RECLAMATION
Managing Water in the West

BIGHORN LAKE
SEDIMENT MANAGEMENT STUDY

FINAL REPORT
March 2010


Bighorn Lake, Horseshoe Bend

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

US Army Corps of Engineers®
Omaha District

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Executive Summary

Bighorn Lake was created when the Bureau of Reclamation constructed Yellowtail Dam across the Bighorn River in the 1960s. Since dam closure, sediments have accumulated within the pool area and are impacting lake resources. A reconnaissance level technical study was conducted to evaluate several sediment management alternatives. The study used existing cross section, hydrologic, and sediment data for the reservoir as input to a one-dimensional sediment transport model. The sediment model was used to assess alternative scenario sediment conditions compared to existing conditions. Major points of the study scope include:

- Reconnaissance study level of detail, not suitable for final design
- Focus on alternative screening and comparison
- Highlight constraints, issues, and impacts of sediment management within Bighorn Lake
- The study has a technical emphasis, the evaluation of additional factors included in a typical planning process was not included

In April 2007, Reclamation initiated the Bighorn River System Long Term Issues Working Group (Group) to begin a collaborative process with parties across Montana and Wyoming to address public concerns and develop long term proposals and procedures to improve all of the benefits of the Yellowtail Unit. One of the Group's specific concerns was the deposition of sediment in the Bighorn Lake and how it is affecting the Bighorn Canyon National Recreation Area.

The primary recreational opportunities are located in the southern portion of the reservoir before the lake enters the reservoir canyon areas. The Group's particular area of sedimentation concern is at Horseshoe Bend (HSB), which is located immediately upstream of the canyon entrance. HSB is a remnant oxbow of the natural river, which provides an overly wide flood plain. Due to the narrow canyon downstream of HSB, public access at this location is an important recreation feature. The HSB area acts as an efficient stilling basin that traps sediments before it can enter the canyon. Deposition at HSB has exceeded 50 feet in several areas and can prevent access to the reservoir when the pool falls below the safe boat launch elevation identified by the National Park Service.

Six different alternatives were investigated with the sediment analysis. These alternatives consist of:

a. Maintain Higher Reservoir Levels During the Recreation Season.
b. Trap Sediment in the Pool Upstream of the Lovell Hwy 20 Causeway.
c. Flush Sediment Through the Horseshoe Bend Area.
d. Manage Sediment at Horseshoe Bend with a Separation Berm.
e. Manage Watershed Sediments.
f. Dredge Horseshoe Bend Sediments.

A one-dimensional hydraulic and sediment model was developed using existing geometry to evaluate future base and alternative conditions. The model allows predictions of sediment impacts within the pool and specifically at Horseshoe Bend. Simulations were performed using the 2007 survey data and then repeating the historical flow and pool record from October 1966, after the pool was initially filled, to July 2007. This simulation period allows evaluation of future conditions for a 40 year period assuming historical conditions, both flow and sediment are representative of the future.

Base and alternative condition analysis conclusions are as follows:

General

- All alternatives illustrate the ability to impact sediments within the pool and at HSB.
- The model demonstrated the ability to assess pool level impact on sediment deposition. For a variety of future operation scenarios that alter pool levels, the model could be employed to predict future bed elevations.
- Sediment modeling results showed a level of accuracy of 5 to 15 percent when simulating the historic period. The model is best used as a tool to compare change between alternatives instead of actual elevation that is likely to have an error band of ± 5 feet at locations between HSB and the Causeway.
- Results assume that flow and sediment rates observed in the past remain similar in the future. Caution should be used when looking at time values. Since 1967 was an extreme event, results would be completely different if the model simulations started with year 2001 instead of year 1966.
- Sediment is episodic. Extreme events with the accompanying high sediment load will alter projections. Evaluation of alternatives should focus on long time intervals of 20 to 40 years.
- Alternatives which modify pool levels illustrate that pool level is a critical component. Pool levels affect equilibrium elevations within HSB and upstream areas as well as the rate of delta migration toward the dam.
- Some of the alternatives, such as Alt. C and Alt. F with the dredge discharge into the pool, have a negative effect by increasing the rate of delta migration toward the dam. This negative impact should be considered when evaluating alternative implementation.
- 2007 survey elevations within HSB indicate an average bed elevation of 3608 feet. Base condition modeling predicts that the sediment deposition level within the HSB will be in the range of elevation 3620 feet within 10 to 20 years from 2007.
- Over time, bed elevations within HSB will approach a new equilibrium level. Based on location within HSB, the equilibrium average bed elevation is predicted to vary from elevation 3622 to 3627 feet. The time to reach this level is predicted to vary from 25 to 35 years from 2007.
- 2007 survey elevations at Barry’s Landing indicated that less than 20 feet of sediment has deposited at this location with an average bed elevation of 3480 feet. While formation of the delta front and slope is difficult to predict with accuracy, model results show the delta front advancing beyond Barry’s Landing within a 30 to 40 year time period. Model results predict reaching a near equilibrium bed elevation in the range of 3600 feet at this location.

Alternative A

- Alternative A, maintaining higher seasonal reservoir levels, will likely provide additional recreational water depths for a period of 15 to 25 years compared to the base condition during years when the elevated pool level is attained. However, during drought years, the elevated sediment within HSB will impact recreation more severely than the base condition.
- Alternative A is consistent with current park management, no significant changes to resource management is anticipated if lake levels do not exceed 3640 feet for prolonged periods of time during the summer use season.

Alternative B

- Alternative B, the upstream sediment basin, provides benefits to the HSB that will continue as long as the basin is maintained although the maximum trap efficiency that can be sustained is likely around 70 percent.
- Alternative B benefits the lake portion of park. Sediment trapping would alter habitat and fisheries within Yellowtail Habitat area and visitor use. Sediment trap issues include project life maintenance and blowing sands.

Alternative C

- Alternative C, sediment flushing through HSB, is not recommended as the recreational use of HSB is negatively impacted, sediments are moved at a faster rate toward the dam, and implementation would likely impact reservoir operations and releases.

Alternative D

- Alternative D, the HSB dike, shows the potential to maintain sediment levels near the current elevation within HSB. However, the sediment model is not capable of accurately modeling the local sediment deposition that would occur at the recreation area connections to the river section.
- Additional sediment deposition would occur within the protected portion of HSB due to general turbidity.
- Alternative D has implementation issues with impacts to HSB recreational access, watercraft safety, fisheries within Horseshoe Bend area, and structure maintenance.

Alternative E

- Alternative E, to manage watershed sediments, was not evaluated in this study. Successful implementation would require a fairly long time period through extensive watershed coordination. In addition, it is projected to require a fairly high level of maintenance to maintain effectiveness over a long time period.

Alternative F

- Alternative F, dredging within HSB, illustrates the ability to maintain lower elevations to provide recreation access. However, disposal within the pool downstream in the narrow canyon will impact future bed elevations within the HSB and move sediments at a faster rate toward the dam. Land disposal is extremely expensive.
- Alternative F has implementation issues with continued dredging costs, boater safety within HSB, and likely impacts to fisheries due to dredging operations within HSB.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ATTACHMENTS

BIGHORN LAKE SEDIMENT MANAGEMENT STUDY

1. INTRODUCTION.

Bighorn Lake was created when the Bureau of Reclamation constructed Yellowtail Dam across the Bighorn River in the 1960s. Since dam closure, sediments have accumulated within the pool area and are impacting lake resources. A reconnaissance level technical study was conducted to evaluate several sediment management alternatives. The study used existing cross section, hydrologic, and sediment data for the reservoir as input to a one-dimensional sediment transport model. The sediment model was used to assess alternative scenario sediment conditions compared to existing conditions. Major points of the study scope include:

- Reconnaissance study level of detail, not suitable for final design
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1.1 BACKGROUND.

The Yellowtail Unit in south-central Montana is a multipurpose development of the Pick-Sloan Missouri Basin Program providing benefits through hydropower generation, flood control, irrigation, municipal & industrial water supply, recreation, and fish & wildlife enhancement. Facilities consist of Yellowtail Dam and Bighorn Lake on the Bighorn River, Yellowtail Powerplant, and the Yellowtail Afterbay Dam. Yellowtail Dam, at the northern end of Bighorn Canyon, impounds flows of the Bighorn River creating the Bighorn Lake which begins in Montana and extends south into the Bighorn Basin of Wyoming. Yellowtail Dam operations are the responsibility of Reclamation while the National Park Service (NPS) manages the Bighorn Canyon National Recreation Area. Yellowtail Dam was closed in November 1965 with full pool reached in the summer operating season of 1966.

The reservoir, at full pool, impounds approximately 1.32 million acre-feet of water, covers approximately 17,200 acres, and is approximately 71 miles long. The reservoir is operated as a multi-use facility for the purposes of flood control, hydropower, recreation, and water supply. To meet these demands the reservoir is generally filled to the maximum elevation of 3630 to 3640 feet by mid July and held near this elevation until the fall. The reservoir is then drawn down through the winter until it reaches an elevation of approximately 3600 to 3610 feet in April. Reservoir pool elevations vary annually with many factors. All elevations reported in this study use the Reclamation project vertical datum for Yellowtail Dam and Bighorn Reservoir which corresponds to feet above mean sea level.

Approximately half of the basin runoff and sediment input is controlled by the Boysen, Anchor, and Buffalo Bill Dams. The sediment contributing portion of the basin is arid, steep, and sparsely vegetated, which tends to yield relatively large amounts of sediment. The project is currently operated to fill during the peak flow spring runoff season which is also the highest sediment producing period.

1.2 STUDY FOCUS.

In April 2007, Reclamation initiated the Bighorn River System Long Term Issues Working Group (Group) to begin a collaborative process with parties across Montana and Wyoming to address public concerns and develop long term proposals and procedures to improve all of the benefits of the Yellowtail Unit. One of the Group's specific concerns was the deposition of sediment in the Bighorn Lake and how it is affecting the Bighorn Canyon National Recreation Area.

The primary recreational opportunities are located in the southern portion of the reservoir before the lake enters the reservoir canyon areas. The Group's particular area of sedimentation concern is at Horseshoe Bend (HSB), which is located immediately upstream of the canyon entrance. HSB is a remnant oxbow of the natural river, which provides an overly wide flood plain. Due to the narrow canyon downstream of HSB, public access at this location is an important recreation feature. The HSB area acts as an efficient stilling basin that traps sediments before it can enter the canyon. Deposition at HSB has exceeded 50 feet in several areas and can prevent access to the reservoir when the pool falls below the safe boat launch elevation identified by the National Park Service.

1.3 SEDIMENT MANAGEMENT ALTERNATIVES.

Six different alternatives were investigated with the sediment analysis. These alternatives consist of:

g. Maintain Higher Reservoir Levels During the Recreation Season.
h. Trap Sediment in the Pool Upstream of the Lovell Hwy 20 Causeway.
i. Flush Sediment Through the Horseshoe Bend Area.
j. Manage Sediment at Horseshoe Bend with a Separation Berm.
k. Manage Watershed Sediments.
l. Dredge Horseshoe Bend Sediments.

1.4 STUDY METHODOLOGY.

Study methodology consists of several steps as summarized below:

- Collect available data required for the sediment model
- Construct the sediment model, fill in missing data gaps as necessary
- Evaluate the model for existing conditions with limited calibration
- Modify the model for each alternative
- Evaluate and compare model results
- Use the model evaluation to provide a basis for study recommendations

1.5 METHOD FOR RESULTS COMPARISON.

Comparison of model simulated results to observed conditions and the comparison of model simulated results between alternatives relies on the average bed elevation for each cross section. The thalweg, or minimum elevation within the section, does not always reflect the sediment deposition that occurs. The average bed elevation is a computational method to evaluate change within a larger portion of the section. Average bed elevation computed by the model is dependent upon the selected bank stations. A sensitivity analysis was performed to evaluate the impact of bank stations on the average bed elevation. Minimal difference was determined on the net average bed elevation change due to varying bank station location. Therefore, bank stations were selected to facilitate the computation of an average bed elevation that reflects both the change in channel elevation and the floodplain elevation due to sediment deposition.

2. STUDY AREA OVERVIEW.

The Bighorn River is a tributary of the Yellowstone River and is approximately 461 miles long. The upper reaches of the Bighorn River, south of the Owl Creek Mountains in Wyoming, are known as the Wind River. For practical purposes, Boysen Reservoir in the Owl Creek Mountains may be considered to be the start of the Bighorn River. From Boysen Dam, the Bighorn River flows north through central Wyoming toward Montana. Principal tributaries in Wyoming include the Nowood, Greybull, and Shoshone Rivers. Near the border with Montana, the river turns northeast and flows past the north end of the Bighorn Mountains and toward Yellowtail Dam, located in Montana. The reservoir and the surrounding area are part of the Bighorn Canyon National Recreation Area. An outline of the basin area is shown in Plate 1. A site visit was conducted in May 2008 and is included as Attachment A.

2.1 BASIN SEDIMENTS.

This study did not include a detailed evaluation of drainage basins from the perspective of sediment yield. A review of available literature indicates that sediment accumulation in Bighorn Lake is the result of several factors including the erodible quality of the bedrock, lack of ground cover in the basin, and steep stream gradients in the Bighorn River Basin. Sediments flowing in the Bighorn River as it enters the southern end of Bighorn Lake have been estimated to be about 4,000 tons per day, with the identified sources being erosion of streambanks, flows returned to the river after cropland irrigation, erosion from croplands due to irrigation practices, and erosion from rangeland (Soil Conservation Service, 1994).

A limited detail evaluation was conducted to check drainage basin area with respect to constructed dams. Reservoir impoundments act to store sediments that may impact sediment delivery to Bighorn Lake. A cursory evaluation was performed to check for major basin construction efforts that would impact the sediment inflow to Bighorn Lake. The cursory review was performed to evaluate the historic sediment record with respect to specifying the Bighorn and Shoshone flow – sediment relationship within the model.

Within the Bighorn River basin, numerous dams have been constructed. There are over 30 reservoirs within the basin that each have 500 acre-feet or more of storage. The majority of these were constructed in the early 1900's (Wyoming Water Commission, 2003, Chap 2, pg. 44). The largest reservoirs in the basin were constructed by the Bureau of Reclamation.

Boysen Dam – Old Boysen Dam was constructed on the Wind River about 1.5 miles downstream of the present dam location with dam closure in 1908. Following a flood in 1923 that resulted in upstream flooding, a portion of the dam was removed to reduced future flood impacts. After additional studies, the remaining portion of the old dam was removed in 1948 in conjunction with establishing desirable tailwater conditions for the Boysen powerplant. Construction of the new dam at the present dam site 1.5 miles upstream of the old dam began in 1947. Closure of the new dam and first reservoir storage began in October 1951. The contributing drainage area is about 7,700 square miles (Reclamation, 1994).

Buffalo Bill Dam – Located on the Shoshone River, near Cody, Wyoming, dam closure occurred in May 1910. The contributing drainage area to the reservoir is 1,504 square miles. The structure has been modified on numerous occasions.

Yellowtail Dam – Located on the Bighorn River, the dam is located near the mouth of Bighorn Canyon about 21 miles north of the Montana-Wyoming state line. Dam closure occurred in November 1965. Contributing drainage area is 19,650 square miles.

A review of the Yellowtail Sedimentation Definite Project Report (Reclamation, 1949) and the Bighorn Lake Sedimentation Survey (Reclamation, 1982) revealed the following major points with respect to sediment contribution:

- Tributaries, both perennial and intermittent, have high gradients ranging from about 50 feet per mile in the foothill zone to about 20 feet per mile in the central portion of the basin.
- Physiographic factors in the central valley area favor high sediment production. Factors including high stream gradients, low precipitation, erodability of the underlying rock strata, and the lack of ground cover to protect the ground surface are favorable for sediment production.
- Analysis of Bighorn River collected sediment data at Kane indicates a sediment load increase of almost double from that at Thermopolis while the runoff increase is only about one half. Accordingly, sediment production in the Bighorn basin is much greater relative to runoff than that in the Wind River Basin to the south.

- Based on limited gage records, the total sediment contribution to Yellowtail Dam was estimated as just under 5,000 ac-ft per year (Reclamation, 1949). Following the reservoir sedimentation survey, the volume of sediment accumulated in the reservoir correlated to an average sediment rate of 3,224 acre-feet per year from November 1965 through July 1982 (Reclamation, 1986, Pg. 1). Results from the 2007 survey performed by Reclamation to update sediment rates were not available for this study.

2.2 HORSESHOE BEND AREA.

Horseshoe Bend is an extremely pronounced, incised meander located about 45 miles upstream from Yellowtail Dam. Compared to the rest of the reservoir canyon which has an average width of 500 to 600 feet, HSB has a large cross-sectional area with a 2,000 to 3,000 foot width that results in lower flow velocities and, consequently, lower sediment carrying capability than at other locations. HSB sediment accumulation is of particular concern as this location is the major visitor use facility with access to Bighorn Lake. HSB is one of the few suitable sites for recreational development because most of the lakeshore consists of deeply incised canyon walls without any developed facilities for lake access.

Previous studies have been conducted to evaluate sediment accumulation at HSB as summarized in the following paragraph (NPS, 1996, pg. 63).

> A recent review of sediment rates and patterns by the National Park Service's (NPS) Water Resources Division (Martin 1995), in conjunction with the Bureau of Reclamation, yielded an estimate that sedimentation will continue to accumulate until it reaches an elevation of approximately 1,103 m (3,620 ft). At that point, under the current operating constraints, it is thought that sediment accumulation in the Horseshoe Bend Area will reach a state of equilibrium with most incoming sediments moving downstream towards the dam, rather than accumulating at Horseshoe Bend. It is estimated that the remaining 3.4-3.7 m (11-12 ft) of sediment, before a state of equilibrium is reached, will accumulate over the next 4 to 20 years. The report points out that sediment transport can be highly episodic. Consequently, time remaining until an equilibrium point is reached could be less than 4 years or greater than 20 years.

The preceding summary has several interesting points including the estimate that an equilibrium sediment deposition elevation near Horseshoe Bend is 3620 feet for the **current operating conditions** and that the time to reach this condition is between 4 and 20 years. Also of note is that a change in reservoir pool levels is expected to alter sediment deposition within Bighorn Lake.

3. MODEL FORMULATION.

The construction of a sediment model requires the assembly of geometric, hydraulic, and sediment data. The data assembly and model construction procedures are described in detail in the following sections.

3.1 MODEL SELECTION.

Two models were considered to evaluate the alternatives. The models were HEC-RAS version 4.0 and SRH-1D version 2.1. Both models are one-dimensional hydraulic and sediment transport models for use in natural rivers. These models have similar input data requirements and capabilities. Initial analysis was performed with each model to evaluate preliminary results and form a basis for model selection. Based on this comparison, the SRH-1D model was selected.

General notes regarding the model are stated below. Refer to the users manual (Reclamation, 2008) for a complete description.

> SRH-1D is a general numerical model developed to simulate and predict cohesive and non-cohesive sediment transport and related river morphological changes due to natural or human

influences. SRH-1D is an engineering tool for solving fluvial hydraulic problems with the following limitations:

(1) SRH-1D is a one-dimensional model for flow simulation. It should not be applied to situations where a two-dimensional or three-dimensional model is needed for detailed simulation of local hydraulic conditions. Phenomena such as secondary currents, lateral diffusion, superelevation, and transverse sediment movement are ignored.

(2) Many of the sediment transport modules and concepts used in SRH-1D are simplified approximations of real phenomena. Those approximations and their limits of validity are embedded in the model.

The latest information about SRH-1D is placed on the Web and can be found by accessing http://www.usbr.gov/pmts/sediment and following the links on the web page. Requests may be sent directly to the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Attention: SRH Support, U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, P.O. Box 25007 (86-68540), Denver, CO 80225).

SRH-1D is under continuous development and improvement. A user is encouraged to check the SRH-1D web page regularly for updates.

Source: SRH-1D Users Manual. (Reclamation, 2008, pg. 2)

As discussed above, SRH-1D is a one-dimensional model with numerous capabilities. The SRH-1D model also has important limitations that should be considered when evaluating study results. For example, the flow phenomena occurring within Horseshoe Bend have important multi-dimensional characteristics which should be considered when evaluating results. However, for the purpose of this reconnaissance analysis and the comparison of alternatives, the selection of a one-dimensional model was determined as appropriate.

3.2 MODEL FLOW AND BOUNDARY CONDITIONS.

Model assembly requires the specification of flow at the upstream boundary and stage or water surface elevation at the downstream boundary. The daily Yellowtail pool record is used to specify the downstream boundary condition. Flow input to the model for the upstream boundary consists of Bighorn River daily flow values for the period of model simulation. Model inflow was assembled for the period from 1965 through 2007, corresponding to the interval between the cross section surveys. Available flow data consisted of the pool inflow record and USGS flow records. Flow data assembled for model input is summarized in Table 1.

Table 1

Model Flow Sources

Location	Notes
Yellowtail Pool Inflow Drainage Area 19,650 sq. mi	Record, 1965 – 2007, Derived from pool release and stage – storage curve. Drainage area of 9,204 sq.mi. controlled by Boysen and Buffalo Bill dams. Other small dams also affect sediment inflow
Bighorn River at Kane Drainage Area 15,762 sq.mi	Gage Record Oct 1928 through current, Gage ID 06279500
Shoshone River at Lovell Drainage Area 2350 sq.mi	Gage Record Oct 1966 through current, Gage ID 06285100
Ungaged Tributary Inflow – Drainage area of 1,538 square miles. Several tributaries enter Bighorn Lake downstream of the gaged inflow station including Crooked Creek, drainage area of 119 square miles, and Porcupine Creek, drainage area of 135 square miles.	

A brief analysis was performed of the inflow data set to determine the range of conditions experienced during the period from 1965 through 2007. Data is summarized in Table 2. Computed inflow represents all inflow to the reservoir other than the Bighorn River. Computed inflow is derived from the change in pool elevation and the pool elevation – volume relationship. As the data illustrates, the difference between the computed inflow and the Shoshone record is generally small, with an average flow value of about 300 cfs. A few time periods show spikes that are probably caused by a difference in timing between the flow records. A plot of observed daily values from an example 5 year period, October 1995 to September 2000, is shown in Figure 1.

Table 2. Flow Period Statistics

Statistics Computed From Flow Period 1 Oct 1966 thru 30 Nov 2007, All Flows Cfs

	Combined Pool Inflow[1]	Bighorn Kane USGS Flow	Shoshone Lovell USGS Flow	Compute All Lateral Inflow [2]	Compute Ungaged [3]	Yellowtail Pool Elev
Max	29,776	24,800	15,200	12,450	5,797	3,656.4
Median	2,635	1,680	621	968	309	3,620.9
Min	-213	350	27	10	-4,204	3,572.8
75th Percent.[4]	3,687	2,380	890	1,442	608	3,633.1
90th Percent. [4]	5,577	3,510	1,340	2,141	929	3,637.6

[1] Combined pool inflow from Bureau of Reclamation records, derived from pool elevation and pool elevation vs. volume relationship.
[2] Computed from the pool inflow record minus the Bighorn at Kane flow record.
[3] Computed from the pool inflow record minus the Bighorn and Shoshone flow records.
[4] Refers to the kth percentile rank of the values in the record.

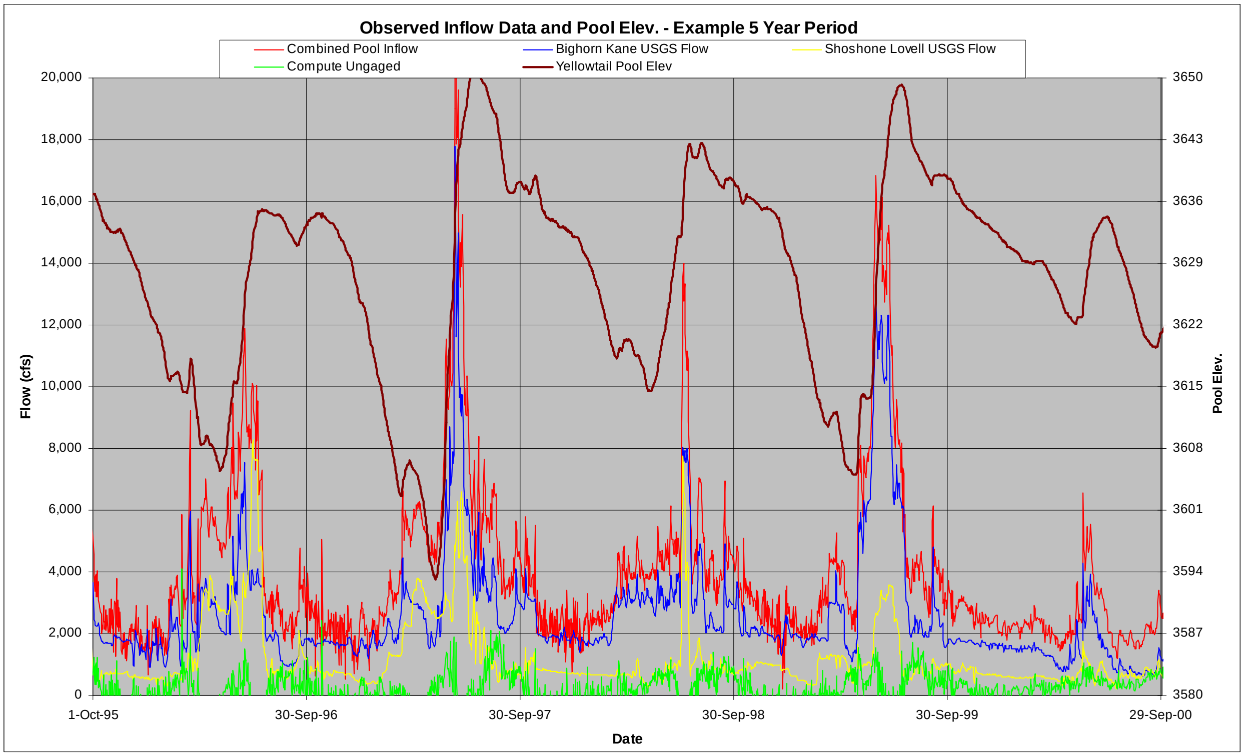


Figure 1

3.2.1 Ungaged Drainage Area.

Ungaged drainage area refers to the portion of the total inflow to Yellowtail Dam that is not captured by the gaged inflow stations on the Bighorn and Shoshone Rivers. The drainage area for the Bighorn River at Yellowtail Dam is 19,650 sq. mi. The sum of the gaged inflow drainage area from both the Bighorn River at Kane and the Shoshone River at Lovell is 18,112 sq.mi. The remaining drainage area of 1,538 sq. mi is ungaged. Accounting for the Boysen and Buffalo Bill reservoirs drainage areas, the uncontrolled drainage area at Yellowtail Dam is 10,446 sq mi. The 1,538 sq. mi. ungaged drainage area is about 15 percent of the uncontrolled drainage area.

