


Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options

Volume I of II

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region

Washington State Department of Ecology

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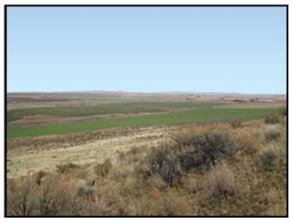
Cover Photos:
Left to right: Crab Creek, Sand Hollow,
Foster Creek, and Hawk Creek

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Preface

The Columbia River Water Management Program, an ongoing effort by the State of Washington to work with Tribal, federal, state, and local governments, and other stakeholders, desires to develop a long-term approach to water allocation from the mainstem Columbia River. Allocation and development of water supplies was addressed by the Washington State Legislature and Governor Gregoire in February 2006, with the addition of Title 90, Section 90.020 to the Revised Code of Washington (RCW). This law states that *"a key priority of water resource management in the Columbia River Basin is the development of new water supplies that includes storage and conservation in order to meet the economic and community development needs of people and the instream needs of fish."*

RCW 90.90.020 directs that the Washington State Department of Ecology (Ecology) shall focus its efforts to develop water supplies for the Columbia River Basin based on the following needs:

- Alternatives to ground water for agricultural users in the Odessa subarea aquifer
- Sources of water supply for pending water right applications
- A new uninterruptible supply of water for the holders of interruptible water rights on the Columbia River mainstem that are subject to instream flows or other mitigation conditions to protect stream flows
- New municipal, domestic, industrial, and irrigation water needs within the Columbia River Basin

The State of Washington, the U.S. Bureau of Reclamation (Reclamation), and the three Columbia Basin Project irrigation districts signed a Memorandum of Understanding (MOU) in December 2004 to provide a framework for the parties to work together to support projects designed to optimize existing water management and to explore options for new storage that would provide additional water for priority uses at key times.

The primary purpose of the current *Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options* is to conduct appraisal-level investigations of four sites, as selected by Reclamation in consultation with Ecology. The overall objective is to assess the relative merits of these four sites and to determine if one or more of these sites should be recommended for investigation at a feasibility level of detail.

Abbreviations and Acronyms

A&E	architect and engineering
AACE	American Association of Cost Engineers
AF	acre-feet
APE	area of potential effect
Appraisal Evaluation	*Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options*
bgs	below ground surface
BPA	Bonneville Power Administration
CFR	Code of Federal Regulations
CFRD	concrete-faced rockfill dam
cfs	cubic feet per second
CRBG	Columbia River Basalt Group
DCM&I	domestic, commercial, municipal, and industrial
DOE	Determination of Eligibility
DPS	distinct population segment
Ecology	Washington State Department of Ecology
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FCV	fixed cone valves
FE	Federally listed as endangered
fps	feet per second
FSOC	Federal Species of Concern
FT	Federally listed as threatened
ft^2	square feet
GCPUD	Grant County Public Utility District
gpm	gallons per minute
hp	horsepower
ID/IQ	indefinite delivery/indefinite quantity
k	ranges of permeabilities
KAF	thousand acre-feet
km^2	square kilometers

km^3	cubic kilometers
kV	kilovolt
MAF	million acre-feet
Management Program	Columbia River Water Management Program
MOU	memorandum of understanding
mm	millimeters
MVA	megavolt amperes
MW	megawatt
NAIP	National Agriculture Inventory Program
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NPV	net present value
NRHP	National Register of Historic Places
PMF	probable maximum flood
PMP	probable maximum precipitation
P/T	pump/turbine
O&M	operation and maintenance
OS	Operational Scenario
Reclamation	U.S. Bureau of Reclamation
RCC	roller-compacted concrete
RCW	Revised Code of Washington
RI	relative importance
ROW	right-of-way
RR	railroad
SC	State candidate (species of concern)
SE	State listed as endangered
SHPO	State Historic Preservation Office
SPS	State priority species
SR	State Route
SS	State sensitive
ST	State listed as threatened
TCP	Traditional Cultural Property

typ	typical
UCRSRB	Upper Columbia River Salmon Recovery Board
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WNHP	Washington Natural Heritage Program
WSDOT	Washington State Department of Transportation
WSEL	water surface elevation

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1 Introduction

This section identifies the authorization for the *Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options* (Appraisal Evaluation), its purpose and need, its goals, and the study process.

1.1 Storage Study

Following from and building on the work contained in the December 2005 Pre-Appraisal Report, titled *Off-Channel Storage Assessment Pre-Appraisal Report*, this Appraisal Evaluation is part of an overall effort to identify and assess long-term, off-channel storage opportunities along the mainstem Columbia River.

1.2 Authorization

The authority for this study was contained in Task Order No. 03C810150B of Contract No. 03CA10150B for an indefinite delivery/indefinite quantity (ID/IQ) architect and engineering (A&E) Contract for A-E services dated August 8, 2006, and signed by Mr. Terry K. Ford, Jr., U.S. Bureau of Reclamation (Reclamation).

1.3 Purpose and Need

The purpose of the Appraisal Evaluation is to conduct appraisal-level investigations of four off-channel sites with an overall objective to determine if one or more of these sites should be approved for investigation at a feasibility level of detail.

The need for additional storage and water along the Columbia River mainstem is for the following anticipated or projected water requirements:

- Agriculture
- Flow augmentation for protection and enhancement of fishery resources
- Domestic, commercial, municipal, and industrial (DCM&I)
- Flexibility to respond to potential impacts of climate change and address water needs under different conditions

For the purpose of the Appraisal Evaluation, recreation and power production are considered secondary benefits.

In addition to the current Appraisal Evaluation, Reclamation and the Washington State Department of Ecology (Ecology) are receptive to partnering with other jurisdictions (or states) for regional solutions that involve new storage. The Appraisal Evaluation is focused on new water supply within the Columbia River Basin; however, since the potential new off-channel storage sites have the potential to supplement water needs throughout the region, irrigation water needs within tributaries of the upper Columbia River Basin were considered in the current Appraisal Evaluation.

1.4 Storage Study Goals

Reclamation and Ecology have developed the following storage study goals for the Appraisal Evaluation:

- Improve the water supply for pro-ratable irrigation water rights in dry years as well as secure water for future irrigation.
- Improve anadromous fish habitat by restoring and supplementing the flow regimes of the Columbia River.

- Meet future municipal, domestic, and industrial supply needs for existing users, as well as provide an additional water supply for population growth to the year 2050.

1.4.1 Irrigated Agriculture

Columbia Basin Project

The Columbia Basin Project is a federally authorized project with multiple purposes: irrigation, power production, flood control, municipal water supply, recreation, and fish and wildlife benefits. Water is provided to three irrigation districts: Quincy-Columbia Basin Irrigation District, East Columbia Basin Irrigation District, and South Columbia Basin Irrigation District, all of which in turn deliver water to their members (Ecology, 2006a).

The Columbia Basin Project is authorized to irrigate 1,029,000 acres at its completion. The project currently provides water to approximately 671,000 acres (Ecology, 2006a). The amount of additional water that would be necessary to irrigate the Columbia Basin Project at full development is 1,365,000 acre-feet. Future irrigation needs as part of the Appraisal Evaluation are based on the additional water necessary to irrigate the Columbia Basin Project at full development.

Additional agricultural irrigation needs for existing irrigation associated with changes in crop acreage, crop type and distribution, and the irrigation profile for various crops was also included in the Appraisal Evaluation. The additional long-term agricultural needs were estimated by Ecology during the *Water Supply Inventory and Long-Term Water Supply Demand Forecast* as 330,000 acre-feet (Ecology, 2006b).

Yakima Project

Within tributary basins to the Columbia River mainstem, the Yakima Project is the largest irrigation project. The Yakima Project is designed and authorized to supply water to approximately 465,000 acres in Kittitas, Yakima, and Benton Counties, and currently irrigates about 361,000 acres (Ecology, 2006a).

As part of the Yakima River Basin Water Storage Feasibility Study, Reclamation evaluated Columbia River water availability to examine the feasibility and acceptability of its use for storage augmentation within the Yakima River Basin (Reclamation, 2004). Conceptual water delivery plans indicate that it is physically possible to meet all or most of Yakima Basin’s additional future water rights demands from the Columbia River in lieu of the Yakima River (Reclamation, 2004). This potential water exchange would reduce the demands within the Yakima Basin and allow more water to be reserved for flow augmentation. Potential water exchange participants that were identified during the Yakima River Basin Water Storage Feasibility Study include the Roza and Sunnyside divisions of the Yakima Project.

The current Appraisal Evaluation maintains the same assumption that a potential water exchange could occur. Yakima Project irrigation needs as part of the Appraisal Evaluation were identified by Reclamation. During average and wet water years, the irrigation needs for the Roza and Sunnyside Divisions is 810,410 acre-feet; during dry water years, irrigation could only receive 662,046 acre-feet.

Interruptible Irrigators along the Columbia River

In 1980, Washington adopted an administrative rule for protecting instream flows on the Columbia River (Chapter 173-563 WAC). The rule required that water rights on the Columbia River mainstem issued after 1980 be subject to the state instream flow rule. These water rights (interruptible rights) can be curtailed in low flow conditions to maintain adequate flows for fish. Water rights conditioned on instream flows are called “interruptible rights” because the use of the right is subject to being interrupted when river levels fall below established flows. Interruptible rights can be curtailed when the March 1 forecast for April through September runoff at The Dalles Dam on the lower Columbia River is less than 60 million acre-feet (Ecology, 2006a). Interruptible water rights are not guaranteed to water users in low flow years.

Ecology amended the rule in 1998 and provided that all water right applications filed after July 27, 1997, would be subject to evaluation for impacts on fish as well as existing water rights (Ecology, 2006a). Ecology is directed to consult with “appropriate local, state, and federal agencies and Indian tribes” in determining whether there would be an impact on fish (WAC 173-563-020(4)). Any permit Ecology approves may be subject to instream flow protection or mitigation as necessary, determined case-by-case (WAC 173-563-020(4)).

Water users on the Columbia River who have interruptible water rights are primarily located in the central Columbia River Basin—in Benton, Kittitas, Chelan, Douglas, Lincoln, Grant, Franklin, and Yakima Counties—and include agricultural, municipal, residential, and industrial users (Ecology, 2006a). To date, Ecology has issued approximately 340 interruptible water rights for a total of 392,838 acre-feet per year on the Columbia River mainstem (Ecology, 2006a).

1.4.2 Instream Flow

Columbia River

The Columbia River Water Management Program is pursuing this Appraisal Evaluation to evaluate the potential to store additional water from the Columbia River mainstem for seasonal release to meet the needs of out-of-stream water users, and instream flows to maximize benefits for salmon and steelhead populations.

As mandated by Section 90.90.020 of the Revised Code of Washington (RCW), water supplies secured through the development of new storage facilities made possible with funding from the Columbia River Basin water supply development account is required to be allocated as follows:

- Two-thirds of active storage is required to be available for appropriation for out-of-stream uses
- One-third of active storage is required to be available to augment instream flows to maximize benefits to salmon and steelhead populations

The timing of releases of this water will be determined by Ecology, in cooperation with the Washington Department of Fish and Wildlife (WDFW) and fisheries co-managers, to maximize benefits to salmon and steelhead populations (Ecology, 2006a).

The value of flow augmentation water to benefit the survival of anadromous salmon and steelhead trout in the Columbia River is significant, and it is difficult to place a dollar value on the benefits of new off-channel storage relative to flow augmentation. A comparative assessment of anadromous fish benefits is provided in Appendix A relative to the location of new off-channel storage within the Columbia River Basin.

Yakima River

The current Appraisal Evaluation is focused on the water-related needs of the Columbia River Basin. Since the potential new off-channel storage sites may be able to supplement water needs in the Yakima Basin as well, irrigation water needs within the Yakima Basin were considered in the Appraisal Evaluation. As discussed in Section 1.4.1 for the Yakima River, it may be possible to meet Yakima Project water rights from the Columbia River, which would allow more Yakima River water to be reserved for flow augmentation (Reclamation, 2004).

1.4.3 Domestic, Commercial, Municipal, and Industrial Supply

Long-term DCM&I water supply and demand forecasts were prepared as part of the Columbia River Water Management Program. Demand forecasts for the Municipal Sector, which is defined as Domestic and Commercial/Industrial, is based on estimated actual water use projected to the year 2025 (Ecology, 2006b). Since the planning period for new storage facilities would likely exceed the 25-year demand forecast, the upper range of demand estimates were used in the Appraisal Evaluation.

1.5 State of Washington Participation

The Washington State Department of Ecology was directed through the Columbia River Water Management Act (RCW 90.90.020) to "aggressively pursue the development of water supplies to benefit both instream and out-of-stream uses." Ecology is currently in the process of developing a Columbia River Water Management Program (Management Program) to facilitate implementation of the legislation. The Management Program includes administration of the Columbia River Basin Water Supply Development Account, which the legislation created to fund storage, conservation, and other projects to provide new water supplies for the Columbia River Basin.

1.6 Process

Reclamation's Upper Columbia Area Office in Yakima, Washington, is managing and directing the Appraisal Evaluation in cooperation with Ecology's Central Regional Office.

The Appraisal Evaluation builds on the work contained in the Pre-Appraisal Report, which was completed in December 2005. The objective of the Appraisal Evaluation is to determine which off-channel storage sites warrant further investigation, if a Feasibility Study is conducted.

1.7 Alternatives

From the array of 11 potential off-channel storage options identified in the Pre-Appraisal Report, Reclamation and Ecology have determined that the following four off-channel storage alternatives warrant being carried forward into the Appraisal Evaluation:

- Crab Creek
- Sand Hollow
- Foster Creek
- Hawk Creek

These four sites are shown in Figure 1-7.1. Appraisal-level designs for the dam and appurtenant structures, which include intake structures, inlet/outlet conveyance facilities, pumping/power plants, and transmission lines, were developed to support evaluation of the suitability of each project. The criteria/methodology used to develop appraisal-level designs, cost estimates, and the evaluation/ screening criteria used to compare the sites is presented in Section 3.

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Insert Figure 1-7.1

Location Map (front)

Insert Figure 1-7.1

Location Map (back)

2 Results of the Pre-Appraisal Evaluation and Introduction to the Appraisal Evaluation

This section identifies the process used to arrive at the four sites selected for the Appraisal Evaluation. The criteria and screening process applied to earlier storage alternatives are described.

2.1 Alternatives Evaluated

The December 2005 *Columbia River Mainstem Storage Options, Off-Channel Storage Assessment Pre-Appraisal Report* (Ecology and Reclamation, 2005) identified 11 potential off-channel storage site options that meet the following broad criteria and requirements:

- Minimum active storage of 300,000 acre-feet
- Maximum pumping distance ±10 miles from mainstem Columbia River
- Maximum 800 feet of total lift from Columbia River required for reservoir fill
- Impoundment will not cross into Canada
- No towns or cities will be inundated

The following 11 storage site options meet these criteria (from upstream to downstream location along the Columbia River):

- Ninemile Flat
- Hawk Creek
- Goose Lake
- Foster Creek
- Mission Creek
- Moses Coulee
- Sand Hollow
- Crab Creek
- Alder Creek
- Rock Creek East
- Kalama River

2.2 Screening of 11 Sites to 4 Sites by Ecology and Reclamation

Following from and building on the work contained in the Pre-Appraisal Report, Reclamation and Ecology used professional judgment supported by limited evaluation from technical staff to further refine project requirements. Such requirements included minimum reservoir size and integration with the Columbia Basin Project. Reclamation and Ecology then considered additional information to determine which among these 11 alternatives would warrant Appraisal Evaluation. As part of preparing for the Appraisal Evaluation, CH2M HILL and JPA have reviewed the reasoning and factors used to select a shortlist of alternatives for Appraisal Evaluation, and find that the Reclamation and Ecology conclusions are sound, and based on professional judgment and clear-cut exclusionary factors.

2.2.1 Evaluation Criteria

The evaluation criteria used to determine which among the 11 alternatives warrant Appraisal Evaluation focused on four "exclusionary" (fatal-flaw) factors:

- Site is not available for study or for project implementation

- Site location cannot be sufficiently integrated with Columbia Basin Project operations
- Site cannot support a reservoir with storage capacity of at least 1 million acre-feet
- Dam and reservoir cannot safely and economically be built due to unsuitable geotechnical conditions

2.2.2 Evaluation Results

From the array of 11 potential off-channel storage options identified in the Pre-Appraisal Report, Reclamation and Ecology have determined that the following four options warrant being carried forward into the Appraisal Evaluation:

- Crab Creek
- Sand Hollow
- Foster Creek
- Hawk Creek

The remaining seven Pre-Appraisal alternatives were eliminated from further consideration due to one or more exclusionary constraints, as summarized on Table 2-1.1 and explained below.

1. **Site is not available for study or for project implementation**: Both the Ninemile Flat and Goose Lake options are located on the Colville Reservation. After completion of the Pre-Appraisal Report, with its identification of these two sites as potentially viable candidates for off-channel storage, Ecology consulted with the Confederated Tribes of the Colville Reservation to determine if the sites should be included in further, more detailed analysis. The Colville Tribal Council requested that these sites not be considered at this time. Therefore, the Ninemile Flat and Goose Lake options were eliminated from further study.
2. **Site location cannot be sufficiently integrated with Columbia Basin Project operations**: The fundamental objectives of an off-channel storage project are to provide additional water at key times—and in key locations—for agriculture, fish and wildlife, and municipal and industrial uses. To meet these fundamental objectives, the reservoir must be integrated with the existing federal Columbia Basin Project. Such integration can only be effectively achieved if the storage is located upstream of Priest Rapids Dam. The Alder Creek, Rock Creek East, and Kalama River options do not meet this requirement and were thus eliminated from further consideration.
3. **Site cannot support a reservoir with storage capacity of at least 1 million acre-feet**: The Pre-Appraisal Report used a minimum potential storage volume of 300,000 acre-feet. Further analysis of the storage volume required to meet all project objectives indicates that this minimum should be 1 million acre-feet, with 1.5 million acre-feet or more highly desirable. Also, any plan to combine two smaller sites to meet the desired total storage capacity is judged too difficult and will not take advantage of economies of scale. Thus, since the Mission Creek site option could only support a reservoir of less than 500,000 acre-feet capacity, it does not meet the exclusionary screening criteria for this Appraisal Evaluation.
4. **Dam and reservoir cannot safely and economically be built because of unsuitable geotechnical conditions**: Geologic and geotechnical stability is a fundamental requirement for locating any dam site. Further analysis has

revealed that the Moses Coulee site does not appear to be feasible from a geotechnical perspective, based on information from staff of Ecology's Dam Safety Program. As noted in Table 2-1.1, Reclamation and Ecology identified that there is also uncertainty about the geologic and geotechnical suitability of the Foster Creek site. However, additional study is needed to eliminate this site from further investigation.

Table 2-1.1
Screening of Pre-Appraisal Study Alternatives

Exclusionary Factors	Criteria	Pre-Appraisal Study Alternatives: Ninemile Flat	Hawk Creek	Goose Lake	Foster Creek	Mission Creek	Moses Coulee	Sand Hollow	Crab Creek	Alder Creek	Rock Creek E	Kalama River
Feasibility: Site availability	Site is available for study or for project	No*	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Feasibility: Location--integration with CBP operations	Site location can be sufficiently integrated with Columbia Basin Project operations		Yes		Yes	Yes	Yes	Yes	Yes	No	No	No
Feasibility: Required reservoir storage volume	Site can support a reservoir with storage capacity of at least 1 million acre-feet (MAF)		Yes		Yes	No	Yes	Yes	Yes			
Feasibility: Dam Safety & Integrity	Dam and reservoir can safely and economically be built due to suitable geotechnical conditions		Yes		??		No	Yes	Yes			

Eliminated from further study

Carried forward to Appraisal Evaluation

* No = Site cannot meet requirement
Yes = Site can/may be able to meet requirement

3 Approach, Criteria, and Methodology for the Appraisal Evaluation

This section presents the criteria and methodology used to develop and evaluate the four sites and their components in this Appraisal Evaluation.

3.1 Fatal Flaw Analysis

The prospect of "fatal flaws" in any of the four sites was evaluated as part of the Appraisal Evaluation. Fatal flaws are defined as severe constraints, concerns, or combinations of constraints and concerns that affect alternatives so that they no longer appear to be realistic or viable or if there is significant risk. Sites that are designated as having a "fatal flaw" will be recommended to be dropped from further consideration and analysis. This criterion is addressed early in the Appraisal Evaluation process to minimize unnecessary effort and cost on evaluation of sites that do not warrant further study.

3.2 Appraisal-Level Design

Developing the components of storage projects at the Crab Creek, Sand Hollow, Foster Creek, and Hawk Creek sites consisted of the following three steps:

- Establishing facility sizes
- Selecting facility locations
- Characterizing facilities by developing conceptual layouts and conceptual (appraisal-level) designs

The following text describes the approach to completing these steps.

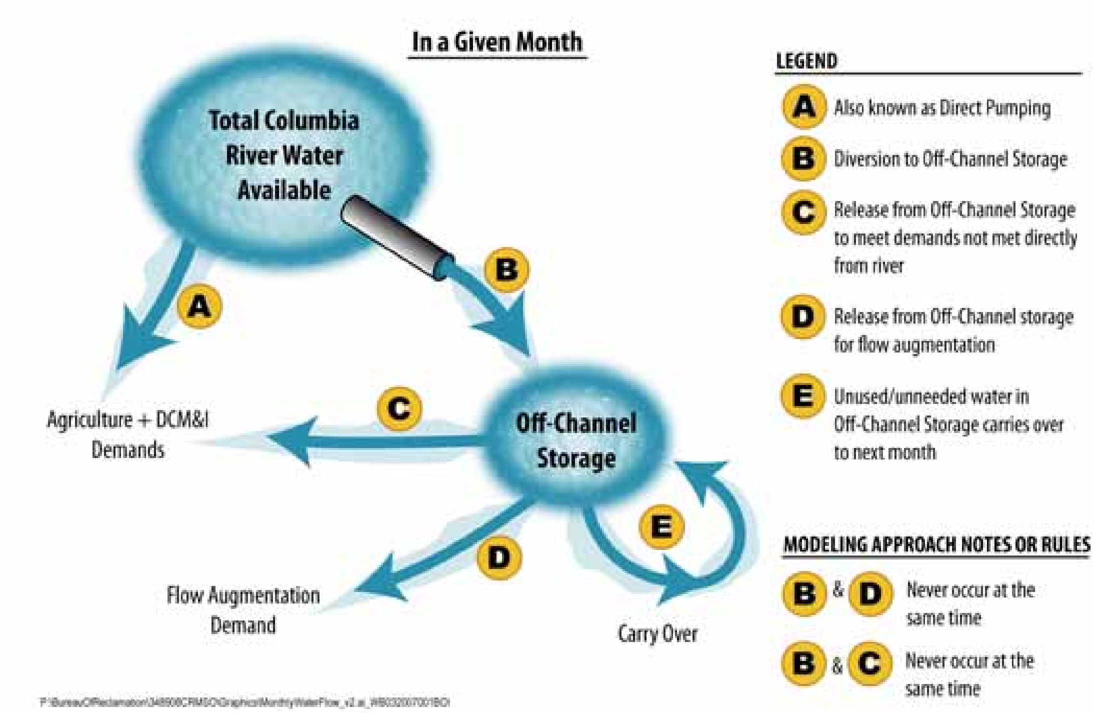
3.2.1 Establishing Facility Sizes

Sizing of dams, diversion/intake structures, conveyance facilities, power generation facilities, and other components of each project/alternative relied on first developing a water balance of total supplies and demands over time. The water balance model was used to optimize the flow rates (cubic feet per second; cfs) and reservoir volumes (acre-feet) needed to meet demands, and to establish various operational scenarios for each site. With the flow rates, volumes, and operational scenarios identified, sizing of specific features such as the dams, pipelines, pumps, and other major system components was completed.

