream flow regime is recommended for consideration by decisionmakers and resource managers as a means to protect the basic needs of aquatic life in the Sheyenne and Red Rivers.

RECOMMENDED AQUATIC NEEDS FLOW REGIME

Maintaining the hydrologic and geomorphologic needs of aquatic resources requires the protection of natural flow regimes (Table 8 lists flows by month and study site). In the Sheyenne and Red Rivers, the recommended aquatic needs flow regime is intended to balance the needs of the aquatic community. Any sustained deviation from this flow regime (for example, prolonged increase in flow) might benefit some fish species while harming others, depending on location and the season.

Fishery goals of state resources agencies would determine if alternative flow regimes were desirable. In addition, the potential of a reduced food supply due to increased flows might be more limiting than the fishery habitat. This information should prove useful for comparing effects of various flow alternatives on aquatic resources.

BANKFULL FLOWS

Periodic bankfull flows in March-May would be important to maintain channel stability and diversity of habitats of the Sheyenne and Red Rivers (Tables 11 and 12).

RIPARIAN MAINTENANCE

High flows in late May to early July would normally benefit riparian vegetation seedling establishment by increasing the availability of required continuously moist surface soil conditions. Based on historic unregulated flow records, however, high flows in late May-early July rarely occur in the Sheyenne and Red Rivers, and therefore may not be a desirable management strategy when considering the natural flow regime.

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