If significant ungaged inflow occurred between the Shoshone River and HSB, the additional flow would affect the energy available to move sediments toward the dam. However, this additional flow would also be offset by a likely sediment contribution. Examination of the tributary drainage channels entering the Bighorn River between the Shoshone River and HSB did not indicate any overly large channels. Since the sediment model is not used to compute pool levels from the inflow, the derivation of ungaged inflow is not required. Therefore, the Shoshone River inflow and sediment load were used to represent all tributary inputs between the Lovell Causeway and HSB.

3.2.2 Input to Model.

Input to the model consists of the boundary conditions and lateral inflow. Flow may be entered within the model as an upstream boundary condition inflow, a point lateral inflow (all flow enters at a single location), or a distributed uniform lateral inflow (flow is distributed to occur over a specified reach).

An important consideration when evaluating the method used to specify model flow input is that all sediment input to the model is correlated with flow by a specified relationship. Therefore, when flow enters the model, sediment is also entered that is derived from the flow-sediment relationship.

Model boundary conditions and inflow were included as follows:

1) Upstream boundary inflow - Bighorn River at Kane daily flow record, enters at the upstream model limit, station 399,490 or river mile 75.66.

2) Point lateral inflow - Shoshone River at Lovell daily flow record, enters at model station 295,790 or river mile 56.02.

3) Distributed lateral inflow to add sediment, simulated to enter between model stations 241,000 and 210,000 to represent contributions from Crooked Creek and Porcupine Creek. NOTE: Not based on gaged data, added to model to better replicate observed sediment survey results.

4) Distributed lateral inflow to add sediment, simulated to enter between model stations 100,000 and 50,000 to represent contributions from Dry Head Creek. NOTE: Not based on gaged data, added to model to better replicate observed sediment survey results.

5) Downstream boundary condition entered as the Bighorn Lake pool daily elevation record, model station 0.

3.3 SEDIMENT DATA COLLECTION AND INPUT FORMULATION.

Data collection for the Bighorn sediment model revealed a sparse data set available to provide required model input parameters. The available data was used to assemble the best estimates of sediment inflow and gradation required to provide model input. Table 3 summarizes model input requirements, the available data to provide the model inputs, and identifies data gaps. The sparsity and wide variation in measured sediment data is an important factor to consider in evaluation of model results.

Table 3. Sediment Data Summary

Parameter	Source	Notes
Sediment Inflow	USGS Gage Station: Bighorn River at Kane (Mar 1946 – Sep 1964, Inter. 1964-current) Shoshone River at Kane (Oct 1959 – Sep 1964) Shoshone River at Lovell (Inter. 1966–current)	Limited duration record, daily record ends Sep 1964. Intermittent values, the available data shows wide scatter.
Sediment Inflow Gradation	Sparse set of data tested at USGS gage stations	Limited data set available, with most of the data prior to 1965. Data shows wide scatter.
Bed Material Gradation	Sparse set of USGS gage station data 1982 gradation test results at range lines from the USGS survey	Dominant data set is the 1982 range line survey data set available (Reclamation, 1986).
Pool Level	Available for period of record	Complete data set for pool levels.
Water Temperature	Incomplete data set from USGS gage record	May be specified daily or as a constant temperature
Erosion / Deposition Limits	Specific for each cross section	May specify limits of the erosion / deposition at each cross section if needed
Sediment Transport	Estimated flow – sediment relationship from USGS gage record	Wide variation in data and flow/sediment relationship
Cohesive Sediment Parameters	None available	Critical factor due to the high percentage of cohesive material in the sediment, limitation on model.
Bedrock Geometry	None available	Not really a factor to model reservoir delta deposition

3.3.1 River Gage Sediment Data.

Sediment gage data from the Bighorn River at Kane USGS gage station and the Shoshone River at Lovell were evaluated to develop the flow – sediment relationships. Evaluated data is illustrated in Figure 2 and Figure 3.

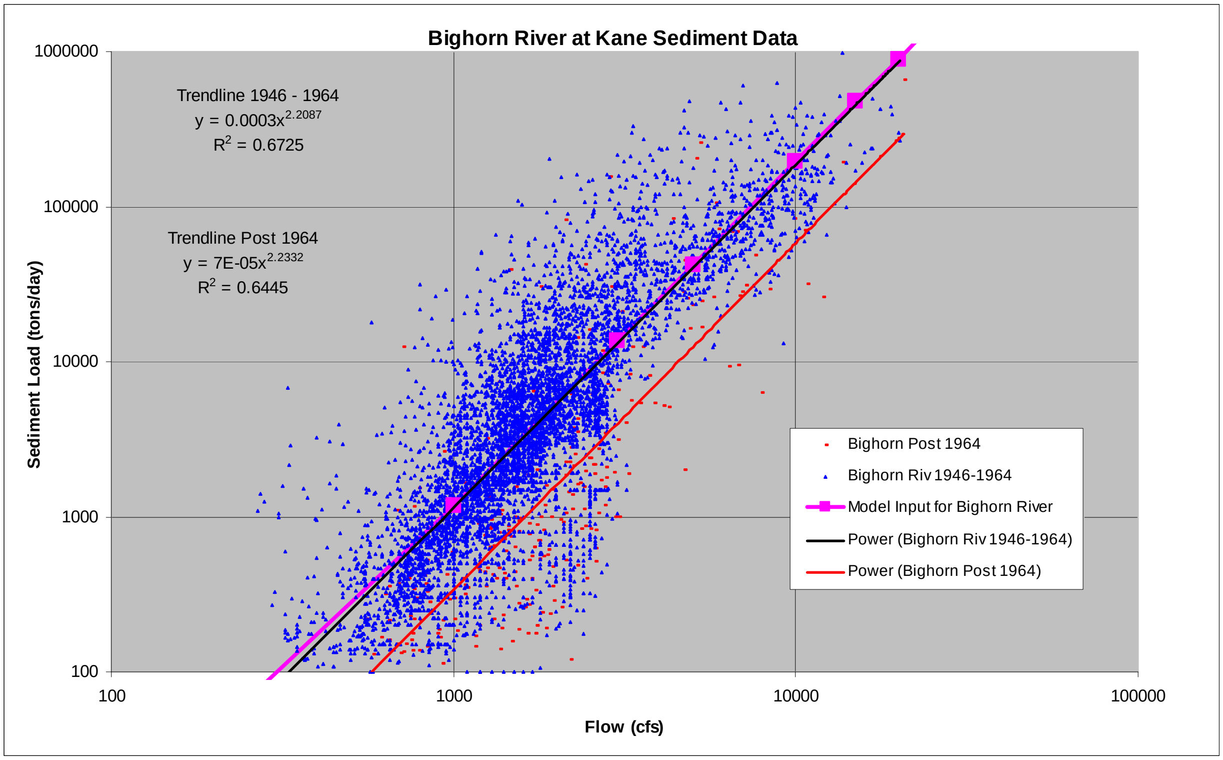


Figure 2

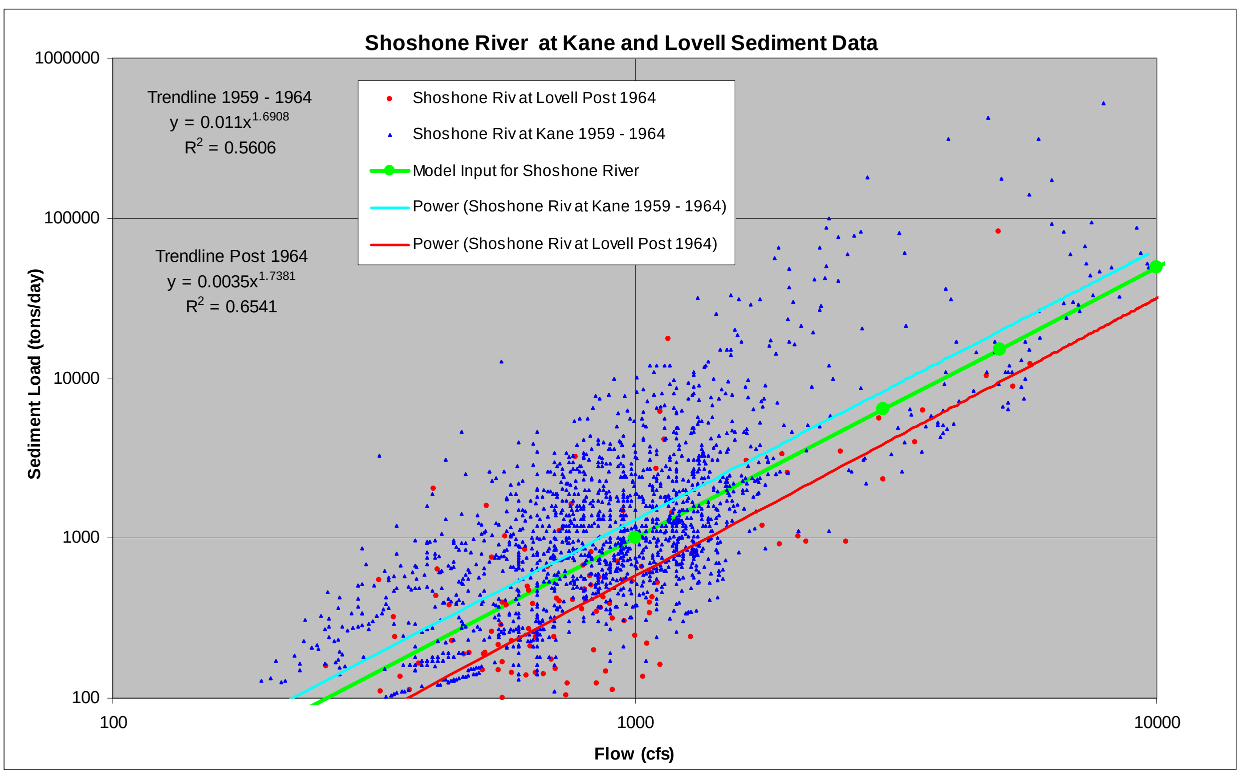


Figure 3

Gage data illustrates the wide variation in measured suspended sediment load vs flow. Both gages indicate that the more recent data has had lower sediment load levels as shown by the estimated trend line. However, this is based on a much smaller subset of data, less than 5 percent of the measured values occurred after 1964. Model analysis was used to evaluate and select the flow – sediment relationship illustrated in Figure 2 and Figure 3 as the Model Input curve. Evaluation determined that if the post 1964 relationship was used, the model results appeared to be sediment deficient. A tabulated version of the model input sediment load relationships are shown in Table 4.

Table 4 – Model Sediment Input Loads
(tons/day)

Flow (cfs)	Bighorn 1947 - 64	Bighorn Post 64	Bighorn River Model Input	Shoshone 1959 - 64	Shoshone Post 64	Shoshone River Model Input
100	10	2	10	26	10	20
1,000	1,270	351	1,190	1,300	573	1,000
3,000	14,400	4,076	13,540	8,327	3,869	6,390
5,000	44,520	12,754	41,870	19,752	9,403	15,160
10,000	205,840	59,965	193,710	63,767	31,367	48,910
15,000	504,110	148,301	474,590	126,569	63,465	97,050
20,000	951,760	281,941	896,260	205,861	104,638	157,820
25,000	1,558,150	464,064	1,467,590	300,213	154,215	230,110
30,000	2,330,930	697,277	2,195,820	408,610	211,715	313,150

3.3.2 Ungaged Tributary Sediment Inflow.

As previously described in the ungaged inflow section, about 15 percent of the Yellowtail contributing drainage area is ungaged. These ungaged drainage areas are expected to contribute both flow and sediment. A review of bed elevation change over time was conducted to evaluate inflowing sediment locations. As shown in Figure 4, the bed elevation change provided by the survey data indicates the location of additional sediment input in the vicinity of the dam, near station 80,500, and a smaller input in the reach downstream of HSB from station 240,000 to 200,000. These inputs are shown by the spike in bed change near station 80,500 and the prolonged smaller bed change from station 240,000 to 200,000.

Range Line 4 at station 80,552 is located just downstream of Dry Head Creek which appears to be a likely source for some of the sediment shown on Figure 4. Another tributary, Black Canyon Creek, enters just upstream of Range Line 2 at station 24,183 and is another likely sediment source in this vicinity. Further, a landslide occurred sometime before 2007 at a location about 7,500 feet upstream of Range Line 3. The landslide material may be partially responsible for preventing bed load transport downstream of the constriction which would result in upstream deposition.

The reach downstream of HSB corresponds to the location of Crooked Creek, near Range Line 11 at station 238,985 and Porcupine Creek, which enters just upstream of Range Line 10 at station 212,968. The 1982 survey illustrates some sediment inputs in this reach as the delta face advancing into the pool is not defined. The 2007 survey results do not reveal the sediment contribution in this area since the delta has advanced farther into the pool. Detailed surveys illustrating the location of the delta front in 2007, likely located between Range Line 10 and 11, were not available for this analysis.

Methods to input ungaged inflow / sediment were evaluated by using the flow record for the Bighorn and Shoshone Rivers combined with an assumed reduction factor. Determination of ungaged inflow from a specific tributary may be computed by using a drainage area ratio or regional equations. These methods require development of detailed drainage basin areas, evaluation of gaged tributaries of similar drainage area and runoff characteristics, and knowledge of the sediment – flow relationship for the tributary. This information was not readily available and deemed to be beyond the scope of this study.

Empirical simulation of the sediment input at Dry Head Creek was included in the model since this location could start to interact with delta sediments at some point in the future. The further downstream sediment source apparent near Yellowtail Dam was not attempted. The derivation of the flow – sediment combination that generates elevations similar to the observed condition can be a tedious process. Initial evaluations using an assumed ratio of the Bighorn inflow record were unsuccessful and appeared to contribute to instability. The issues were assumed to be related to the peak inflow pattern and the pool fluctuation. After some comparison, the most consistent results occurred by simply assigning a constant inflow record at the inflow location and deriving the sediment relationship to match observed elevations. It should be noted that this method is highly empirical and suitable only for use within the model comparison scenario. Derived sediment inflow rate using this method has no relationship to the actual tributary flow - sediment transport relationship. The derived tributary sediment volume for the period from 1965 to 2007 entered into the model is completely empirical from the available survey information.

It is possible that including the estimated ungaged inflow may impact computed results. Therefore, simulations were performed both with and without the ungaged inflow. Simplification of model input may be preferable to minimize potential confusion with alternative comparison. A comparison of results did not reveal any significant difference in result in the reach between HSB and Yellowtail Dam. Alternative simulations included estimated sediment input from Crooked / Porcupine Creek and Dry Head Creek.

3.3.3 Model Sediment Input.

Input to the model can occur using a number of methods. Sediment data was evaluated and entered with a power function that allows the model to compute the sediment load from flow. The values are shown in Table 5.

$$Q_s = a * Q^b$$

Where Qs = sediment discharge, tons per day
Q = average daily flow rate (cfs)
a = coefficient 1
b = coefficient 2

Table 5. Model Sediment Input Discharge Coefficients

River	Coefficient a	Coefficient b
Bighorn (Upstream Boundary)	0.00028	2.21
Shoshone (Sta 295,790)	0.0085	1.69
Ungaged, Sta 241,000-200,000 (Crooked / Porcupine)	0.065	1.84 (applied to constant flow of 200 cfs)
Ungaged, Sta 100,000 – 50,000 (Dry Head Creek)	0.32	1.9 (applied to constant flow of 200 cfs)

The relationship expressed by the above equation can also be used to determine the sediment contribution from the Bighorn and Shoshone Rivers for the period of record using the daily flow values. Computed sediment load was compared to the previous average sediment rate of 3,224 acre-feet per year from November 1965 through July 1982 (Reclamation, 1986, Pg. 1). The comparison determined that model input exceeded the observed value by about 20 percent. It is likely that some of this difference is due to model performance within the upstream model sections which were not surveyed in 2007. Model results show considerable deposition in the reach upstream of the Lovell Causeway. It is also possible that sediment deposition extended beyond the bounds of the 1982 survey which would tend to underestimate the total Bighorn River sediment load. In any case, the computed values show that the model sediment inputs are in the range of accepted values and that the Bighorn River is estimated to contribute the majority of inflowing sediments, in the range of 80 to 90 percent of the total. The sediment source evaluation does not address contribution from other smaller tributaries. Results of the sediment source evaluation are shown in Table 6.

Table 6. Sediment Model Input Evaluation

Item	Computed From Daily Bighorn River Record	Computed From Daily Shoshone River Record
Maximum (tons/day)	1,544,760	99,250
Median (tons/day)	4,030	440
Minimum (tons/day)	126	1
Average Annual (acre-feet)	3,735	320
Total Sediment (acre-feet)[1]	156,860	13,530
Total Sediment Reduced (acre-feet) [2]	122,150	13,530
Average Annual Sediment Reduced (acre-feet) [2]	2,908	320
Percent of Total	≈ 90%	≈ 10%

1 Computed with a sediment weight of 60 lb/cu ft
2 The Bighorn River average annual sediment volume (ac-ft/yr) was reduced to match the observed sediment rate of 3,224 ac-ft/yr. The Shoshone River and downstream tributaries are not included in the correction.
NOTE: Sediment sources from other smaller tributaries such as Dry Head Creek, Black Canyon Creek, Porcupine Creek, and Crooked Creek not included.

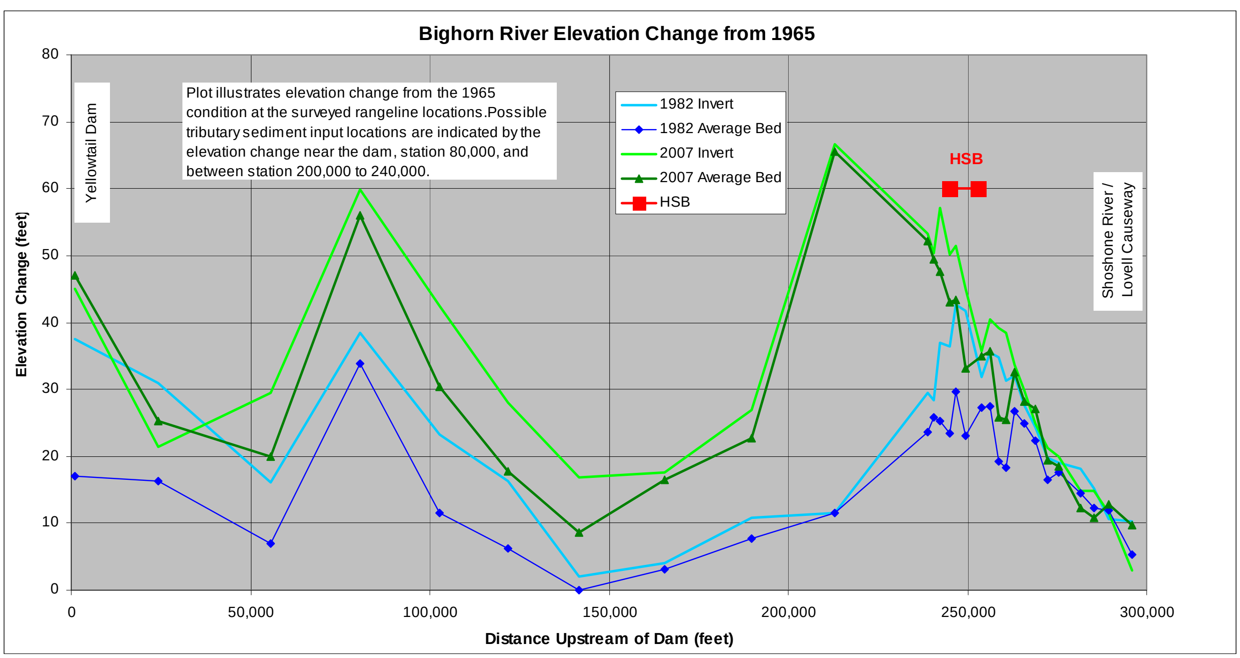


Figure 4

3.3.4 Sediment Gradations.

Sediment input to the model must be specified by size. Two sources were available for this information. The first source of gradation data is from the samples collected in 1982 along the reservoir range lines (Reclamation, 1986). The gradation range at the different range lines is illustrated in Figure 5.

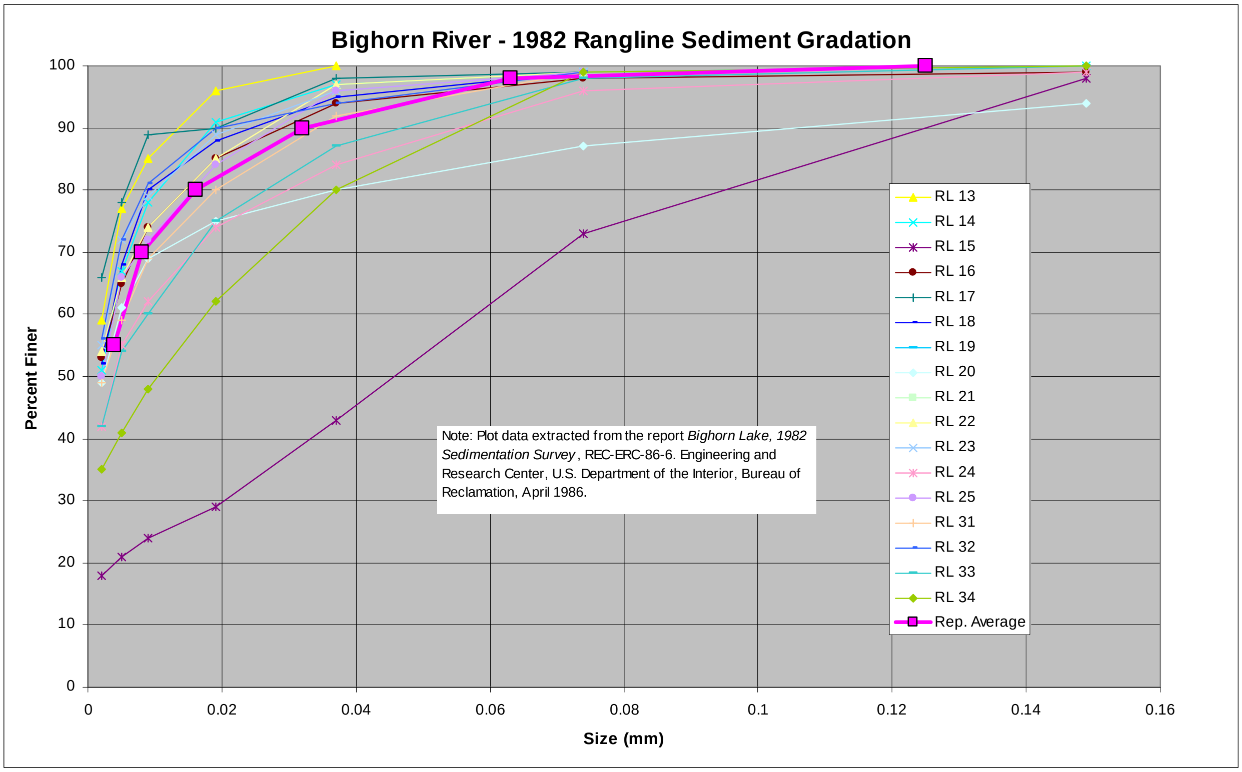


Figure 5

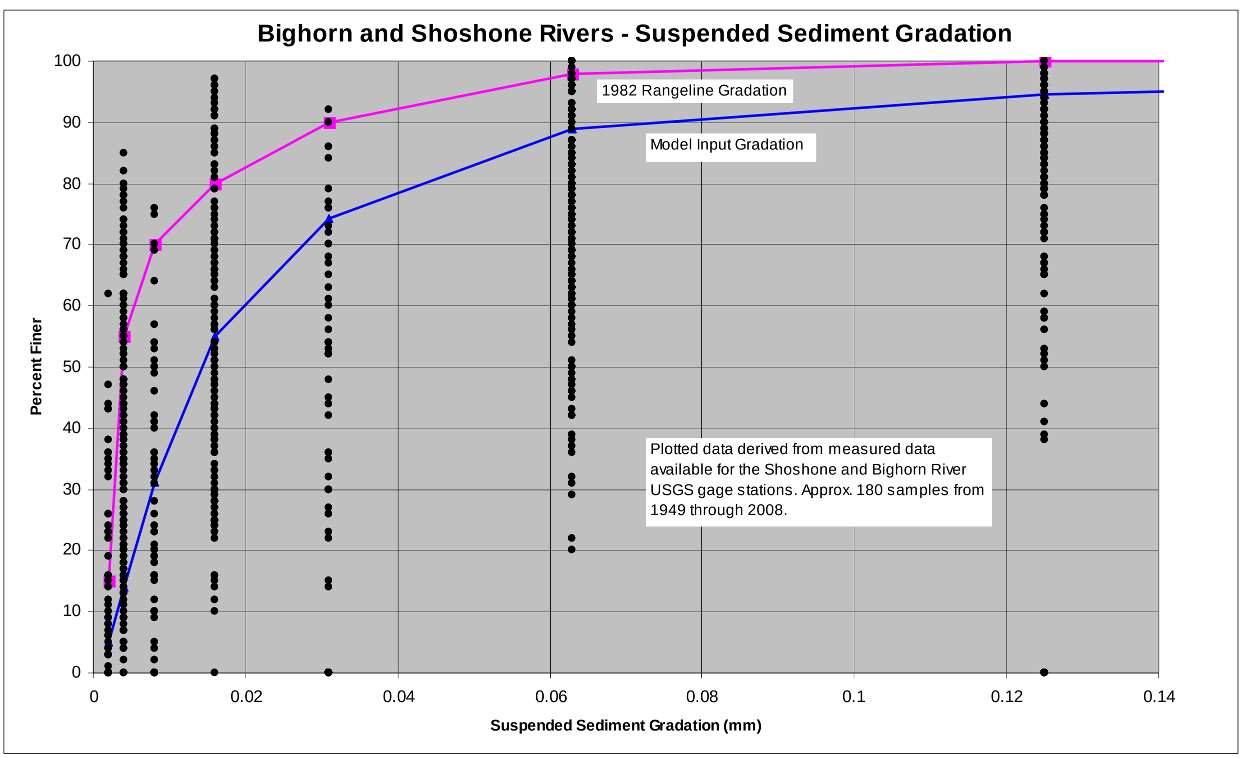


Figure 6

The second source of data is from a limited number of gradation data available for the USGS gage station records on both the Bighorn and Shoshone Rivers. This data is illustrated in Figure 6, along with the 1982 range line gradation data and the model input gradation.