Water Balance Analysis

A spreadsheet water balance model was developed to simulate the incorporation of a new off-channel storage facility as a means of meeting projected future demands. For the purpose of the Appraisal Evaluation, demands are defined as the water needs presented in Section 1.4, *Storage Study Goals*: irrigated agriculture, instream flows, and DCM&I. Figure 3-2.1 illustrates conceptually the elements of the water balance model.

FIGURE 3-2.1
Water Balance Analysis Model



Principal supply and demand components of the model were as follows:

- Supply: Columbia River "available water" (based on 50 years of record) and local precipitation
- Demand: Projected future water needs for agricultural and DCM&I purposes; and off-channel reservoir releases to supplement flow augmentation needs in the Columbia River mainstem

Seepage and evaporation losses associated with the new off-channel reservoir are also estimated and included in the model.

The model was constructed as an overall water budget that adds supply and subtracts demand each month for a 50-year period of record to determine the amount of water that can be diverted to and then ultimately released from new off-channel storage. The model also accounts for agricultural and DCM&I demands that could be met through direct pumping from the Columbia River (that is, not from an off-channel reservoir). The analysis assumes that in any given month when Columbia River water is available to meet demands, those demands would be met first through direct pumping at the demand location in lieu of releases from new off-channel storage reservoirs. Any remaining balance of available Columbia River flows can be diverted to off-channel storage, if the reservoirs are not already full. Conversely, when demands are not fully met by such direct pumping, water is released from new off-channel storage reservoirs to meet the remaining demands. Neither the water balance analysis nor this Appraisal Evaluation evaluate what facilities must be built (for example, pumps and conveyance facilities) to facilitate water deliveries via direct pumping at the demand location.

Water Supply

Columbia River Mainstem Water Availability for Diversion The Bonneville

Power Administration (BPA) developed a computer model called HYDROSIM (BPA, 1992) that models operations on the Columbia River for a 50-year period of simulation from 1929 through 1978. Table 3-2.1 shows the average monthly Columbia River water volumes that are available for diversion in excess of downstream flow objectives under current operations. Estimates of water volumes available for diversion from the Columbia River are often more than 20 million acre-feet annually.

The volumes shown in Table 3-2.1 represent flows that are available to divert from the Columbia River just downstream of Priest Rapids Reservoir. Although it is recognized that the water available for diversion would vary from site to site, the same monthly water volumes shown in Table 3-2.1 were used in the water balance analysis for all potential new off-channel storage reservoirs.

Local Hydrology Natural inflows to new off-channel storage were accounted for using either historical U.S. Geological Survey (USGS) streamflow data or precipitation data where gage data were unavailable. Compared to the volumes proposed to be diverted from the Columbia River, natural inflows at the dam site are negligible. Site-specific hydrology information is provided in Appendix C.

Water Demands The current estimate for total annual demands are approximately 3,368,000 acre-feet and include agricultural, DCM&I, and flow augmentation. As shown in Table 3-2.2, the largest water demands are associated with agriculture, which accounts for approximately 75 percent of the total.

Columbia Basin Project The Columbia Basin Project is authorized to irrigate 1,029,000 acres at its completion, and currently irrigates 671,000 acres (Ecology, 2006a). The average annual historical flow and full development estimates for irrigation are 2,711,300 and 4,076,000 acre-feet, respectively. Since historical water diversions have already been accounted for in the water supply, the new incremental demand used in the water budget model is the difference between monthly historical flow and full development estimates. Therefore, the amount of additional water that would be necessary to irrigate the Columbia Basin Project at full development is 1,364,800 acre-feet. The water balance analysis assumes that this full development demand would be met by either direct pumping or the potential new off-channel storage reservoir. Table 3-2.3 summarizes the new incremental, monthly irrigation water needs to meet full development for the Columbia Basin Project.

TABLE 3-2.2

Water Demands to be Met by Direct Pumping or New Off-Channel Storage

	Annual Demand (acre-feet)
Columbia Basin Project	1,364,800
Yakima Project	662,046 – 810,410
Additional Agriculture	330,000
DCM&I	109,100
Flow Augmentation	754,000[1]

[1]Flow augmentation demands vary from year to year based on annual consumptive demands and the amount of water that is available to meet demands through direct pumping. The value shown is the median flow augmentation release from a new 3 million acre-feet reservoir, which is intended to show an order-of-magnitude estimate/proportion of flow augmentation relative to other demands.

Table 3-2.1 - Columbia River Water Available for Diversion (KAF)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr1	Apr2	May	Jun	Jul	Aug1	Aug2	Sep	Total
1929	1387	0	0	1286	0	0	0	0	0	0	0	0	0	640	3313
1930	1844	0	0	0	362	0	153	0	0	0	0	0	0	834	3193
1931	1587	0	0	0	0	0	298	0	0	0	0	0	0	1095	2980
1932	1666	0	0	0	0	615	1780	971	2552	234	216	0	0	801	8835
1933	1451	0	1537	5222	3198	0	795	0	0	5587	5137	0	0	1353	24280
1934	2858	2591	7443	10999	7327	4400	4028	927	823	0	0	0	0	729	42125
1935	1543	0	963	4610	4697	0	623	0	0	0	26	0	0	879	13341
1936	1667	0	0	0	0	123	262	0	4174	0	0	0	0	440	6666
1937	1662	0	0	0	0	0	84	0	0	0	0	0	0	530	2276
1938	1828	0	829	5977	895	2519	1190	0	3774	0	0	0	0	860	17872
1939	1489	0	0	1902	0	347	298	0	159	0	0	0	0	509	4704
1940	1811	0	324	1009	179	2476	733	0	0	0	0	0	0	380	6912
1941	1470	0	1013	2094	0	0	11	0	0	0	0	0	0	637	5225
1942	1314	0	3706	5673	253	0	80	0	0	2049	463	0	0	585	14123
1943	1632	0	1387	4318	2178	2121	2826	593	3646	1462	2075	0	0	512	22750
1944	1458	0	89	1731	0	0	0	0	0	0	0	0	0	734	4012
1945	1462	0	0	0	0	0	52	0	0	1323	0	0	0	315	3152
1946	1690	0	231	2869	2088	2868	1613	39	4587	0	857	0	0	904	17746
1947	1060	0	3937	5674	3158	4252	982	0	2430	0	236	0	0	737	22466
1948	3993	1699	2887	5379	1229	2015	1301	0	4441	15620	2691	0	0	1927	43182
1949	1814	0	955	2297	1497	3462	494	695	3845	0	0	0	0	205	15264
1950	1490	0	156	3091	4423	4935	1890	281	1920	7856	3747	0	0	1160	30949
1951	2294	2627	5332	7953	6321	3344	2042	1050	6477	0	1613	0	0	1416	40469
1952	3124	412	3340	4990	2673	2978	1625	220	5346	0	0	0	0	513	25221
1953	1422	0	0	2093	3594	190	298	0	1877	3934	1955	0	0	885	16248
1954	1747	81	2368	4107	4192	2541	1816	0	3299	6281	3923	952	3	4452	35762
1955	2454	1170	2056	1044	0	0	446	0	0	8682	6263	0	0	1037	23152
1956	2271	1976	4676	8003	2812	3760	2451	2216	8134	7434	2711	0	0	875	47319
1957	1724	0	2704	3532	0	919	2296	0	3918	5691	0	0	0	514	21298
1958	1372	0	398	3136	2625	2876	569	0	3261	2619	0	0	0	657	17513
1959	1394	1019	3747	7579	4872	2461	2217	0	1540	5052	3306	0	0	3983	37170
1960	4693	3082	4817	4475	1370	1872	3908	438	0	956	372	0	0	839	26822
1961	1623	553	964	3981	3484	3073	2499	0	502	8336	0	0	0	384	25399
1962	1401	0	59	3733	0	0	2566	626	0	0	0	0	0	517	8902
1963	1587	1047	3703	3899	1114	1340	565	0	1034	272	41	0	0	1006	15608
1964	1240	0	375	3640	665	0	298	0	0	5979	4743	0	0	1657	18597
1965	2742	159	4194	7821	4269	3464	1547	626	3902	1899	243	0	0	667	31533
1966	1579	223	1993	4767	0	153	1909	0	0	0	698	0	0	589	11911
1967	1344	0	1184	5768	5729	643	1972	0	0	7189	3661	0	0	1208	28698
1968	1593	220	2042	4925	3010	2513	0	0	0	2511	2700	0	0	2291	21805
1969	2484	1528	2892	6828	4322	1967	3454	1085	6553	629	185	0	0	619	32546
1970	1453	0	530	4042	2436	497	280	0	0	1986	0	0	0	0	11224
1971	1185	0	452	5101	6073	2486	1516	455	7258	4962	3308	0	0	792	33588
1972	1158	103	2025	5336	6007	5846	4269	0	6591	10615	4977	528	0	1421	48876
1973	1545	0	2564	5397	0	0	0	0	0	0	0	0	0	0	9506
1974	1300	0	3694	9959	7484	3970	2795	1477	6382	8111	7671	129	0	1513	54485
1975	1149	0	800	5034	2409	3166	902	0	2225	2737	5096	0	0	801	24319
1976	1888	2160	5986	7108	5041	1848	2678	335	5064	106	3843	1453	1062	5103	43675
1977	1753	0	313	1936	0	0	0	0	0	0	0	0	0	431	4433
1978	938	0	860	3575	698	3889	1514	0	1714	0	1131	0	0	1040	15359
AVERAGE	1773	413	1791	4078	2254	1719	1319	241	2149	2602	1478	61	21	1040	20936
MAXIMUM	4693	3082	7443	10999	7484	5846	4269	2216	8134	15620	7671	1453	1062	5103	54485
MINIMUM	938	0	0	0	0	0	0	0	0	0	0	0	0	0	2276
DRIEST 10-YR AVG (37-46)	1582	0	758	2557	559	1033	689	63	1217	483	340	0	0	597	
WETTEST 10-YR AVG (67-76)	1510	401	2217	5950	4251	2294	1787	335	3407	3885	3144	211	106	1375	

NOTES:

1) Data was provided by Reclamation (Appendix B of the Columbia River Water Availability Analysis - Preliminary Work Product dated September 5, 2006).
2) Data represents volume of water available for diversion in excess of downstream flow objectives under current operations. Available to divert just downstream of Priest Rapids Reservoir.

TABLE 3-2.3
New Incremental Irrigation Needs (Demands) to Meet Full Development for the Columbia Basin Project

	Demands (acre-feet)		Demands (acre-feet)
October	80,800	April	69,400
November	0	May	162,900
December	0	June	281,500
January	0	July	317,300
February	0	August	268,300
March	25,400	September	159,200
		Total	**1,364,800**

Yakima Project In addition to the current Appraisal Evaluation, Reclamation is investigating other water storage project alternatives within the Yakima Basin. The potential new off-channel storage sites under the current Appraisal Evaluation have the potential to supplement water needs in the Yakima Basin as well; therefore, it was assumed that the Roza and Sunnyside Divisions, as part of a Columbia off-channel storage project, would obtain water from the Columbia River in lieu of the Yakima River. This potential water exchange would reduce the demands within the Yakima Basin and allow more water to be reserved for flow augmentation.

During average and wet water years, the total demand for the Roza and Sunnyside Divisions is 810,410 acre-feet; during dry water years, the total demand is 662,046. The water balance analysis assumes that demand in all years would be met by either direct pumping or the potential new off-channel storage reservoir. Tables 3-2.4 and 3-2.5 summarize the monthly irrigation water needs to supply the Roza and Sunnyside Divisions of the Yakima Project in dry, average, and wet water years.

TABLE 3-2.4
Yakima Project Irrigation Needs (Demands) for the Roza and Sunnyside Divisions in Average and Wet Years

	Demands (acre-feet)		Demands (acre-feet)
October	49,760	April	89,660
November	0	May	128,920
December	0	June	145,620
January	0	July	147,270
February	0	August	147,270
March	0	September	101,910
		Total	**810,410**

TABLE 3-2.5
Yakima Project Irrigation Needs (Demands) for the Roza and Sunnyside Divisions in Dry Years

	Demands (acre-feet)		Demands (acre-feet)
October	44,470	April	77,920
November	0	May	104,364
December	0	June	115,265
January	0	July	116,959
February	0	August	116,959
March	0	September	86,109
		Total	**662,046**

Additional Agriculture Additional agriculture demands associated with future irrigation water needs were also included in the water balance analysis. Future irrigation needs are related to changes in the total crop acreage, crop type and distribution, and the irrigation profile for various crops. The *Water Supply Inventory and Long-Term Water Supply Demand Forecast* (Ecology, 2006b) was used to identify future additional irrigation demands for existing agriculture.

Ecology recommends using Tier 2 estimates from the *Water Supply Inventory and Long-Term Water Supply and Demand Forecast* to identify future additional irrigation demands based on changes in existing agricultural usage, because the Tier 2 demand forecasts are based on estimated actual water use using water data projected to the year 2025 (Ecology, 2006b). Since the planning period for new storage facilities would likely exceed the 25-year demand forecast, the upper range of the Tier 2 demand estimates was used in the water balance analysis. Tier 2 demand estimates from the *Water Supply Inventory and Long-Term Water Supply and Demand Forecast* estimate 330,000 acre-feet of additional agricultural demands. The water balance analysis assumes that this demand would be met by either direct pumping or the potential new off-channel storage reservoir. Table 3-2.6 shows the additional monthly irrigation water needs for existing agriculture.

TABLE 3-2.6
Additional Agricultural Irrigation Water Needs (Demands) for Existing Agriculture

	Demands (acre-feet)		Demands (acre-feet)
October	13,000	April	13,000
November	8,000	May	34,000
December	8,000	June	56,000
January	8,000	July	72,000
February	8,000	August	64,000
March	8,000	September	38,000
		TOTAL	**330,000**

Interruptible Water Rights No specific volumes have been assigned for interruptible water right demands. New large storage facilities would no doubt provide drought-year water supplies to interruptible water right holders. However, because the current water budget analysis incorporates the water supply that can be diverted from the Columbia River under current operational scenarios after all other water obligations were met, it is difficult to identify when and how much interruptible water demand was not met in the absence of additional detail from BPA's HYDROSIM model.

It is recommended that a comprehensive evaluation of interruptible water rights be examined during subsequent Feasibility Level Analyses to identify which interruptible water rights could be converted to uninterruptible status.

DCM&I DCM&I uses of the Columbia River are minor when compared to the agricultural demands. Demand estimates are based on the *Water Supply Inventory and Long-Term Water Supply and Demand Forecast* (Ecology, 2006b) for the Municipal Sector, which is defined as Domestic and Commercial/Industrial.

Since the planning period for new storage facilities would likely exceed the 25-year demand forecast, the upper range of the Tier 2 demand estimates was used in the water balance analysis. DCM&I demands (that is, 109,100 acre-feet) would be met by either direct pumping or the potential new off-channel storage reservoir. Tables 3-2.7 and 3-2.8 present monthly domestic and commercial/industrial demand volumes, respectively.

TABLE 3-2.7

Domestic Water Needs (Demands)

	Demands (acre-feet)		Demands (acre-feet)
October	2,700	April	2,700
November	1,600	May	6,900
December	1,600	June	11,400
January	1,600	July	14,700
February	1,600	August	13,000
March	1,600	September	7,800
		TOTAL	**67,200**

TABLE 3-2.8

Commercial/Industrial Water Needs (Demands)

	Demands (acre-feet)		Demands (acre-feet)
October	1,700	April	1,700
November	1,000	May	4,300
December	1,000	June	7,100
January	1,000	July	9,100
February	1,000	August	8,100
March	1,000	September	4,900
		TOTAL	**41,900**

Flow Augmentation As described in Section 1.4.2, *Instream Flow*, RCW 90.90.020 requires that two-thirds of new water developments is allocated to out-of-stream use and one-third is allocated to instream flows. For the purposes of the Appraisal Evaluation and the water balance model, it is assumed the "new water" represents water that is released from potential new off-channel storage reservoirs. Therefore, two-thirds of water released from new off-channel reservoirs will be allocated to out-of-stream uses (that is, irrigated agriculture and DCM&I), and one-third of water released from new off-channel storage will be allocated to annual flow augmentation. Flow augmentation demands are calculated based on the total annual demands for each year after direct pumping volumes have been met. Water demands that are met by direct pumping, such as water diverted and delivered to water users directly from the Columbia River that are never stored in an off-channel reservoir, do not need to be accounted for in the determination of the one-third allocated to flow augmentation.

The timing of flow augmentation requests and subsequent releases from off-channel storage reservoirs would vary from year to year as determined by Ecology in cooperation with WDFW. For the purposes of the current water balance analysis, it is assumed that all flow augmentation releases would occur during July and August, a period when water supplies are low and demands are high in order to conservatively size potential new off-channel storage facilities.

Reservoir Losses

Seepage For the purposes of the current water balance estimate, it is assumed that seepage rates do not change with increasing saturation beneath the reservoir. This is a conservative assumption that likely overestimates the actual seepage since the amount of seepage would likely be greatest during the initial reservoir filling, because typically reservoir floors tend to become silted in with fine-grained materials over time.

For each site, the seepage rate was estimated using a weighted average of published ranges of permeabilities (k) in gallons per day per square foot (gal/day/ft^2) of the underlying materials of the reservoir area. Typically, geologic materials exhibit a wide range of permeabilities. In addition, the vertical ‘k’ is generally orders of magnitude lower than the horizontal ‘k’ in horizontally stratified materials. Therefore, the seepage estimates incorporate the lowest values of ‘k.’

The monthly seepage rates shown in Table 3-2.9 were estimated based on a 1,500,000 acre-feet reservoir footprint. Because seepage rates would vary based on depth of water in the reservoir, the water balance assumes three varying seepage rates to simplify the spreadsheet computations. For reservoir volumes less than 900,000 acre-feet the seepage rate is one-half of the values shown in Table 3-2.9; for reservoir volumes greater than 2,100,000 acre-feet, the seepage rate is twice what is shown in Table 3-2.9. The water balance analysis estimates monthly seepage losses based on the previous month’s reservoir volume.

Seepage losses are estimated only for the reservoir and do not include any losses that occur in conveyance facilities, such as unlined tunnels or canals.

TABLE 3-2.9
Monthly Seepage Rates

	Seepage Rate (acre-feet/month/acre)
Crab Creek	0.05
Sand Hollow	0.03
Foster Creek[1]	16
Hawk Creek	0.1

[1]A final water balance analysis was not prepared for Foster Creek because of geotechnical issues and risk that deemed the site a “fatal flaw”.

Evaporation Evaporation losses were estimated using evapotranspiration data from the George, Washington, weather station. The average annual evaporation based on Kimberly Penman evapotranspiration is 41 inches. The water balance analysis estimates monthly evaporation losses based on the previous month’s reservoir surface area.

Evaporation losses are only estimated for the reservoir and do not include any losses that occur in conveyance facilities such as canals.

Approach to Sizing Specific Features

The volumes and flow rates determined in the water balance analysis were used to size the various elements of the storage and conveyance facilities. Facility sizing was performed in accordance with the assumptions and criteria provided in Table 3-2.10. This information represents a standardized approach to facility sizing for all sites and operational scenarios. Specific considerations for particular sites are addressed in Section 4, *Project Descriptions for Off-Channel Storage Alternatives*.

Operational Scenarios Development

The water balance model was used to develop the seven Operational Scenarios (OS), or alternatives, that are presented in the Appraisal Evaluation (Table 3-2.11).