Of the inflowing sediment gradations, 12 percent was estimated as sand, 74 percent silt, and 14 percent clay at a flow of 5,000 cfs. Input to the model is specified by size class that follows standard definitions. Within the model, the maximum clay size is 0.004 mm, the maximum silt size is 0.0625 mm, and the maximum sand size is 0.2 mm. The size classes, associated classification, and variation with flow that was assembled for model input is shown in Table 7.

Table 7. Sediment Input Gradation Varied by Flow

Size (mm)	0.004	0.008	0.016	0.032	0.0625	0.125	0.25	0.5	1
Flow(cfs)	Clay	VFM	FM	MM	CM	VFS	FS	MS	CS
10	0.950	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.148	0.181	0.243	0.182	0.141	0.061	0.033	0.007	0.004
1000	0.140	0.172	0.238	0.193	0.145	0.058	0.036	0.010	0.007
5000	0.139	0.170	0.237	0.195	0.146	0.057	0.037	0.010	0.008
10000	0.137	0.168	0.236	0.197	0.147	0.057	0.038	0.011	0.009
15000	0.133	0.162	0.233	0.204	0.149	0.055	0.040	0.012	0.011
20000	0.129	0.159	0.230	0.209	0.151	0.054	0.041	0.013	0.012
25000	0.126	0.155	0.228	0.213	0.152	0.053	0.043	0.014	0.014
30000	0.123	0.151	0.226	0.217	0.154	0.052	0.044	0.015	0.015

Many other sediment parameters are required to specify additional SRH model input. A sediment data summary that contains some of the different parameters specified as input to the model is illustrated in Plate 2.

3.4 MODEL GEOMETRY.

The SRH sediment model represents the river geometry similar to other 1-D models. The river is described by individual cross sections located at specified intervals. The location of the individual cross sections should be selected to represent important channel behaviors and controls. The distance between sections should be suitable for the accuracy of the model solution. Range line survey sections were used to construct sediment model geometry of the reservoir area from upstream of the Lovell Causeway Highway 14A bridge to the dam. Range line sections were originally established in the period from 1962 to 1965, before the dam was constructed. The original range line survey included 54 sections on the Bighorn River with additional sections on a few of the major tributaries including the Shoshone River. A plan layout of the model reach, range line location, and centerline stationing is shown in Plates 3 and 4.

Range line survey data used to construct model cross section geometry was received from Ron Ferrari of the Bureau of Reclamation Technical Service Center following the 2007 survey from the dam to the Lovell Causeway. All model geometry and results employ a consistent vertical datum, the Reclamation project datum for Yellowtail Dam and Bighorn Reservoir which corresponds to feet above mean sea level. This datum is consistent with that used in the 1965, 1982, and 2007 range line surveys.

3.4.1 Model Stationing.

GIS was used to define a channel centerline and station the range line sections. Section location was described using the centerline stationing. Data was provided in an Excel spreadsheet format which was then converted to the format required for sediment model input. Specific areas of interest include the Horseshoe Bend area, at Range Lines 14-16, and Range Line 31, located upstream of the Lovell causeway. Stationing the dam at 0+00, the HSB area is from about station 245+000 to 253+000 and the

Lovell causeway is at station 320+000. A typical range line cross section in the HSB area is shown in Figure 7.

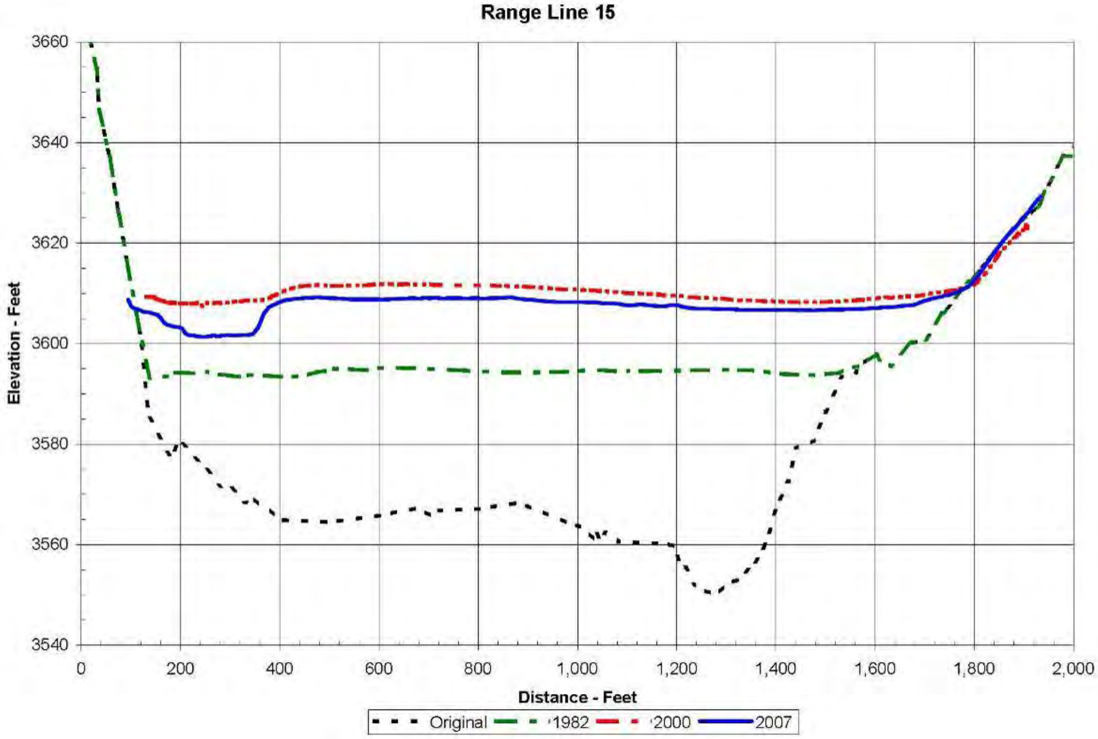


Figure 7

The 2007 survey data set included surveys of Range Lines 1 through 31. Range Line 31 in the preliminary data set had some inconsistencies and was not used. In order to extend the model upstream and provide a stable model input boundary condition, additional sections were inserted upstream of Range Line 31. These sections were roughly based on the geometry illustrated within the sediment survey report (Reclamation, 1982) at Range Lines 43 and 39, corresponding to river centerline stations 399,490 and 374,470. Table 8 illustrates the range line sections used within the model and the centerline stationing.

Table 8. Range Line Centerline Station

Range Line Number and Station Distance from Dam Face (feet)					
43[1]	399,490	21	263,222	10	212,968
39[1]	374,490	20	260,615	9	189,780
34[1]	321,400	19	258,696	8	165,630
31	321,400	18	256,391	7	141,773
30	295,790	17	253,921	6	121,984
28	289,416	16	249,463	5	102,670
27	285,360	15	246,853	4	80,552
26	281,432	14	245,082	3	55,774
25	275,347	13	242,263	2	24,183
24	272,289	12	240,739	1	1,138
23	268,993	11	238,985	Dam	0
22	265,953				

[1]Not surveyed, included in the model to aid stability.

3.4.2 Bank Stations.

Within the model, the user specifies the bank station at each cross section. This is generally set using hydraulic criteria to separate the bed and bank. However, since the average bed elevation was used to compare model results, the bank station was modified to allow a reflection of more of the cross section. While not hydraulically correct, use of the bank stations in this manner greatly enhanced the use of average bed elevations in model result comparison. Sensitivity evaluation was performed to verify that model results were not adversely affected by the bank station location and roughness used to represent the cross section.

3.4.3 Model Roughness.

Roughness values were selected based on the site visit and general values for similar type streams. A change in roughness was assigned upstream of Horseshoe Bend to reflect geometry and vegetation changes that occur in the upper end of the modeling reach. Selected roughness encompasses many parameters including sinuosity, bed material, bed forms, vegetation, bed load and suspended material, and other contributing factors (Chow, 1959, pg. 101). High pool levels and flow depths tend to minimize the effect of the selected roughness value. No calibration of roughness values was possible due to a lack of measured values. Selected model roughness values are illustrated in Table 9.

Table 9. Model Roughness Values

Location	Overbank Roughness	Channel Roughness
Upstream to Station 263,222 (Range Line 21)	.075	.035
Station 260,615 to Dam (Range Line 20)	.05	.025

Selected channel roughness values are higher than normal for the upstream sections where an n value in the range of 0.028 to 0.030 was initially selected. A sensitivity analysis was conducted to evaluate model roughness. Model simulations in the upper end of the model performed slightly better with the higher n value although differences were very minor, in the range of 1 to 2 feet of change in average bed elevation.

3.4.4 Interpolated Sections.

Initial analysis with the model indicated that cross section spacing at the upstream end of the model and the lower end of the model was greater than desired with some stability issues shown. Interpolated sections were used at a 5,000 foot maximum interval to reduce the section length and increase model stability. Interpolated sections were used from station 399+490 to 295+790 and from station 238+985 to station 55+774.

3.4.5 Lovell Causeway.

Within the model, the only bridge crossing occurs at the Lovell Causeway, Highway 14A. The bridge structure itself was not included in the model since detailed model results in the bridge vicinity was not a focus of this study. The Shoshone River enters just downstream of Highway 14A at Range Line 30, station 295+790.

3.4.6 Model Computation Time.

Within the model, the computational time step is specified. This value is generally selected based on computation results and to reflect input data variation. Initial model runs were performed with a value of 3 hours that resulted in a computer run time of over 1 hour. For the final model runs, the computational time step was reduced to 1 hour to smooth results. This resulted in a computer run time of over 4 hours.

4. BASE CONDITION SIMULATION.

In order to develop suitable model parameters to increase alternative comparison accuracy, simulation of the base condition from dam closure to the most recent range line survey, November 1965 through July 2007, was simulated with the SRH model. Model input parameters were revised until a reasonable approximation of the 2007 survey conditions was reached. Survey results from the 1982 survey were also used to provide an intermediate check. The procedure of using historic data to determine model input parameters is often referred to as the calibration process. For the Bighorn River SRH model, sufficient data to perform detailed calibration and verification was not available. Therefore, while the model was assessed to be suitable for the purpose of alternative comparison, it is not regarded as a fully calibrated model. While the model appears adequate at simulating the historic record, insufficient analysis was performed to determine that the model is capable of simulating future conditions with a high level of accuracy.

4.1 SELECTED PARAMETERS.

Many of the sediment parameters were evaluated with respect to comparing output results and are summarized in Table 10. Refer to Plate 2 for additional information on the sediment parameters.

Table 10 – Optimization of SRH Sediment Parameters

Parameter	Optimization Notes
Sediment Transport Equation	SEQ Record. A number of different transport equations including Laursen, Laursen-Madden, Ackers, Ackers-White, and Yang were evaluated. Selected Equation - Laursen-Madden
Sediment Input Coefficients	US2 Record. Evaluated the sediment inflow to the model by modifying the sediment transport equation coefficients. The equation form $S_x = a_s Q^b$.
Cohesive Sediment Deposition	CSD Record. Evaluated parameters regulating cohesive sediment deposition that predicts transport for all particles smaller than 0.0625 mm.
Cohesive Sediment Erosion	CER Record. Specifies parameters for cohesive critical shear stress for erosion.
Cohesive Sediment Fall Velocity	CF1 Record. Specifies the relationship between fall velocity and sediment concentration using four separate points of paired data.

4.2 SENSITIVITY ANALYSIS.

Selected model parameters stated above as well as additional parameters such as model roughness were further evaluated with a sensitivity analysis. In general, the sensitivity of a selected model input parameter was evaluated by altering the numerical value of the selected parameter by 20 percent. Observed changes were noted compared to the normal condition. However, it should be stressed that, while changing input parameters modified results, the net difference when comparing models was similar in most cases when making reasonable input parameter changes.

For instance, varying the roughness by 20 percent altered the historic condition evaluation. If the varied roughness was also modeled for an alternative condition, then the relative change between base and alternative conditions was within an acceptable tolerance range.

4.3 RESULTS EVALUATION.

The selected output parameters were used to simulate the historic conditions. Model results were compared to the range line surveys collected in 2007. The evaluation between model runs consisted of comparing the average bed elevation and visual inspection of cross section plots. Selected parameters achieved moderate accuracy but acceptable calibration results.

Model results were compared using the average bed elevation. This elevation allows a more complete comparison of the cross section than simply using the invert or lowest elevation. The average bed elevation is computed by the SRH model from the specified bank stations. Similar location of the bank stations between the various models was used to allow reasonable comparison. For the roughly 40 year simulation from October 1965 to July 2007, a predicted average bed elevation change that was within 20 percent was deemed acceptable in the reach from the Shoshone River to downstream of the HSB. Average bed elevation change was computed as:

$$(\text{Avg Bed Change}_{\text{Model 1965 - 2007}} - \text{Avg Bed Change}_{\text{Obs 1965-2007}}) / (\text{Avg Bed Change}_{\text{Obs 1965 - 2007}})$$

Sediment transport modeling is notoriously difficult. The data utilized to predict bed change is fundamentally uncertain and the theory employed is empirical and highly sensitive to a wide array of physical variables (HEC, 2008, pg. 13-1). However, with reasonable quality data, a calibrated sediment model to predict regional, long term trends that can inform planning decisions and can be used to evaluate project alternatives is possible.

Model results illustrated that a tradeoff occurs between the specified sediment inflow, the cohesive settling velocity, and the distribution of sediment between the Bighorn, Shoshone, and ungaged tributary inflows. Since most data for the Bighorn and Shoshone Rivers is from prior to 1965 and no data is available for the ungaged areas, the decision was made to focus model calibration on predicting elevations from the Lovell Causeway to HSB and the location of the delta as shown by the 2007 range line survey.

For alternative comparison, the desire to evaluate changing elevations within HSB and the predicted delta migration into the pool for future scenarios was a large factor in model construction and parameter selection. Other parameters that affect sediment elevation at a particular cross section will have similar variation between the alternatives. These decisions allow a realistic comparison of alternatives that does not underestimate potential impacts to all alternatives. Table 11 provides a tabulated comparison of average bed results. Plate 5 illustrates a comparison between the model computed average bed elevations. Plates 6 – 8 illustrate range line cross sections and compare simulated geometry with 2007 measured geometry.

Insufficient data was available to perform detailed model calibration and verification. Evaluation of future condition results should recognize this limitation.

- Modeled average bed elevation was within 5 to 15 percent of actual from the Causeway to HSB.
- Unless otherwise noted, all profile plots and tabulated comparisons are based on average bed elevations derived from model output. This applies to 1965, 1982, and 2007 data.
- Examination of results illustrates that the model is adequate for comparing alternatives and assessing long term changes.
- Surveys of range lines upstream of the Lovell Highway 14A Causeway in 2007 were not available to verify modeled elevations in this reach. The upstream portion of the model was extended with limited quality data.
- The model did a reasonable job of predicting the delta movement into the pool. Due to the limited number of range lines downstream of Horseshoe Bend, accurate location of the 2007 delta front was only predicted as between Range Line 11 (station 238+985) and Range Line 10 (station 212+968).

- At some locations, reproduction of the observed section was very accurate. At other locations, the model produced less than desirable results. However, meaningful comparison of alternatives is feasible throughout the model by comparing the change between simulations.
- Model parameter selection is a tradeoff of several parameters with many unknowns. The final model also considered the intended model use to compare alternatives.
- The greatest error occurred in the reach from the dam to Range Line 9, the lower 35 miles. Results illustrate the impact of tributary sediment inflow and the previous landslide for which no data was available. Results in this reach are also likely impacted by the difficulty of modeling very fine sediments.

Table 11 – Historical Model Average Bed Elevation Comparison

Range Line	Station	**1965 Survey**	**2007 Survey**	**Model**	**% Change**
30	295790	3617.9	3628.4	3622.9	-52.2%
28	289416	3608.2	3621.8	3619.9	-13.6%
27	285360	3607.3	3618.2	3619.8	15.3%
26	281432	3603.6	3615.8	3617.1	10.6%
25	275347	3594.3	3612.8	3615.8	16.2%
24	272289	3594.6	3614.0	3617.6	18.4%
23	268993	3585.6	3613.9	3612.7	-4.1%
22	265953	3582.3	3610.6	3613.3	9.6%
21	263222	3578.4	3611.0	3610.9	-0.4%
20	260615	3570.9	3609.7	3607.1	-6.6%
19	258696	3578.7	3608.2	3603.6	-15.6%
18	256391	3572.4	3610.7	3606.8	-10.2%
17	253921	3570.1	3608.7	3604.1	-11.9%
16	249463	3569.9	3608.9	3614.4	14.1%
15	246853	3561.0	3607.2	3607.4	0.5%
14	245082	3560.7	3606.2	3603.8	-5.2%
13	242263	3553.4	3601.1	3598.3	-5.9%
12	240739	3556.5	3601.6	3597.9	-8.0%
11	238985	3548.4	3601.9	3597.5	-8.3%
10	212968	3513.8	3579.4	3578.1	-2.0%
9	189780	3488.7	3512.8	3497.6	-62.9%
8	165630	3464.2	3480.7	3466.8	-84.4%
7	141773	3439.7	3448.3	3440.3	-92.7%
6	121984	3413.3	3431.1	3416.7	-80.9%
5	102670	3395.3	3418.5	3396.2	-96.4%
4	80552	3354.2	3410.2	3408.2	-3.6%
3	55774	3299.5	3319.4	3307.8	-58.3%
2	24183	3212.0	3237.3	3213.1	-95.5%
1	1138	3197.4	3244.4	3197.5	-99.6%

5. ALTERNATIVE ANALYSIS.

A number of alternatives were evaluated with the sediment model and compared to the base condition. A brief description of each alternative is provided along with model implementation notes. For all alternatives, the historic record period was simulated from October 1966, after full pool was attained, to July 2007. Since sediment inflow is episodic and related to specific events, using the historic record maintains the link to actual events. Consequently, looking at short time interval sediment response is not recommended since the flow / sediment inflow to the model will be a critical factor in how fast the model responds. When using the historic record, a minimum of 10 years is recommended and generally the entire 40+ year period should be considered to avoid issues that occur as a result of considering specific events.

To minimize model calibration accuracy concerns, the evaluation between model runs consisted of comparing the average bed elevation along with visual inspection of cross section plots. Unless otherwise noted, all profile plots and tabulated comparisons are based on average bed elevations derived from model output.

5.1 BASE CONDITION.

The base condition consists of the 2007 survey geometry modeled with the historical record from October 1966 to July 2007 using the calibrated parameters determined in the historic modeling. The base model results serve as the comparison basis for all alternatives.

5.2 ALT. A – HIGHER RESERVOIR LEVEL DURING THE RECREATION SEASON.

This alternative involves a change in the operations of the Yellowtail Dam in order to have higher reservoir levels throughout the recreation season within HSB. By altering the pool elevation during the peak sediment inflow period, the primary location of sediment deposition is moved. Due to the higher pool, the number of low pool years that act to flush sediments past HSB are eliminated. The impacts on other reservoirs to maintain the higher pool was not evaluated as part of this study. Historical pool records show that, in the period from 1970 to 2006, the annual reservoir peak has been below elevation 3,630 feet in seven years. Of those seven years, five of them have occurred since 2001. Pool records also indicate that it may be difficult to attain the pool elevation of 3,630 feet by the date of May 15 prior to the peak runoff period.

Model Implementation – Maintain Higher Pool Levels.

This alternative was modeled by artificially setting the Yellowtail pool elevation at a minimum elevation of 3,630 feet during the period from 15 May through 15 Sep. An example period of the altered pool levels is shown in Figure 8.

NOTE: The sediment model does not track pool volume and levels. Artificially setting the pool at the desired minimum is only valid to indicate possible impact on sediment. A detailed routing model is required to evaluate actual pool levels that may be achieved.

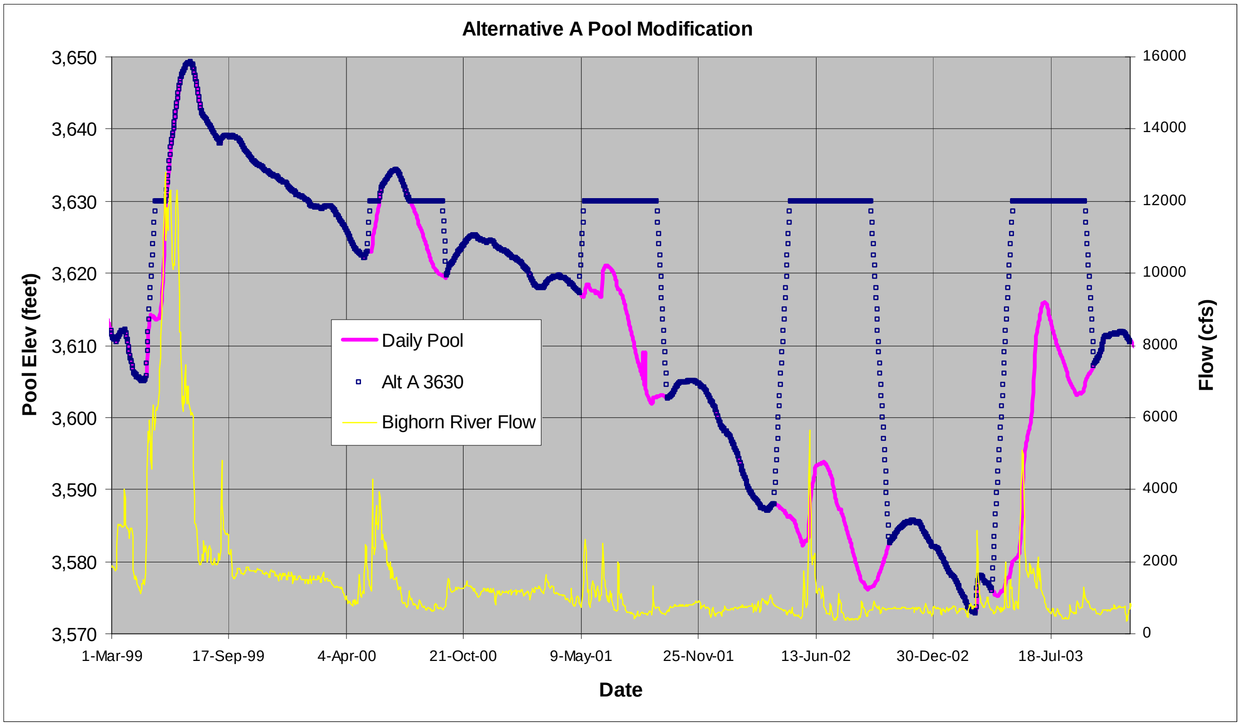


Figure 8

5.3 ALT. B – TRAP SEDIMENTS UPSTREAM.

This alternative involves trapping sediment in the southern portion of the reservoir, and releasing clear water into the main portion of the reservoir. There is a causeway across the lake east of Lovell, Wyoming, that may be able to serve as a dam to impound the water. Elevation mapping of the causeway was obtained from the Wyoming DOT.

Two methods were evaluated to achieve sediment deposition. Features could be constructed to reduce the flow opening through the Causeway by restricting the opening size or even adding flow control gates. Another alternative would be to add a series of flow barrier dikes. Flow barrier dikes were selected for cost evaluation although model results, sediment deposition areas, and the impact to HSB would be similar for either alternative.

Updated surveys in this area were not available to assist with design. The 1982 range line surveys upstream of the Causeway were reviewed to determine the practical length of deposition. Elevations indicate the maximum possible detention area would end between Range Line 40 and 41 or a distance of about 27,000 feet upstream of the Causeway. With a floodplain elevation at the Highway 14A Causeway of 3,630 feet, the average deposition depth was estimated as 10 feet.

Causeway Opening Restriction

The detailed survey information required to design the opening restriction was not available. However, in order to impact lower flows and maximize the sediment trapping ability, it is likely that a severe restriction in the opening size would be required. This would also likely significantly increase the duration and height of ponded water on the road embankment. Coordination with Wyoming DOT and design computations would be required to evaluate feasibility. Using the Causeway as a dam with differential water surface may not be acceptable. Installing flow control gate(s) within the causeway opening, while adding significant cost and operation requirements, would also allow operation flexibility.

Flow Barrier Dikes

A series of flow barrier dikes would be constructed within the channel and floodplain to increase travel time and allow sediments to deposit. Due to the high fines content, it is likely that several nearly floodplain wide structures would be required. Detailed design of these structures would be required to assure that the flow is not fixed in a negative manner that prevents sediment deposition. The effect of the dikes would be to result in a secondary storage facility. Construction would provide a very wide retention area. Design parameters are summarized in Table 12. A conceptual layout for the sediment basin is illustrated in Figure 9.

Table 12 - Sediment Trap Design Concepts

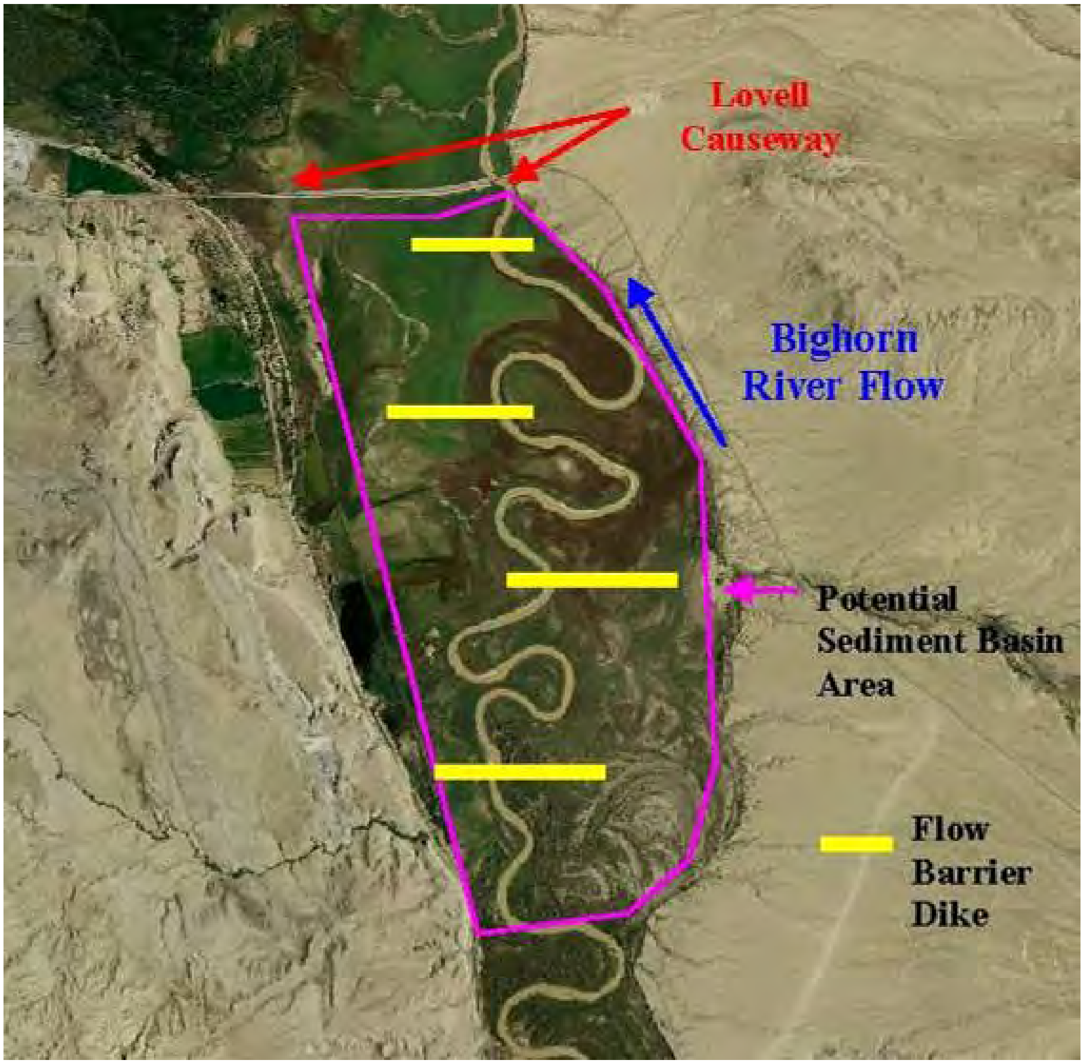
Bridge Top of Road – Elev 3660.
Bridge Low Chord Elev 3649.7
Causeway Top of Road – Elev 3658.6
Causeway Length – 8,200 feet
Sediment Storage Area – 2300 acres
20,000 feet long, Avg Width of 5,000 feet
Basin Storage Volume – 23,000 ac-ft
(Average Depth of 10 feet)
Assumed Maximum Deposition Depth - 5 feet
(to maintain trap efficiency)

The constructed area would be fairly shallow relative to its length with a best case scenario trap efficiency estimated to average 0.7 during the life of the basin. It is likely that several flow barrier dikes would need to be constructed to increase travel time and the sediment trap efficiency. As the basin fills, the trap efficiency will reduce. If successful, the sediment trapped in this area could be removed, and this would then perpetuate the life of the lake.

Without sediment removal, the benefit of initially trapping the sediments would remain but additional trapping of sediments would not occur as the sediment basin filled. It is likely that sediment deposition greater than 3-5 feet would reduce the trap efficiency. However, large scale sediment removal may not be feasible due to financial limits. A disposal site would also be required for the removed sediment. For the conceptual evaluation, the sediment excavation and containment area for sediment disposal was assumed to consist of an area sufficient to store 2,000,000 cubic yards or 1,240 ac-ft of material. Using 23,000 ac-ft of storage, a 70 percent trap efficiency, and the sediment inflow rate of 3,224 ac-ft per year, the basin would fill in about 5 years.

Model Implementation – Alter Bighorn River Sediment Load.

This alternative was modeled by reducing the Bighorn River sediment load by 70 percent for the entire period of simulation. This would require periodic sediment excavation to maintain storage capacity. Sediment inflow from all other areas was not altered.



Conceptual Layout for Upstream Sediment Basin

Figure 9

5.4 ALT. C – FLUSH SEDIMENT THROUGH HORSESHOE BEND.

This alternative involves maintaining lower reservoir pool levels during the heavy sediment producing months so the sediments are flushed past Horseshoe Bend and further into the canyon. There is an added risk that the reservoir may not reach full pools in drought years as the pool level will be held lower before the spring runoff is initiated. Maintaining a low pool level may be difficult during high runoff years and could also impact downstream releases.

The principle of the sediment flushing alternative is illustrated by recent operations. As shown by surveys from 2000 and 2007 in Figure 7, a small amount of bed lowering occurred within HSB during this seven year period. During this period, low reservoir pool levels, combined with minimal sediment inflow correlated with low Bighorn River inflow, resulted in the establishment of a lower channel within the cross section compared to the 2000 survey. Examination of the reservoir water surface elevation illustrates that, for the period from 2001 to 2005, the reservoir was below the HSB average bed elevation of about 3610 feet for nearly the entire period. The bed lowering shown in Figure 7 is likely due to main channel downcutting as reservoir levels dropped along with possible consolidation of overbank material.

Table 13 summarizes the combined maximum inflow to the pool and the date of occurrence. As Table 13 illustrates, the maximum inflow often occurs during the recreation season. An example period illustrating the modified pool level is shown in Figure 10.

Table 13. Annual Maximum Inflow Summary (All flow values in cfs.)

Flow	Date	Flow	Date	Flow	Date	Flow	Date
29,776	1-Jul-67	23,215	19-May-78	5,286	21-Jun-89	6,554	18-May-00
14,764	10-Jun-68	9,371	30-May-79	7,117	12-Jun-90	10,117	14-Jun-01
18,607	26-Jun-69	8,830	27-Jun-80	18,264	15-Jun-91	6,116	2-Jun-02
16,850	29-Jun-70	19,005	10-Jun-81	11,020	16-Jun-92	7,515	20-Jun-03
15,649	28-Jun-71	10,891	17-Jun-82	13,873	4-Jul-93	2,858	22-Sep-04
13,926	10-Jun-72	12,928	8-Jul-83	6,207	30-Mar-94	13,371	12-May-05
10,255	21-May-73	11,200	17-Jun-84	18,073	15-Jul-95	6,756	24-May-06
17,285	23-Jun-74	4,416	12-May-85	11,909	17-Jun-96		
15,680	12-Jul-75	17,180	21-Jun-86	21,006	11-Jun-97		
11,837	23-Jun-76	11,670	28-May-87	13,999	6-Jul-98		
5,131	11-May-77	17,217	8-May-88	16,854	31-May-99		

Model Implementation – Maintain Lower Pool Levels.
This alternative was modeled by artificially setting the pool elevation for the downstream boundary at a minimum elevation during peak inflow periods. This alternative was modeled with two scenarios to illustrate the impact of lowered pool levels. Review of the flow record indicates that time of occurrence of peak flow varies significantly. Therefore, the simplifying assumption was made to link the model pool level to the observed peak inflow. Whenever the peak inflow rate exceeded 3,000 cfs during the period from April 1 through July 30, the pool level was reduced to elevation 3615 or 3595 feet.

NOTE: The sediment model does not track pool volume and levels. Artificially setting the pool at the desired minimum is only valid to indicate possible impact on sediment. A detailed routing model is required to evaluate actual pool levels that may be achieved.

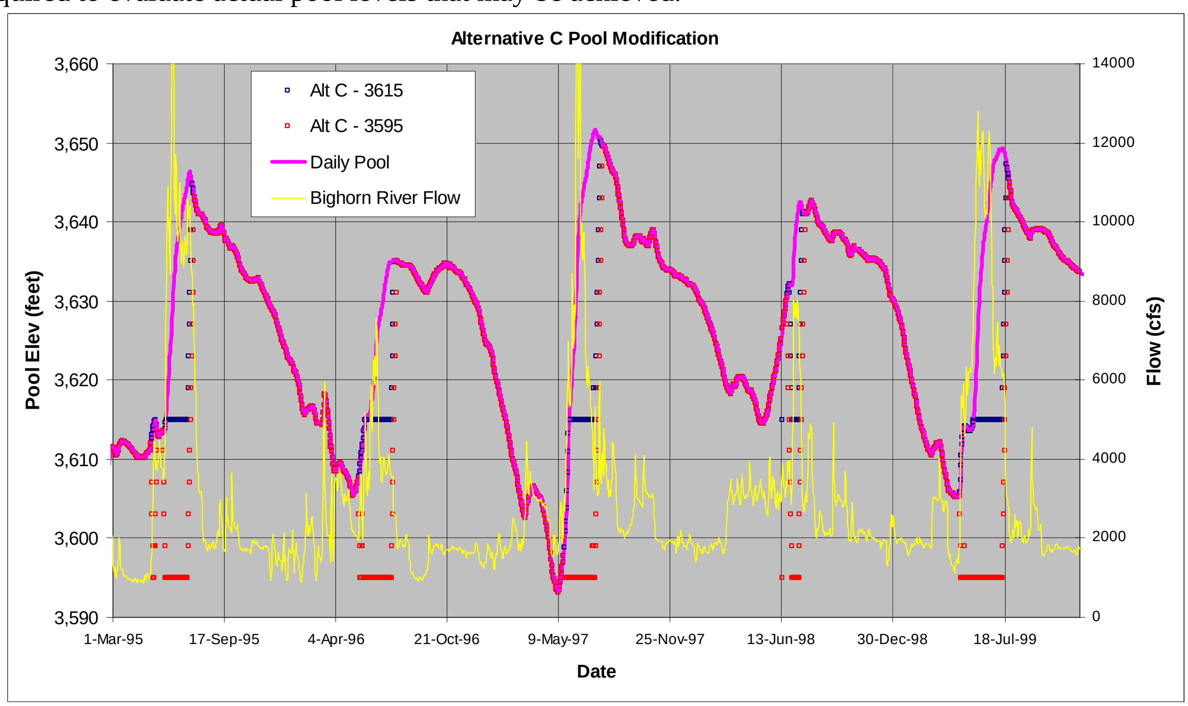


Figure 10

5.5 ALT. D – MANAGE SEDIMENT IN THE HORSESHOE BEND AREA.

This alternative involves implementation of local features to control the amount and process by which sediment deposits and transports past HSB. This would require construction of a dike that separates the HSB recreation area from the flowing river as shown by the concept in Figure 11. This would allow sediments to be flushed past HSB with minimal impacts to the recreation facilities. This alternative is the most independent of all the other management activities, and is the least dependent on hydrology. However, this alternative is still linked to the general turbidity of the river and subject to sediment deposition from fine particles. Only the large particles located lower in the water column will be flushed through HSB. The rock berm would have the following features as shown in Table 14.

Table 14 – HSB Dike Concepts

Rock Dike Located About 600 feet from the bank
Length – 9,000 feet
Elevation – Assumed to slope from elevation 3615 to 3620 feet (about 15 feet above the current bed)
Geometry – 6 foot top width, 1.5 H on 1V side slopes, results in 800 sq ft/ft of area
Rock Quantity – 250,000 tons (assume 24 inch D_{100}, factor of 1.55 to convert cu yd to tons)
Earth/Rock Dike – Assume 3 foot rock layer over earth core.
Earth quantity – 118,000 cu yd of compacted material
Rock Dike – 69,000 tons

Model Implementation – Construct HSB Rock Dike.

This alternative was modeled by simulating the artificial construction of a long rock dike that would artificially confine the Bighorn River to a smaller width to maintain sediment transport through HSB. The confined flow area channel width was set at 600 feet based on the downstream canyon width. Detailed evaluation would be required to determine the optimum spacing and height.

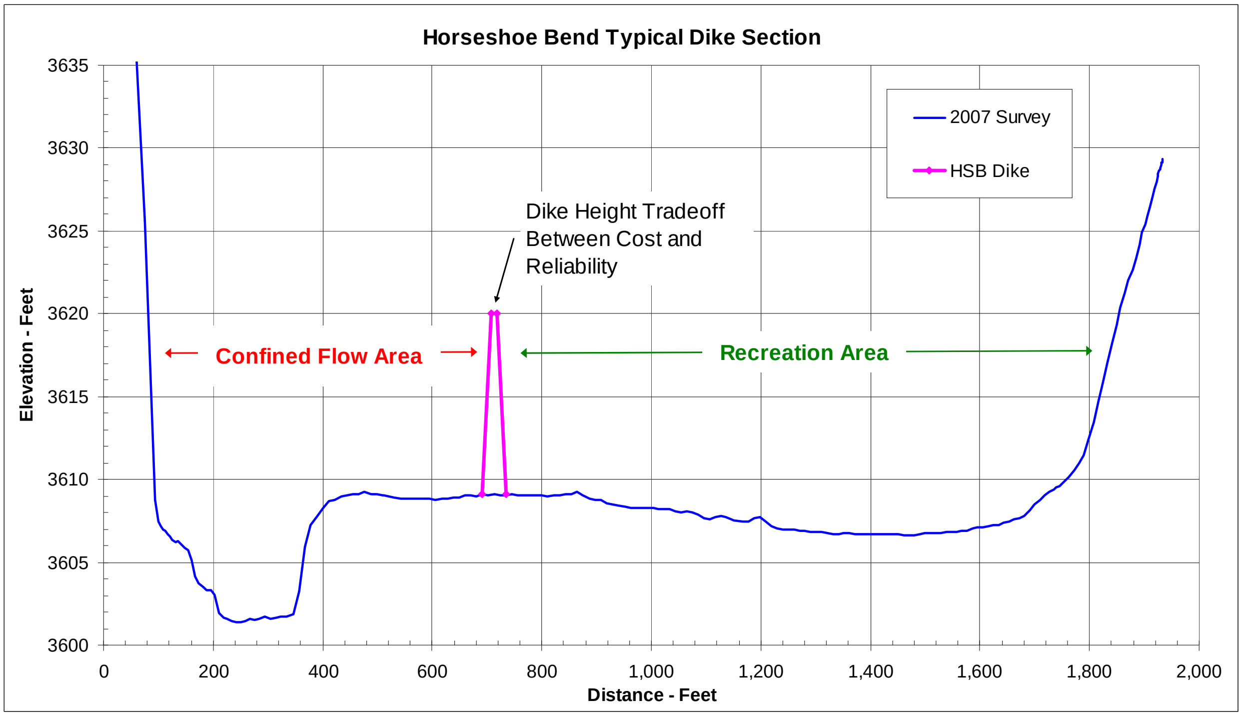


Figure 11

5.6 ALT. E – MANAGE SEDIMENTS IN THE WATERSHED.

This alternative involves implementing best management practices in the basin to reduce the amount of sediment entering the reservoir. While it is likely that the total sediment yield could be reduced, it may not be practical for the type of materials that exist within the basin to achieve significant sediment reduction over a large area. In addition, implementation of this alternative is likely to require considerable time to actually achieve positive results that are noticeable at HSB. Further study of this alternative would require coordination on a watershed scale. Conservation measures in the watershed could be pursued for general resource management reasons but were not evaluated within this study.

5.7 ALT. F – DREDGE SEDIMENTS WITHIN HORSESHOE BEND.

This alternative consists of sediment removal within HSB. The process would consist of dredging the sediments within HSB and discharge to a downstream location within the pool or disposal at an upland site. This would be a temporary solution to sediment levels within HSB and required periodic dredging to maintain the desired elevation range. It also may be environmentally hazardous if the dredged material contains heavy metals, polychlorinated biphenyls (PCBs), or other toxic compounds. For the option to dispose of dredge sediments in the reservoir downstream of Horseshoe Bend, it was necessary to assume sediment deposition within the pool. To simulate this, the approximate dredge volume was added to the cross sections downstream of HSB. No attempt was made to evaluate how the sediments would deposit following dredge discharge. For the conceptual analysis, the deposition range was assumed to be downstream of HSB. Due to the narrow canyon, sediment deposition depths will exceed the HSB excavation depth to equal the dredge volume.

Note: Due to the huge difference in cost and the probability that pool disposal will be required, all tabulated and plotted model results reflect the option to discharge sediments within the pool downstream of the HSB.

Model Implementation – Lower HSB Channel Bottom Elevations and Raise Downstream Sections. This alternative was modeled by removing sediments throughout the HSB down to an elevation of 3590 feet. This corresponds to an average excavation depth of 20 feet. While this will give excess depth, it may be more efficient to dredge to greater depth and less frequently. To simulate the deposition of the dredged material, elevations were raised in a range from 5 to 45 feet. The deeper locations, and higher elevation increases, are located downstream of HSB. The method to raise downstream elevations was not evaluated in detail and would require detailed modeling to determine an estimated deposition pattern of dredged sediments.

Dredge Quantity – Estimated as 20,000,000 cubic yards
Dredge Deposition – First 40,000 feet downstream of HSB, depth ranged from 5 to 45 feet

5.8 ALTERNATIVE IMPLEMENTATION COSTS.

A summary of the alternative implementation methods and approximate cost is provided in Table 15. Cost estimates were prepared by the Bureau of Reclamation, Montana Area Office based on approximate design details. These are order of magnitude costs for the various options. Further design is required to develop more reliable costs and an evaluation of life-cycle operation and maintenance.

Table 15 – Cost Implementation Summary

Alternative	Cost / Notes
A – Higher Rec. Season Pool	Construction Cost – NA Likely to include indirect costs as modified pool levels alter project benefits.
B – Sediment Trap Upstream	Construction Cost - $34,000,000 Cost estimate includes initial construction cost plus a one-time excavation cost for 2 million cubic yards. Will incur additional significant O&M cost due to removal of deposited materials to maintain sediment trap.
C – Lower Pool During Peak Inflow	Construction Cost – NA Likely to include indirect costs as modified pool levels alter project benefits.
D – HSB Dike	Construction Cost - $24,000,000 (All rock dike) Costs may be lower by using an earth core rock dike, geotubes, or similar product. Will incur significant O&M cost to maintain structure, also dredging will be required at connection locations, possibly throughout area due to general turbidity.
F – Dredge HSB	Construction Cost - $145,000,000 (Dredge and remove sediments to disposal area) Construction Cost - $73,000,000 (Dredge and discharge in pool downstream of HSB) Will incur significant O&M cost to dredge repetitively.

Estimates include 5% mobilization and preparation, 15% unlisted, 25% contingency and 20% non-contract costs. All costs are present-value, and the maintenance and dredging costs would be subject to fund indexing due to the multi-year nature of the work.

6. EVALUATION OF RESULTS.

Alternatives were compared to the base condition simulated elevation and by computing a difference from the base. Comparison was performed using the computed results for the average bed elevation. Figure 12 illustrates the concept of average bed elevation that reflects changes within the general cross section. Figure 12 illustrates how changes in the thalweg, or minimum channel elevation, could be misleading since the floodplain could be experiencing significantly more change.

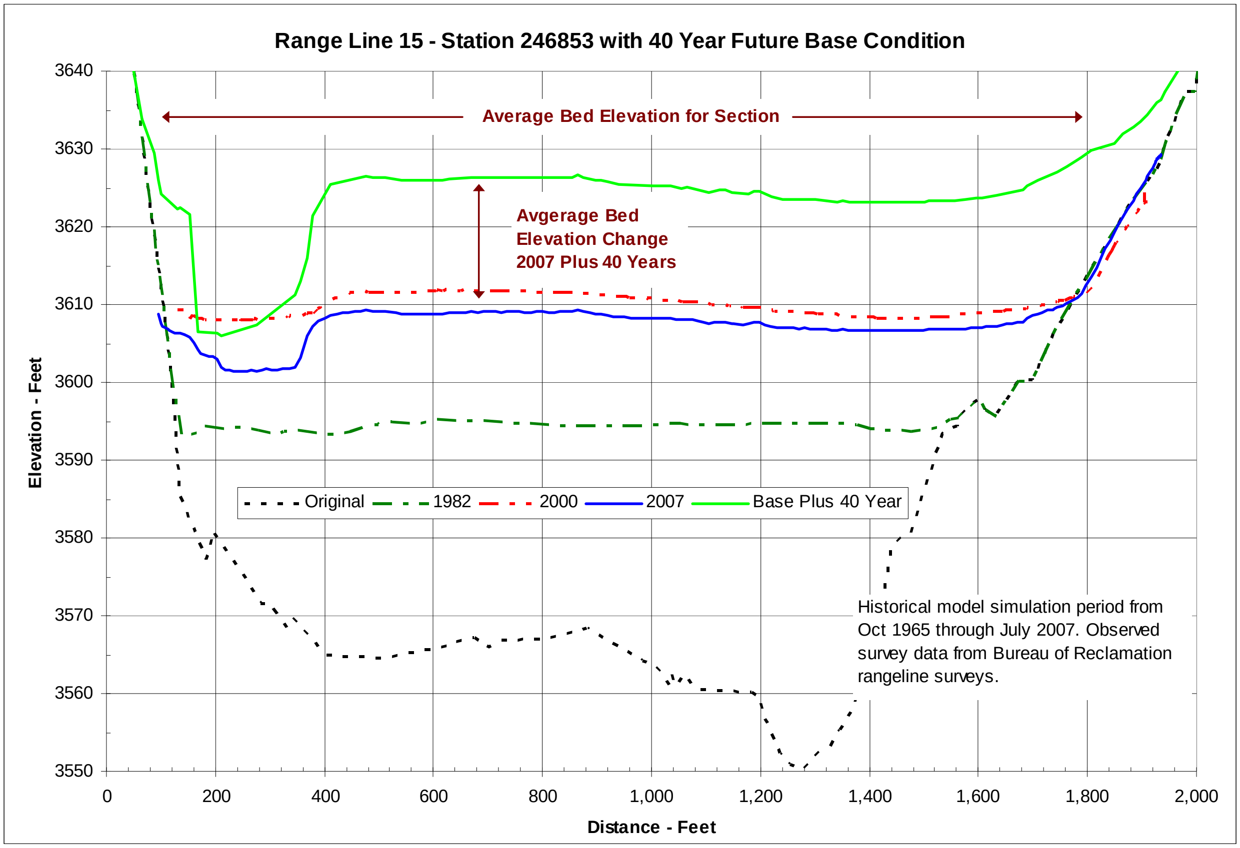


Figure 12

Plate 9 illustrates actual model computed elevations for the base and alternative conditions. Caution should be used when evaluating the model computed elevations since the more reliable method is to compare based on the difference between different alternatives. Plates 10 – 13 illustrate the average bed elevation change from the base condition for each alternative after 10, 20, 30, and 40 years. While interesting to evaluate with time, the evaluation of results should consider that sediment inflows vary by period and that a longer period will provide a better indication of average conditions. Table 16 provides a tabular comparison of the change in average bed elevation computed by the model in a summary format.

Very large values are noted in Table 16 when comparing the base condition to alternative condition results. These large differences occur in the location of the advancing delta. For comparison purposes, the average within HSB and the average upstream of HSB are probably the most informative. The minimum or maximum change value provides an indication if more or less sediment is progressing towards the dam and if the sediment will impact dam operations sooner.

Table 16 – Alternative Summary

Alternative Results Difference Comparison Alt. Computed Elev - Base Condition Elev. (feet)										
	Alternative A - Higher Rec Season Pool Change From Base for All Alternatives					Alternative B - Upstream Sed Trap Change From Base for All Alternatives				
	Year 5	Year 10	Year 20	Year 30	Year 40	Year 5	Year 10	Year 20	Year 30	Year 40
Min	-34.1	-56.5	-59.1	-70.7	-88.0	-41.0	-67.5	-84.8	-107.8	-122.8
Max	4.3	5.5	3.8	4.0	4.1	0.0	0.0	0.1	0.1	0.0
Avg. HSB-Causeway	1.4	1.8	1.8	1.2	1.2	-1.8	-2.7	-4.1	-5.0	-5.0
Avg. HSB	3.2	3.2	3.0	1.7	1.6	-4.7	-5.7	-6.7	-8.3	-7.5
	Alternative C - Lower Pool to 3595					Alternative C - Lower Pool to 3615				
	Year 5	Year 10	Year 20	Year 30	Year 40	Year 5	Year 10	Year 20	Year 30	Year 40
Min	-8.5	-8.7	-12.9	-15.9	-15.5	-7.6	-7.2	-7.8	-11.1	-10.6
Max	56.9	81.9	114.2	129.3	143.7	60.4	85.7	114.2	136.7	153.3
Avg. HSB-Causeway	-2.1	-2.7	-3.6	-4.7	-4.7	-1.8	-2.3	-3.1	-4.2	-4.3
Avg. HSB	-5.2	-5.9	-7.0	-9.2	-8.5	-4.7	-5.3	-6.0	-8.2	-7.7
	Alternative D - HSB Berm					Alternative F - Initial Dredge HSB				
	Year 5	Year 10	Year 20	Year 30	Year 40	Year 5	Year 10	Year 20	Year 30	Year 40
Min	-12.4	-13.4	-15.4	-19.4	-19.5	-14.2	-7.2	-6.1	-7.7	-7.7
Max	19.6	33.0	46.2	75.1	85.8	30.9	25.8	30.6	59.9	69.1
Avg. HSB-Causeway	-1.5	-2.1	-3.1	-4.5	-4.8	-1.3	-0.9	-1.2	-1.9	-1.9
Avg. HSB	-5.5	-7.8	-10.7	-14.2	-14.7	-6.7	-5.2	-5.3	-7.0	-6.6

All tabulated values are the change from the base condition simulation. For instance, if the base simulation determined an average bed elevation of 3610 feet after 40 years at an individual cross section and the alternative condition elevation was 3615 feet, then a difference of +5 from base was reported for that alternative at that location.