TABLE 3-2.10
Facility Sizing Assumptions and Criteria

Project Element/Facility	Criteria or Assumption	Comment
Columbia River Intake/Outlet Facilities		
Fish Screens	• Minimum 20-foot river depth assumed available within reasonable distance from river bank (river bathymetry not available during Appraisal Evaluation) • Assume 15-foot-wide fish screen bays, based on past experience as a workable maximum width, and a pier thickness between bays of 24 inches • Include one extra bay for every 15 screen bays to park screen cleaner • Design for minimum operating water surface in Columbia River, based on data provided by Reclamation and Ecology • Maximum average approach velocity 0.4 foot per second • Wedgewire or profile wire stainless steel screens with 1.75 mm spacing, with adjustable baffles directly behind the screen (and diffuser) to provide for uniform flow distribution over the screen surface • Screen designs based on vertical flat plate configuration with automatic cleaning by a wiper/brush system • Service deck and access roads placed 3 to 5 feet above the maximum flood elevation of the Columbia River	Fish screens provide a barrier to prevent juvenile or adult fish from being entrained into the diverted flow. The 0.4 foot per second (fps) approach velocity is based on state and federal criteria, and is defined as the water velocity component perpendicular to and approximately 3 inches in front of the screen face. It is calculated using the total flow through the screen and the total area of the screen face (excluding piers), and is intended to be low enough to prevent salmonid fry from being impinged on the screen. Fish screens are assumed not to be needed for deep lake intakes above Grand Coulee Dam.
Diffusers	• Same depth assumptions as for fish screens • Design for minimum operating water surface in Columbia River • Maximum approach velocity 1.0 feet per second (maximum approach velocity for diffuser assumed not applicable to emergency turbine bypass applications) • 3/16-inch diffuser bars with clear spacing of 1 inch	Diffusers provide a barrier to entry by fish that may be attracted to the source of flow, and the 1.0 fps velocity is based on state and federal criteria and is intended to minimize the attraction and thus prevent fish from injury by challenging the diffuser.
Trash Racks	• 1 inch clear bar spacing on a 1:4 (horizontal:vertical) slope • Automated cleaning of the trash racks with Atlas Polar trash rakes (or equivalent systems), with each unit assumed capable of covering 100 to 150 feet of width	Placed where needed to collect/remove debris that would otherwise interfere with facility operations
Baffled Apron Drop	• Design for 50 cfs per foot width, approximately twice the capacity cited in Reclamation design literature but consistent with notations about short duration operation	Needed downstream of fixed cone valves for emergency release if turbines are down, but only at sites in which the release is directly into Columbia River channel

TABLE 3-2.10
Facility Sizing Assumptions and Criteria

Project Element/Facility	Criteria or Assumption	Comment
Intake/Outlet Channels	• Manning's roughness 0.015 for concrete-lined sections, 0.040 for sections cut into rock; assume channel will be a combination of these depending on material encountered along its length • Limit headloss in channel to 5 feet or less between P/T facility and Columbia River • Based on channel widths selected, maximum velocities of 2.5 to 7 fps would be allowed for reservoir releases. For reservoir supply flows, maximum velocities would be 1 to 3 fps.	Analyzed and sized channel width using HEC-RAS model. Set channel width as required to achieve low head loss, which in turn minimizes pumping costs (in reservoir supply mode) and maximizes power yield from the turbines (in reservoir release mode).
Tunnels	• Size single tunnels for up to 30 feet diameter • Maximum velocity up to 15 fps • Assume all tunnels lined by either steel plating or concrete with a Hazen-Williams C factor of 120.	Steel plating needed when earth cover over the tunnel is less than one-half of the pressure head plus the rise for transients. For this evaluation, it was assumed that transients would be about 30 percent above the pressure head.
Pumps	• Assume size of up to 45,000 HP for a single pump • Pump efficiency 85 percent • No extra installed pumps for redundancy • Base cost estimate on the inclusion of one extra pump (not installed)	
Combined Pumping/Turbine (P/T) Units	• P/T units are enclosed in a reinforced concrete structure that includes a Service Bay. Structure is set deep in an open-cut, rock excavation to accommodate submergence requirements. All plants have an indoor arrangement, which provides water-tight concrete enclosure walls around the Machine Hall. • Top of the P/T structure is set 3 feet above the reservoir's maximum, flood, water-surface elevation. • Bottom of the P/T structure is set by the submergence, (or back pressure at minimum tailwater elevation), required to the centerline of impeller for the pumping operation and the draft tube depth. • A minimum of 3 units would be used to provide flexibility if one unit is out of service; larger flow alternatives have 4 units. • A bridge crane would service the units. Crane capacity varies with unit size, generally ranging from 200 to 350 tons. The crane is supported on pilasters (concrete columns integral with the longitudinal walls). A concrete beam spans the top of the pilasters to support the crane and crane rail.	Reversible P/T units are provided at each site to pump water into an off-site storage reservoir during high flow months, and to recapture some of the pumping energy upon release of the water into the Columbia River during dry months. Plant flow, head, and number of units for each site and alternative are summarized in the *Combined Pump/Turbine Facilities* section for each alternative described in Section 4.

TABLE 3-2.10
Facility Sizing Assumptions and Criteria

Project Element/Facility	Criteria or Assumption	Comment
	• The service bay is sized approximately 20 percent larger than a unit bay. • Concrete 3 feet thick surrounds each side of the spiral case and is under the draft tube elbow. • The draft tube is circular from the runner to the fish screen/diffuser structure. At the fish screen/diffuser structure, it transitions into a rectangle to match the intake gate. Draft tube gates are provided for all plants for maintenance of the draft tube area. The draft tube has been sized for a velocity of 6 fps to conserve energy. • The primary closure device for the reversible flow intake is a wheeled gate located at the end of the entrance transition.	Unit bay structures are sized to accommodate the P/T units. A service bay is provided at one end of each plant, allowing room for routine maintenance or emergency repairs. An additional 20 feet of space is provided upstream of the generator to accommodate auxiliary mechanical and electrical equipment. Features that govern the dimensions of the P/T structure are the spiral case for width and draft tube for depth and length. Dimensions of the P/T units are obtained from Reclamation publications described in Section 4.
	• The intake/outlet from the draft tubes is set with the face parallel to shore. For sites with a forebay or channel adjacent to the draft tubes, a bar rack is provided in front of the fish screen/diffuser structure to screen out large debris.	The intake is a reversible flow reinforced concrete structure sized to slowly decelerate or accelerate flow so as to minimize head loss during the pumping or generation mode. A bulkhead gate is provided upstream of the intake gate to allow servicing of the intake gate. A butterfly guard valve is provided for each unit to shut off flow in the event an intake gate fails to close.
	• A bypass valve facility is provided at all sites to allow uninterrupted release of flow in the event a unit is off-line during the release period. The bypass facility consists of a number of fixed cone valves (FCV) in synchronous release with the P/T units. Synchronous operation means the valves will open when the P/T units are required to shut down for forced or routine maintenance, or for a grid induced power outage. Branch pipes to bypass the P/T units come off the penstocks at a 30 or 45 degree angle, and are sized approximately 70% larger than the FCV diameter.	Flow (Q) through one bypass valve is matched to the maximum release through each P/T unit, and is assumed to be: $Q = 5.354 * D^2 * H^{1/2}$ Where: D = Diameter of the Valve; and H = net head. Heads of 700 feet have been assumed feasible for the FCVs. The FCVs would operate even with a loss of power. A stored energy system, either hydraulic or electric, would be provided to allow two complete open-close cycles of the valves.
Fencing	• Both sides of channels • Perimeter of facilities (assume 1,000 feet for each facility—dams, fish screen sites, P/T facilities, etc.)	
Dams		
Concrete Faced Rockfill Dam (CFRD) Embankments	• Embankment slopes of 1.5:1 on the upstream side and 1.5:1 on the downstream side for rock fill • Top width of 40 feet at the dam crest • Dam crest set 15 feet above full reservoir elevation for freeboard and wave run-up	

TABLE 3-2.10
Facility Sizing Assumptions and Criteria

Project Element/Facility	Criteria or Assumption	Comment
Rockfill Embankments	• Same as CFRD except slopes are 1.7:1 upstream and downstream	
Inlet/Outlet Facilities	• Each off-channel dam to have multiple-level inlets/outlets with control gates for better control/selection of water quality and temperature for downstream releases	
Emergency Spillways	• Design for PMF (probable maximum flood) • Fixed concrete spillway crest (without gates); concrete lined unless rock is judged to be geologically adequate to resist flow • Crest shape varies from broad crested weir to ogee crest. Chute lining depends on topography, varied from unlined to concrete lining • Stilling basin varies with topography and geology (roller bucket at roller compacted concrete dam for Crab Creek; hydraulic jump basin for Sand Hollow)	The PMF for each site was crudely estimated using drainage basin area and available Reclamation hydrology information for existing dams in eastern Washington. While this provided a very rough estimate of the PMF for initial comparison of the sites, future work will require detailed development of the probable maximum precipitation (PMP) and the PMF. For this comparative design for PMF with combination or routing and storage for Crab Creek and Sand Hollow, and storage of the PMF at Hawk Creek.
Power Transmission	• Sized to serve maximum pumping loads expected at each site • Existing transmission lines within the flooded lake area were relocated above and away from the lake edge. • Substations were sized as radial bus configurations. More expensive bus configurations could be used if additional reliability is desired. • New right-of-way (ROW) would be needed for the new transmission line and its structures. The new ROW width depends upon the type of transmission line anticipated. Access roads must be created or improved to handle large construction vehicles and trucks hauling materials and equipment. • Constructing the transmission line would typically require 12- to 14-foot-wide straight sections of unpaved access roads, and 16- to 20-foot-wide sections at curves to allow safe movement of construction equipment and vehicles. Access roads would be contained within the transmission line ROW to the extent possible. • An area 100 square feet would be cleared at each structure location for construction activities. A smaller footprint would remain after construction for maintenance access. Another area, totaling 500 square feet, would be cleared for each substation required at a project.	The voltage rating of the line was selected based on available transmission lines in the area. This voltage was then verified to be adequate to carry the expected loads. Line miles for 115 kV voltages were multiplied by 0.80 and submarine cable miles by 11.5 as equalizing factors to bring them to the same cost base as the 230 kV. Costs for relocated lines are included in the same total line mileage as costs for new lines.

TABLE 3-2.11
Operational Scenarios

	Reservoir Volume (acre-feet)	Required Columbia River Diversion Capacity (cfs)	Required Off-Channel Reservoir Release Capacity (cfs)
Crab Creek OS1	1,000,000	2,500	6,500
Crab Creek OS2	2,000,000	5,500	13,500
Crab Creek OS3	3,000,000	8,500	18,500
Sand Hollow OS1[1]	1,000,000	2,500	6,500
Hawk Creek OS1	1,000,000	2,500	6,500
Hawk Creek OS2	2,000,000	5,500	13,500
Hawk Creek OS3	3,000,000	8,500	18,500

[1]Sand Hollow is limited to one OS because site topographic constraints limit the dam and reservoir size.

Reservoir Volume Operational scenarios for each project (except Foster Creek) are based on reservoir volumes, as follows:

- OS1 = 1 million acre-feet
- OS2 = 2 million acre-feet
- OS3 = 3 million acre-feet

These volumes were selected for the operational scenarios to compare how each potential project could meet various water demands. Operational scenarios are not applied to Foster Creek because that project failed the "fatal flaw" analysis, as described in Section 4.

The maximum reservoir volume of 3 million acre-feet was selected for OS3 because it was the smallest off-channel reservoir volume that could meet 100 percent of the agricultural, DCM&I, and flow augmentation demands that are currently estimated (see Table 3-2.2) 80 percent of the time. In other words, 3,368,000 acre-feet of agricultural, DCM&I, and flow augmentation needs are met by either direct pumping from the Columbia River mainstem when water is available, or by releases from new off-channel storage.

The minimum reservoir volume of 1 million acre-feet was selected for OS1 to maintain the same minimum volume criteria used by Reclamation and Ecology during the initial screening process presented in Section 2.2. This minimum reservoir volume is far too small to yield the 3,368,000 acre-feet of demands listed in Table 3-2.2. This imbalance does not allow for enough reservoir carryover from month-to-month to meet the full irrigated agriculture and flow augmentation demands during July and August. To maintain the same "performance criteria" or "reliability" as other operational scenarios (that is, 100 percent of the demands met 80 percent of the time), the total annual demands had to be reduced to approximately 35 percent of the full 3,368,000 acre-feet. Therefore, approximately 1,179,000 acre-feet of agricultural, DCM&I, and flow augmentation demands would be met by either direct pumping from the Columbia River mainstem when water is available, or by releases from new off-channel storage 80 percent of the time. In a practical sense, this "reduction of demands" means that OS1 (and, to a lesser degree, OS2) projects would be less ambitious relative to the buildout and demands. This reduction targets the cumulative agricultural and DCM&I demands and does not specifically reduce one or the other; rather, it reduces the total demand. If this alternative is selected to be evaluated in the subsequent Feasibility Study, the demands should be reevaluated to determine an appropriate target for agricultural, DCM&I, and flow augmentation needs. Figure 3-2.2 illustrates how the monthly demands were reduced so that 100 percent of the demands are met 80 percent of the time for a given reservoir capacity.

The 2 million acre-feet reservoir volume was selected for OS2 to provide insight into the feasibility or differences among various reservoir sizes at each site. As with the 1 million acre-feet reservoir volume, the 2 million acre-feet reservoir volume does not allow for enough reservoir carryover from month-to-month to meet the demands listed in Table 3-2.2. The total annual demands had to be reduced to approximately 70 percent of the full 3,368,000 acre-feet. Therefore, approximately 2,358,000 acre-feet of agricultural, DCM&I, and flow augmentation demands are met by either direct pumping from the Columbia River mainstem when water is available, or by releases from new off-channel storage 80 percent of the time. As with the 1 million acre-feet reservoir, if this alternative is selected to be evaluated in the subsequent Feasibility Study, the demands should be reevaluated to determine an appropriate target for agricultural, DCM&I, and flow augmentation needs.

Columbia River Mainstem Diversion Capacity The water balance model was used to optimize peak diversion rates to new off-channel storage. For a given reservoir capacity, there is an optimum fill

FIGURE 3-2.2

Reduction of Monthly Demands to Meet 100 Percent of Demand for 80 Percent of the Time

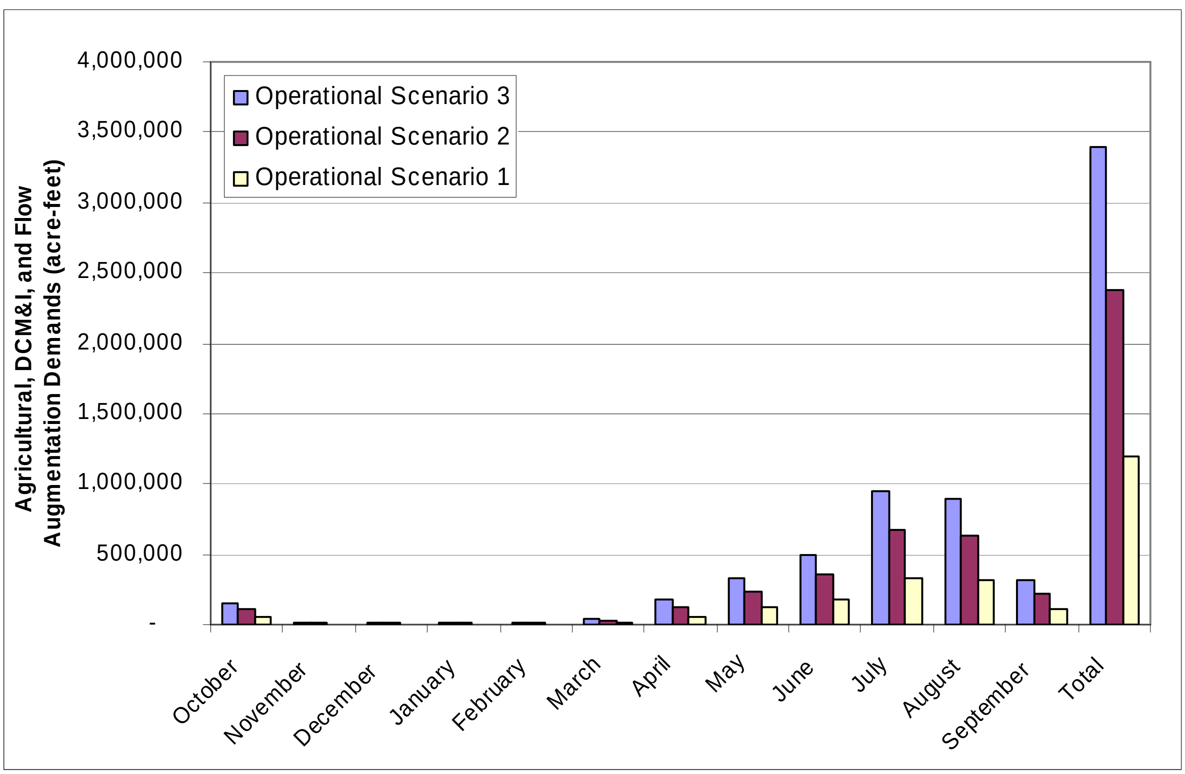
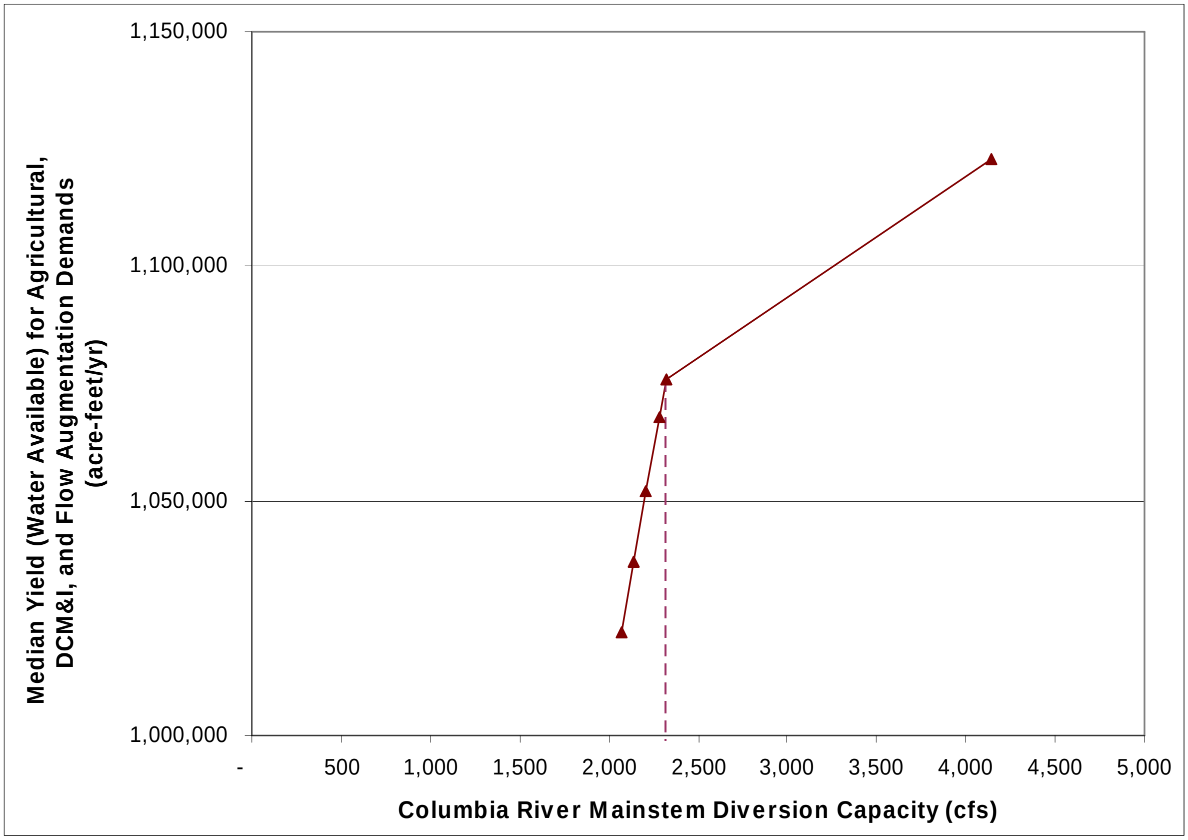


FIGURE 3-2.3
Optimal Diversion Capacity to Meet Median Yield for Demand



rate for each reservoir size. For example, if the diversion capacity is too large for a given reservoir volume, the reservoir would fill quickly and the capital and operation and maintenance (O&M) costs of large conveyance facilities may not warrant the large capacity or flow rate because water could not be stored in the already full reservoir. On the other hand, if the diversion capacity is too small for a given reservoir volume, the ability to capitalize on Columbia River mainstem water when it is available is reduced. Figure 3-2.3 displays the process used to select the diversion rate for OS1. As can be seen by Figure 3-2.3, as the diversion rate extends beyond 2,300 cfs, the rate of yield attributed to additional diversion capacity begins to decrease.

Diversion and conveyance facilities for OS1 at all sites are sized to accommodate a 2,500 cfs diversion from the Columbia River mainstem to new off-channel storage (rounded to the nearest 500 cfs).

The same process was used to optimize the diversion rate for OS2. Diversion and conveyance facilities for OS2 at all sites are sized to accommodate a 5,500 cfs diversion from the Columbia River mainstem to new off-channel storage (rounded to the nearest 500 cfs).

The diversion rate for OS3 at all sites is based on the lowest diversion rate that can meet 100 percent of the demands 80 percent of the time for a 3 million acre-feet reservoir. Diversion and conveyance facilities for OS3 at all sites are sized to accommodate an 8,500 cfs diversion from the Columbia River mainstem to new off-channel storage (rounded to the nearest 500 cfs).

Off-Channel Release Capacity The water balance analysis was used to select the release capacity for conveyance facilities based on the peak monthly demand. The peak demand occurs during July when off-channel reservoir releases are highest to meet agricultural, DCM&I, and flow augmentation demands. Conveyance facilities have been sized to convey 6,500 cfs, 13,500 cfs, and 18,500 cfs release capacities for OS1, OS2, and OS3, respectively.

It is important to note that the release capacities are much higher than the Columbia River mainstem diversion capacities quantified in the previous section. Larger release capacities are necessary to meet significant agricultural and flow augmentation demands during July and August when all of the flow augmentation flows are released. Conveyance and power generation facilities have been sized to maintain adequate capacity for off-channel releases to meet demands and to provide feasible power generation facilities. Additional detail relative to conveyance and power generation facility sizing is provided in Section 4, *Project Descriptions for Off-Channel Storage Alternatives*.

Model Results

Appendix C provides background data, numerical monthly values, discussion of the computations used in the water balance analysis, and numerical monthly results/output for each operational scenario. Base data presented in Appendix C includes but is not limited to the following:

- Columbia River mainstem water available for diversion
- Local hydrology (for example, runoff or precipitation)
- Evaporation losses
- Seepage losses

Model outputs and results include but are not limited to the following:

- End-of month reservoir volume
- Columbia River mainstem diversion to meet demands via direct pumping
- Columbia River mainstem diversion that is stored in new off-channel reservoir
- Releases from new off-channel reservoir to meet demands

3.2.2 Selecting Facility Locations

The locations of the facilities (including fish screen/diffuser structure structures, conveyance routes, its relationship to the Columbia River, spillways, and other features) were selected principally based on the most appropriate dam axis location. The preferred dam axis was typically located on the most favorable geologic and topographic setting that would maximize expected and favorable foundation conditions and available storage, and minimize conveyance from the Columbia River. The appurtenant structures for each dam site were then located with respect to the proposed dam and conveyance facility locations. The geologic and topographic configuration of the site, the available intake areas near the Columbia River, and the conveyance distances and pumping lift were all accounted for when locating appurtenant structures. Each location has a unique setting, and details of the locations of the facilities at each site are discussed in more detail in Section 4, *Project Descriptions for Off-Channel Storage Alternatives*, in each section.

3.2.3 Conceptual Layout and Design

Layouts of the proposed dam sites, dam types, and the associated diversion, conveyance, power generation, and power transmission facilities were developed based on brief field observations of topography and surface conditions, and on available maps and a literature review of the proposed sites, consisting primarily of the following:

- Aerial photographs
- Quadrangle maps showing topographic features and approximate elevations
- Available water well logs near the project
- Brief field inspection of selected surface exposures of soil, rock, and areas of groundwater seepage
- Review of published information about regional and local geology at the site
- Limited mapping of soil and rock exposures, landslides, and characterization of earth materials
- Evolution of potential types and quantities of available borrow materials
- Site geomorphology
- Soil and wetland maps, when available
- Geologic hazards
- Columbia River operational data, specifically the minimum and maximum water surface elevations in the Priest Rapids and Wanapum pools and in Lake Roosevelt

References used as source material for this evaluation are included in Section 7. The Appraisal Evaluation did not include any subsurface explorations or detailed geotechnical investigations.

Conceptual design layouts were prepared as a means of depicting locations, key concepts, and critical size parameters that would affect estimates of cost and assessments of benefits and impacts. Detailed discussions of the facility layouts for each site are presented in Section 4.