Min, Max, Average – Refers to the minimum, maximum, and average change for sections listed in Table 8. Value was computed at all sections from station 295+790 and downstream (the 30 sections between the Shoshone River and Yellowtail Dam).

Avg. HSB – Computed average for station 249+463 to station 245+082, within Horseshoe Bend only.

Refer to Plates 9 – 14 for a graphical representation of results.

6.1 Base Condition at HSB and Areas of Interest.

Base and alternative condition average bed elevations are illustrated in Plate 9. Similar to the previous sediment evaluation previously described in report Section 2.2, the modeling for this study for the base condition predicts that the sediment deposition level within the HSB will be in the range of elevation 3620 feet within 10 to 20 years from 2007. The average bed change within HSB determined by the sediment model varies with time and location. Over time, bed elevations within HSB will approach a new equilibrium level. Based on location within HSB, the equilibrium average bed elevation is predicted to vary from elevation 3622 to 3627 feet. The time to reach this level is predicted to vary from 25 to 35 years from 2007. While this information is helpful in assessing HSB useful life, pool elevation is much more critical to evaluating annual recreation use.

Another area of interest to assess recreation impacts is Barry's Landing, which is located downstream of Range Line 8 (station 165+630). As shown on Plate 5, the 2007 surveys indicated that less than 20 feet of sediment has deposited at this location with an average bed elevation of 3480 feet. Model results show the delta advancing downstream with dramatic changes in bed elevation as this occurs. The formation of the delta front and slope is difficult to predict with accuracy and is likely to vary as the delta advances into the deeper canyon. Model results on Plate 9 show the delta front advancing beyond Barry's Landing in the 30 to 40 year time period. Model results predict reaching a near equilibrium bed elevation in the range of 3600 feet at this location.

It should be noted that the model predicted equilibrium elevation and time periods are based on assumptions regarding pool levels and sediment inflow. Since sediment events are episodic, short term fluctuations, such as those that occurred in the early 2000's due to abnormally low pool levels, should be expected. Base condition changes are summarized in Table 17.

Table 17 - Base Condition Model Summary at HSB

	Years in the Future From 2007				
HSB Avg. Bed Change	0 to 5	5 to 10	10 to 20	20 to 30	30 to 40
Rate (feet /year) *	+1.1	+0.80	+0.6	+0.5	+0.4
Time to Reach Average Bed Elevation of 3620 Feet -	10 to 20 years				
Time to Reach Average Bed Elevation of 3625 Feet -	25 to 35 years				

* Average bed change rates are based on model simulation reflecting assumed pool and inflow conditions. Since sediment events are episodic, it is likely that actual conditions will differ from predicted results. However, the basic condition that deposition will occur at a faster rate during initial years is expected if conditions are within a normal range.

6.2 ALTERNATIVE A.

Table 16 illustrates that the alternative to raise pool elevations will also raise sediment deposition levels as a new equilibrium elevation is established due to the higher pool. In addition, the alternative will reduce the occurrence of low pool elevation periods that act to flush sediments past HSB. Initially, raising the pool will provide more flow depth within HSB. However, the model results show that sediment deposition will start to reduce the additional depth. Within 5 years the average bed elevation is likely to be 3 to 4 feet higher within HSB compared to the base condition. The higher bed elevation is offset by the higher pool level so the available depth may be greater. After a period of 20 years the additional sediment accumulation begins to decline with an average difference of only 1.6 feet higher than the base condition after 40 years. During low pool level drought periods, the increased sediment level, compared to the base condition, within the HSB could be an issue.

Model results illustrate that raising normal pool levels will change sediment distribution with more deposition within HSB and upstream. As a result, the advance of the delta toward the dam proceeds at a slower rate. Previous surveys between 1982 and 2000 indicated a deposition depth of 15 to 20 feet during the 18 year period for a deposition rate of between 0.8 and 1.1 feet per year. The low pool level years from 2001-2007 actually resulted in some degradation. Pool levels and operation practice will alter the rate of HSB deposition. Alternative A will likely provide additional recreational water depths for a period of 15 to 25 years compared to the base condition during years when the elevated pool level is attained. However, during drought years, the elevated sediment within HSB will impact recreation more severely than the base condition.

If under Alternative A or any of the proposed alternatives, the level of the lake is anticipated to rise to elevation 3640 feet or higher for lengthy periods of time during the summer visitation season, it will be necessary to mitigate the loss of boat in camping facilities in the Black Canyon campground and other boating facilities along the lake. Maintaining the lake at this higher level will also necessitate significant changes to the operation of the swimming area, ramp, and docking facilities at the Ok-A-Beh Marina.

6.3 ALTERNATIVE B.

Table 16 illustrates that alternative B effectively lowers sediments within HSB. The upstream sediment basin provides benefits to the HSB by reducing the sediment inflow. Results within HSB are similar to Alternative C without the negative impact of lower pool levels. The benefit continues to occur for the 40 years of simulation assuming that the trap efficiency of the upstream sediment basin can be maintained. After a period of 20 years, the average benefit appears to be a reduction of deposition depth in the range of 6 to 8 feet within HSB as shown in Plate 10. The sediments stored within the sediment basin equates to between 6,900 and 11,500 ac-ft of material. Using the average annual estimated Bighorn River sediment load (Table 6) of 2,908 ac-ft and a 70 percent trap efficiency, the basin would require sediment removal on a three to five year interval.

6.4 ALTERNATIVE C.

The model results for alternative C show a prolonged benefit with a sediment reduction within HSB of 6 to 8 feet after 20 years. While the HSB sediment deposition level remains lower, the impact to recreation may be an issue due to the low pool levels during the recreation season. The model does illustrate that sediments are moved downstream by the flushing action that is induced by the lower pool levels. The model results also illustrate the dramatic change in the location of the delta as it advances much farther toward the dam since the sediment storage within HSB and the upstream region between HSB and the Lovell Causeway is reduced. The advance is magnified by the decreased deposition within not only HSB but also upstream areas. All of the sediment no longer stored within HSB or upstream areas is passed downstream toward the dam. The advance of the delta should be considered as it may have negative consequences. Possible delta advance impacts to the operation of the reservoir were not evaluated. However, it is likely that this alternative would significantly shorten the period required for sediments to reach the dam and affect operations including the evacuation outlet at elevation 3300 feet and the irrigation outlet at elevation 3400 feet.

6.5 ALTERNATIVE D.

Results from alternative D illustrate that it is technically feasible to construct a structure to entrain sediments and keep them moving through HSB. Model results show that the structure would keep sediment levels near the present elevation. Further technical evaluation of this alternative is recommended prior to implementation. The positive results will be offset by the sediments that will be introduced at the connection location to the lake and deposition within the recreation zone due to general turbidity. Results also show that the delta migration rate toward the dam is higher for this condition than the base since the sediments passed through HSB cause a faster downward progression. Compared to Alternative C, the increased delta migration is not as severe since the rate of sediment deposition upstream of HSB is not significantly changed from the base condition.

6.6 ALTERNATIVE F.

Model evaluation was performed for both dredge disposal methods consisting of disposing of the dredge material within the pool downstream of HSB and completely removing the material to a land disposal site. All results previously shown reflect disposal within the pool. Model results demonstrated that the placement of sediments downstream of the reservoir could impact elevations within HSB as shown on Plate 14. Therefore, one time dredging within HSB with downstream pool disposal is not recommended. This action would likely raise the future equilibrium bed elevation within HSB. Any dredging action should be performed with a commitment to the future continuation of dredging as needed.

Using the historic record for the model simulation, the approximate time to deposit back to an average elevation of 3610 feet was evaluated. It should be noted that the time to fill the dredged area will vary with actual events. Also, over time, the dredged area of HSB will trap more sediments as the downstream pool is filled. The ability of the model to deposit sediments within HSB after dredging should be regarded as approximate due to the complex flow phenomena within HSB. The model estimated time to reach an average bed elevation of 3610 feet was about 5 years. Model results do demonstrate that after dredging the bed elevation is lower than the base condition throughout the 40 year simulation.

Comparing to the average annual sediment deposition rate of 3,200 acre-feet per year (about 5.2 million cubic yards per year), the total dredge amount of 20 million cubic yards equates to about 4 years of average sediment inflow. Although not all sediments will deposit within the dredged area of HSB, the observed sedimentation rate supports the model results of needing to dredge every 5 to 10 years to maintain levels within HSB. Previous surveys between 1982 and 2000 indicate a deposition depth of 15 to 20 feet during the 18 year period for a deposition rate of between 0.8 and 1.1 feet per year. Pool levels and operation practice will alter the rate of HSB deposition. However, it is likely that the deposition rate following dredging would exceed the previous rate experience from 1982 to 2000 since the delta migration has passed HSB.

7. SUMMARY AND RECOMMENDATIONS.

Bighorn Lake was created when the Bureau of Reclamation constructed Yellowtail Dam across the Bighorn River in the 1960s. Since dam closure, sediments have accumulated within the pool area and are impacting lake resources. A reconnaissance level technical study was conducted to evaluate several sediment management alternatives. The study used existing cross section, hydrologic, and sediment data for the reservoir as input to a one-dimensional sediment transport model of the reservoir. This sediment model was used to assess the impacts of the alternatives compared to existing conditions. Major points of the study scope include:

- Reconnaissance study level of detail, not suitable for final design
- Focus on alternative screening and comparison
- Highlight constraints, issues, and impacts of sediment management within Bighorn Lake
- The study has a technical emphasis that focuses on using a sediment model to compare alternatives and does not include other alternative formulation factors.
- The model provides a tool for use with evaluating future operation changes that will alter pool levels.

The model was calibrated to the observed range line surveys to the extent practical. Although not precise, the model results indicated suitable accuracy sufficient for comparison of alternatives. Notes regarding the historical model calibration are as follows:

- Insufficient data was available to perform detailed model calibration and verification. Evaluation of future condition results should recognize this limitation.
- The model did a reasonable job of predicting the delta movement into the pool and average bed elevations observed by simulating from 1965 to 2007.
- At some locations, reproduction of the observed section was very accurate. At other locations, the model produced less than desirable results. However, meaningful comparison of alternatives is feasible throughout the model.
- Model parameter selection is a tradeoff of several parameters with many unknowns. The final model parameters selected also considered the intended model use to compare alternatives.
- Model simulation downstream of the delta near the dam was not performed in detail and ignores several of the smaller tributaries that had limited sediment data. Historical accuracy in this area is limited.

The base condition model was used to assess the impact of several alternatives on sediment within the pool and specifically at Horseshoe Bend (HSB). Simulations were performed using the 2007 survey data and then repeating the historical flow and pool record from Oct 1966, after the pool was initially filled, to July 2007. This simulation period allows evaluation of future conditions for a 40 year period assuming historical conditions, both flow and sediment, are representative of the future.

A summary of each alternative is provided in Table 18. Input received from Bighorn Canyon National Recreation Area (BICA) is also indicated in the form of bullet comments for each alternative.

<table>
<tr><th colspan="4">Table 18
Summary of Alternative Evaluations</th></tr>
<tr><th>Alternative</th><th>Cost</th><th>O&M Notes</th><th>Pros / Cons</th></tr>
<tr><td>A – Higher Rec. Season Pool</td><td>NA[1]</td><td>NA[1]</td><td>+ Higher pool for recreation season
+ Increases sediment deposition rate upstream
+ Reduce rate of delta migration toward dam
- Likely to require system operation modification to implement, achieve higher pool by May 15
- Increases sediment deposition rate within HSB, heighten drought impact
- Achieving pool level likely to impact other reservoir operations</td></tr>
<tr><td colspan="4">BICA Impact:
▪ Alternative is consistent with current management of park resources.
▪ Anticipate no significant changes to maintenance, resource management, or visitor management if the level of the lake does not exceed 3640 feet for prolonged periods of time during the summer use season.</td></tr>
<tr><td>B – Sediment Trap Upstream</td><td>$34,000,000</td><td>Removal of deposited material on 3 to 5 year interval</td><td>+ Trapped sediments benefit all downstream areas
- High initial and periodic sediment removal cost to maintain trap efficiency over time
- No impact on current HSB sediment levels
- Disposal area impact / cost (real estate, permit, loss of use)
- Possible impact to Causeway with ponded water and upstream lands</td></tr>
<tr><td colspan="4">BICA Impact:
▪ Alternative would benefit the lake portion of park.
▪ Sediment trapping could alter habitat and fisheries within Yellowtail Habitat area and alter some visitor use or access necessitating mitigation of these changes by the park.
▪ Sediment traps could create issues with blowing sand in the area during dry periods of the year, which may impact local landowners.
▪ It is unclear which agency would be responsible for sediment trap maintenance through the life of the project.</td></tr>
<tr><td>C – Lower Pool During Peak Inflow</td><td>NA[1]</td><td>NA[1]</td><td>+ Maintains lower sediment levels at HSB
- Low pool for portion of recreation season
+Reduces sediment deposition rate within HSB and upstream
- Increase rate of delta migration toward dam, lessens project life
- Achieving pool level likely to impact other reservoir operations and releases</td></tr>
<tr><td colspan="4">BICA Impact:
▪ Potential to impact visitor access to Horseshoe Bend Marina during the main visitation season.
▪ Unknown factors related to how the sedimentation buildup within the area north of Horseshoe Bend will impact navigation of the canyon or the fisheries.
▪ The lower water levels would severely restrict use of the Horseshoe Bend Marina. Visitor opportunities would be limited. Economic impact to the local community would be significant.</td></tr>
</table>

Table 18
Summary of Alternative Evaluations

Alternative	Cost	O&M Notes	Pros / Cons
D – HSB Dike	$24,000,000 (All rock dike)	Maintain structure Some dredging at connection locations	+ Maintains lower sediment levels within HSB + Minimal impact to sediment beyond HSB boundaries + Independent of other activities - High initial and maintenance cost - Does not impact turbidity, fine sediments in the water column and will deposit in the recreation area - Public safety, access from HSB to pool - Likely need to raise structure over time as sediments accumulate
BICA Impact: ▪ Design will likely impact access to and from the river into Horseshoe Bend creating watercraft safety issues that will need to be addressed between NPS and Wyoming Game and Fish. ▪ Potential to impact fisheries within Horseshoe Bend area. ▪ Should reduce annual influx of debris into Horseshoe Bend area thus improving boater safety, but will likely increase debris into other areas of the park. ▪ Unclear as to which agency would have responsibility for maintenance of the dike. ▪ It is unclear as to how the change in sedimentation flows within the canyon will impact navigation or fishery.			
E- Manage Watershed Sediments	Unknown	Projected high level to maintain effectiveness	Not evaluated in this study - Would likely require extensive watershed coordination with a long time period to implement
F – Dredge HSB	$145 mil (land disposal) $73 mil (pool)	Repetitively dredge on a 5 to 10 year interval	+ Land disposal removes sediment and benefits project - High initial and maintenance dredging cost - Permit issues with dredging, contaminants, discharge or disposal of material - Pool disposal advances delta migration rate - High volume will result in a nearly perpetual dredge - Downstream of HSB pool disposal impacts the sediment equilibrium bed elevation within HSB, therefore continuation of the dredging program is required to avoid permanently higher elevations
BICA Impact: ▪ Unclear as to which agency will be responsible for the costs associated with continued dredging. ▪ Continuous dredging will create the need to develop navigational protocols for boats using the Horseshoe Bend area. ▪ Unknown impacts to fisheries due to dredging operations in Horseshoe Bend.			

1 Modified pool levels will alter project benefits derived from pool levels and flows with likely indirect costs not evaluated for this study.

Base and alternative condition analysis conclusions are as follows:

General

- All alternatives illustrate the ability to impact sediments within the pool and at HSB.
- The model demonstrated the ability to assess pool level impact on sediment deposition. For a variety of future operation scenarios that alter pool levels, the model could be employed to predict future bed elevations.
- Sediment modeling results showed a level of accuracy of 5 to 15 percent when simulating the historic period. The model is best used as a tool to compare change between alternatives instead of actual elevation that is likely to have an error band of ± 5 feet at locations between HSB and the Causeway.
- Results assume that flow and sediment rates observed in the past remain similar in the future. Caution should be used when looking at time values. Since 1967 was an extreme event, results would be completely different if the model simulations started with year 2001 instead of year 1966.
- Sediment is episodic. Extreme events with the accompanying high sediment load will alter projections. Evaluation of alternatives should focus on long time intervals of 20 to 40 years.
- Alternatives which modify pool levels illustrate that pool level is a critical component. Pool levels affect equilibrium elevations within HSB and upstream areas as well as the rate of delta migration toward the dam.
- Some of the alternatives, such as Alt. C and Alt. F with the dredge discharge into the pool, have a negative effect by increasing the rate of delta migration toward the dam. This negative impact should be considered when evaluating alternative implementation.
- 2007 survey elevations within HSB indicate an average bed elevation of 3608 feet. Base condition modeling predicts that the sediment deposition level within the HSB will be in the range of elevation 3620 feet within 10 to 20 years from 2007.
- Over time, bed elevations within HSB will approach a new equilibrium level. Based on location within HSB, the equilibrium average bed elevation is predicted to vary from elevation 3622 to 3627 feet. The time to reach this level is predicted to vary from 25 to 35 years from 2007.
- 2007 survey elevations at Barry's Landing indicated that less than 20 feet of sediment has deposited at this location with an average bed elevation of 3480 feet. While formation of the delta front and slope is difficult to predict with accuracy, model results show the delta front advancing beyond Barry's Landing within a 30 to 40 year time period. Model results predict reaching a near equilibrium bed elevation in the range of 3600 feet at this location.

Alternative A

- Alternative A, maintaining higher seasonal reservoir levels, will likely provide additional recreational water depths for a period of 15 to 25 years compared to the base condition during years when the elevated pool level is attained. However, during drought years, the elevated sediment within HSB will impact recreation more severely than the base condition.
- Alternative A is consistent with current park management, no significant changes to resource management is anticipated if lake levels do not exceed 3640 feet for prolonged periods of time during the summer use season.

Alternative B

- Alternative B, the upstream sediment basin, provides benefits to the HSB that will continue as long as the basin is maintained although the maximum trap efficiency that can be sustained is likely around 70 percent.
- Alternative B benefits the lake portion of park. Sediment trapping would alter habitat and fisheries within Yellowtail Habitat area and visitor use. Sediment trap issues include project life maintenance and blowing sands.

Alternative C

- Alternative C, sediment flushing through HSB, is not recommended as the recreational use of HSB is negatively impacted, sediments are moved at a faster rate toward the dam, and implementation would likely impact reservoir operations and releases.

Alternative D

- Alternative D, the HSB dike, shows the potential to maintain sediment levels near the current elevation within HSB. However, the sediment model is not capable of accurately modeling the local sediment deposition that would occur at the recreation area connections to the river section.
- Additional sediment deposition would occur within the protected portion of HSB due to general turbidity.
- Alternative D has implementation issues with impacts to HSB recreational access, watercraft safety, fisheries within Horseshoe Bend area, and structure maintenance.

Alternative E

- Alternative E, to manage watershed sediments, was not evaluated in this study. Successful implementation would require a fairly long time period through extensive watershed coordination. In addition, it is projected to require a fairly high level of maintenance to maintain effectiveness over a long time period.

Alternative F

- Alternative F, dredging within HSB, illustrates the ability to maintain lower elevations to provide recreation access. However, disposal within the pool downstream in the narrow canyon will impact future bed elevations within the HSB and move sediments at a faster rate toward the dam. Land disposal is extremely expensive.
- Alternative F has implementation issues with continued dredging costs, boater safety within HSB, and likely impacts to fisheries due to dredging operations within HSB.

8. REFERENCES.

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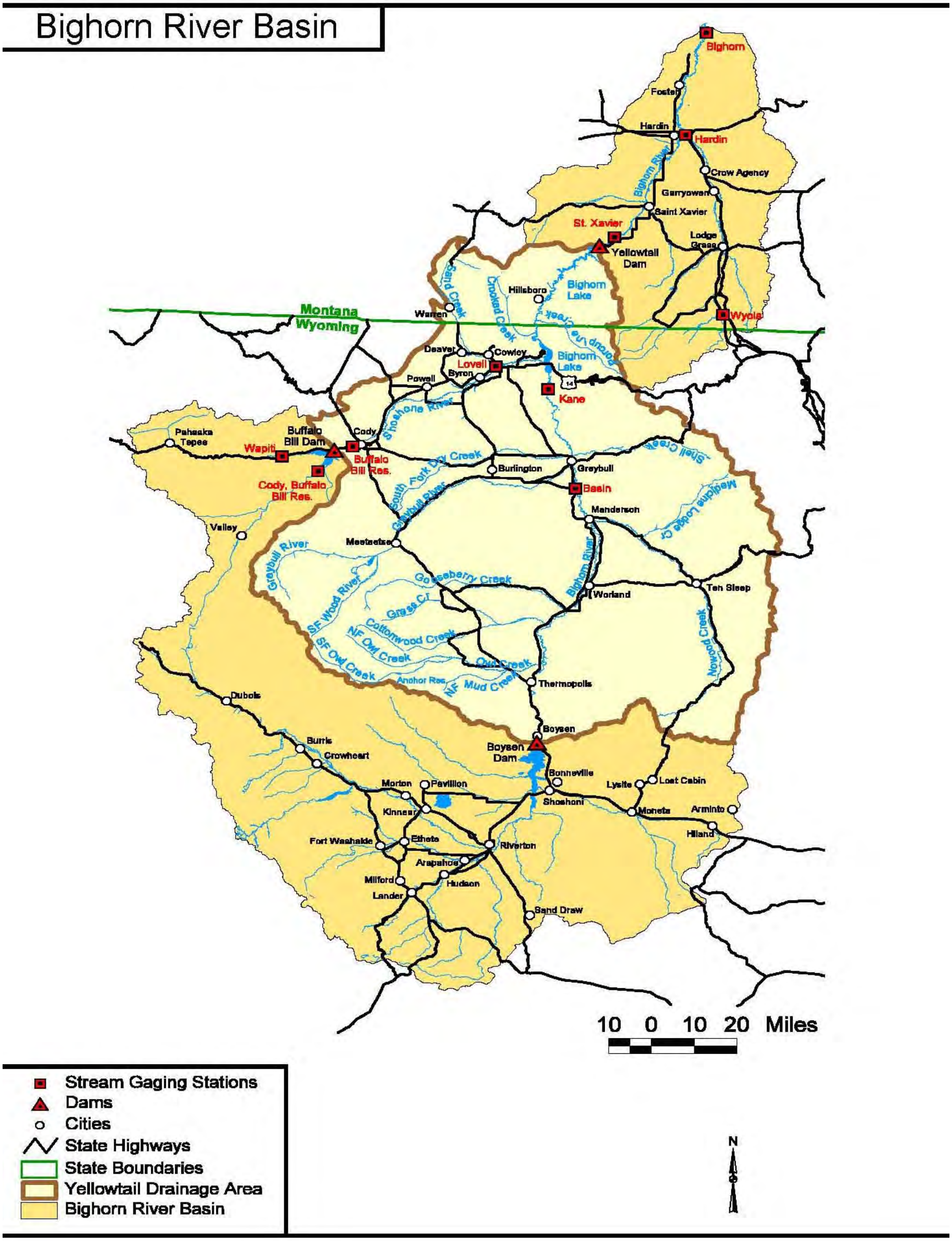

Bighorn River Basin
Bighorn
Foster
Hardin
Crow Agency
Garryowen
Saint Xavier
St. Xavier
Lodge Grass
Yellowtail Dam
Bighorn Lake
Hillsboro
Wyola
Montana
Wyoming
Warren
Deaver
Cowley
Lovell
Byron
Powell
Kane
Cody
Buffalo Bill Dam
Pahaska Tepee
Wapiti
Buffalo Bill Res.
Cody, Buffalo Bill Res.
Burlington
Greybull
Basin
Manderson
Valley
Meeteetse
Worland
Ten Sleep
Thermopolis
Dubois
Boysen
Boysen Dam
Burris
Crowheart
Morton
Pavillion
Kinnear
Bonneville
Shoshoni
Lysite
Lost Cabin
Moneta
Arminto
Hiland
Fort Washakie
Ethete
Riverton
Arapahoe
Milford
Hudson
Lander
Sand Draw
Shoshone River
Shell Creek
Medicine Lodge Cr
Nowood Creek
Greybull River
SF Wood River
Gooseberry Creek
Grass Cr
Cottonwood Creek
NF Owl Creek
SF Owl Creek
Owl Creek
Anchor Res.
NF Mud Creek
Bighorn River
Sand Creek
Crooked Creek
10 0 10 20 Miles
Stream Gaging Stations
Dams
Cities
State Highways
State Boundaries
Yellowtail Drainage Area
Bighorn River Basin
N

Model Sediment Input Parameters

```
***     imin      wfrac     bfracmin  bfracmax
SMN             1       0.7       0.5      0.85
***
SEQ     LAURSENM
***
***
SA2        399500    308595    263000         0
***     angle1(ab(angle2(be nalt      alphad    alphas    blength
SAT            30        30         2       0.2       0.5       250         0         0         0          !
SAT            30        30         2       0.2       0.5       250         0         0         0          !
SAT            30        30         1       0.2       0.5       250         0         0         0          !
SAT            90        90         1       0.2       0.5       250         0         0         0          !
***
CS2             0
***     stdep_f   stdep_p   concEq    er_lim
CSD         0.002     0.003       0.2       0.1
***
CE2             0
***     stpero    er_stme   stmero    er_mass         0.2      0.67       0.5         2
CER           0.2       0.4       0.5         1
***     c1        v1        c2        v2        c3        v3        c4        v4
CF1          0.10      0.20     10.00      6.00    100.00      4.00    500.00      0.04
***     densC_I   densC_f   densC_e   time_e
CSC         40.00     60.00     53.00   1000.00
***     xc
CD2             0
***     densityClay
CDI            46        46
***     End       of        River             1
***     end       message
END
```