3.3 Cost Estimating

3.3.1 Field and Annual Costs

Estimates of both capital cost and annual cost were developed to compare the potential sites and overall projects. Components of cost used in this comparison are as follows:

- Capital Cost—construction contracts (including mobilization and allowances for unlisted items) and contingencies, plus non-contract costs as defined below
- Annual Cost—power consumption, O&M labor and expenses, replacement costs, and power generation revenue (as an offset)

Non-contract costs, as included under Total Capital Costs, include acquisition of land, environmental studies and reports, permitting, site investigations, water rights or power contract proceedings, feasibility studies and final engineering design, construction management, inspection, mitigation, and contract administration.

3.3.2 Net Present Value Analysis

Using the estimates of field and annual cost, a net present value (NPV) analysis was performed to combine initial and long-term costs for implementation of the various projects. This analysis is necessary to adequately account for possible imbalances between initial and annual costs while comparing the potential sites and operational scenarios. The NPV calculated for each site and operational scenario accounts for initial capital cost; power consumption, power generation, and annual operations and maintenance costs over each year of the project’s life; intermittent replacement costs; and salvage value at the end of the project's life.

3.3.3 Developing the Estimates

Table 3-3.1 summarizes the approach used (and unit costs, where applicable) to develop the cost estimates for this project.

TABLE 3-3.1
Summary of Unit Costs and Key Assumptions for Development of Cost Estimates

Capital or Annual Cost	Cost Component	Unit Cost, Assumption, or Approach
Capital Costs	Fish Screen/Diffuser Structures (including Associated Buildings)	Scale-up/scale-down from constructed projects
	Pump Stations or Combined P/T Facilities (including associated draft tubes)	Compilation of unit price factors and comparable projects into a lump sum estimate for each site
	Pipelines or Penstocks	$15 per diameter inch per foot length
	Tunnels	Empirical equation based on tunnel diameter, tunnel length, and adding cost for steel plating (dollars per pound), stiffeners, and access shafts
	New Bridges	$400 per square foot
	New Excavated Channels	Aggregation of unit costs ($ per cubic yard) for different types of material and different excavation methods
	Security Fencing	$30 per linear foot
	Road Relocation, or New Access Roads	Conceptual-level lump sum estimate prepared for 3-mile re-route of SR-26
	Special Structures (e.g., Energy Dissipaters)	Scale-up/scale-down from constructed projects
	Dam Embankments – Rock Fill	$18.40 per cubic yard
	RCC Dam Sections	$82.00 per cubic yard
	Spillways	Cursory lump sum estimates for each site/operational scenario
	Dam Inlet/Outlet Structures	Scale-up/scale-down from constructed projects
	Power Transmission Lines and Associated Facilities	$1.1 million per breaker for substation switchyards, $540,000 per mile of lines and towers, and $11,000 per megavolt amperes (MVA) for substation power transformation
	Mobilization	5% of base capital cost
	Allowance for Unlisted Items	15% of base capital cost
	Contingency	30% of capital cost after mobilization and allowances are added in
Annual Costs	Power Consumption Costs	$0.03 per kW-hour and overall pumping system efficiency of 75%
	O&M Labor and Expense and Replacement	Percentage of capital cost per 1-year or multi-year period, varying by facility
	Power Generation Revenue	$0.025 per kW-hour
Net Present Value Analysis	Discount Rate	4.875%
	Evaluation Period (Project Life)	100 years

3.3.4 Limitations of the Estimates

The appraisal-level capital cost and annual cost estimates developed during this Appraisal Evaluation are for the sole purpose of comparing the potential sites and projects, and are not intended to be at the feasibility level required to request project authorization for construction and construction appropriations by Congress. Costs reflect current market conditions and have not been escalated to account for inflation.

This Order-of-Magnitude (or Class 5) estimate was prepared in accordance with the guidelines of the American Association of Cost Engineers (AACE). According to the definitions of AACE, the Order-of-Magnitude estimate is defined as an estimate that is made without detailed engineering data, using information such as cost capacity curves, scale-ups or scale-downs from constructed projects, and unit price extensions from cursory quantity takeoffs. It is normally expected that an estimate of this type would be accurate within +50 percent or -30 percent.

The cost estimates shown, and any resulting conclusions on project financial or economic feasibility or funding requirements, have been prepared for guidance in project evaluation and implementation from the information available at the time of the estimate. The final costs of the project and resulting feasibility would depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. As a result, the final project costs will vary from the estimates presented here. Because of these factors, project feasibility, benefit/cost ratios, risks, and funding needs must be carefully reviewed prior to making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

3.4 Evaluation/Screening Criteria

The array of criteria used to evaluate off-channel storage alternatives and compare them against each other is shown in Table 3-4.1, Appraisal Evaluation Screening Criteria. As shown, alternatives are evaluated from three perspectives:

- Implementation/Technical Feasibility
- Benefits/Objectives Achievement
- Impacts (potential environmental, cultural, or socioeconomic impacts)

The data/ratings for each candidate site and scenario, for all criteria listed on Table 3-4.1, are reported in the respective site-specific sections of Section 4, *Project Descriptions for Off-Channel Storage Alternatives*. The method by which these data are used to compare the alternatives, and the results of the comparative analysis, are described in Section 5, *Decision Support Model*.

3.5 Regional Context and Similarities among Alternatives

3.5.1 Socioeconomic Factors and Criteria

Impacts to socioeconomic resources are evaluated based on three primary factors containing multiple criteria, as listed in Table 3-5.1.

Table 3-4.1

Appraisal Evaluation Screening Criteria

Perspective	Categories	Factors	Criteria	Units of Measure (base data/score)
A. Implementation/ Technical Feasibility				
	Cost	Annual equivalent cost	Net Present Value	$
			Net Present Value/50 yrs yield	$/AF of yield
	Risk Factors	Safety & integrity	Relative risk/hazard	Rating on 0-10 scale (0=highest, 10=lowest risk)
		Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	Rating on 0-10 scale (0=highest, 10=lowest risk)
	Time to Build	Construction duration	Construction start to on-line service	Years
B. Objectives/ Benefits Achievement				
	Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	acre-feet/year
		DCM&I Supply	Meeting projected demand (yield)	acre-feet/year
		Flow augmentation	Meeting projected demand (yield)	acre-feet/year
	Secondary Benefits	Power generation	Power balance	Revenue/Cost
		Expandibility	Potential for expansion to increase storage volume in the future	Yes = 10 No = 0
C. Impacts				
	Socio-economic	Land Ownership	Private land acquisition requirement	Acres
			Federal & State land acquisition requirement	Acres
		Land Use	Residential use	No. residences
			Irrigated Agriculture--High value crops	Acres
			Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	Acres
		Infrastructure	Highway (State, federal) impacts	Miles
			Local road impacts	Miles
			Railroad impacts	Miles
			Irrigation Infrastructure	Miles
			Transmission line impacts	Miles
	Cultural	National Register-eligble resources and Traditional Cultural Properties	Potential for resource impacts	Rating on 0-10 scale (0=major conflict, 10=none)
	BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	Miles
			Anadromous Fish--Downstream Habitat Affected	Miles
			Federal aquatic T & E species--Habitat Inundated	Miles
			Federal aquatic T & E species--Downstream Habitat Affected	Miles
			State aquatic Sensitive species--Habitat Inundated	Miles
			State aquatic Priority Species	Miles
			State aquatic Sensitive species--Downstream Habitat Affected	Miles
			Federal terrestrial T & E species impacts	Acres
			State terrestrial T & E and Sensitive species impacts	Acres
			State terrestrial Priority Species	Acres
		Special Status habitat or conservation/preservation designation	Wetland habitat impacts	Acres
			Riparian habitat impacts	Acres
			Sand Dunes habitat impacts	Acres
			Cliffs/Bluffs habitat impacts	Acres
			Shrub-Steppe habitat impacts	Acres
			Candidate Wild & Scenic rivers	Miles
			Wilderness Study Areas	Acres
			National wildlife refuges impacts	Acres
			State wildlife refuges impacts	Acres
			Other National or State conservation/preservation designation	Acres
		Water & Air Quality	Downstream temperature impacts	Rating on 0-10 scale (0=major conflict, 10=none)
			Windblown dust/particulates (from annual reservoir drawdown)	Rating on 0-10 scale (0=major conflict, 10=none)

TABLE 3-5.1
Factors and Criteria Used to Evaluate Socioeconomic Resource Effects

Factor	Criteria
Land Ownership	Private
	State and Federal
Land Use	Residential Use
	Irrigated Agriculture—High Value Crops
	Irrigated Agriculture—Low Value Crops
Infrastructure	Highways
	Local Roads
	Railroads
	Irrigation Facilities
	Transmission Lines

Information in the socioeconomic resources description and evaluation in Section 4 is based on data readily available in the literature. The environmental impacts discussion includes impacts of the reservoir, as well as the dam and all appurtenant structures.

3.5.2 Cultural Resources

Cultural resources consist of the physical remains of, and knowledge about, past human activity. They include archaeological sites, artifact and historic document collections, rock art, buildings, traditional plant gathering and ceremonial places, and human-altered landscapes. Heritage resources are managed within the context of overall management for the long-term benefit of all Americans. This benefit can be realized through such activities as scientific study of past human activities and past environments, traditional use by American Indians, and development of interpretive sites where people can see and appreciate the diversity of past use. Most fundamentally, public benefit comes through maintenance of the sites themselves. Absent any land management conflicts, preserving important sites in place, in good condition, is the overall goal. This can be achieved by protecting them from adverse management activities (or mitigating adverse effects, to the greatest public benefit), vandalism, weathering, alteration of their settings, and other processes that cause them to deteriorate to the point of losing their value. In this way, they stand as a legacy for the future.

For each of the alternative projects, the following federal legislation applies to cultural features and developments:

- The National Historic Preservation Act (NHPA) of 1966 (as amended) is the primary law that guides management activities (36 Code of Federal Regulations [CFR] 800). It requires Agencies to take into account the affect of other management activities on heritage resources (Section 106). It also requires development of long-term management plans that locate and protect heritage sites, and then integrate sites and information into overall agency programs and goals (Section 110). The implementing regulations for Section 106 were amended in 1999 (and revised in 2000), and require higher levels of consultation with Tribes, the State Historic Preservation Office, and communities.
- The American Indian Religious Freedom Act of 1978 protects the rights of American Indians to access and use religious sites, and directs federal agencies to consult with Tribes on ways to ensure this use.
- The Archeological Resources Protection Act of 1979 imposes civil penalties for unauthorized excavation,

removal, damage, or defacement of archaeological resources (36 CFR 296).

- The Native American Graves Protection and Repatriation Act, passed in 1990, requires an inventory of existing artifact collections, return of human remains, sacred objects, and objects of cultural patrimony to appropriate Tribes. It also calls for consultation with Tribes to develop procedures for use in the event that human remains are discovered either by intentional excavation or inadvertent discovery.

Because of the limited cultural resource data available, in addition to varying levels existing studies at the Sand Hollow, Crab Creek and Hawk Creek areas, assumptions have been compiled to support the ranking system associated with each location. The probability that cultural resources are present is ranked on a scale from 0 to 10. Assumptions were based on information collected from the Washington State Historic Preservation Office and professional experience.

3.5.3 Environmental Factors and Criteria

Impacts to environmental resources are evaluated based on three primary factors containing multiple criteria, as listed in Table 3-5.2.

Special status species are those that are listed or are considered for listing by Federal or State governments as threatened or endangered. Special status habitats have a high priority for either management or conservation. Conservation/preservation areas are deliberately set aside for conservation or preservation purposes.

Information in the environmental resources description and evaluation in Section 4 is based on data readily available in the literature. The environmental impacts discussion includes impacts of the reservoir, as well as the dam and all appurtenant structures.

TABLE 3-5.2
Factors and Criteria Used to Evaluate Environmental Resource Effects

Factor	Criteria
Special Status Species	Anadromous Fish
	Aquatic Federally Threatened Species
	Aquatic State Candidate Species
	Terrestrial Federally Threatened or Federally Endangered Species
	Terrestrial State Threatened or State Endangered Species
	State Priority Species
Special Status Habitat	Wetlands
	Riparian
	Cliffs
	Shrub-Steppe
Conservation/ Preservation Areas	Wild and Scenic Rivers
	National Wildlife Refuges
	State Wildlife Refuges
	Wilderness Study Areas
	Areas with other national or State conservation or preservation status

3.5.4 General Geologic Setting of the Columbia River Basin

The four proposed off-channel reservoir sites are located in the geologic province known as the Columbia Basin. The Columbia Basin is an intermontane basin between the Cascade Range and Rocky Mountains. This basin is filled with volcanic rocks and sediments. The stratigraphy includes volcanic rocks of the Columbia River Basalt Group, interbedded sedimentary rocks of the Ellensburg Formation, basin-filling sedimentary rocks of the Ringold Formation, and unconsolidated sediments including fluvial, eolian, and catastrophic flood deposits. The following is a general discussion of the geologic units found at the proposed off-channel reservoir sites.

Columbia River Basalt Group (CRBG)

The CRBG consists of a thick sequence that includes more than 300 continental flood-basalt flows. These flows were erupted over an 11-million-year period from about 17 to 6 million years ago (Swanson et al., 1979). These flood basalts cover an area of over 200,000 square kilometers (km^2) in Washington, Oregon, and western Idaho and have a total estimated volume of over 224,000 cubic kilometers (km^3; Hooper et al., 2002; Camp et al., 2003). The source for most of these flows was a series of north-northwest-trending linear fissure systems located in eastern Washington, northeastern Oregon, and western Idaho. Based on lithological properties, geochemistry, and magnetic polarity, the Columbia River Basalt Group has been subdivided into a number of formations and members.

Intraflow structures of the basalt flows are important because these features control the rock mass characteristics, including rock mass strength, permeability, and groundwater flow. The intraflow structures originate during the emplacement and solidification of each flow and result from the variations in cooling, degassing, thermal contraction, and interaction with surface water. The Columbia River Basalt flows typically consist of a permeable flow top, a dense, relatively impermeable flow interior, and variable flow bottom.

The interiors of the basalt flows consist of colonnades and entablatures. The colonnade consists of relatively well-formed polygonal columns of basalt, usually vertically oriented and one meter or larger in diameter. Entablature is composed of irregular to regularly jointed small columns frequently less than 0.5 meters in diameter. Entablature columns are commonly fractured into hackly, fist-sized fragments. Entablatures typically display a greater abundance of cooling joints than do colonnades.

The layering and stratigraphy of the basalt flows are critical because they control the rock mass strength and groundwater flow. The rock mass strength is lower in the interflow zones because of the fracturing and weathering of the basalt. Interbedded sedimentary layers and intraflow zones including vesicular flow tops, brecciated flow tops, basal pillow complexes, and basal breccia zones, serve as the primary aquifers in the region, while the dense flow interiors commonly act as aquitards.

The following is a general description of the basalt formations mapped at the proposed reservoir sites, summarized from Myers and Price (1979). Specific descriptions of basalt units observed during the site reconnaissance are included in the discussions of each site.

Elephant Mountain Member The Elephant Mountain Member is comprised of one to three flows of transitional to normal magnetic polarity. This member is typically black to dark gray, weathers to reddish-gray, and is fine-grained and non-porphyritic. Sheet-like exposures of this unit average 90 feet thick.

Priest Rapids Member The Priest Rapids Member consists of 3 to 4 flows and is exposed along the Columbia River upstream from Priest Rapids Dam. This unit is black to gray-green, weathers to rusty-brown, fine-grained, glassy, dense, and ranges from aphyric to containing small olivine and plagioclase phenocrysts.

Roza Member The Roza Member is typically comprised of one or two flows that have transitional magnetic polarity, with a total thickness of 100 to 300 feet. This unit is gray-black, weathers to rusty brown, fine- to medium-grained, and characterized by numerous plagioclase phenocrysts.

Frenchman Springs Member The Frenchman Springs Member contains as many as 15 individual flows of normal magnetic polarity, and is over 600 feet in total thickness. Near Vantage, this unit is approximately 350 feet thick. The Frenchman Springs unit is described as having aphyric and phyric units, and is black-gray to greenish-gray, weathers to reddish-brown, fine- to medium-grained, dense, and has plagioclase phenocrysts. The Frenchman Springs Member is known to have numerous sandstone and tuffaceous sedimentary interbeds.

Grande Ronde Basalt The Grande Ronde Basalt is the most aerially extensive unit of the Columbia River Basalts, and the most voluminous, comprising approximately 85 percent of the basalt flows. The Grande Ronde basalt flows are predominantly cliff-forming, and flows range in thickness from 3 feet to over 300 feet. The thickest exposures of the Grande Ronde basalt are generally composed of 30 to 40 individual basalt flows. The Grande Ronde basalt flows are typically fine-grained, non-porphyritic, black, dense, and are normal and reverse magnetic polarity. The flows range from those with well-developed colonnades and entablatures to those with no recognizable subdivisions.

Pre-Columbia River Basalt Bedrock Units

Along the margins of the Columbia River plateau, the CRBG flows overlie a diverse and complex assemblage of Precambrian to Tertiary-aged units, which are collectively known as “basement” rocks. These basement rocks are completely buried by the basalt flows within the interior of the Columbia River plateau, and consequently the basement rocks are only exposed around the perimeter of the plateau. On the northern margin of the plateau, the CRBG flows overlie a mix of crystalline gneisses, plutonic complexes, and schists. Along the northeastern and eastern margins of the plateau, the CRBG flows overlie an irregular landscape of metasedimentary rocks and intrusive rocks (such as the granite of the Idaho Batholith). Basement rocks exposed in the study area include gneiss and granodiorite, and are described in more detail below.

Gneiss Gneiss bedrock is exposed around the northern margins of the Columbia River plateau. The gneiss is described as Cretaceous to Jurassic-age orthogneiss, which is gray, massive, foliated texture, and granitic composition. Structurally, the gneiss exhibited steeply-dipping joints that divided the gneiss into massive blocks.

Gneiss bedrock underlies portions of the lower Foster Creek valley. Based on field observations, the gneiss is typically gray, massive, foliated texture, and granitic composition. Structurally, the gneiss exhibited steeply-dipping joints that divided the gneiss into massive blocks.

Hawk Creek Granodiorite A granodiorite intrusion (Hawk Creek granodiorite) is mapped approximately 4 miles south (upstream) from the proposed Hawk Creek dam site. The granodiorite is gray and fresh to slightly weathered. Structurally, the granodiorite outcrops exhibits dipping joints that separate the granodiorite into massive blocks.

Sedimentary Rocks

Sedimentary rocks in the project vicinity include Ellensburg Formation and Ringold Formation. The following are general descriptions of each of these formations, summarized from Myers and Price (1979).

Ellensburg Formation The Ellensburg Formation includes weakly-lithified clastic and volcaniclastic sediments that occur within the western and central portions of the Columbia Basin. Units of this formation interfinger within the basalt flows of the CRBG and are the result of depositional episodes that occurred in between basalt flows. This unit is commonly described as moderately- to poorly-lithified, white to reddish-brown sand, silt, and clay.

Ringold Formation The Ringold Formation is comprised of sediments deposited in fluvial and floodplain environments in basins. The Ringold Formation is estimated to be between 3.3 and 5.1 million years old, and post-dates the Columbia River basalt flows. This formation typically consists of interbedded clay, silt, sand, and conglomerate. Based on exposures along the Columbia River, the Ringold Formation is estimated to be more than 800 feet thick in some areas.

Surficial Geologic Units

Surficial geologic units in the area include sand dunes, river alluvium, talus, landslides, loess, and colluvium. The following is a general description of each of these deposits.

Sand Dunes Active and inactive sand dunes are present in the project area. The sand dunes consist primarily of fine- to medium-grained quartz sand with minor amounts of silt. Some of the dunes contain basalt fragments and volcanic ash. Intervening blowouts in the sand dunes are covered with gravel lag, which suggests that the dunes are formed by reworked sand deposited by catastrophic floods.

Alluvium Alluvial deposits are found along the Columbia River. These consist of sands and gravels up to boulder size, with a variety of lithology. Alluvial clay, silt, sand, and gravel of variable sorting and thickness have been deposited by local streams in the vicinity. These alluvial deposits consist of reworked Columbia River basalt, Ellensburg formation, and loess.

Talus Actively-forming talus consists of angular clasts of Columbia River basalt and Ellensburg Formation at the bases of cliffs and on steep rock slopes such as the Saddle Mountains. The thickness of the talus varies considerably. The talus forms steep aprons and cones with no bedding or weak stratification.

Landslides Landslide debris includes rotated blocks, slump blocks, earth slides, and flows. Larger, partly eroded, stabilized landslide and landslide complexes along these ridge are likely Pleistocene in age, but possibly older. Holocene-age landslides of basalt are associated with anticlinal ridges and structures that cross-cut these ridges. Active landslides in some parts of the vicinity have been caused by the infiltration of irrigation water.

Loess Loess is comprised of wind-deposited fine sand and silt and mantles much of the Columbia Plateau. Most of the loess in the area is part of the Palouse Formation. This formation consists of tan to light brown, very fine sand to silt-size particles, with mixed in clay and volcanic ash. The thickness of the loess is up to 250 feet.

Colluvium Colluvium of silt, sand, gravel, and rock rubble is generally angular and composed of basalt, reworked Ellensburg Formation, and loess deposits. It also includes slopewash and mass wasting debris. The colluvium is typically less than 3 feet thick.

Catastrophic Flood Deposits
Catastrophic flood deposits in the Columbia River basin include the Pasco

Gravels and the Touchet Beds. The Pasco Gravels consist of fine sands to boulders of mixed lithology. The coarser deposits are commonly either foreset bedded or are associated with flood bars or sheet deposits. These deposits are 100 to 200 feet thick. The Touchet Beds are rhythmically-bedded fine-grained beds of silt to fine sand with stringers of coarse sand and gravels. These sediments were deposited in slackwater environment. They are found on the flanks of anticlinal ridges throughout the Columbia River basin. The Touchet Beds are greater than 25 feet thick in some areas.

Structural Geology

The Columbia Basin has two structural geologic subprovinces: the Yakima Fold Belt and the Palouse Slope. The Yakima Fold Belt consists of a series of generally east-west trending, narrow, asymmetrical anticlinal ridges and broad synclinal valleys formed by folding of the Columbia River basalt flows and sediments. Most of the folds have a steep northern limb, and are typically faulted by imbricate thrust faults. Formation of these folds and associated faults was initiated primarily during the later stages of basalt extrusion and was most intense during Pliocene time. Several of the faults within the Yakima Fold Belt are considered to be potentially seismogenic.

The Palouse Slope forms the eastern part of the Columbia Basin and is less deformed and consists of a few faults and low-amplitude, long-wavelength folds on a gently westward-dipping slope.

3.5.5 General Requirements for Siting Power Transmission Facilities

Power transmission facilities are required to provide energy to the large pump/ turbines that lift water into the off-channel storage reservoirs. These same facilities are then used for delivering the energy that is generated when water is released back through the reversible P/T units. General requirements for selecting transmission voltage and for construction of power transmission facilities apply to all of the off-channel storage alternatives.

Maximum pumping power input requirements were used for the selection of the transmission voltage, number of circuits and substation elements typically used to serve loads of the magnitude involved for each alternative site. However, the total power interactions with BPA, which may affect the size and location of the proposed transmission and substation facilities, will not be known until the following has been completed:

- The project-specific power pumping and generating operational details have been more fully developed.
- A request has been submitted to BPA for their performance of a system impact study, and the results of that study published.

The system impact study helps establish the path rating for Firm Point-to-Point Transmission Service from the Crab Creek pump/storage project to the Project’s load service point at a separate location on BPA’s system. The study predicts the effects that the additional Project power would have on the total interconnected transmission system in its geographical area and identifies any transmission system modifications required on BPA’s and other nearby utilities’ systems to reliably send and receive the additional power to the project. These costs are not included in the feasibility cost estimate.

4 Project Descriptions for Off-Channel Storage Alternatives

This section describes each of the alternative projects selected for analysis in this Appraisal Evaluation:

- Crab Creek
- Sand Hollow
- Foster Creek
- Hawk Creek

All plates supporting this section are presented in Volume II.

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4.1 Crab Creek Dam and Reservoir Site

The Crab Creek Dam and Reservoir site is a potential new off-channel storage alternative located on Lower Crab Creek. As described in Section 3.2, three operational scenarios are under consideration for the Crab Creek Dam and Reservoir site, and each would result in different reservoir volumes:

- **OS1:** 1 million acre-foot reservoir
- **OS2:** 2 million acre-foot reservoir
- **OS3:** 3 million acre-foot reservoir

The majority of the drainage basin ranges in elevation from about 1000 to 1500 feet. Under the three Crab Creek operational scenarios, the reservoir would be approximately 1.5 to 2 miles wide along much of its length and would extend upstream for about 26 miles. An earth core CFRD or RCC (or some combination) would be constructed about 2.5 miles east of the Columbia River. Significant project facilities downstream of the dam would include a rock/concrete lined channel, a fish screen and diffuser, a spillway, and a combined pumping plant/turbine facility.

4.1.1 Site Characteristics

Location

Figure 1-7.1 shows the location of the Crab Creek site relative to other dam sites compared in this study. The Lower Crab Creek basin has a drainage area of approximately 4,900 square miles. The basin drains much of central Washington's Columbia River plateau, extending from just east of the basalt cliffs along the east side of the Columbia River northeast nearly to Spokane, and to the north nearly to Lake Roosevelt along the Columbia River, as shown in Plate 4-1.1. All plates are provided in Volume II.

The proposed dam site is located near the small communities of Schwana and Beverly at the west end of the Crab Creek drainage basin. The configuration of the proposed reservoir is shown in Plates 4-1.2A through 4-1.2E.

Topography

The drainage basin is generally characterized by gently undulating plains and upland plateaus. Elevations within the drainage basin generally vary from approximately 500 feet near the dam site to approximately 2500 feet near the northeastern part of the drainage basin. The majority of the drainage basin ranges from approximately 1000 to 1500 feet.

The topography of the drainage basin is the result of large basalt flows that were scoured by ancient floodwater from the glacial Lake Missoula as large ice dams broke and drained large continental lakes from present-day Montana. The floodwater scoured north Idaho and drained across much of Washington approximately 13,000 years ago. The scouring left large areas of the Lower Crab Creek drainage basin scarred with dry channels called coulees. The turbulent floodwater formed numerous large coulees and scoured nearly all of the central Columbia River Plateau, including the drainage basin for Lower Crab Creek. The scouring removed the overburden soil from many areas creating what are called "scablands" and leaving a relatively thin mantle of recessional alluvial sediments with the remains of the floodwaters.

The topography at the dam site consists of a broad valley approximately 8,000 feet wide with benches and gently rolling landforms of exposed basalt in the north portion of the valley and throughout most of the valley floor. The south side of the valley is flanked by the Saddle Mountains, which rise to elevations of approximately 2200 to 2700 feet. Steep basalt slopes and cliffs dominate the north side of the valley, but the elevation of the north rim is much lower than the Saddle Mountains on the south. The top rim of the north side of the reservoir is generally at 1000 feet. The slopes along the north side of the valley were scoured severely by waters from the Missoula Floods, forming a natural rim from which water flowed into the Lower Crab Creek basin from the north. The Saddle Mountains to the south formed a hydraulic barrier to the flood flows, and diverted the flow to the west toward the present-day Columbia River. The flood flows steepened and scoured the north flank of the Saddle Mountains near its base. In addition, the scouring, deepening, and formation of the channel under the present-day creek may have resulted from the flood waters.

A line of lakes, including Nunnally and Lenice Lakes, lie along the remnant path of an old stream channel or small unnamed coulee at the north side of the valley. The depth of sediments under the old channel is not known.

Socioeconomic Conditions

The proposed Crab Creek Dam and Reservoir site is rural with few structures and diffuse road networks. The primary land uses within the proposed project footprint is recreation with some agriculture. Land ownership appears to be primarily state and federal wildlife preserves with some private land ownership. Section 3.5.1, *Socioeconomic Factors and Criteria*, lists the land ownership, uses, and infrastructure factors that are considered in the socioeconomic characterization and effects analysis.

Land Ownership The distribution of private, state, and federal land ownership within the Crab Creek is described below.

Private Ownership Within the Crab Creek drainage, private land ownership is concentrated near the confluence of Crab Creek and the Columbia River, east of the project boundary. Additional private land ownership is assumed in the central and western portions of the inundation area where agricultural use is prevalent.

State Ownership Within the Crab Creek watershed, land is primarily zoned as Public Open Space or Open Space-Conservation. The Crab Creek drainage contains a portion of the Lower Crab Creek State Wildlife Area.

Federal Ownership The majority of the land within the proposed site footprint is owned and maintained by the U.S. Wildlife Refuge as the Columbia National Wildlife Refuge.

Land Use All criteria land uses are present within the Crab Creek site.

Residential Use Residential use is limited within the Crab Creek proposed project area, and approximately 18 residences are located in the footprint of the proposed project. The area is described by Grant County zoning as Rural Remote and Rural Residential.

Irrigated Agriculture Agriculture is the primary source of employment in Grant County. Eight farm units in Irrigation Block 49 (East CBID) and five farm units in Irrigation Block 88 (Quincy-CBID) would be impacted by a full reservoir in lower Crab Creek. This farm land totals about 1,794 assessed irrigated acres that would be removed from production. The variety of crops found in these farm units includes hay (alfalfa and other), wheat, feed corn, silage, and pasture. However, within the Crab Creek drainage, agriculture is not the predominant land use because this area is managed as wildlife refuges. Agricultural values are rated as either high-value or moderate-value crops based only on land use maps.

Infrastructure Lower Crab Creek County Road spans the entire length of the potential reservoir site. Approximately 2 to 5 miles of State Route (SR)-26 is directly impacted by each of the operational scenarios. A transmission line parallels Crab Creek within the proposed reservoir operational scenarios.

Irrigation Facilities There are no buried pipe drains, but surface facilities (canals, laterals and drains) totaling about 20 miles would have to be abandoned and removed.

Railroads A Chicago, Milwaukee, St. Paul, and Pacific Railroad track is within the reservoir footprint and is currently abandoned. However, the Burlington Northern Santa Fe Railway does have an option for re-activating this line, and the line is currently designated as a cross-state recreational trail. In 2006, the Washington State Legislature passed Senate Bill 6527, which designates the Milwaukee rail line as a recreational area, and also allows the state to "to establish and maintain a rail line over portions of the Milwaukee Road corridor owned by the state between Ellensburg and Lind" by entering into an agreement with a rail carrier. This authorization would sunset in 2009. Also, there are 7.2 miles of a spur railroad line serving the Port of Royal Slope that would be impacted and require modification.

Cultural Features and Developments

Lower Crab Creek contains known cultural resource sites, as well as potential sites that could be located in the future as more of the area is surveyed for cultural resources. Currently, 53 archaeological sites have been documented within the reservoir footprints of the three operational scenarios. The 53 sites consist of 47 prehistoric, four historic and two multicomponent (prehistoric and historic) sites. Most of the surveys (and site documentation) have been done to evaluate the effects of other projects on heritage resources. Some locations of the Lower Crab Creek area (valley bottoms) have higher site densities (based on topography, elevation, vegetation, raw materials, and/or access to water). This provides information to allow predictions about the effects on these areas. The regulatory framework and ranking system (0 to 10) for cultural resource evaluation is presented in Section 3.5.2, *Cultural Resources.*

Ninety-two percent (49) of the previously recorded sites are prehistoric and date to the era of American Indian settlement that pre-dates European settlement (circa 10,000 B.C. to the mid-1800s). Prehistoric site types in this area consist of open temporary camps containing large quantities of lithic materials, talus pits, and rock cairns. Most of these sites are relatively short-term campsites and/or places where people processed plants, butchered animals, collected and worked tool stone, or carried out other activities as part of their cycle of life. These sites probably represent activities by people who were otherwise based in nearby valleys. Several of these sites are outstanding for their ability to teach us about the specific role that upland areas played in people's lives. It is known that many more American Indian sites exist along Lower Crab Creek and near Saddle Mountain. Large drainage channels that discharge into major rivers routinely contain large quantities of cultural resources. Crab Creek borders the north side of Saddle Mountain, which is a source of raw tool stone material, spirit quest locations, and probably sources of plant types used by Native Americans that adds to the significance of the area. A high (0) potential for prehistoric sites exists, primarily along the valley floor between ridge tops and drainage bottoms, areas of lithic source material, low lying deflated areas, or dune “blow outs” with exposed sediments. Sites diminish in size and numbers as the distance from the valley floor increases. The high potential applies for each of the three operational scenarios and the Crab Creek Dam and appurtenant structures as well.

Saddle Mountain has also been identified as a Traditional Cultural Property (TCP). The lead federal agency is required to identify properties of religious or traditional cultural importance in the area of potential effect (APE). The Colville Tribe considers the entire Saddle Mountain Range a TCP (SWCA, 2005; Flenniken and Trautman, 2006). This area has been used by native people for spirit quests and resource procurement. Their identification and long-term protection depends primarily on consultation with the Colville, Nez Perce, Wanapum, and Yakama Tribes and the State Historic Preservation Office (SHPO). A high (0) potential exists for TCPs associated with each of the three Crab Creek Operational Scenarios and the Crab Creek Dam and appurtenant structures.

Eight percent (6) of the sites documented in the Lower Crab Creek area date from the historic European-American settlement era (after the mid-1800s), and include sites primarily related to ranching and farming from the twentieth century. Additional historic sites such as farms, homesteads, or other standing buildings are likely to be on private lands. Additional European-American sites would be documented in the future as more of the area is inventoried for cultural resources. The sites that may be present include debris scatters or rock or earthen structures associated with ranching activities or mineral prospecting likely dating from the 1880s to the present (SWCA, 2005). Overall, there is only a moderate (5) potential for the three Crab Creek Operational Scenarios and the Crab Creek Dam and appurtenant structures to contain historic sites.

No National Register of Historic Places (NRHP) or Washington Heritage Register sites are currently recorded for the Crab Creek Operational Scenarios. This is somewhat misleading. Often, Determinations of Eligibility (DOE) for the NRHP are not conducted when archaeological sites are recorded. This would be identified as part of the process of meeting the requirements of Section 106 of the NHPA and the National Environmental Policy Act (NEPA). When effects are analyzed as part of project planning, there may be some opportunities to redesign some components of the project to avoid some sites or adverse effects, or if necessary, mitigate them.

Therefore, although no sites are currently listed on the NRHP or Washington Heritage Register, there is a high potential for eligible sites once a full inventory is completed, sites recorded, and DOEs completed. A high (0) potential exists for eligible sites for each of the operational scenarios.

In addition, under the Crab Creek Operational Scenarios, the evaluation of lands that would be converted to agricultural production as the result of additional water storage would be conducted under a future phase of project implementation. Future development would be subject to separate environmental analysis.

Environmental Conditions

A variety of environmental resources are present at the Crab Creek Reservoir site. All information provided in this section is based on data readily available in the literature. This site has had more on-the-ground studies available, hence more detail, than the other sites addressed in this Appraisal Evaluation. In general, the area falls within the shrub-steppe vegetation zone dominated by sagebrush with upland bunch grasses. Lower Crab Creek has riparian and wetland vegetation adjacent to the stream. The canyon is bordered by cliffs, bluffs, and steep talus covered slopes. Section 3.5.3, *Environmental Factors and Criteria*, lists the habitats, species, and special areas that are considered in the environmental analysis.

Special Status Species This factor includes criteria for species that are unique to this habitat or are listed as imperiled by federal or state agencies.

Anadromous Fish Upper Columbia River summer steelhead (*Oncorhynchus mykiss*) and Upper Columbia River fall Chinook salmon (*Oncorhynchus tshawytscha*) are found in the Columbia River adjacent to Lower Crab Creek and use portions of the Lower Crab Creek drainage (KWA Ecological Services, Inc., 2004). The Upper Columbia River Steelhead Distinct Population Segment (DPS), formerly Evolutionarily Significant Unit (ESU), is federally listed as threatened (FT) under the Endangered Species Act (ESA) and as a state candidate (SC) species of concern by the State of Washington (WDFW, 2007). This steelhead DPS is discussed further below under the criteria of *Federal Aquatic FT Species* and *State Aquatic SC Species*. The Upper Columbia River Fall Chinook Salmon DPS is not federally listed under the ESA, nor is it a Washington-state-listed species of concern, and is therefore discussed here (WDFW, 2007).

Upper Columbia River Fall Chinook salmon spawn in drainages between McNary Dam and Chief Joseph Dam, the upstream point of mainstem migration on the Columbia River (Reclamation, 2004). Spawning by this DPS peaks in approximately mid-October, eggs incubate in gravels for 5 to 7 months, fry emerge the following spring, and outmigration usually begins within about 3 months (Reclamation, 2004). Spawning is associated with mainstem river reaches and downstream reaches of tributaries.

The extent of use of Lower Crab Creek by fall Chinook salmon is uncertain. Fisheries reports on the Crab Creek Subbasin refer to observations by WDFW biologists that Crab Creek annually attracts several fall Chinook adults at its extreme downstream end, but that spawning success is not clear (KWA Ecological Services, Inc., 2004). Recent studies by Reclamation show that adult fall Chinook salmon migrate up Crab Creek into Red Rock Coulee and that fall Chinook spawning redds have been found in Red Rock Coulee (KWA Ecological Services, Inc., 2004). All or portions of Red Rock Coulee are within the proposed Crab Creek Reservoir site, depending on the footprint of the specific reservoir operational scenario.

Aquatic FT Species The FT Upper Columbia River Steelhead DPS essentially includes steelhead that migrate upstream past Priest Rapids Dam. Peak spawning by this DPS occurs during mid- to late spring, fry emerge from gravels during spring to early summer, and juveniles may remain near their natal stream before outmigrating, primarily as 2- or 3-year-old fish (Reclamation, 2004).

Streamnet fisheries data, which are a compilation of state and federal agency information on fish distribution, show that steelhead adults of this DPS migrate upstream into approximately 54 miles of Lower Crab Creek, including portions of Red Rock Coulee and Hayes Creek (Ecology, 2002). This includes the reach of Crab Creek through the proposed reservoir site. These drainages, including the project reach of Crab Creek and several unnamed tributaries to Lower Crab Creek, have been designated as critical habitat for Upper Columbia River steelhead (70 FR 52630-52858). Adult steelhead have been caught at the mouth of Red Rock Coulee. However, spawning habitat in Lower Crab Creek is reported to be limited because of high silt loads and warm water temperatures. Researchers have suggested that because of warm water temperatures, if steelhead are spawned in Crab Creek, they may move downstream into the Columbia River to rear soon after emerging from gravels.

The Crab Creek steelhead population is one of five steelhead populations that comprise the Upper Columbia River Steelhead DPS (the others being the Wenatchee, Entiat, Methow, and Okanogan steelhead populations). The Proposed Upper Columbia River Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan (Upper Columbia River Salmon Recovery Board [UCRSRB], 2006) states that recovery of the Upper Columbia River Steelhead DPS will require the recovery of the Wenatchee, Entiat, Methow, and Okanogan populations but not the Crab Creek population. The Proposed Recovery Plan notes that the decision to designate steelhead in Crab Creek as an independent population occurred too late for the Upper Columbia Salmon Recovery Board to seek participation by the appropriate entities and stakeholders. The Proposed Recovery Plan states that "given the uncertainty of consistent stream flows (in Crab Creek) and the assumption that the resident component of the (Crab Creek) population was the primary driver in the historic population," other steelhead populations in the Upper Columbia River were not and are not dependent on the Crab Creek population to be a viable DPS (UCRSRB, 2006). The Proposed Recovery Plan states, "Therefore, recovery of the DPS can be achieved without the recovery of steelhead in Crab Creek." (UCRSRB, 2006).

Aquatic SC Species The WDFW lists imperiled wildlife species within the state. The Upper Columbia River Steelhead DPS is the only fish SC species occurring in Lower Crab Creek, including the project reach (WDFW, 2007). SC indicates a species is in danger of being listed as state threatened (ST) or state endangered (SE) if it is further imperiled.

Terrestrial FT or FE Species No terrestrial FT or FE species or habitat are present at this site. However, there are several federal Species of Concern (FSOC). Gray cryptantha (*Cryptantha leucophaea*), Hoover's desert parsley (*Lomatium tuberosum*), and Wanapum crazyweed (*Oxytropis campestris var. wanapum*) are plant FSOC with habitat or individuals at this location. A FSOC is an unofficial category that indicates these species appear to be in jeopardy, but there is insufficient data to support federal ESA listing as FE or FT at this time.

Terrestrial ST or SE Species The Washington Natural Heritage Program (WNHP), within the Washington Department of Natural Resources (WDNR), is responsible for identifying and listing imperiled plant species in the state. Several terrestrial ST or SE species or habitat for those species are found at the Lower Crab Creek site.

Wanapum crazyweed is a SE species with a state rank of S1 (critically impaired with 5 or fewer known occurrences in the state). Geyer's milk vetch (*Astragalus geyeri)* also has a state rank of S1, but is listed as a ST species. Sukdorf's monkey flower (*Mimulus suksdorfii*) is a state Sensitive (SS) species, meaning it is vulnerable or declining and could become ST or SE in Washington. The state rank for this species is S2 (imperiled with 6 to 20 known occurrences in the state). Gray cryptantha and Hoover's desert parsley are also SS species, but have a state rank of S2/S3, indicating they are intermediate between S2 and S3 ranks. An S3 species is rare or uncommon, with 21 to 100 known occurrences in the state.

State Priority Species (SPS) There are a variety of SPS at the Crab Creek site. SPS are those identified by the WDFW as having a high priority for either management or conservation. Priority species can be listed as P1, P2, or P3, as described below:

- P1—Species determined to be in danger of failing, declining, or vulnerable as a result of limited numbers, disease, predation, exploitation, or habitat loss or change. These are SE and ST species, as well as those that are candidate species for SE, ST, or SS classification.
- P2—Uncommon species, including state Monitor species that may be affected by habitat loss or change.
- P3—Species for which the maintenance of a stable population and surplus for recreation may be affected by habitat loss or change. These species include those for which people hunt or fish.

The sandhill crane (*Grus canadensis*) is the only terrestrial P1 listed SPS at Crab Creek. Sharptail grouse (*Tympanuchus phasianellus*), which also occur in the project area, can have a P1 or P3 listing depending on location. Terrestrial P3 listed species that occur in the project area include mule deer (*Odocoileus hemionus hemionus*), Rocky Mountain elk (*Cervus elaphus nelsoni),* chukar (*Alectoris chukar*), ring-necked pheasant (*Phasianus colchicus*), and California quail (*Callipepla californica*). Aquatic P3 listed species associated or potentially associated with portions of the Lower Crab Creek drainage include largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieui*), rainbow trout (*Oncorhynchus mykiss*), and walleye (*Stizostedion vitreum*). Waterfowl concentration areas at the site are listed as P2 or P3.

Special Status Habitats This factor includes criteria for habitats that have a high priority for either management or conservation. All of the special status habitats described here are present at the Crab Creek site. Designated critical habitat in Lower Crab Creek for Upper Columbia River steelhead was discussed under *Aquatic FT Species*.

Wetlands Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands must have one or more of the following attributes:

- The land supports, at least periodically, predominantly hydrophytic plants.
- Substrate is predominantly undrained hydric soils.
- The substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

Wetlands have been listed as a Priority Habitat because they have comparatively high fish and wildlife density, have high fish and wildlife species diversity, are important fish and wildlife breeding habitat, are important fish and wildlife seasonal ranges, have limited availability, or have a high vulnerability to habitat alteration.

Riparian Riparian areas are adjacent to aquatic systems with flowing water that contains elements of both aquatic and terrestrial ecosystems, which mutually influence each other. In riparian systems, the vegetation, water tables, soils, microclimate, and wildlife inhabitants of terrestrial ecosystems are influenced by perennial or intermittent surface water or shallow groundwater. Simultaneously, the biological and physical properties of the aquatic ecosystems are influenced by adjacent vegetation, nutrient and sediment loading, terrestrial wildlife, as well as organic and inorganic debris. Riparian habitat encompasses the area beginning at the ordinary high water mark and extends to that portion of the terrestrial landscape that is influenced by, or that directly influences, the aquatic ecosystem. Riparian habitat may include the entire extent of the floodplain, depending on the availability and distribution of surface water and groundwater, and riparian areas of wetlands that are directly connected to stream courses.

Riparian areas have been listed as a Priority Habitat because they have high fish and wildlife density, have high fish and wildlife species diversity, are important fish and wildlife breeding habitat, are important wildlife seasonal ranges, are important fish and wildlife movement corridors, have a high vulnerability to habitat alteration, or are unique or have species dependent on them.

Open water and riparian resources are prevalent in the Crab Creek drainage. Many of these open water and riparian resources were created by glacial scouring and deposition, which have created areas of low infiltration and scoured potholes that collect water. The proposed reservoir would inundate a portion of Nunnally Lake and completely inundate Merry and Lenice Lakes and multiple unnamed ponds, as well as Lower Crab Creek.

Cliffs Cliffs are vertical, or nearly so, rock faces that are greater than 25 feet (7.6 meters) high and occur below 5000 feet (1524 meters) in elevation. Cliffs, or bluffs, have been listed as a Priority Habitat because they are significant wildlife breeding habitat, have limited availability, and have species dependent on them.