Plate 2

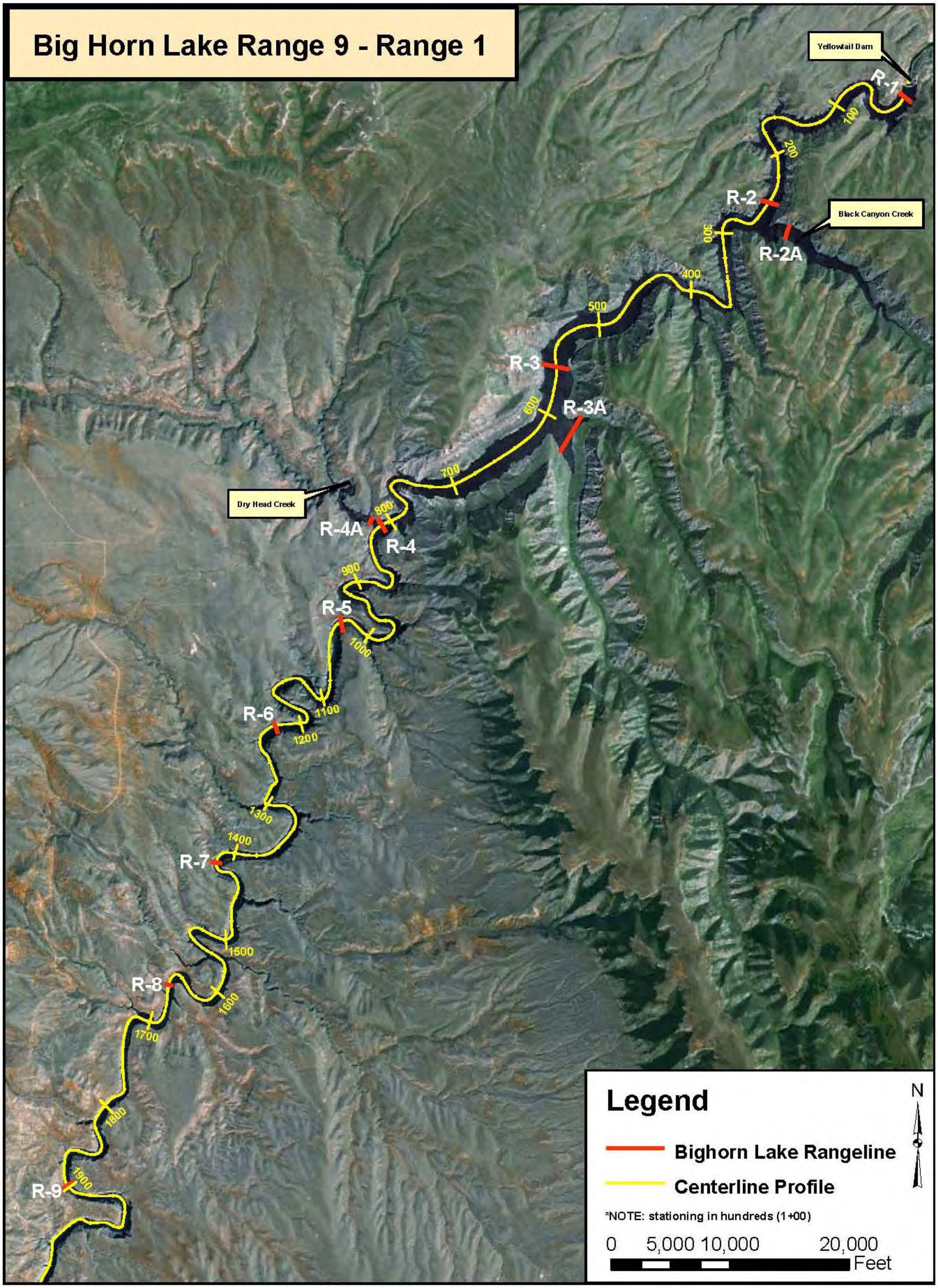
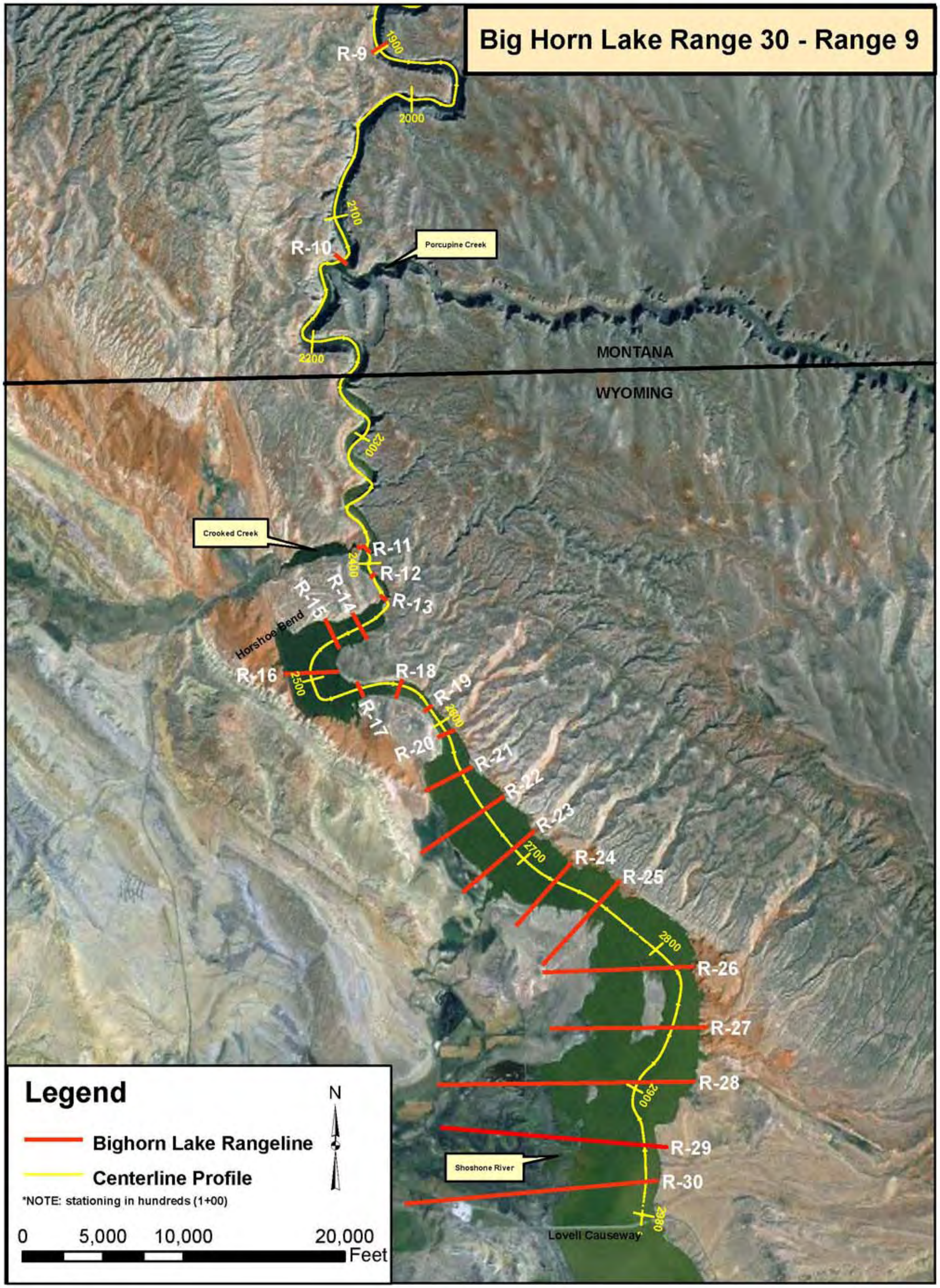
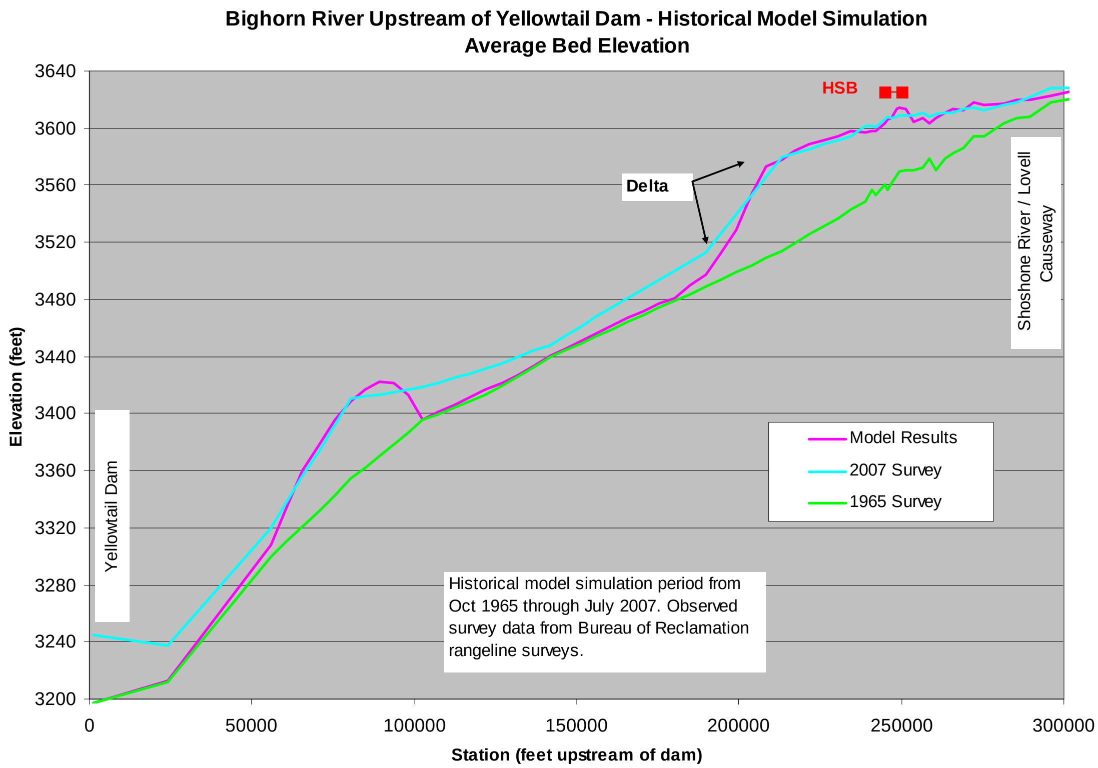

Big Horn Lake Range 9 - Range 1
Yellowtail Dam
Black Canyon Creek
Dry Head Creek
R-1
R-2
R-2A
R-3
R-3A
R-4A
R-4
R-5
R-6
R-7
R-8
R-9
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
Legend
Bighorn Lake Rangeline
Centerline Profile
*NOTE: stationing in hundreds (1+00)
0 5,000 10,000 20,000
Feet
N

Plate 3


Big Horn Lake Range 30 - Range 9
R-9
1900
2000
2100
R-10
Porcupine Creek
2200
MONTANA
WYOMING
2300
Crooked Creek
R-11
2400
R-12
R-13
R-14
R-15
Horshoe Bend
R-16
2500
R-17
R-18
R-19
2600
R-20
R-21
R-22
R-23
2700
R-24
R-25
2800
R-26
R-27
R-28
2900
R-29
Shoshone River
R-30
2980
Lovell Causeway
Legend
Bighorn Lake Rangeline
Centerline Profile
*NOTE: stationing in hundreds (1+00)
N
0
5,000
10,000
20,000
Feet


Bighorn River Upstream of Yellowtail Dam - Historical Model Simulation
Average Bed Elevation
Elevation (feet)
Station (feet upstream of dam)
HSB
Delta
Yellowtail Dam
Shoshone River / Lovell Causeway
Model Results
2007 Survey
1965 Survey
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.
3640
3600
3560
3520
3480
3440
3400
3360
3320
3280
3240
3200
0
50000
100000
150000
200000
250000
300000

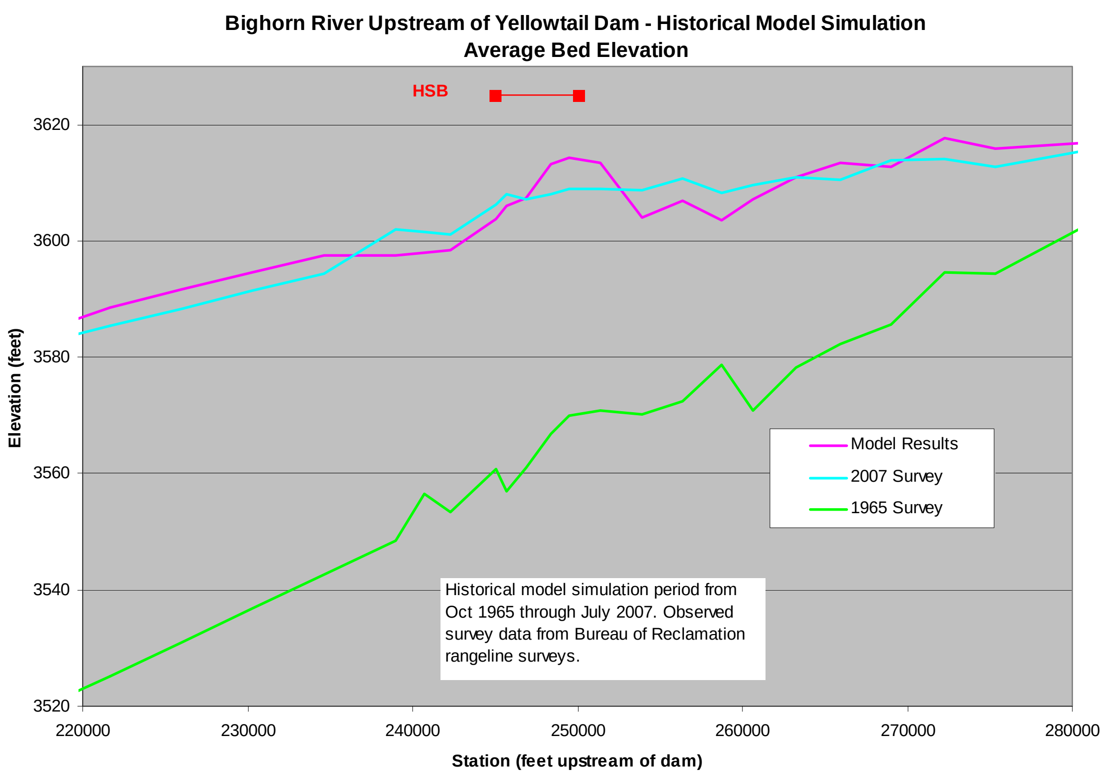
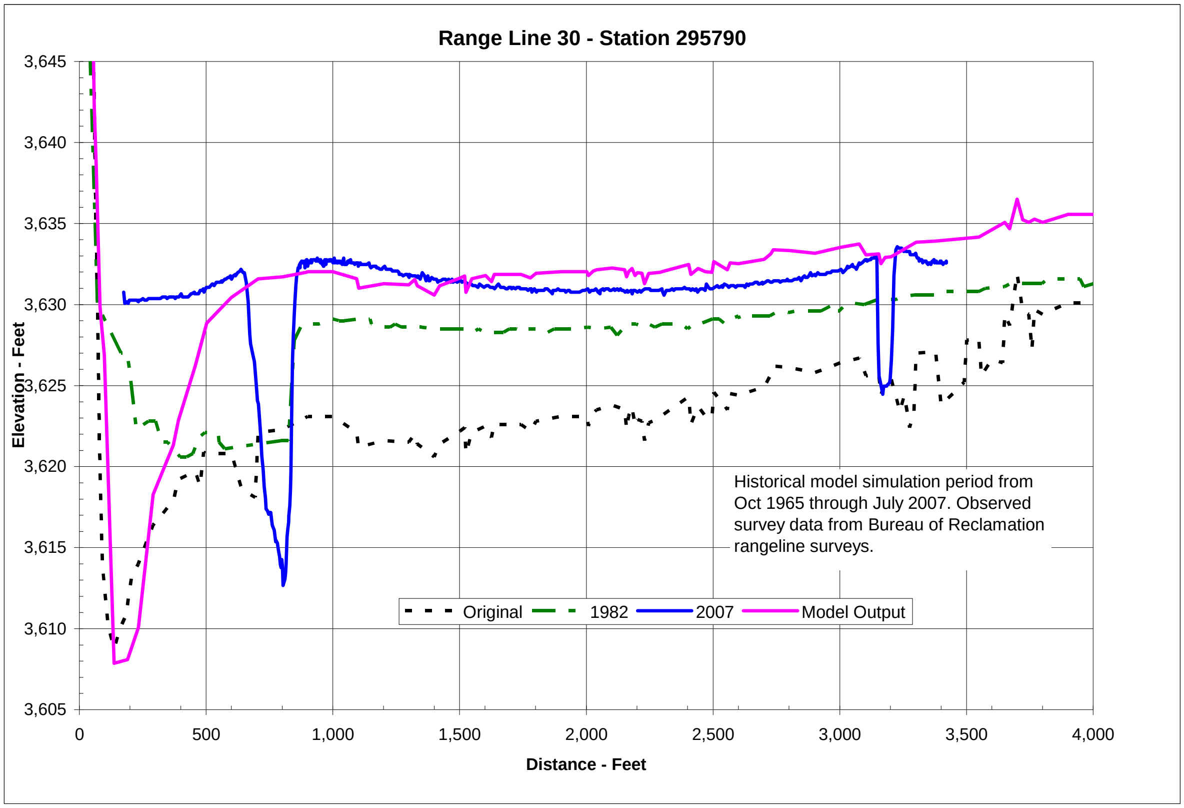

Bighorn River Upstream of Yellowtail Dam - Historical Model Simulation
Average Bed Elevation
Elevation (feet)
Station (feet upstream of dam)
HSB
Model Results
2007 Survey
1965 Survey
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.
3620
3600
3580
3560
3540
3520
220000
230000
240000
250000
260000
270000
280000

Plate 5


Range Line 30 - Station 295790
Elevation - Feet
Distance - Feet
3,645
3,640
3,635
3,630
3,625
3,620
3,615
3,610
3,605
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.
Original
1982
2007
Model Output

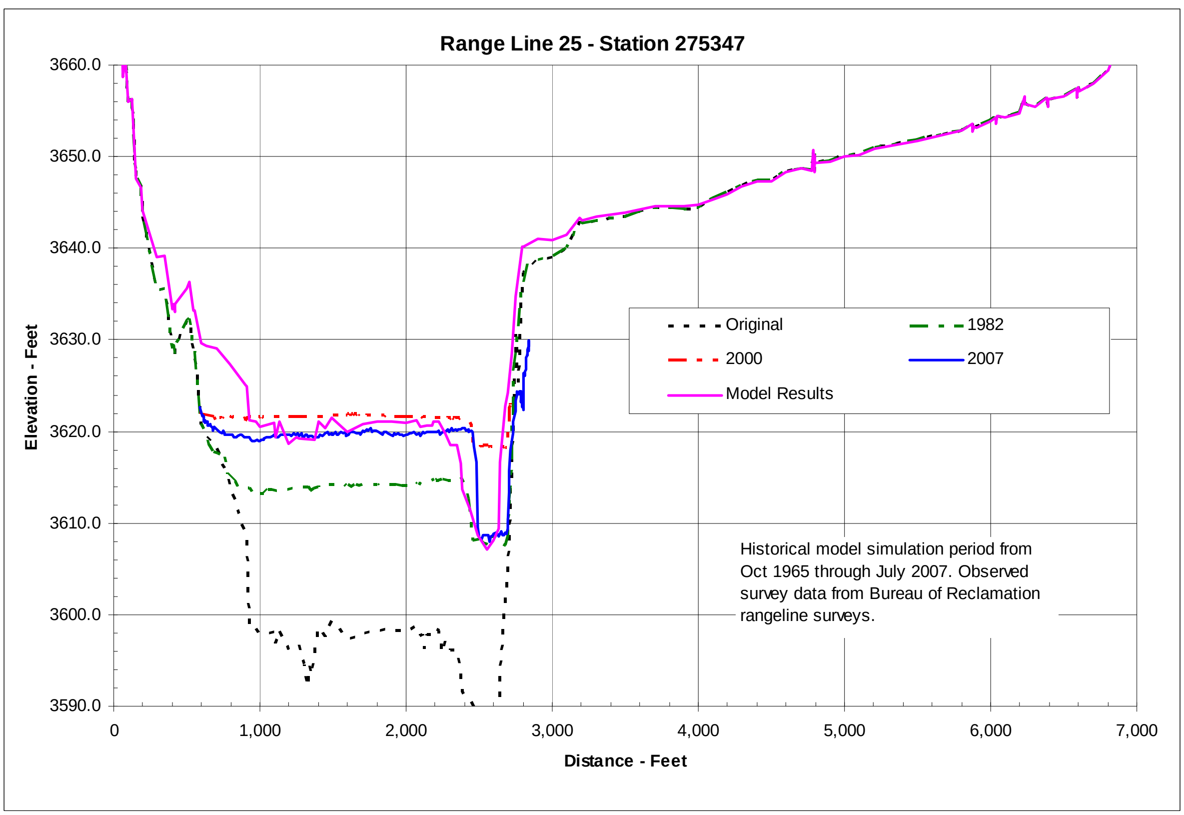
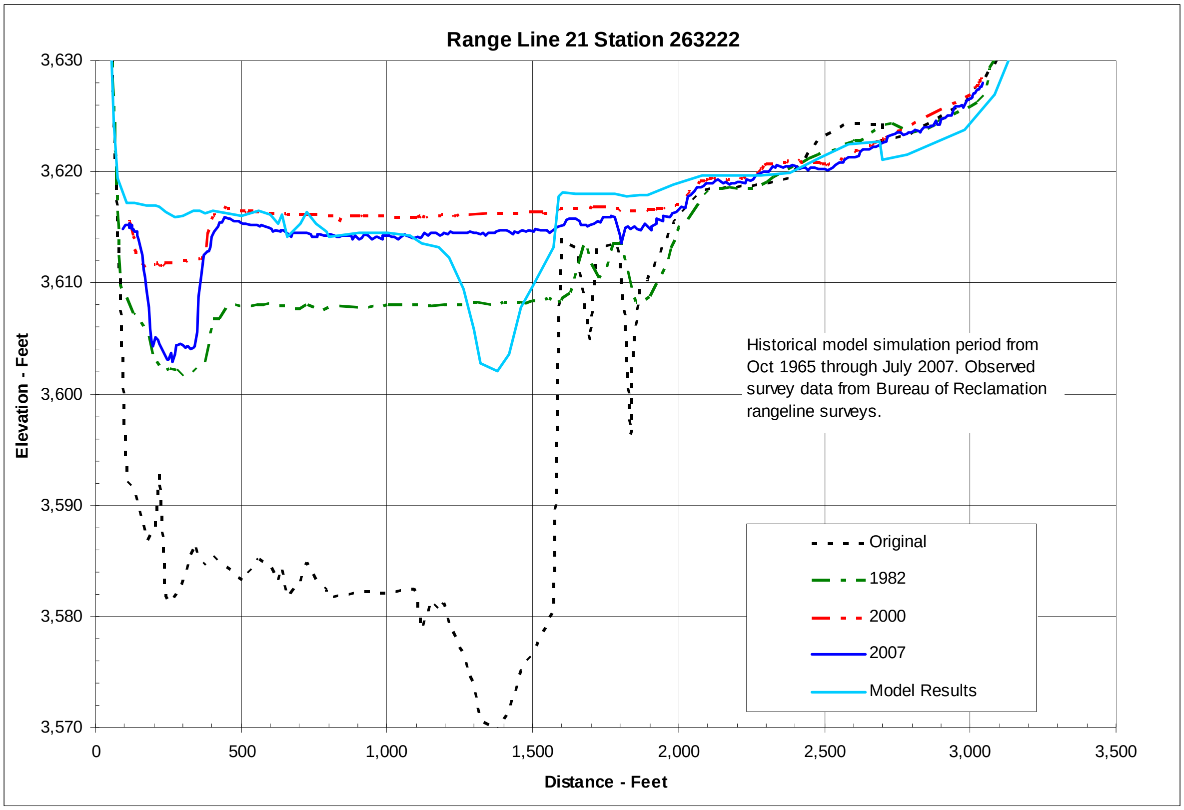
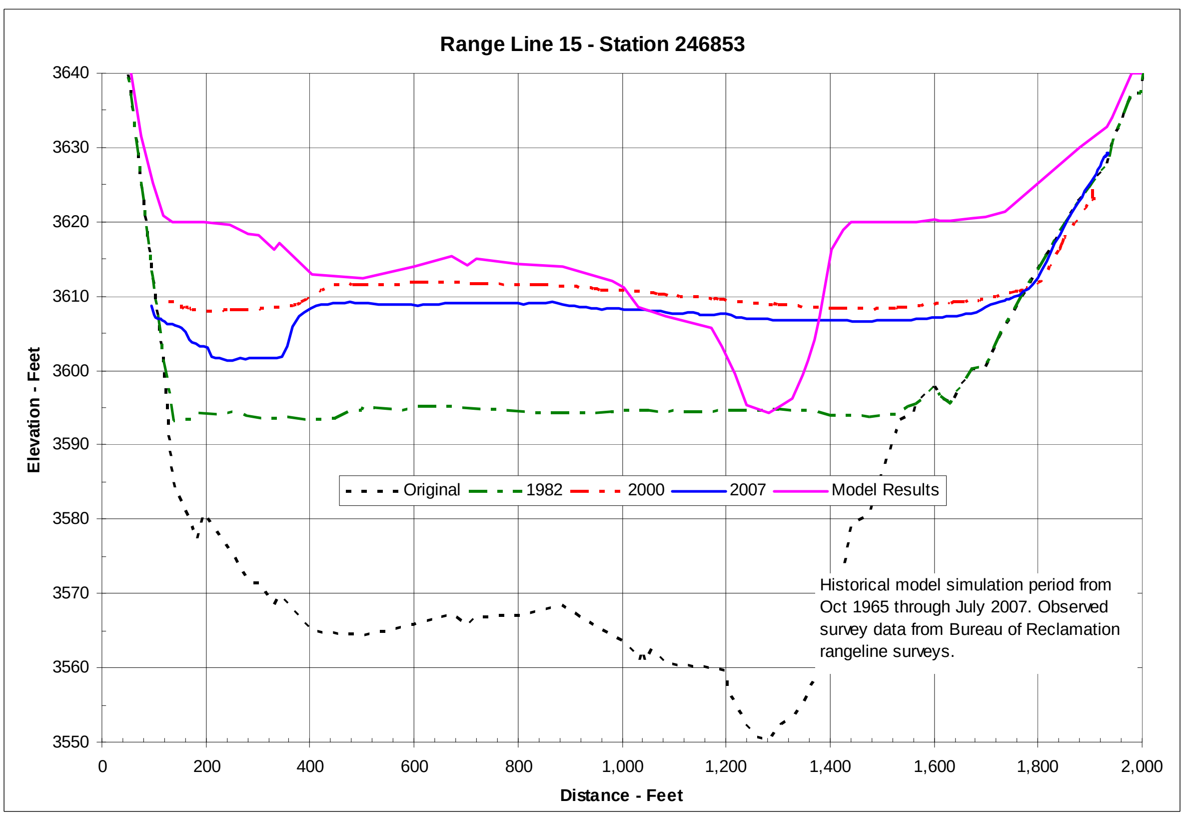

Range Line 25 - Station 275347
Elevation - Feet
Distance - Feet
3660.0
3650.0
3640.0
3630.0
3620.0
3610.0
3600.0
3590.0
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Original
1982
2000
2007
Model Results
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.