Shrub-Steppe Shrub-steppe habitat has been listed as a Priority Habitat because it has comparatively high fish and wildlife density and species diversity, is important fish and wildlife breeding habitat and seasonal ranges, has limited availability, is highly vulnerable to habitat alteration, is unique, and has species that are totally dependent on it (obligate species). Shrub-steppe habitat can be identified as a large tract or as a small tract, as follows:

- *Large Tracts*: Tracts of land greater than 640 acres (259 hectares) in size and consisting of plant communities with one or more layers of perennial grasses and a conspicuous, but discontinuous, layer of shrubs. Large tracts of shrub-steppe contribute to the overall continuity of the habitat type throughout the region, because they are relatively unfragmented, contain a substantial amount of interior habitat, and are near other tracts of shrub-steppe. These tracts contain a variety of habitat features (such as topography, riparian areas, canyons, habitat edges, and plant communities). Another important component is habitat quality based on the degree with which a tract resembles a site's potential natural community, which may include factors such as soil condition and degree of erosion; and distribution, coverage, and vigor of native shrubs, forbs, grasses, and cryptogams.

- *Small Tracts:* Tracts of land less than 640 acres (259 hectares), with a habitat type consisting of plant communities with one or more layers of perennial grasses and a conspicuous, but discontinuous, layer of shrubs. Although smaller in size and possibly more isolated from other tracts of shrub-steppe, these areas are still important to shrub-steppe obligate and other state-listed wildlife species. Also important are the variety of habitat features and habitat quality aspects as listed above under large tracts.

Conservation/Preservation Areas The Crab Creek site contains both national and state wildlife refuges. Portions of the Columbia National Wildlife Refuge and the Crab Creek State Wildlife Refuge are located at this site.

Geology

The general geological setting of the Columbia River Basin is described in Section 3.5.4.

Local Geologic Setting The Crab Creek site is located in an east-west trending coulee formed by the Missoula Floods. Crab Creek flows westward through the valley toward the Columbia River. The southern side of the proposed reservoir would be underlain by talus and basalt flows that form the steep northern flank of the Saddle Mountains. The northern parts of the proposed reservoir would be underlain by relatively flat-lying, shallow basalts. The floor of the proposed reservoir would be underlain primarily by alluvium of Crab Creek, eolian sand dunes, basalt bedrock, and occasional Missoula Floods gravels and silts.

A geologic map of the area by WDNR is presented in Plate 4-1.3. Plate 4-1.4 shows a geologic map of the Crab Creek Dam site prepared using information from existing geologic mapping and geologic reconnaissance conducted during the site visit. Topographic and geologic information is shown on the cross section on Plate 4-1.5.

Bedrock in the vicinity of the Crab Creek site consists primarily of basalt bedrock of the Columbia River Basalt group, and is described in Appendix B. Surficial geologic units in the vicinity of the proposed Crab Creek site, also described in Appendix B, include stream alluvium, Missoula Flood deposits, eolian sand dunes, eolian loess deposits, colluvium, talus, and talus fans.

Project Facilities Geology The geologic setting for all project facilities consists primarily of the bedrock Columbia River basalts. Facility-specific geologic issues are described in detail in Appendix B and summarized below:

- **Reservoir Geology:** The Columbia River basalts are exposed along much of the length of the proposed reservoir along the northern side of Lower Crab Creek Road, while the south side of the reservoir would be underlain by talus and scattered exposures of basalt along the northern flank of the Saddle Mountains.
- **Damsite, Spillway, and Outlet Works Geology:** The bedrock underlying the proposed dam abutments and valley section beneath the proposed Crab Creek Dam consists of Columbia River basalt, alluvial deposits, and sand dunes. It appears that the bedrock

surface drops in elevation toward the Columbia River, and thus the alluvial deposits in the Crab Creek drainage are thicker closer to the Columbia River. The proposed spillway would be located on the roller-compacted concrete (RCC) portion of the proposed dam. The outlet works would be founded primarily on basalt bedrock that underlies the valley floor. This bedrock would provide suitable foundation conditions.

- **Intake, Combined Pump/Turbine Facility, Conveyance, and Power Transmission Facilities Geology:**
  - The fish screen/diffuser structure would likely be constructed in river alluvium and flood gravels.
  - The combined pump/turbine facility would be built on basalt bedrock near the north abutment of the proposed dam, at the end of the intake channel.
  - Between the proposed Crab Creek Dam site and the east side of Beverly, the combined inlet and outlet channel would be constructed primarily in basalt bedrock. On the west side of Beverly to Crab Creek, the input/output channel would be constructed in alluvium and flood gravels.

Groundwater

Groundwater in the vicinity of the Crab Creek site is found primarily in the alluvial deposits along Crab Creek, in the alluvial and Missoula Floods deposits near the Columbia River, and in fractured and interflow zones deep in the basalt bedrock. The alluvial deposits along Crab Creek consist primarily of silts and sands that contain groundwater. However, these deposits are thin and the permeability of these deposits is anticipated to be low to moderate, depending on the material types and percent of fines (such as silts). These deposits are not anticipated to contain an appreciable amount of groundwater.

Downstream from the proposed dam site, groundwater is found in alluvial deposits of the Columbia River and Missoula Floods deposits along the main Columbia River valley. The gravelly alluvial and flood deposits near the Columbia River are anticipated to transmit large quantities of groundwater. Based on drillers' logs of wells to the west of the proposed dam axis and completed in alluvial or Missoula Floods deposits, the depth to groundwater in the Lower Crab Creek floor ranges from 21 to 82 feet below ground surface (bgs). Groundwater yields in these wells, completed in loose sands and gravels, range from 40 to 150 gallons per minute (gpm).

The groundwater in the vicinity of the dam axis could be influenced to some degree by water elevations in Priest Rapids Reservoir. Areas next to Crab Creek and the coulee near the north abutment are expected to encounter shallow water near the existing ground surface. No evidence of artesian pressures were observed or noted at this site.

Groundwater within Columbia River basalt flows was noted on well logs drilled north of the right abutment. On the basalt benches north of the main valley floor, groundwater ranges from 70 to 160 feet bgs and well yields range from 60 to 2,500 gpm in wells completed within Columbia River basalt flows.

Localized, perched zones of groundwater appear to be present in the basalt flows that form the northern side of Crab Creek valley, along the northern rim of the proposed reservoir. This groundwater discharges as springs and seeps along the valley walls. Numerous springs and seeps were observed during the site visit and locations of these are noted on the geologic map. The discharge from these springs and seeps was not measured. It appears that these springs and seeps are the result of agricultural return flows from irrigated fields on the flat bench north of the Crab Creek valley. In addition, it appears that these springs and seeps provide recharge for Nunnally and Lenice Lakes.

Seismotectonics

The dam would be located in an area of relatively high seismicity from earthquakes known as the Yakima Fold Belt. Several of the faults within the Yakima Fold Belt are considered to be potentially seismogenic.

Potentially active faults (described as “Class A”, which is defined by the USGS as “geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features”) in the vicinity of the proposed Crab Creek Dam site include the Frenchman Hills Fault, Saddle Mountains Fault, Central Gable Mountain Fault, and Ahtanum Creek Fault. The closest mapped active fault is the Saddle Mountains Fault, which is mapped along the base of the Saddle Mountains. This fault is a south-dipping thrust fault, and has a total length of approximately 160 miles. The Saddle Mountains Fault is estimated to have a recurrence interval of “thousands to tens-of-thousands” of years, with an average slip rate between 0.2 and 1.0 millimeters per year (mm/year). One seismically active fault is known to be present under the dam footprint. Geologic investigations would be carried out to confirm that no other faults exist.

Based on the USGS seismic hazard, the probabilistic ground motion at the proposed Crab Creek Dam site is approximately 0.09g for a 10 percent probability of exceedance in 50 years (500-year return period) and 0.2g for a 2 percent probability of exceedance in 50 years (2,500-year return period). Design considerations for a rockfill dam would require special attention in regards to seismicity and potential dynamic displacement of the rockfill.

Probable Maximum Flood

The drainage basin area at the Crab Creek Dam site is approximately 4,842 square miles, based on the drainage area reported for the USGS gauging station near the dam axis. This area compares with the drainage basin area for O’Sullivan Dam of 3,920 square miles. The PMF was very roughly estimated from the PMF reported by Reclamation for O’Sullivan Dam based on the ratio of the drainage basin areas. No flood routing was performed to estimate the spillway flow requirements, so the crest spillway can probably be shorter than shown, but since it is an overflow gravity section and we need the gravity dam for the inlet and power house facilities, there is no benefit to reduce the crest length of the spillway at this time. The peak inflow volume and flowrate used for the conceptual spillway layout and design at Crab Creek are 493,000 acre-feet and 65,000 cfs, respectively (Reclamation, 2007b).

4.1.2 Project Facilities

Dam and Appurtenant Structures

Plates 4-1.5 and 4-1.6 show the proposed layout for the dam and appurtenant structures, spillway, the inlet/outlet channel, as well as existing structures and facilities along the proposed axis for the dam. Analysis of wave run-up and overtopping protection indicates that approximately 15 feet would be required for minimum freeboard. Table 4-1.1 shows the storage volumes, surface area, estimated dam heights, estimated embankment volumes, and water surface elevations (WSEL) for the three operational scenarios.

Several design considerations are associated with the construction of a large embankment dam in the Lower Crab Creek Valley, none of which are considered to be "fatal flaws." It is believed that a safe dam can be constructed, and that no unusual measures or features beyond what is typical for a major embankment dam would be required.

A composite rockfill/RCC dam appears to be most appropriate for a dam at this location for several reasons. Because of significant scouring and removal of sediments during recent glacial flooding in the area surrounding the dam site, there is a relative lack of impervious soils or even unconsolidated pervious soils at or near the dam site in the quantities needed for earthfill dam construction. On the other hand, basalt rock is present throughout the dam and reservoir area, with relatively little soil cover in most areas. The basalt, through quarrying, would provide a virtually unlimited source of rockfill for the project. It is anticipated that the basalt rock would meet the gradation and durability requirements for rockfill dam construction.

A rockfill dam is also advantageous considering the location in a zone of relatively high seismicity. High ground motions and the potential for fault movement require a dam type that is seismically stable even under very large loadings. Rockfill dams are recognized to be one of the most earthquake-resistant dams, primarily because the design affords a large downstream portion that retains high-strength, possesses high permeability, and thereby remains unsaturated, while allowing seepage water to pass through in the event that the impervious element of the dam is cracked or damaged during a seismic event.

Rock Fill Portion—Crab Creek Dam
The crest of the proposed concrete-faced, rockfill portion of the Crab Creek Dam is assumed to be 40 feet wide. At this preliminary level of design, both the upstream and downstream slopes would be set at 1.5H:1V. These slopes are flatter than many rockfill dams of this type; however, considering the preliminary stage of analysis for the dam, high seismicity, and potential questionable areas of rock quality and size, these slopes appear justified at this time. As the design continues into more detailed phases following field and laboratory analyses, steeper slopes may be suitable and thus less material may be required.

TABLE 4-1.1
Crab Creek Dam and Reservoir Data

	Storage Volume (acre-feet)	Surface Area (acres)	Dam Height[1] (ft)	Dam Embankment Volume[2] (yd^3)	Maximum WSEL (ft)
Crab Creek OS1	1,000,000	16,950	137	4,302,226	623
Crab Creek OS2	2,000,000	23,500	199	10,898,923	685
Crab Creek OS3	3,000,000	29,400	236	16,576,477	722

[1]Height above the valley bottom to the maximum water surface elevation plus 15 feet freeboard.
[2]Based on 1.5H:1V upstream and downstream slopes.

For purposes of the cost estimate, an upstream sloping concrete membrane is assumed for the water barrier based on the types of borrow materials available for construction near the site (lack of silty well-graded sand and gravel for a central or sloping earth core). Thus, a sloping concrete face is assumed at this point for this project. A concrete grout curtain/cutoff would be required because of concern about seepage through the dam foundation. If materials for an earth core are found, a rockfill with upstream and downstream slopes of 1.7:1 could be considered in lieu of a CFRD. Plate 4-1.7 shows typical cross sections for both proposed rockfill dams at this location: a rockfill with an earthen core, and a concrete-faced rockfill. Plate 4-1.8 shows the transition between the rockfill and RCC dam.

RCC Portion—Crab Creek Dam The RCC portion of the Crab Creek Dam would be approximately 2,800 feet long, 1,500 feet of which would comprise the spillway. The upstream face of the RCC dam would be vertical, and the downstream face would be sloped at 0.8H:1V. The crest of the RCC dam would be 30 feet. Aggregate for use in the RCC dam could be provided either from local basalt sources or gravelly alluvial deposits along the Columbia River. The RCC dam would have grout curtain cutoff below the upstream portion of the dam.

A drain that extends vertically into the subsurface would be installed from and daylight into the gallery.

The RCC dam would be joined to the rockfill dam using wrap-around sections.

Potential Borrow Sources For purposes of this evaluation, it is assumed that the rock for rockfill in the dam and aggregate for the concrete would be obtained from the construction of the inlet/outlet channel, and also quarried from the base of the valley floor or from the valley sidewalls within the reservoir area. The filters for the rockfill would require processing to achieve the required gradations. However, the excavations must be monitored to ensure that poor quality, fractured rock that may be subject to leakage is not left exposed in the quarry walls and floors. Testing would be required to determine the durability and hardness of the rock, but the available rock is believed to be of high quality.

The impervious zone for the dam could be a sloping concrete membrane, a central or sloping upstream core of silt, or a well-graded mixture of silty sand and gravel. Inspection of the area was made for potential borrow sources for construction materials. The upper plateau consists of silt and sand with limited areas of silty sand and gravel. The thickness of these alluvial, colluvial, and eolian sediments is not well known, but is generally believed to be relatively shallow, based on observations of exposed rock in the field, knowledge of the scouring that removed soils during the Missoula Floods, and existing well logs in the vicinity. Also, fine-grain sediments were observed in some zones of the proposed reservoir bottom, but the thickness is not known and the areal extent is limited. It is also recognized that removal of these natural soils is undesirable because these fine-grained soils currently help blanket and protect the bottom of the reservoir from future leakage if left in place.

Based on current information and judgments, it is assumed that the rockfill portion of the dam would be concrete faced. The concrete liner would require good filter zones under the concrete and a continuous rock foundation and plinth under the upstream toe of the dam. The filter materials can be constructed from basalt sources in the valley and abutment areas of the dam. However, the type of rockfill and the choice between a concrete RCC or an all-RCC structure would be made in the feasibility or final design phase based on economic factors, among other considerations.

Dam Alignments The proposed dam alignment is shown in Plate 4-1.2A. For purposes of this discussion, the primary axis is indicated at the preferred location, but additional studies would be required to verify suitable conditions. Secondary locations could be considered during subsequent feasibility studies. The proposed axis is located slightly east of the axis location shown in the Pre-Appraisal Report (Ecology and Reclamation, 2005). There are two initial considerations for determining the axis location of the dam:

- Shifting the axis far enough to the east to allow construction of an upstream cofferdam that avoids the main body of the existing Nunnally Lake near the north side of the valley. This shift in location might lead to reduced thickness of alluvial sediment under the dam at the old coulee channel; however, the variability of depth to rock within the old coulee is unknown. Elsewhere, it appears that basalt rock would be encountered at or very near the ground surface.
- The depth of alluvial and lacustrine sediments overlying basalt rock under the present-day Lower Crab Creek. A shift to the east would likely reduce the depth to rock in this area.

Hard, competent basalt rock is exposed at or near the ground surface across much of the valley floor. The valley floor can be divided into two segments: a bedrock plateau on the north side of the valley, and the lower valley floor through the central dam axis extending to the south abutment. The north plateau slopes gently to the south (approximately 2.5 percent). The plateau varies in elevation from approximately 640 to 680 feet and is approximately 1,300 feet wide. The lower valley floor through the central part of the dam is approximately 5,650 feet wide and varies in elevation from approximately 500 feet near Lower Crab Creek to approximately 580 feet near the center of the valley.

Both abutments would be founded on basalt. The south abutment should be founded on bedrock after removing talus, and is overshadowed by very steep rock and talus slopes extending more than 1000 feet in elevation above the top of the dam. Depending on the operational scenario, the north abutment would tie into the toe of the basalt cliffs that rise above the basalt bench. Other axis locations are expected to encounter similar conditions throughout the valley floor and abutments.

Dam Foundation As noted previously, the valley floor consists primarily of hard basalt bedrock exposed at or near the ground surface throughout most of the valley. Basalt bedrock is generally exposed at or near the ground surface at most locations north of the old Chicago, Milwaukee, St. Paul, and Pacific Railroad grade (RR grade) and generally north of Lower Crab Creek Road. Bedrock may also be located at shallow depths for several hundred feet south of the RR grade along the primary axis, but scouring may have left the bedrock surface much deeper under the Lower Crab Creek stream, based on available water well logs located downstream of the primary axis.

Water well logs show that approximately 8,000 feet west of the primary dam axis, the basalt extends about 120 feet deep below the existing ground surface.

However, approximately 7,500 feet upstream of the primary axis, bedrock was observed during the field inspection at the ground surface under and near the Lower Crab Creek stream. For purposes of this report, rock is assumed to be approximately 100 feet deep under the deepest part of the valley near the stream at the primary dam axis and is thought to vary in depth from 0 to 100 feet bgs or more under the south portion of the valley (south of the RR grade), with the deepest section perhaps occurring near the existing Lower Crab Creek stream channel. Plate 4-1.5 shows a typical cross section of the valley under the primary dam axis.

Very steep slopes exist above the left (south) abutment and rise 1,000 feet or more above the top of the proposed dam crest. Preparation of the foundation at the south abutment would require excavation to remove loose talus rock and slope debris from the base of the slopes and expose sound bedrock.

At the north end of the dam, the embankment would decrease in height because the dam would be founded on a higher bedrock plateau. The dam would tie into the base of steep rock slopes at the north edge of the bedrock plateau. The wide bedrock plateau near the north abutment varies in elevation from approximately 640 to 680 feet. Talus must be removed and excavations would extend to the north into the base of a 230-foot-high rock cliff and steep slopes far enough to encounter sound rock.

It is assumed that the entire dam would be constructed on sound basalt rock foundation material. Since bedrock is at or near the ground surface in most areas of the valley, excavations should be limited and control of groundwater should not be a significant issue. However, where the rock foundation is found to be deep or where it is below the groundwater table, deep excavations and groundwater control measures would be required. This could occur primarily in two areas as previously described, under Lower Crab Creek and under the north coulee. Foundation treatment (dental concrete or RCC rockfill) would be needed to prepare an acceptable foundation profile for the rockfill.

During construction, the streams must be diverted and groundwater control measures would be required to remove the overburden soils and expose sound bedrock under the footprint of the dam. The stream can be diverted in a channel and/or pipeline around the work areas. This diversion would likely be made around the north side of the deep excavation under Lower Crab Creek. A slurry wall cutoff to rock or groundwater dewatering wells would also be required to control the groundwater for this work. Exploration would be required to determine the depth and degree of difficulty in making excavations near the Lower Crab Creek stream and under the north coulee.

The existing coulee near the north side of the valley would require dewatering and groundwater control under the dam. It is assumed that a cofferdam would be constructed upstream and downstream of the dam footprint, and the foundation under the dam in this area would also be excavated to sound basalt rock. The thickness of alluvial sediments in the coulee is unknown, but is anticipated to be low. Water currently flows along the coulee from seepage sources emanating from several miles of basalt slopes along the north side of the proposed reservoir. This flow was roughly estimated at approximately 30 cfs discharging from the west end of the lake at the time of the field trip and would require diversion around the work area during excavation and construction of the dam embankment through this area.

The natural rock foundation for the dam would require grouting and construction of a permanent seepage cutoff system. These elements should be constructed and the embankment materials placed to bring the constructed grade back up to the existing ground surface under the dam.

As the bedrock is exposed during construction, it is expected that rock quality could vary significantly as different areas of one flow or different flows are exposed. Flexibility would be required during construction to ensure a suitable foundation is achieved. Considerable onsite geologic and geotechnical presence would be needed to determine the adequacy of the bedrock and the degree of foundation treatment measures such as additional excavation, foundation grouting, slush grouting, and filter placement. In addition, the varying bedrock composition and quality would require additional investigations during advanced design phases to better understand the bedrock properties and permeability (fracture density, openness, infilling characteristics, and other features), to develop a foundation grouting program, explore foundation conditions, and potentially reduce bedrock seepage.

Because of the very steep natural slopes that rise 1,000 feet or more above the proposed dam at the south abutment, large rocks and talus can be expected to roll down on the end of the dam in the future. These rolling rocks could damage structures or facilities that are too close to the slopes. A significant element of the dam that requires protection is the concrete membrane at the upstream slope. It is assumed that if a concrete membrane is used, it would be protected by blanketing and covering the concrete with a rockfill having a suitable slope and aerial extent to buffer, catch, and contain the boulders. Rock falls are expected to occur at random times throughout the year as a result of exposure to natural weathering elements and animal disturbance; however, the most significant exposure from this hazard may occur during earthquake ground shaking when large rocks could be shaken loose to roll down the steep natural slopes.

Reservoir Inlet/Outlet Facilities The inlet/outlet structure would be attached to the upstream RCC dam section and have a vertical face. It would be connected to the pump/turbine facility by penstocks passing under this part of the dam as depicted in Plates 4-1.9 and 4-1.10.

Spillway The concept drawing (Plate 4-1.6) shows the proposed spillway location. The drainage area for Lower Crab Creek is very large, and consequently a large spillway would be required that is capable of passing the PMF. The south abutment of the dam is very steep and not well suited for a spillway, and a spillway at the north abutment would require a tunnel or very deep excavation in basalt bedrock.

Therefore, the spillway would be constructed using an RCC section that would comprise a portion of the dam. The spillway would be approximately 1,500 feet wide. The base of the spillway would have a roller bucket and a stilling basin in order to dissipate the energy of the water and reduce the velocity of the floodwater. The water would then drain through a channel into the existing Crab Creek, some distance below the dam. The spillway channel between the dam and Crab Creek would have to be constructed with appropriate width and gradient to convey the floodwaters into Crab Creek.

The channel is anticipated to be primarily underlain by basalt bedrock covered with eolian sand dunes. The channel would have to be constructed in rock for erosion protection and possibly lined with concrete if weak, fractured bedrock is found.

Reservoir

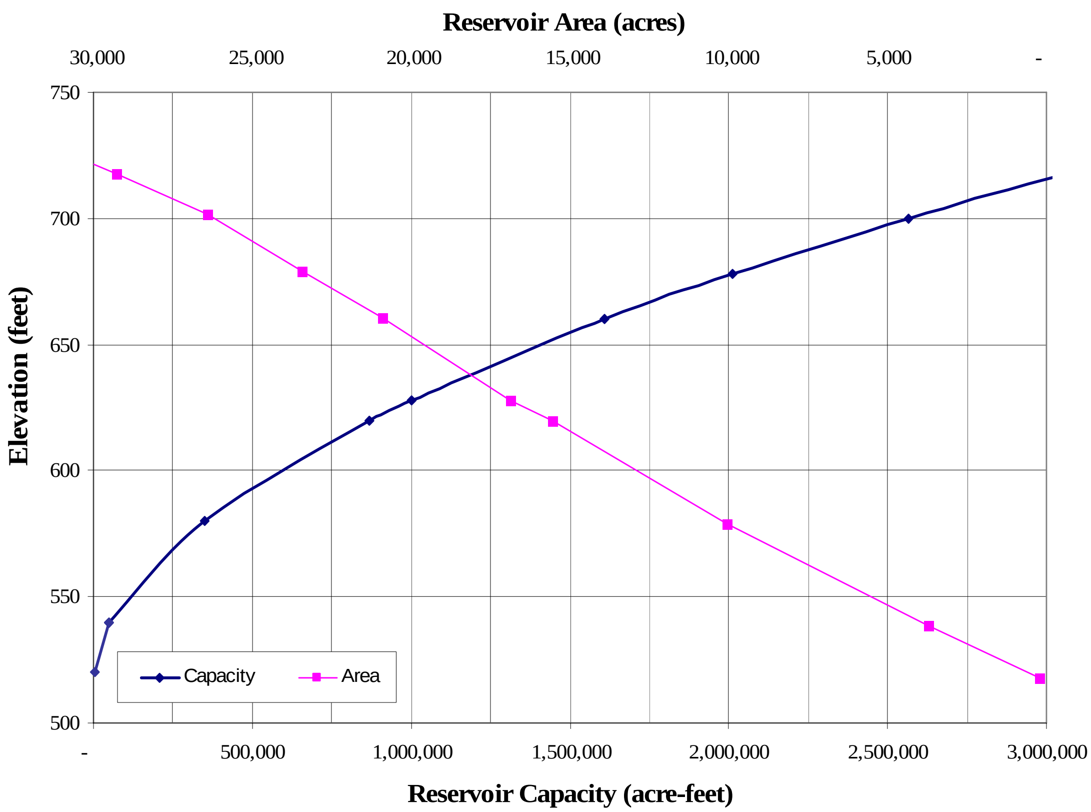
Plates 4-1.2A through 4-1.2E show the proposed reservoir configuration. The area/storage curve for this reservoir compared to elevation is shown in Figure 4-1.1.

The water surface of the reservoir would be in contact with talus and colluvium below basalt cliffs on both sides of the 26-mile-long reservoir; and primarily basalt bedrock, and alluvial silt, sand, and gravel sediments in the valley floor. At full reservoir levels, the lake would be in contact primarily with erosion-resistant materials except for small areas near the head of the reservoir, and steep talus and colluvial deposits along the south side of the reservoir, which could be eroded into steep, wave-cut cliffs. As the reservoir water levels drop, additional shallow water zones of alluvial sediments would be exposed to wave action and disturbance, which could lead to some increased turbidity at times.

Shallow water zones could also lead to increased solar heat gain. It may be possible to exclude certain shallow-water zones from the upper end and sides of the reservoir by constructing levees that exclude and contain the water in these shallow warm water zones. This would

FIGURE 4-1.1

Elevation-Storage and Elevation-Area Curves for Crab Creek



prevent these warmer water zones from entering and mixing with the deeper water zones in the reservoir as the reservoir level is lowered. It is also possible that such dikes and containment behind them might be used for wetland enhancement associated with lost habitat from other portions of the project. Greater dam heights and reservoir depths are expected to result in improved water quality associated with greater depth of storage.

Because of the rocky conditions, including talus slopes that predominate throughout the reservoir area, the reservoir is expected to encounter generally stable sideslopes associated with rapid drawdown of the reservoir levels during discharge periods to the Columbia River. It is possible that wave-cut cliffs in the saturated talus and colluvium would slump during drawdown. Also, since the reservoir would be relatively large compared to the dam height, the rate of drawdown during maximum withdrawal periods would be relatively low compared to other sites. Reduced rates of drawdown are also expected to lead to improved water quality.

Little is known about potential for reservoir leakage at this location through the abutments or floor of the reservoir. However, based on field observation of relatively shallow seepage from the slopes north of the reservoir, and given that the ponds and lakes hold water in the valley bottom areas, it appears that the bedrock has low permeability. Additionally, it is noted that significant areas of the valley sediments near Lower Crab Creek are currently blanketed with 10 feet or more of silt, sand, and clay alluvial sediments that are expected to form a natural barrier to vertical seepage in the base of the reservoir in these areas.

However, the CRBG consists of a large number of individual basalt flows that are separated by fractured and weathered zones and permeable sediment layers. Also, a thrust fault has been mapped along the base of the Saddle Mountains, leakage through fractured zones could occur under the south side of the reservoir.

Leakage through the interbedded basalts beneath the abutments is a possibility, and it is anticipated that grouting or cutoff to less-permeable rock, or a combination of methods, would be required. Overall, however, the relatively low hydraulic head at this dam site would reduce the potential for leakage that is associated with taller dams that produce greater hydraulic heads.

Based on the above considerations, it may be more likely that leakage rates through the near horizontally bedded surfaces exposed in the bottom of the reservoir may be less than leakage rates from interbed contacts that are exposed most predominantly at the perimeter side slopes of the reservoir. These conclusions have generally been confirmed at other reservoir sites located in similar geologic formations of the Columbia River Basalt Group. For preliminary purposes, it is estimated that seepage through the reservoir floor and side would be an average of 0.05 acre-feet/month/acre, or approximately 1,500 acre-feet/month for the reservoir at maximum pool level.

Additional information regarding leakage may be obtained by reviewing leakage history from other reservoirs in similar geologic conditions, and experience gained by Ecology’s Dam Safety Division. These other dams may include but not be limited to Pinto Dam, O’Sullivan Dam, Dry Falls Dam, and numerous other dams in the area. In addition, if accurate stream flow data through the Crab Creek valley can be obtained, then indication of loss due to seepage along the valley floor may be estimated.

Columbia River Diversion Facilities

Plate 4-1.6 shows an overall layout of facilities for the potential Crab Creek projects, and Plate 4-1.11 shows the conceptual layout and location of the proposed fish screen/diffuser structure. Although the actual pumps are envisioned to be located about 2 miles off the Columbia River at the end of a large gravity channel, fish protection facilities would be needed on the river itself to prevent delay, false attraction, or stranding of fish. Therefore, a combined fish screen/diffuser structure would be located in the Columbia River just beyond the mouth of this new supply channel.

The fish screen/diffuser structure is shown in Plates 4-1.11 and 4-1.12. The screen structure length would vary from 385 to 1,280 feet, depending on the operational scenario. Access roads connecting from each end of the structure to SR-243 or other local roads would be needed for access by heavy maintenance equipment with limited maneuverability and large turning radii. Water diverted from the river would travel through fish screens and accelerate into the narrower conveyance channel. Accelerating flows would be guided into the channel by means of sheetpile training walls.

During reservoir releases, water would travel back out from the channel and through this structure. Between the end of the channel and the fish screen/diffuser structure, the release water would be guided by training walls provided to improve the distribution of water across the full width of the screen/diffuser face.

In reservoir-release mode, the screen panels would be raised, because they are not typically designed for higher rates of flow or reverse flow. For the river discharge flow, the diffuser panels would be used. The panels would prevent fish from entering the system and would facilitate releasing water at low velocities in accordance with the criteria. Debris collecting in the channel would be removed by the trashrack and automated trashrake system prior to collecting on the diffuser panels.

It should be noted that required screen structure length (diversion screening mode) is nearly identical to the required width for discharge (diffuser mode), because the ratio of maximum flows in each mode (diversion versus discharge) is about the same as the ratio of maximum design velocities according to fisheries protection criteria.

The site would need to include an O&M building to house equipment, spare parts, and sensitive control equipment. For clear presentation of the other site features, the building is not shown in Plate 4-1.11.

Conveyance Facilities

Plates 4-1.6 and 4-1.11 also show the proposed layout and location of the conveyance facilities for the potential Crab Creek projects. It is assumed that a large flow capacity channel capable of carrying peak fill and release flows can be constructed from the Columbia River (Priest Rapids pool) to a point near the base of the downstream side of the dam. This channel would operate in both directions, to convey flow to the base of the new reservoir from the river (for pumping) and to carry water released through the turbines from the dam to the river. The channel would be constructed in a very deep cut (up to about 100 feet) to allow water to be fed to the pumps by gravity. Sections not cut into rock would need to be concrete-lined to resist scour and erosion. Rock excavated from the channel should be suitable for rockfill embankment construction in the dam. It is assumed that the channel would be cut at approximately 1:1 stepped sideslopes, with security fencing bordering each side for public safety.

Some consideration was given to using the existing Crab Creek channel for transporting water both directions between the Columbia River and the new reservoir. However, the need to enlarge and dredge the creek channel significantly and the associated environmental impacts led to the approach of instead constructing a new channel dedicated to this purpose.

One major bridge would need to be constructed over the channel, specifically for SR-243. It is expected that this bridge would be approximately 380 feet long as shown on Plate 4-1.11, assuming that 1:1 cuts would be achievable. The bridge could likely be designed to freespan the channel, but Plate 4-1.11 shows two piers.

It is assumed that no gates are needed in the channel or the diversion facilities. Diversion rates from the Columbia River would be controlled and measured by the pumping units at the base of the new dam. Discharge rates from the new reservoir back to the river would be controlled by the units in the generating mode or the bypass valves.

Combined Pump/Turbine Facilities

The units for pumping into the Crab Creek Reservoir were selected to provide the target flows to the reservoir for the three operating scenarios at the maximum pumping head. In addition they were selected to be reversible units that can generate power when the flow from the reservoir is released back to the river. This allows energy recovery with most of the release flows with a minimum of incremental cost over the cost of the necessary pumping facilities. The selection and sizing of the units followed the procedures outlined in Reclamation Monograph No. 39. The minimum number of units was established as three to provide flexibility and limited reduction in capacity upon loss of use of one unit. Three units were selected for OS1 and four for OS2 and OS3. The minimum pumping flow occurs at the maximum head; therefore, at pumping heads less than the maximum, the pumping capacity would be larger, up to about 2.3 times the target flow at the normal minimum head for the main selected unit rotational speed. Because the head variation for all three operating scenarios exceeds the normal range for reversible units of this type, variable speed units were selected. By lowering the speed, the units can operate safely at heads down to the lowest that would exist when the reservoir is at its minimum level and still have pumping capacity in excess of the target flows. At maximum generating head, the units can utilize almost all of the targeted release flows to produce power. At lower heads, the units cannot pass as much flow, and some of the releases would have to be released by the outlet valves when release demands are at their highest. The rated individual unit capacities for OS1, OS2, and OS3 are 23, 54, and 98 MW respectively, resulting in plant capacities for the three operating scenarios of 69, 216, and 392 MW. These are based on the maximum generating capacities at maximum head.

Plates 4-1.13 and 4-1.14 show the proposed pump/turbine facilities, outlet works, and fish screen/diffuser structure location, and Plate 4-1.15 provides an overall system profile from the Columbia River to the new reservoir site. It is assumed that the combined pump/turbine facility would be located on competent bedrock, near the base of the proposed dam, assuming that a channel would be built to connect to the Priest Rapids Reservoir.

It has been assumed that the bypass release into the forebay at Crab Creek would not be governed by fish or riparian protection issues, and therefore, the fixed cone valves can discharge directly into the intermediate body of water the forebay creates. The fixed cone valve house would be set above the maximum stage in the supply/return channel because the valves do not operate well under water.

Power Transmission Facilities

Power transmission facilities are required to provide energy to the large pump/turbines that lift water from the Columbia River into the Crab Creek Reservoir. These same facilities then deliver the energy that is generated when water is released through the reversible pump/turbine units back into the Columbia River. The maximum power requirements for the three reservoir hydraulic capacity operating scenarios being considered at Crab Creek are estimated in Table 4-1.2.

TABLE 4-1.2
Crab Creek Pumping and Generating Power Requirements

Operating Scenario	Pumping Power Input Max (megawatts; MW)	Generating Power Output Max (MW)
OS1	42	69
OS2	128	216
OS3	236	392

The proposed electric power substation and transmission facilities are shown on Plate 4-1.16. The new single-circuit 230 kilovolts (kV) transmission line is approximately 5.5 miles long and is proposed to connect the Project substation to the existing transmission grid at BPA's Vantage Substation. The transmission line begins at the powerhouse substation and heads almost due west until it reaches the existing BPA Vantage-Midway 230 kV transmission line, where it turns northerly and parallels the BPA line to the Vantage Substation. It is proposed that the new Crab Creek 230 kV line would terminate at Vantage in a new 230 kV breaker/bay.

The general requirements for selecting transmission voltage and for construction of power transmission facilities were described in Section 3.5.5, *General Requirements for Siting Power Transmission Facilities*. A typical single-circuit 230 kV lattice steel transmission structure is shown in Plate 4-1.17. This type of structure closely resembles the existing lattice steel transmission structures in BPA's Vantage-Midway 230 kV transmission line. When constructed, the new structures would be designed for placement adjacent to the BPA structures on a structure-to-structure basis for visual uniformity. The height of each structure would vary slightly by location as dictated by surrounding land features.

The ROW needed for the new transmission line and its structures is assumed to be 100 feet wide. However, this width may change depending upon the final conductor span lengths selected and adjacent property uses.

The following structures would be needed at each substation:

- Crab Creek Substation—A new 230 kV bay would be constructed near the Crab Creek powerhouse as indicated on Plate 4-1.16. New equipment within the substation would include a 230 kV-

13.8 kV power transformer, power circuit breakers, switches, buswork, potential transformers, substation dean-end towers, buried grounding system, and perimeter fencing.

- Vantage Substation—A new bay would be constructed within the existing fenced yard of the Vantage Substation. New equipment within the substation would include power circuit breakers, switches, buswork, potential transformers, and substation dean-end towers.

Relocation Once filled to capacity, the reservoir would cover the following transmission lines requiring their relocation to elevations above and away from the maximum fill elevation level. These transmission lines are shown on Plate 4-1.2A through 4-1.2E:

- Avista owned Wanapum-Walla 230 kV—relocate 37.1 miles (via overhead)
- BPA owned Midway-Potholes No. 1 230 kV relocate 2.1 miles via submarine cable
- BPA owned Midway-Potholes No. 2 230 kV relocate 2.1 miles via submarine cable
- BPA owned Midway-Rockyford 230 kV relocate 2.1 miles via submarine cable
- Grant County Public Utility District (GCPUD) owned Taunton-Warden 115 kV—relocate 6.5 miles (via overhead)

Two of the GCPUD 230 kV transmission lines are proposed to be relocated using submarine cable as they cross the reservoir in a north-south orientation, making this type of crossing substantially more economical than relocating the lines overhead.

4.1.3 Alternative Operational Scenarios

A detailed explanation of the development of all three operational scenarios is provided in *Operational Scenarios Development*, which is discussed in Section 3. Numerical monthly results for the three scenarios are presented in Appendix C, *Water Balance Reports*.

This sub-section describes the operational scenarios for the Crab Creek Dam and Reservoir site. The same approach, and the same set of three figures, are used for each operational scenario, as follows:

- Figure A: End-of-Month Off-Channel Reservoir Contents
- Figure B: Releases from Off-Channel Reservoir
- Figure C: Median Annual Agricultural, DCM&I, and Flow Augmentation Demand Distribution

Figures A and B within each operational scenario show the minimum, maximum, median, first, and third quartiles for end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record, respectively. Quartiles divide a data set into quarters. The value that divides the lower half into halves is called the first quartile (q1). The value that divides the upper half into halves is called the third quartile (q3). These statistics are shown to provide insight into the results of the 50-year period of record and present outliers that can skew the average. Figure C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for each operational scenario.

For each of the operational scenarios, water would be delivered to agricultural, DCM&I, and flow augmentation demands either via direct pumping from the Columbia River mainstem or from the new off-channel reservoir based on median values for the 50-year period of record used in the water balance model. This value represents the "yield" or benefit to water users as a result of implementing this alternative. This yield is the basis of the cost/benefit analysis in the Decision Support Model.

Operational Scenario 1

OS1 is a 1 million acre-feet, off-channel reservoir with a 2,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 6,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands. Figures 4-1.2A and 4-1.2B show the end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record for OS1.

Figure 4-1.2C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS1.

FIGURE 4-1.2A

End-of-Month Off-Channel Reservoir Contents: Crab Creek OS1

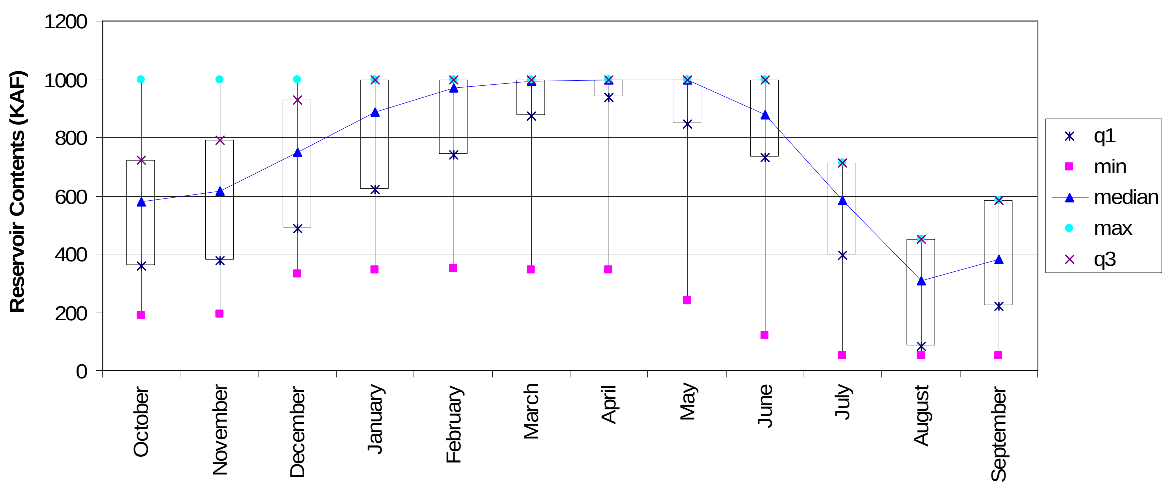


FIGURE 4-1.2B

Releases from Off-Channel Reservoir: Crab Creek OS1

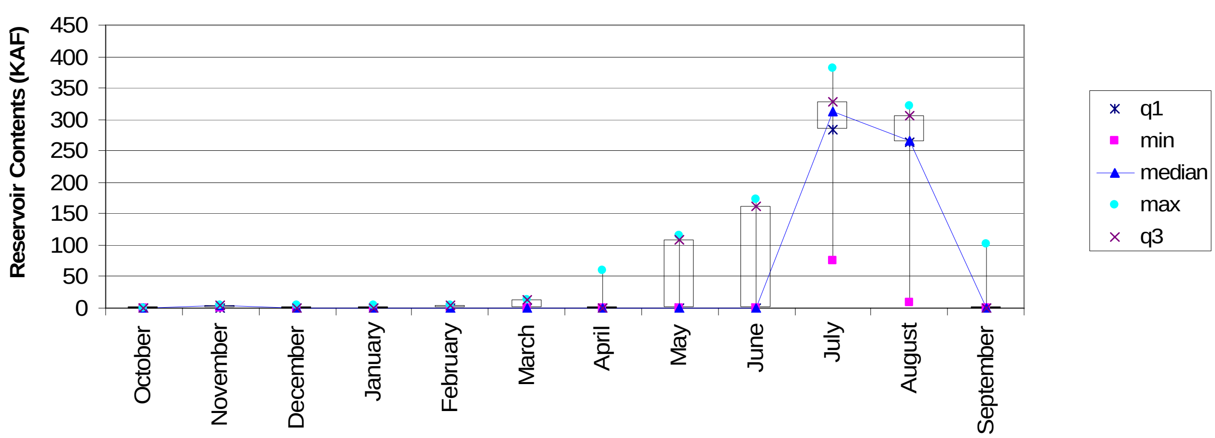
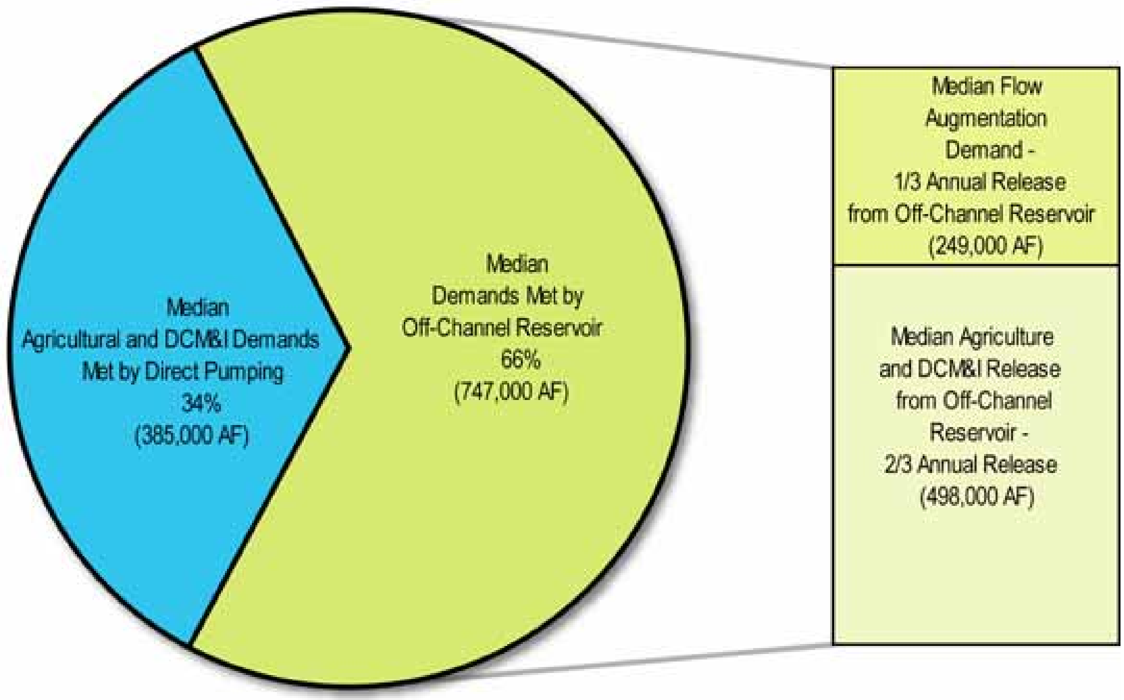


FIGURE 4-1.2C
Median Annual Demand Distribution: Crab Creek OS1



OS1 allows for a total of 1,132,000 acre-feet of water (385,000 acre-feet direct pumped and 747,000 acre-feet off-channel reservoir) to be delivered to agricultural, DCM&I, and flow augmentation demands; this yield is the basis of the cost/benefit analysis.