Plate 6

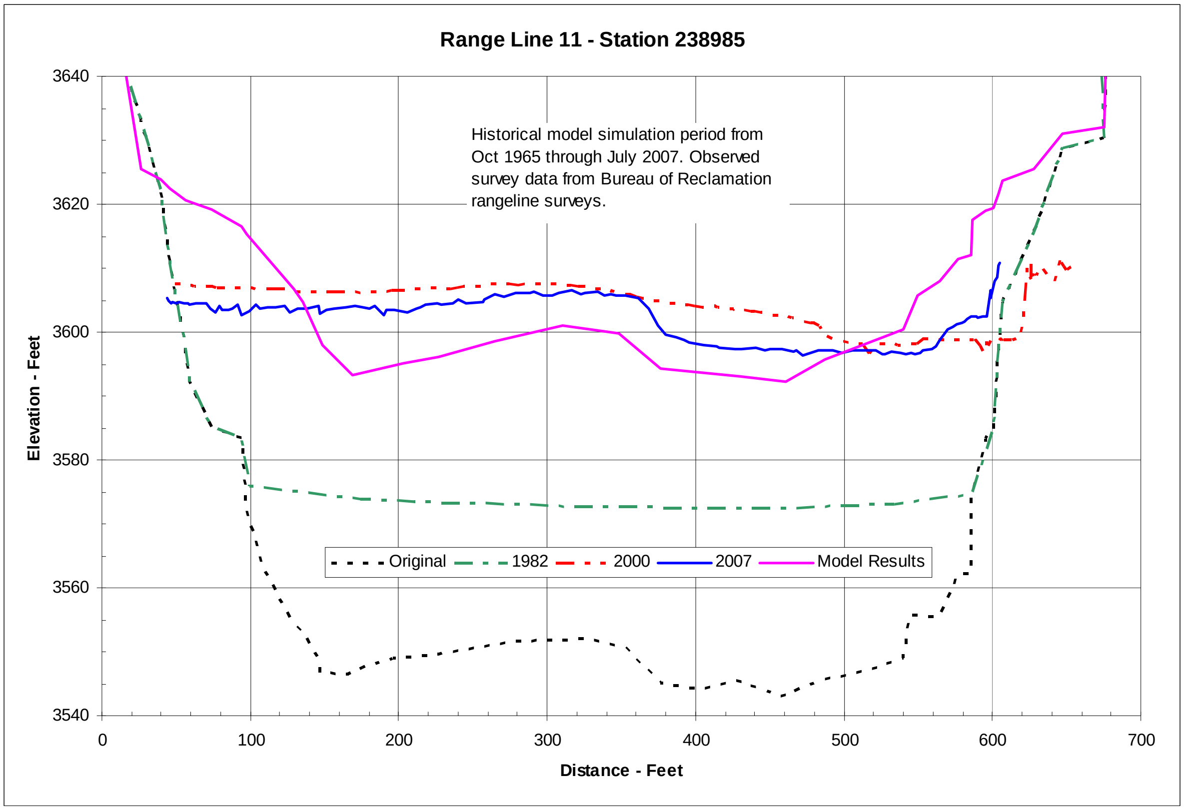


Range Line 21 Station 263222
Elevation - Feet
Distance - Feet
3,630
3,620
3,610
3,600
3,590
3,580
3,570
0
500
1,000
1,500
2,000
2,500
3,000
3,500
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.
Original
1982
2000
2007
Model Results

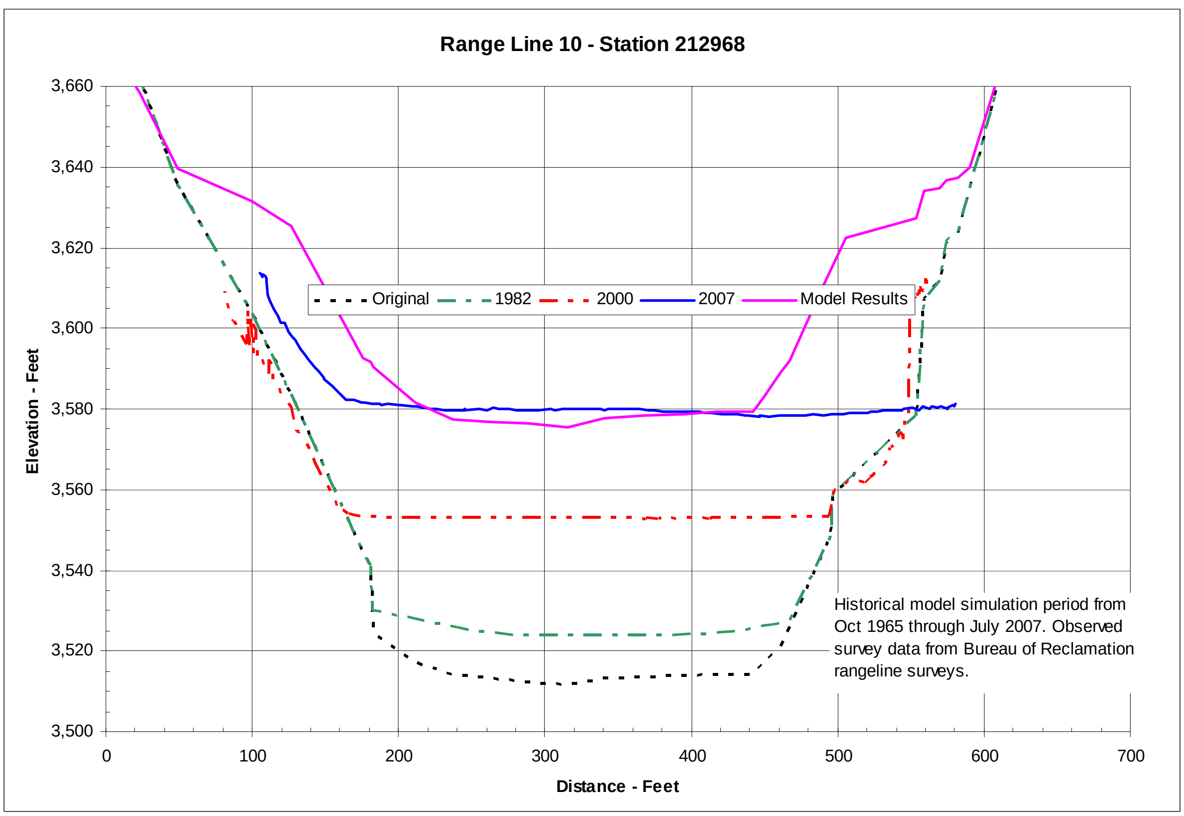


Range Line 15 - Station 246853
Elevation - Feet
Distance - Feet
3640
3630
3620
3610
3600
3590
3580
3570
3560
3550
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
Original
1982
2000
2007
Model Results
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.

Plate 7

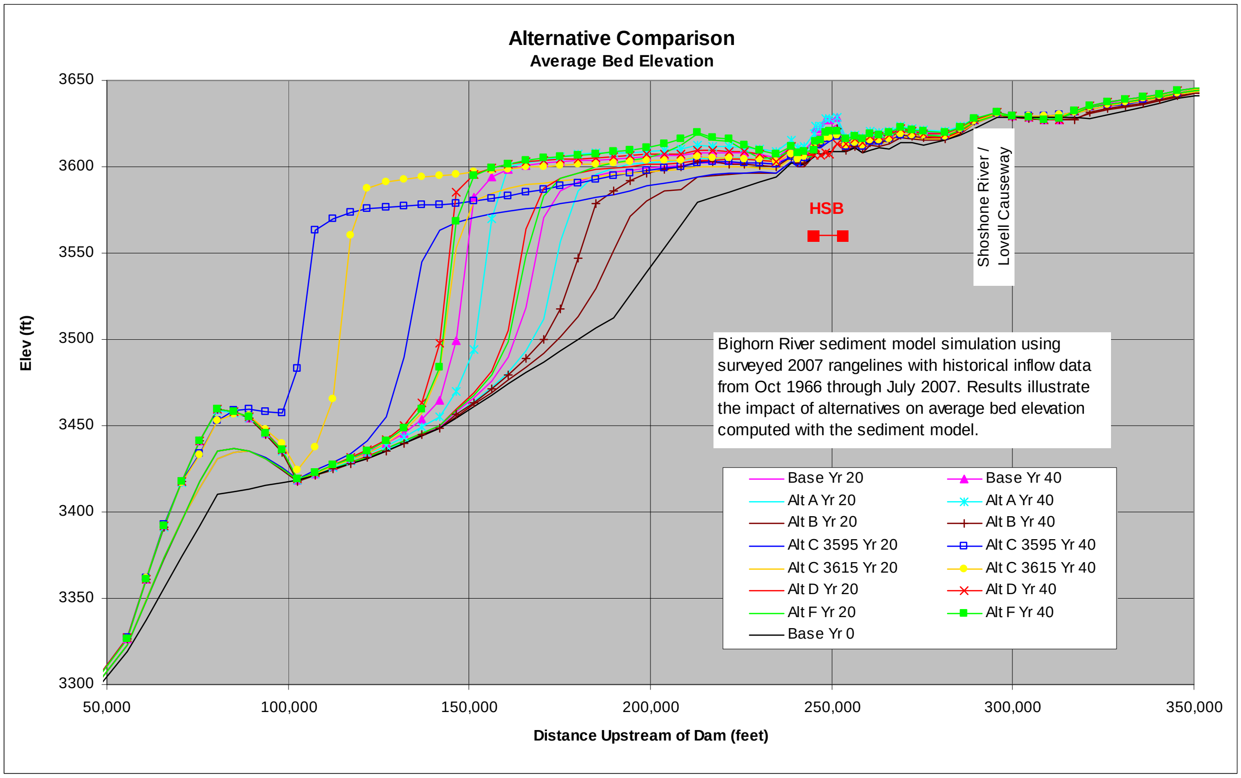


Range Line 11 - Station 238985
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.
Original
1982
2000
2007
Model Results
Elevation - Feet
Distance - Feet
3640
3620
3600
3580
3560
3540
0
100
200
300
400
500
600
700

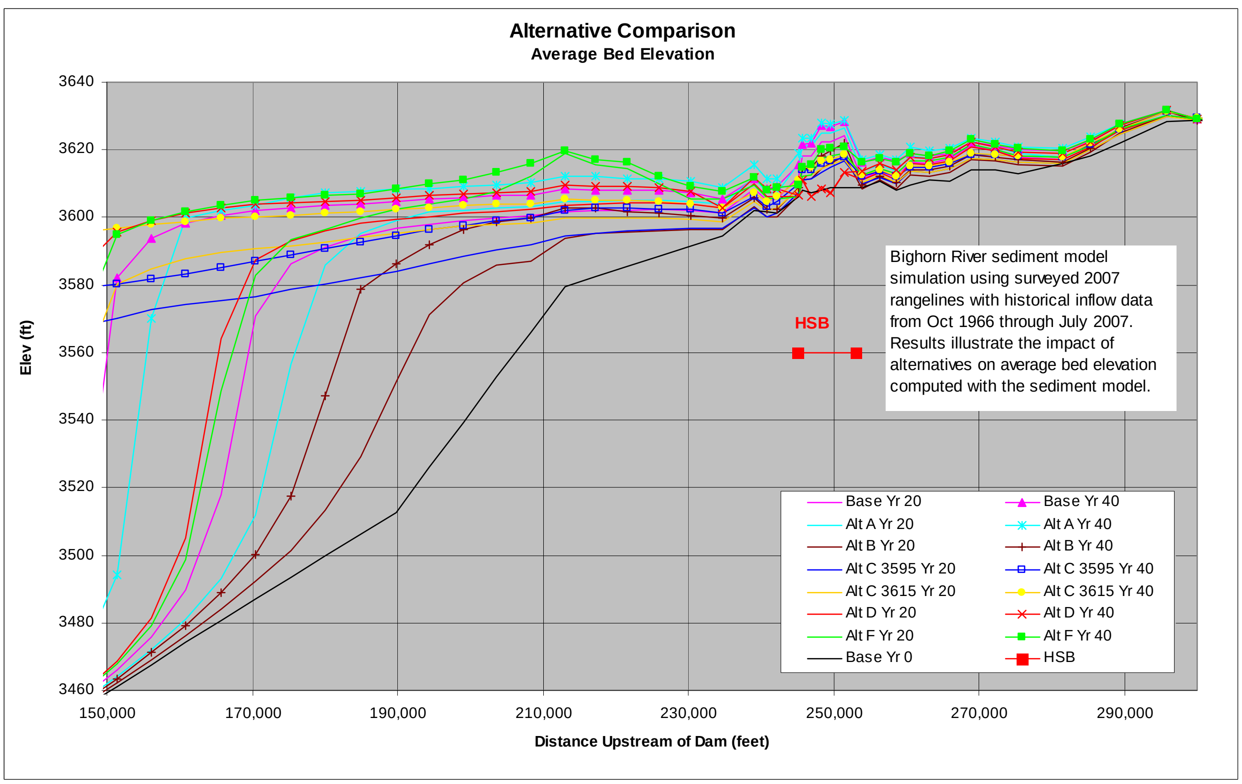


Range Line 10 - Station 212968
Original
1982
2000
2007
Model Results
Historical model simulation period from Oct 1965 through July 2007. Observed survey data from Bureau of Reclamation rangeline surveys.
Elevation - Feet
Distance - Feet
3,660
3,640
3,620
3,600
3,580
3,560
3,540
3,520
3,500
0
100
200
300
400
500
600
700

Plate 8

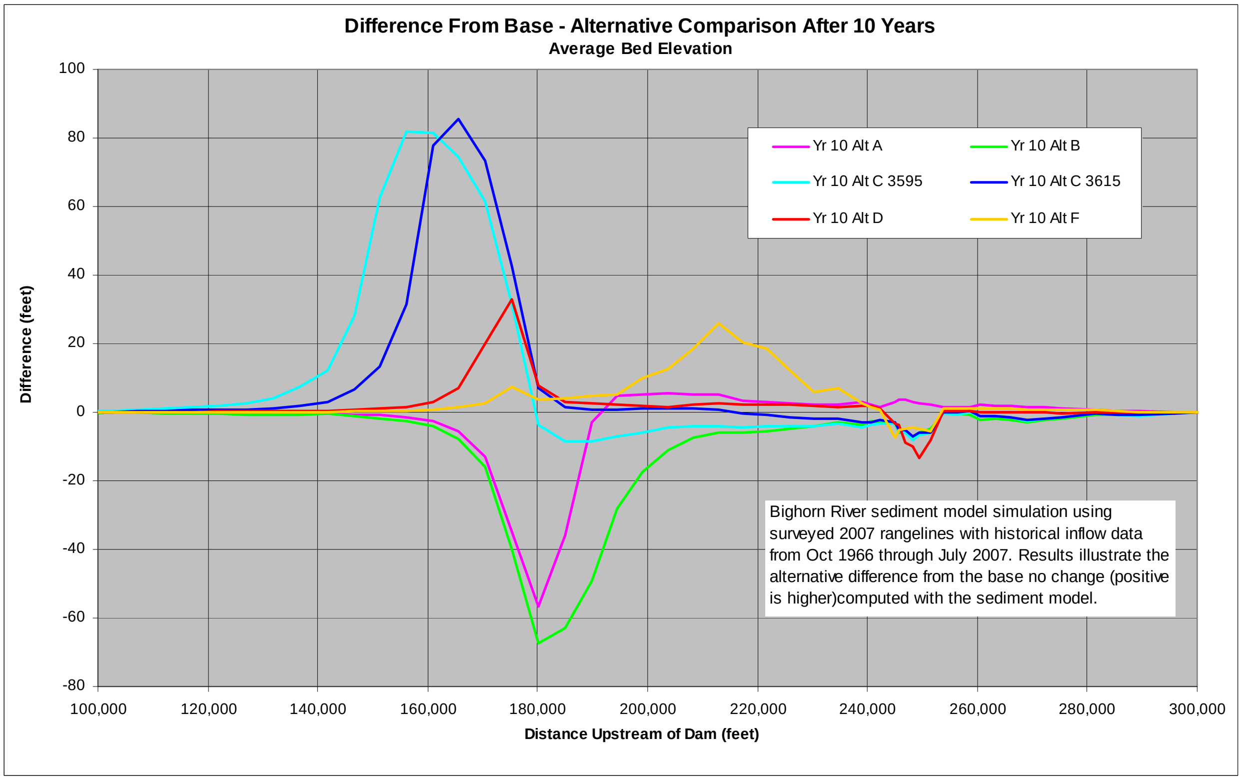


Alternative Comparison
Average Bed Elevation
Elev (ft)
Distance Upstream of Dam (feet)
HSB
Shoshone River / Lovell Causeway
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the impact of alternatives on average bed elevation computed with the sediment model.
Base Yr 20
Base Yr 40
Alt A Yr 20
Alt A Yr 40
Alt B Yr 20
Alt B Yr 40
Alt C 3595 Yr 20
Alt C 3595 Yr 40
Alt C 3615 Yr 20
Alt C 3615 Yr 40
Alt D Yr 20
Alt D Yr 40
Alt F Yr 20
Alt F Yr 40
Base Yr 0



Alternative Comparison
Average Bed Elevation
Elev (ft)
Distance Upstream of Dam (feet)
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the impact of alternatives on average bed elevation computed with the sediment model.
Base Yr 20
Base Yr 40
Alt A Yr 20
Alt A Yr 40
Alt B Yr 20
Alt B Yr 40
Alt C 3595 Yr 20
Alt C 3595 Yr 40
Alt C 3615 Yr 20
Alt C 3615 Yr 40
Alt D Yr 20
Alt D Yr 40
Alt F Yr 20
Alt F Yr 40
Base Yr 0
HSB

Plate 9


Difference From Base - Alternative Comparison After 10 Years
Average Bed Elevation
Difference (feet)
Distance Upstream of Dam (feet)
100
80
60
40
20
0
-20
-40
-60
-80
100,000
120,000
140,000
160,000
180,000
200,000
220,000
240,000
260,000
280,000
300,000
Yr 10 Alt A
Yr 10 Alt B
Yr 10 Alt C 3595
Yr 10 Alt C 3615
Yr 10 Alt D
Yr 10 Alt F
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.

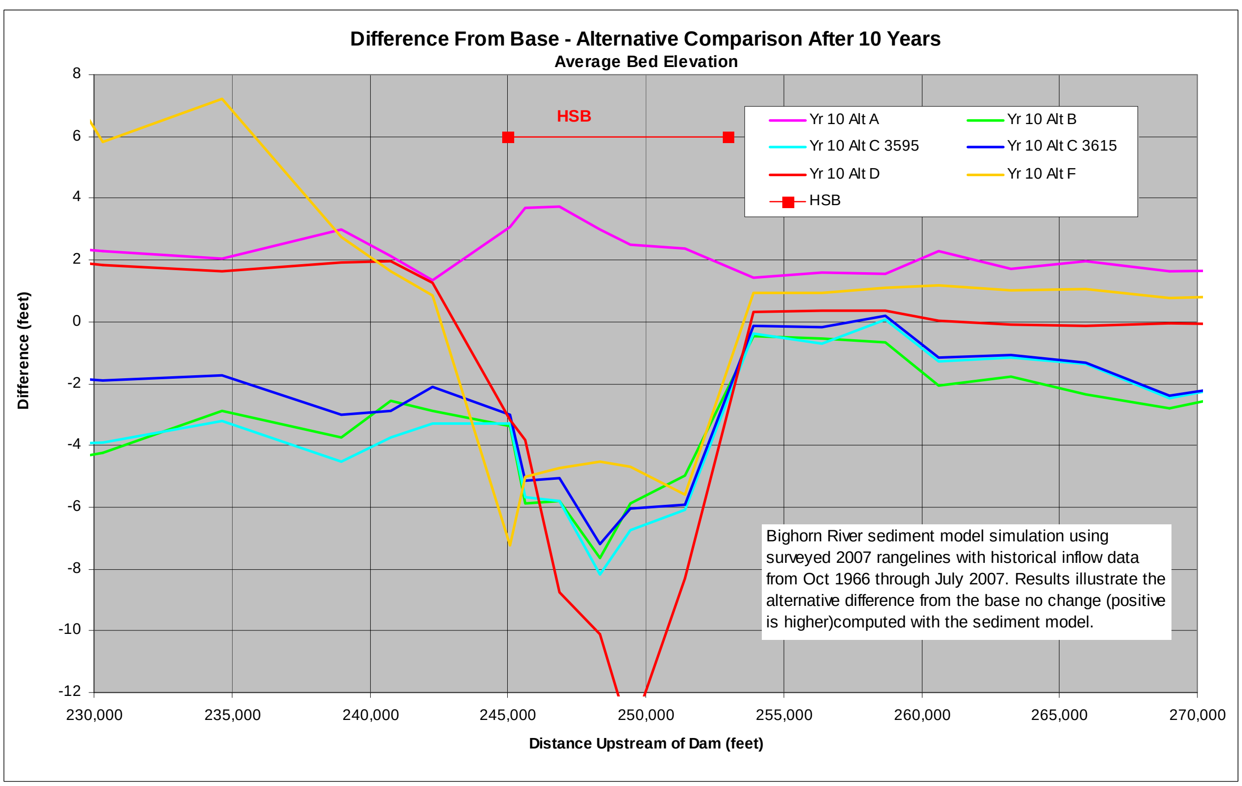
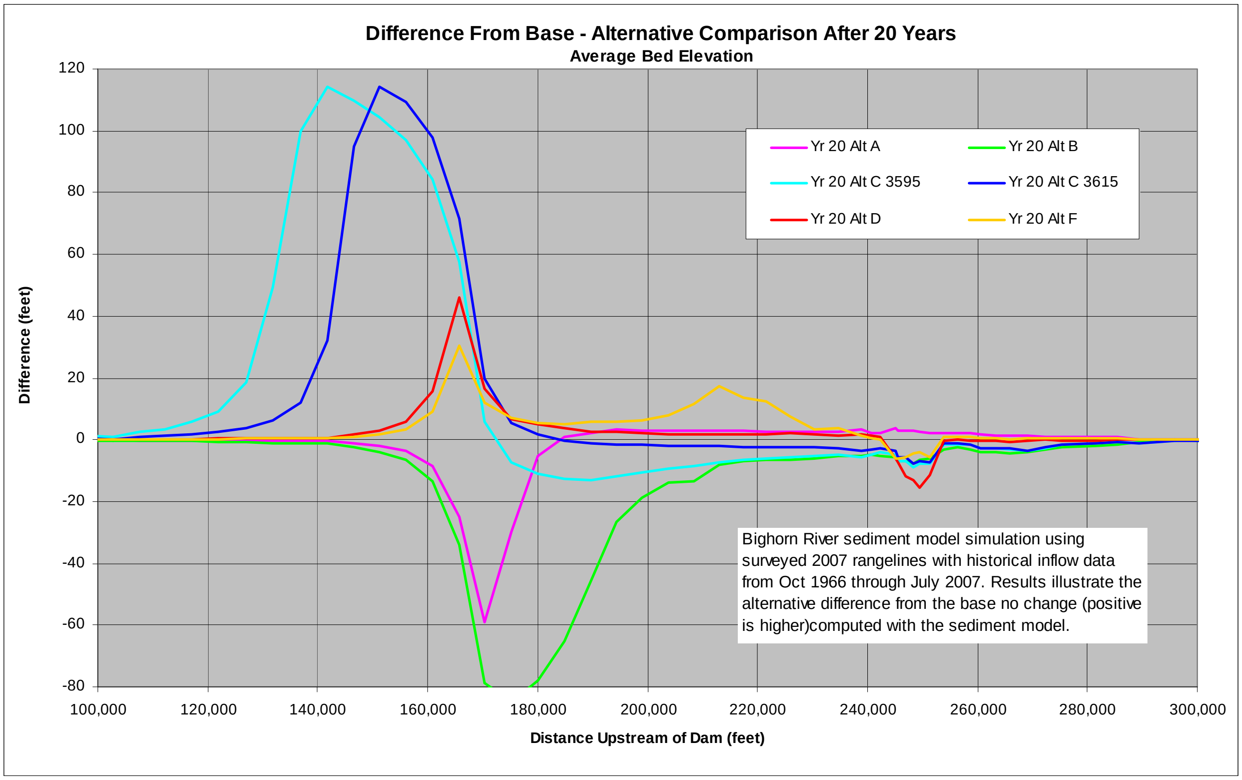

Difference From Base - Alternative Comparison After 10 Years
Average Bed Elevation
Difference (feet)
Distance Upstream of Dam (feet)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
230,000
235,000
240,000
245,000
250,000
255,000
260,000
265,000
270,000
HSB
Yr 10 Alt A
Yr 10 Alt B
Yr 10 Alt C 3595
Yr 10 Alt C 3615
Yr 10 Alt D
Yr 10 Alt F
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.

Plate 10


Difference From Base - Alternative Comparison After 20 Years
Average Bed Elevation
Difference (feet)
Distance Upstream of Dam (feet)
Yr 20 Alt A
Yr 20 Alt B
Yr 20 Alt C 3595
Yr 20 Alt C 3615
Yr 20 Alt D
Yr 20 Alt F
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.

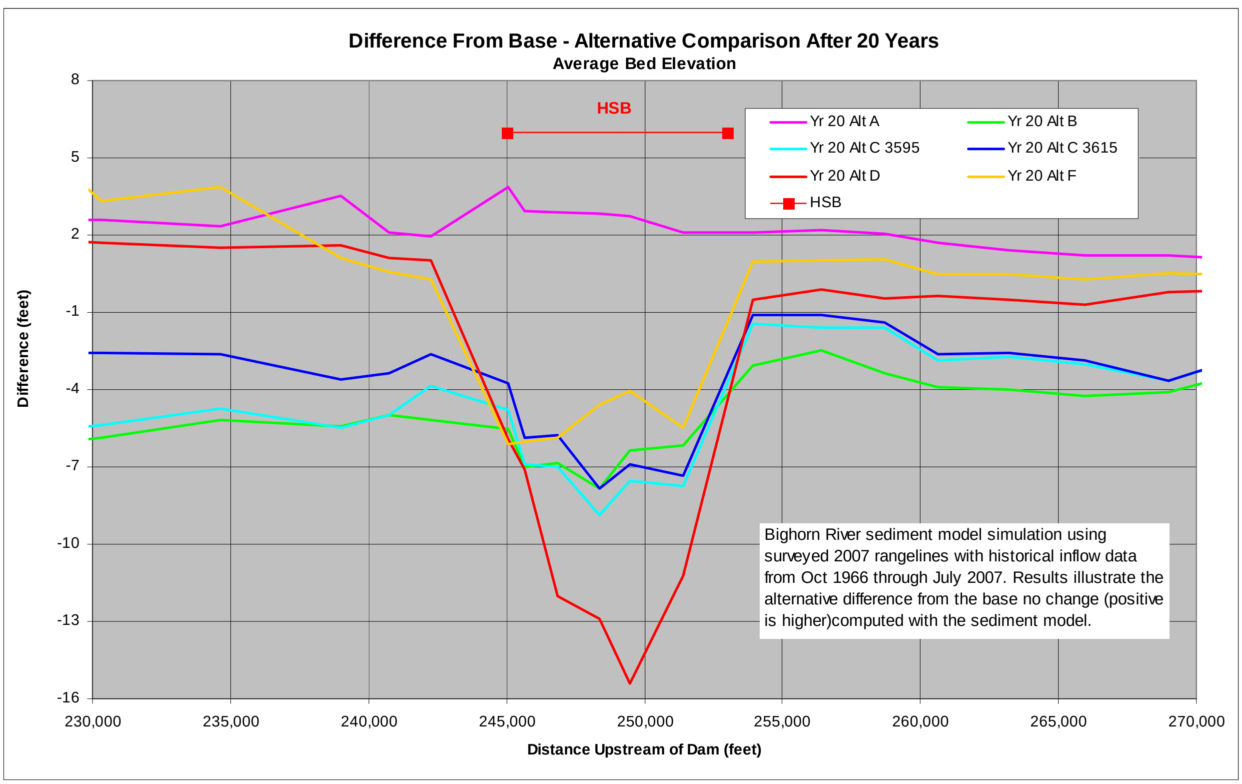
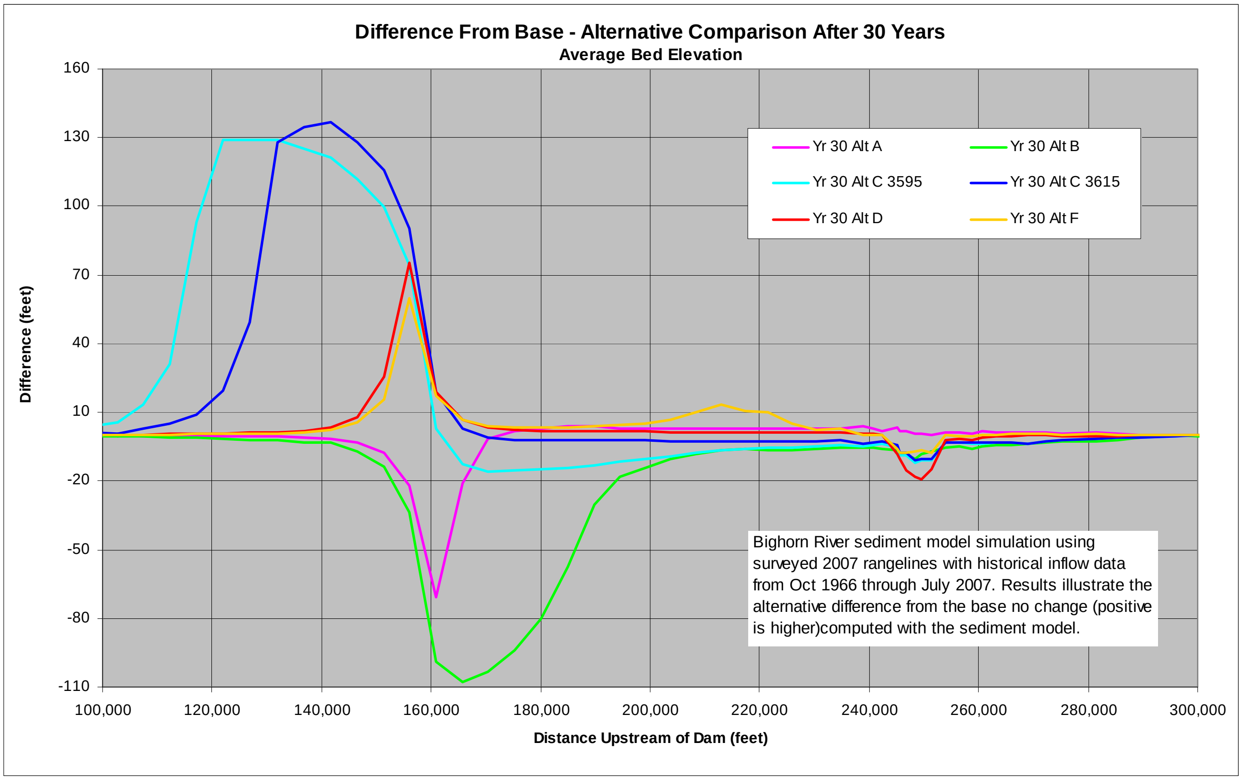
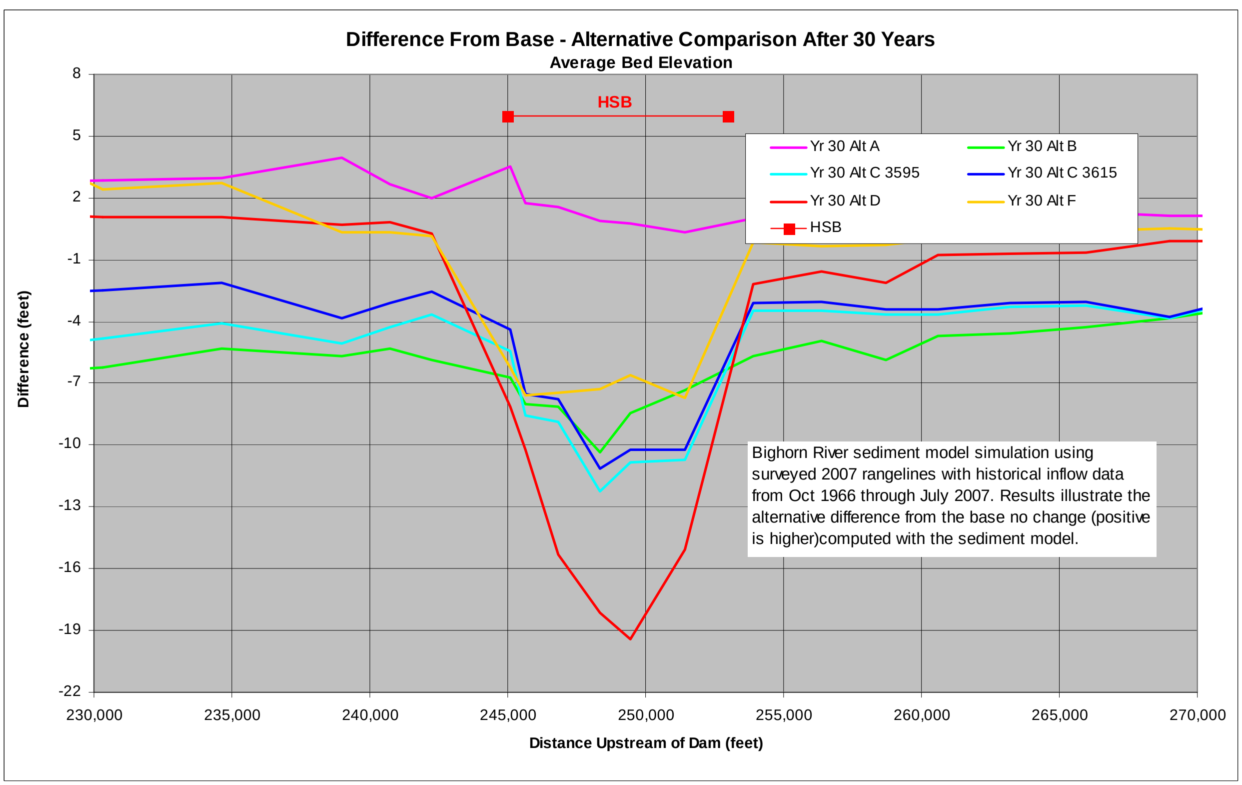
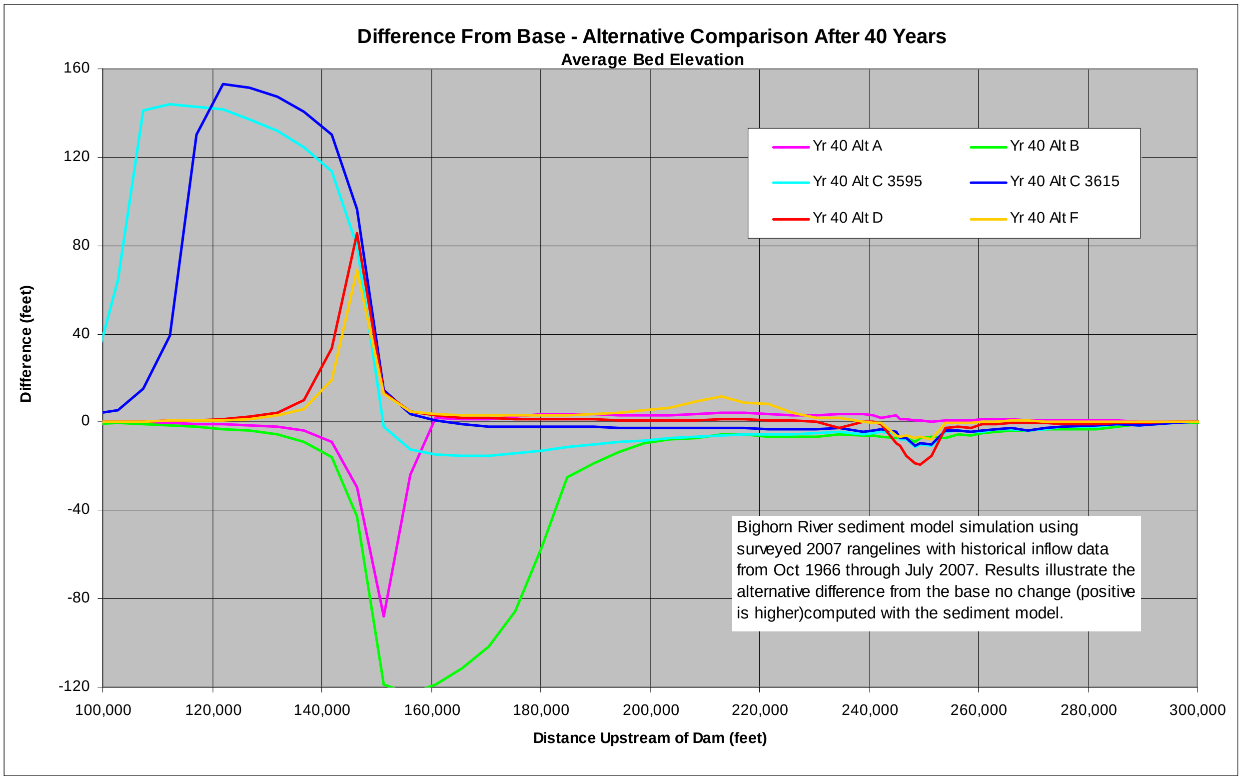

Difference From Base - Alternative Comparison After 20 Years
Average Bed Elevation
HSB
Difference (feet)
Distance Upstream of Dam (feet)
Yr 20 Alt A
Yr 20 Alt B
Yr 20 Alt C 3595
Yr 20 Alt C 3615
Yr 20 Alt D
Yr 20 Alt F
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.

Plate 11


Difference From Base - Alternative Comparison After 30 Years
Average Bed Elevation
Yr 30 Alt A
Yr 30 Alt B
Yr 30 Alt C 3595
Yr 30 Alt C 3615
Yr 30 Alt D
Yr 30 Alt F
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.
Difference (feet)
Distance Upstream of Dam (feet)


Difference From Base - Alternative Comparison After 30 Years
Average Bed Elevation
HSB
Yr 30 Alt A
Yr 30 Alt B
Yr 30 Alt C 3595
Yr 30 Alt C 3615
Yr 30 Alt D
Yr 30 Alt F
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.
Difference (feet)
Distance Upstream of Dam (feet)


Difference From Base - Alternative Comparison After 40 Years
Average Bed Elevation
Difference (feet)
Distance Upstream of Dam (feet)
Yr 40 Alt A
Yr 40 Alt B
Yr 40 Alt C 3595
Yr 40 Alt C 3615
Yr 40 Alt D
Yr 40 Alt F
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.

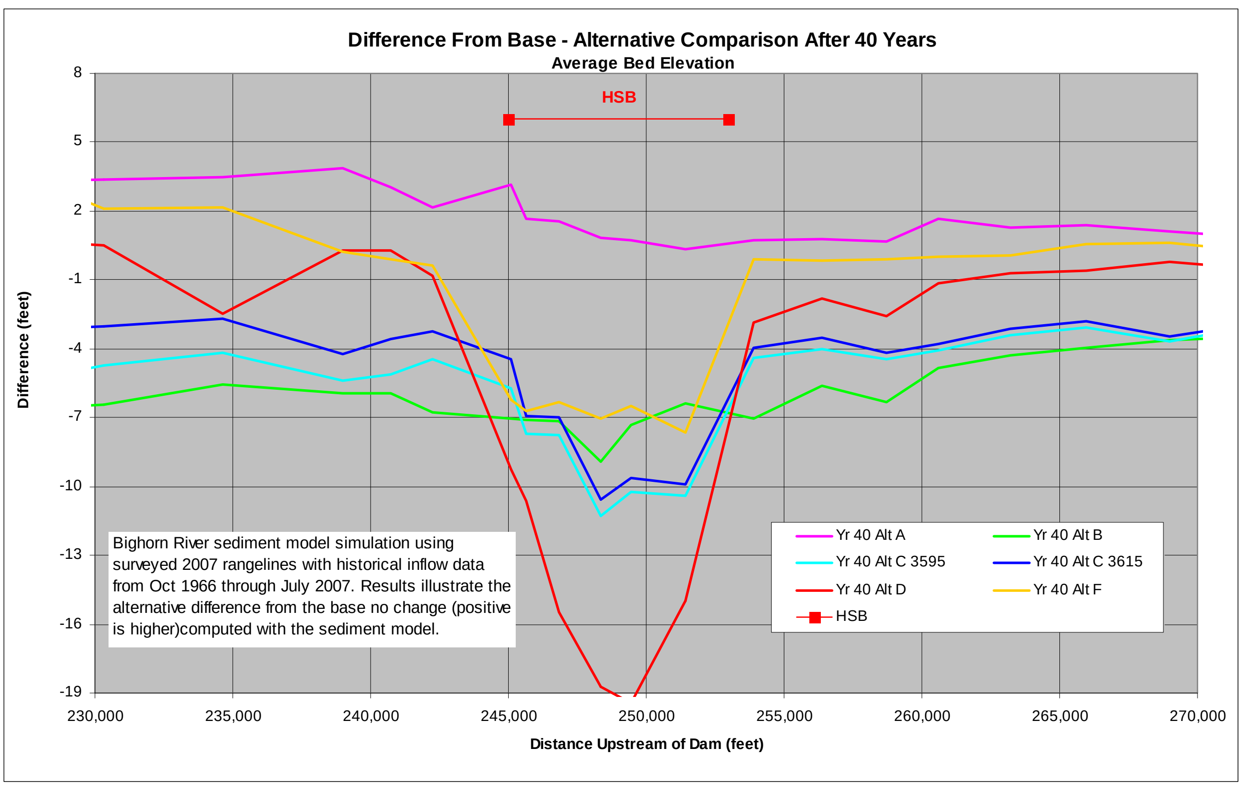
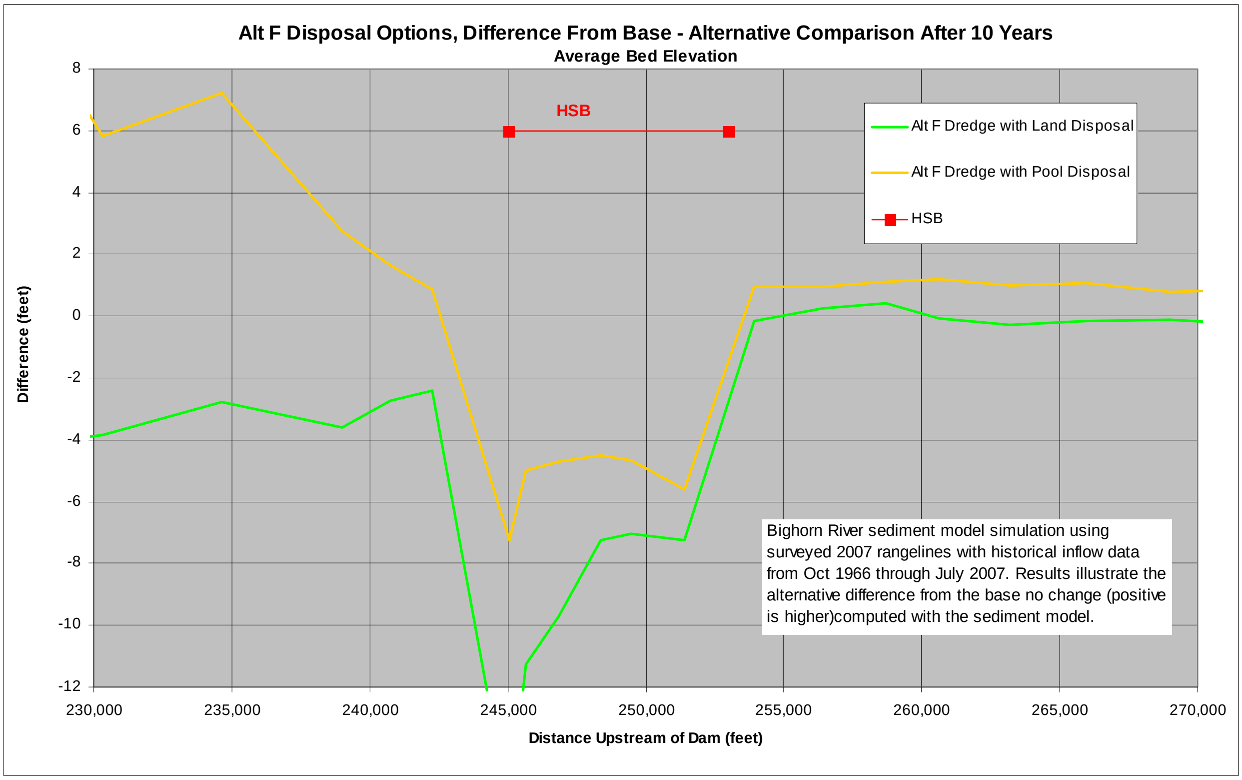
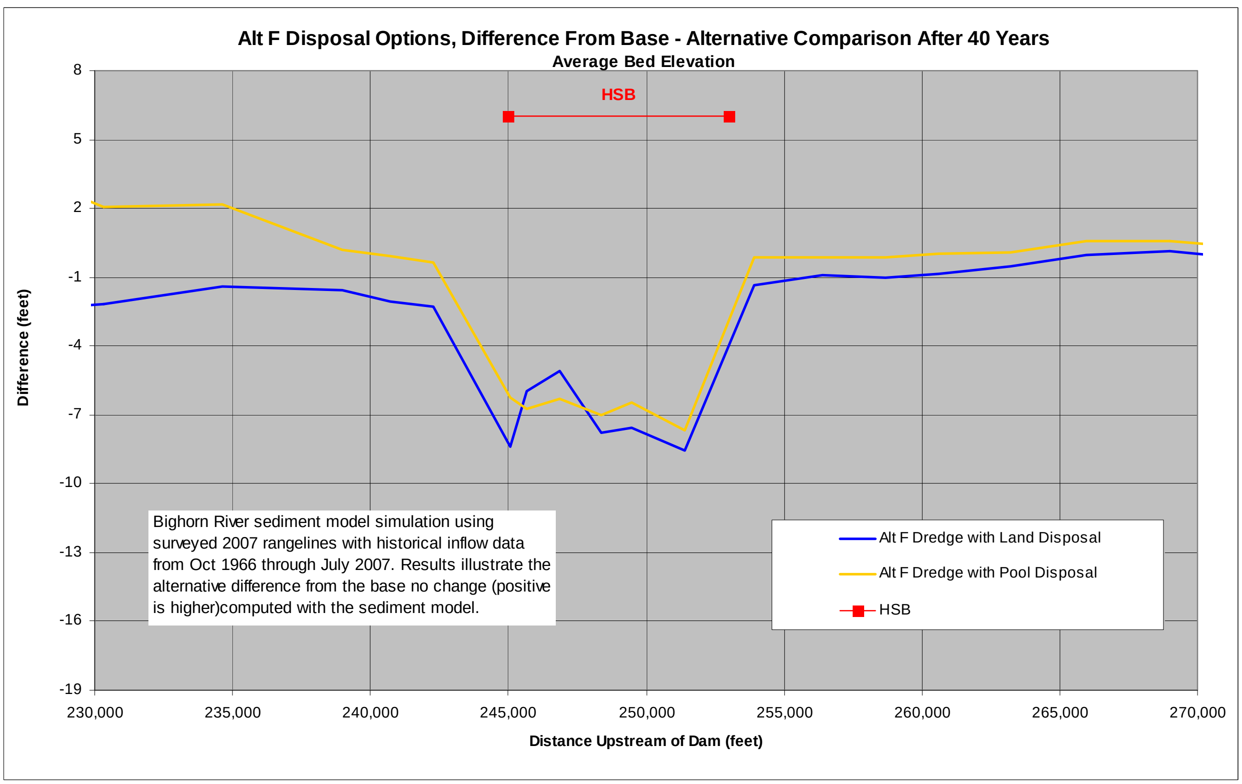

Difference From Base - Alternative Comparison After 40 Years
Average Bed Elevation
HSB
Difference (feet)
Distance Upstream of Dam (feet)
Yr 40 Alt A
Yr 40 Alt B
Yr 40 Alt C 3595
Yr 40 Alt C 3615
Yr 40 Alt D
Yr 40 Alt F
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.

Plate 13



Alt F Disposal Options, Difference From Base - Alternative Comparison After 10 Years
Average Bed Elevation
HSB
Alt F Dredge with Land Disposal
Alt F Dredge with Pool Disposal
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.
Difference (feet)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
230,000
235,000
240,000
245,000
250,000
255,000
260,000
265,000
270,000
Distance Upstream of Dam (feet)



Alt F Disposal Options, Difference From Base - Alternative Comparison After 40 Years
Average Bed Elevation
HSB
Bighorn River sediment model simulation using surveyed 2007 rangelines with historical inflow data from Oct 1966 through July 2007. Results illustrate the alternative difference from the base no change (positive is higher)computed with the sediment model.
Alt F Dredge with Land Disposal
Alt F Dredge with Pool Disposal
HSB
Difference (feet)
8
5
2
-1
-4
-7
-10
-13
-16
-19
230,000
235,000
240,000
245,000
250,000
255,000
260,000
265,000
270,000
Distance Upstream of Dam (feet)

Plate 14

US Army Corps of Engineers ®
Omaha District

BIGHORN LAKE
SEDIMENT MANAGEMENT STUDY
JANUARY 2009

Attachment A
Site Visit

Site Visit
Bighorn Lake
May 8 2008

Introduction

A site visit was conducted on May 8, 2008 by Dan Pridal, Omaha District Corps of Engineers, and Stephanie Hellekson, Bureau of Reclamation, Montana Area Office. Additional members from the National Park Service and the Bighorn River Users Group were present for the site visit.

The site visit consisted of viewing areas along the Bighorn River from Horseshoe Bend upstream to the Lovell Causeway. No sediment samples, surveys, or other type of physical data collection was conducted during the site visit.

Site Observations.

Site photos and observation notes are as follows:

View from the HSB boat ramp looking away from the river and pool toward the outside of the bend, in the bay adjacent to the ramp.

View from the HSB boat ramp looking away from the river and pool toward the outside of the bend, upper end of the bay entering the park region.


View from near boat ramp looking southerly toward upper end of HSB, the Bighorn River enters HSB in the background left side of the photo.


View from HSB boat ramp vicinity looking mostly downriver toward the predominantly east – northeast portion of HSB. The HSB area ends and enters the canyon downstream.

View from overlook south of HSB looking northerly toward the HSB area. The Bighorn River enters from the right side of the photo. The HSB boat ramp is barely visible in the upper right corner of the photo.


View from the south HSB bluff (same as previous photo) looking upstream at the Bighorn River as it enters the upper end of HSB.

View upstream of the Lovell Causeway looking downstream at the bridge.


View from the high bluff on the east side of the Bighorn River valley looking downstream at the Lovell Causeway.

View from south bluff looking downstream toward Lovell causeway, edge of bridge is visible in right corner of the photo. This area is the potential upstream detention basin site.