Operational Scenario 2

OS2 is a 2 million acre-feet off-channel reservoir with a 5,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 13,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands. Figures 4-1.3A and 4-1.3B show the end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record for OS2.

Figure 4-1.3C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS2.

FIGURE 4-1.3A

End-of-Month Off-Channel Reservoir Contents: Crab Creek OS2

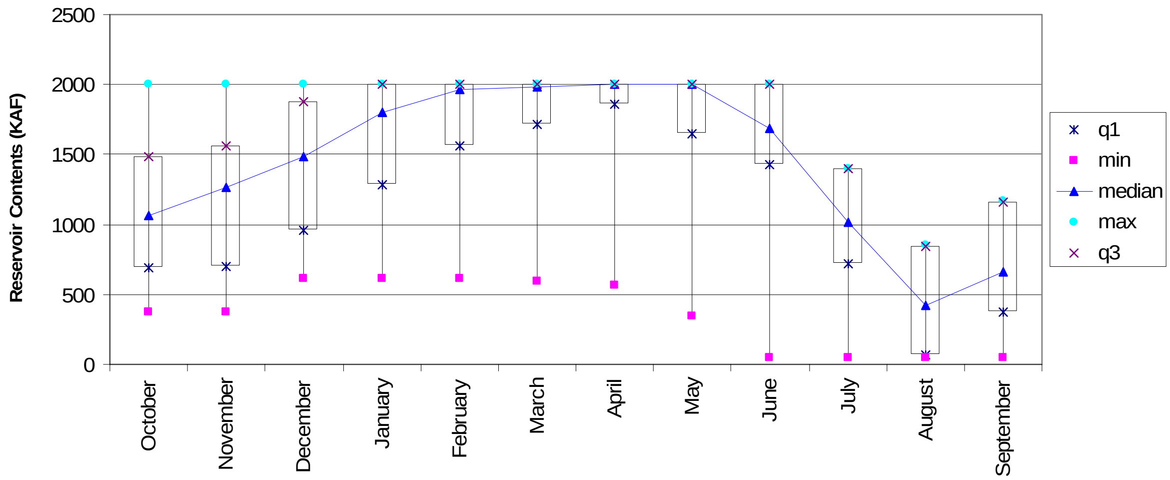


FIGURE 4-1.3B

Releases from Off-Channel Reservoir: Crab Creek OS2

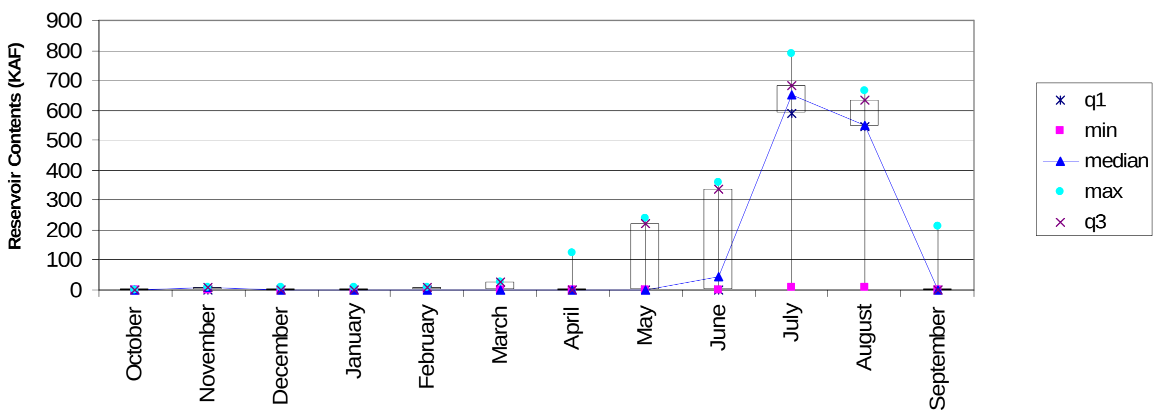
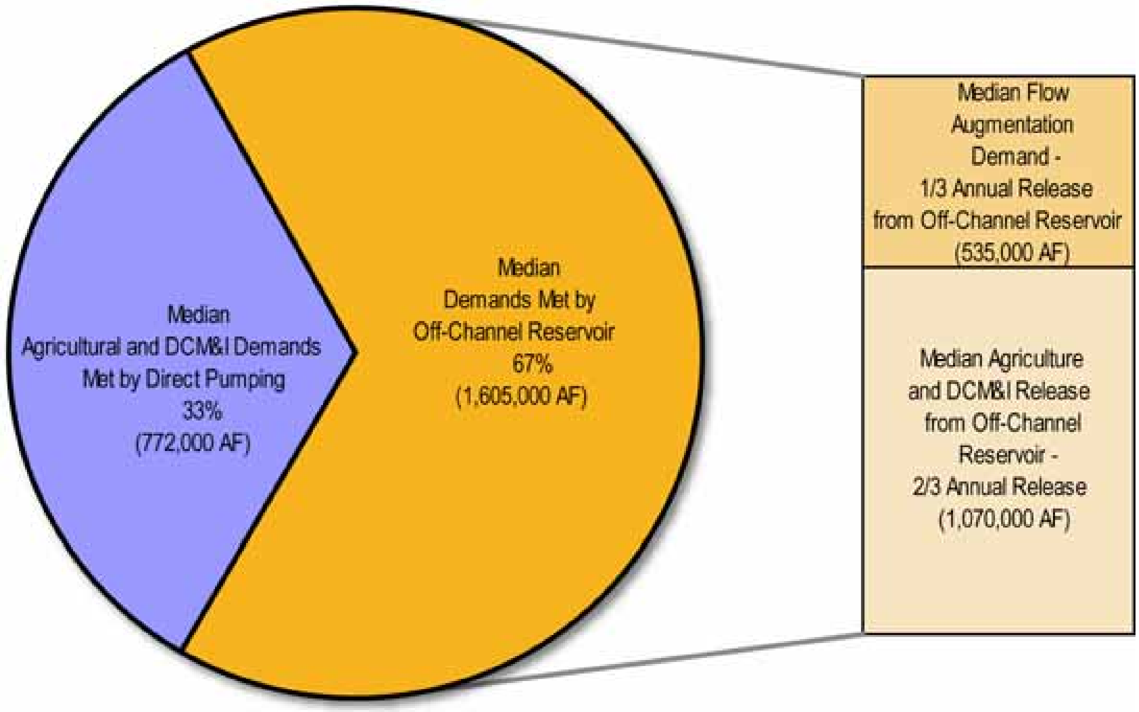


FIGURE 4-1.3C
Median Annual Demand Distribution: Crab Creek OS2



OS2 allows for 2,377,000 acre-feet of water (772,000 acre-feet direct pumped and 1,605,000 acre-feet off-channel reservoir) to be delivered to agricultural, DCM&I, and flow augmentation demands; this yield is the basis of the cost/benefit analysis.

Operational Scenario 3

OS3 is a 3 million acre-feet off-channel reservoir with an 8,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 18,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands.

Figures 4-1.4A and 4-1.4B show the end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record for OS3.

Figure 4-1.4C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS3.

FIGURE 4-1.4A

End-of-Month Off-Channel Reservoir Contents: Crab Creek OS3

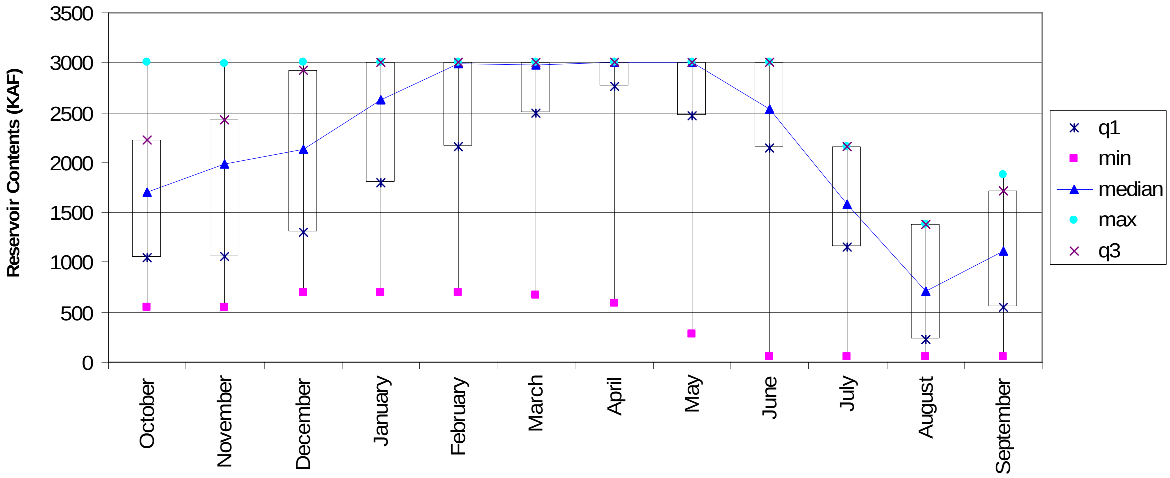


FIGURE 4-1.4B

Releases from Off-Channel Reservoir: Crab Creek OS3

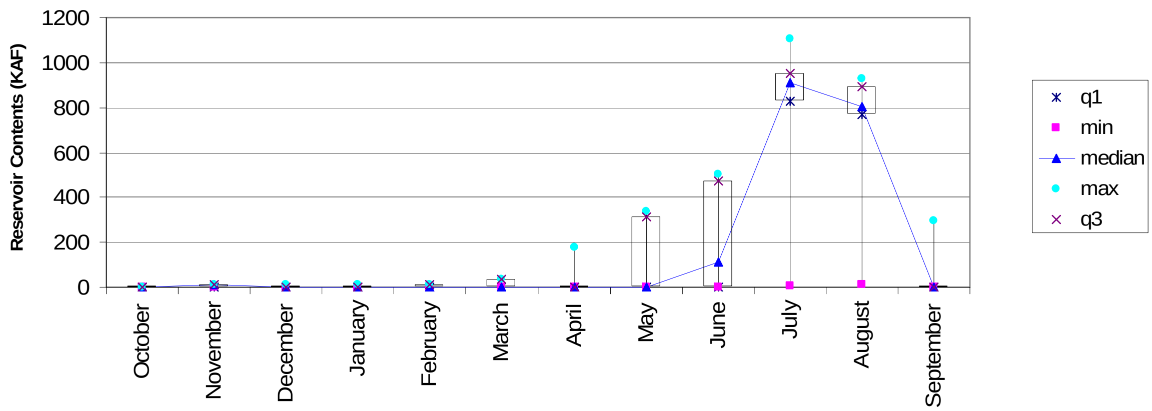
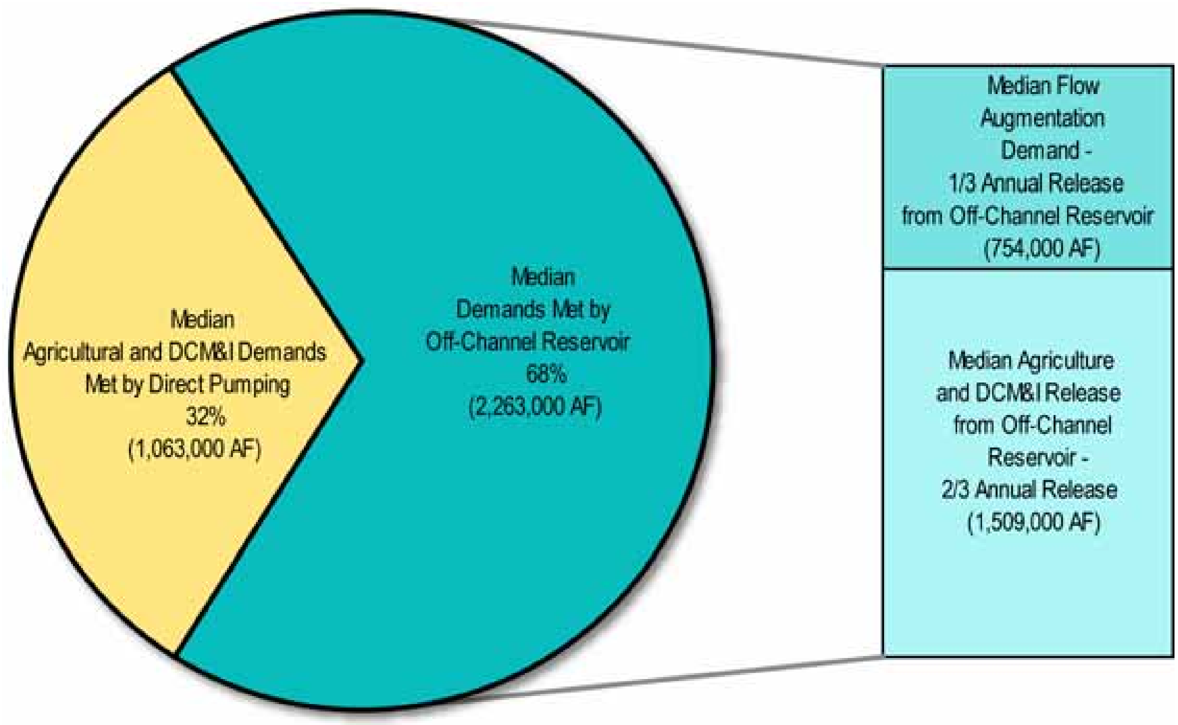


FIGURE 4-1.4C
Median Annual Demand Distribution: Crab Creek OS3



OS3 allows for 3,326,000 acre-feet (1,063,000 acre-feet direct pumped and 2,263,000 acre-feet off-channel reservoir) of water to be delivered to agricultural, DCM&I, and flow augmentation demands; this yield is the basis of the cost/benefit analysis.

4.1.4 Project Cost Estimates

Project cost estimates are shown in Table 4-1.3A, *Estimated Capital Costs for Crab Creek Site and Operational Scenarios*, 4-1.3B, *Estimated Annual Costs for Crab Creek Site and Operational Scenarios*, and 4-1.3C, *Estimated Net Present Values for Crab Creek Site and Operational Scenarios*.

4.1.5 Socioeconomic Resource Effects

Socioeconomic resource effects are summarized on Table 4-1.4.

Operational Scenario 1

Implementation of OS1 would result in the permanent conversion of 18,093 acres of uplands and wetlands to reservoir and associated facilities.

Land Ownership Existing land ownership GIS data within the Crab Creek alternatives is incomplete. However, the available data indicates that state-owned land is most prevalent (7,560 acres) with federally owned land at 1,920 acres. The data generally shows that this area is predominantly managed as state and federal wildlife refuges. Although the existing data set is incomplete, it is assumed that agricultural lands are privately owned, which would indicate that at least 4,989 acres are privately owned.

Table 4-1.3A

Estimated Capital Costs for Crab Creek Site and Operational Scenarios

Facility or Cost Component	Type of Unit	Unit Cost	Reference Project Cost for Scale Ups or Scale Downs	Crab Creek OS1 No. of Units or Scale Factor	Crab Creek OS1 Extended $	Crab Creek OS2 No. of Units or Scale Factor	Crab Creek OS2 Extended $	Crab Creek OS3 No. of Units or Scale Factor	Crab Creek OS3 Extended $
Columbia River Intake Facilities					$ 20,200,000		$ 40,200,000		$ 60,200,000
Fish Screen/Diffuser Structure			$ 9,750,000	2.07		4.12		6.17	
Penstocks and Tunnels									
Penstocks	LF x Dia Inch	$15		194,400	$ 2,900,000	324,000	$ 4,900,000	367,200	$ 5,500,000
Tunnels					$ -		$ -		$ -
Access Shafts									
Total Depth of Shaft(s)	LF	equation							
Diameter of Shaft	Dia Ft	equation							
Tunnels (Concrete Lined Sections)									
Approx Total Tunnel Length	LF	equation							
Diameter of Tunnel	Dia Ft	equation							
Add on for Sections of Steel Lining									
Approx Length Required	LF	equation							
Assumed Thickness of Steel	Lining t (in)	equation							
Allowance for Stiffeners	Percentage								
Channels (see Note 1)					$ 41,500,000		$ 50,400,000		$ 59,300,000
Rock excav. from land-based equip.	CY	$16.00		1,400,000		1,700,000		2,000,000	
Dry gravel excav. from land-based equip.	CY	$6.60		1,400,000		1,700,000		2,000,000	
Marine gravel excavation	CY	$23.50		420,000		510,000		600,000	
Pump/Turbine Facilities	LS	varies		56,900,000	$ 56,900,000	144,300,000	$ 144,300,000	229,900,000	$ 229,900,000
Dams					$ 148,000,000		$ 373,400,000		$ 568,200,000
Dam (rock fill portion with concrete face)	CY	$18.40		3,230,000		8,170,000		12,430,000	
Dam (RCC portion)	CY	$82.00		1,080,000		2,720,000		4,140,000	
Spillway	See Note 1								
Reservoir Inlet/Outlet Works (See Note 2)			$ 40,000,000	0.375	$ 15,000,000	0.50	$ 20,000,000	0.625	$ 25,000,000
Additional Structures					$ 4,000,000		$ 6,100,000		$ 6,600,000
Fixed Cone Valve Structure	LS	varies		1,600,000		2,600,000		2,900,000	
Bypass Pipes	LF x Dia Inch	$15		158,400		230,400		249,600	
Baffled Apron Drop	LS	varies							
Road Relocations	miles	$2,700,000		3.3	$ 8,900,000	9.5	$ 25,700,000	10	$ 27,000,000
Bridges	sq ft	$450		15,840	$ 7,100,000	17,040	$ 7,700,000	18,240	$ 8,200,000
Power Transmission Facilities					$ 137,500,000		$ 137,900,000		$ 138,500,000
Power Transmission Lines/Towers	mile	$540,000		250		250		250	
Substation Power Transformation	MVA	$11,000		30		65		115	
Substation Switchyards	Breakers, EA	$1,100,000		2		2		2	
Security/Safety Fencing	LF	$30		29,600	$ 900,000	29,600	$ 900,000	29,600	$ 900,000
Mobilization		5%			$ 22,000,000		$ 41,000,000		$ 56,000,000
Unlisted Items		15%			$ 66,000,000		$ 122,000,000		$ 169,000,000
Subtotal					$ 531,000,000		$ 975,000,000		$ 1,354,000,000
Contingency		30%			$ 159,000,000		$ 293,000,000		$ 406,000,000
Field Cost (or Construction Contract Cost)					$ 690,000,000		$ 1,268,000,000		$ 1,760,000,000
Noncontract Cost		35%			$ 242,000,000		$ 444,000,000		$ 616,000,000
Total Capital Cost					$ 932,000,000		$ 1,712,000,000		$ 2,376,000,000

Notes:

1. Spillway is incorporated into RCC section, and excavated sections of spillway below dam provide a source of borrow for the dam, so no additional costs have been included for this element of the project.
2. Captures costs for gates, concrete work, and miscellaneous civil works. Costs for tunnels under/around dam are included in Tunnels line items above.

Table 4-1.3B
Estimated Annual Costs for Crab Creek Site and Operational Scenarios

Facility or Cost Component	Type of Unit[1]	Unit Cost	Applicable Portion of Field Cost	Frequency of O&M or R&R (Years Between)	Crab Creek OS1 No. of Units or Capital Cost[2]	Crab Creek OS1 Extended $	Crab Creek OS2 No. of Units or Capital Cost[2]	Crab Creek OS2 Extended $	Crab Creek OS3 No. of Units or Capital Cost[2]	Crab Creek OS3 Extended $
Average Annual Power Consumption Costs						$ 3,090,000		$ 9,330,000		$ 16,380,000
Pump/Turbine Facility	kW-hr	$0.03			103,000,000		311,000,000		546,000,000	
Average Annual Power Generation Revenues						$ 1,520,000		$ 5,150,000		$ 9,020,000
Pump/Turbine Facility	kW-hr	$0.025			60,770,000		205,900,000		360,820,000	
Operation & Maintenance										
Fish Screen/Diffuser Structure										
Structural/Civil Works, Annual	% FC	0.1%	40%	1	$ 42,540,000	$20,000	$ 84,660,000	$30,000	$ 126,780,000	$50,000
Electrical/Mechanical Works, Annual	% FC	0.5%	60%	1	$ 42,540,000	$130,000	$ 84,660,000	$250,000	$ 126,780,000	$380,000
Replacement	% FC	20.0%		25	$ 42,540,000	$8,510,000	$ 84,660,000	$16,930,000	$ 126,780,000	$25,360,000
Pump/Turbine Facility										
Structural/Civil Works, Annual	% FC	0.1%	40%	1	$ 119,830,000	$50,000	$ 303,900,000	$120,000	$ 484,170,000	$190,000
Electrical/Mechanical Works, Annual	% FC	1.0%	60%	1	$ 119,830,000	$720,000	$ 303,900,000	$1,820,000	$ 484,170,000	$2,910,000
Replacement	% FC	20.0%		25	$ 119,830,000	$23,970,000	$ 303,900,000	$60,780,000	$ 484,170,000	$96,830,000
Tunnels/Tunnel Lining										
Repairs and Maintenance	% FC	0.5%		1	$ -	$0	$ -	$0	$ -	$0
Penstocks										
Structural/Civil Works, Annual	% FC	0.5%		1	$ 6,110,000	$30,000	$ 10,320,000	$50,000	$ 11,580,000	$60,000
Dams and Spillways										
Structural/Civil Works, Annual	% FC	0.1%	80%	1	$ 311,690,000	$250,000	$ 786,380,000	$630,000	$ 1,196,630,000	$960,000
Electrical/Mechanical Works, Annual	% FC	1.0%	20%	1	$ 311,690,000	$620,000	$ 786,380,000	$1,570,000	$ 1,196,630,000	$2,390,000
Additional Structures										
Structural/Civil Works, Annual	% FC	0.1%	40%	1	$ 8,420,000	$0	$ 12,850,000	$10,000	$ 13,900,000	$10,000
Electrical/Mechanical Works, Annual	% FC	0.5%	60%	1	$ 8,420,000	$30,000	$ 12,850,000	$40,000	$ 13,900,000	$40,000
Channels										
Dredging, Clearing, and Bank Repair	LS			1		$100,000		$100,000		$100,000
Valving/Gates on I/O Facilities										
Electrical/Mechanical Works, Annual	% FC	0.1%		1	$ 31,590,000	$30,000	$ 42,120,000	$40,000	$ 52,650,000	$50,000
Replacement	% FC	40.0%		25	$ 31,590,000	$12,640,000	$ 42,120,000	$16,850,000	$ 52,650,000	$21,060,000
Power Transmission Facilities										
Clearing and Repairs	% FC	0.5%		1	$ 289,580,000	$1,450,000	$ 290,420,000	$1,450,000	$ 291,680,000	$1,460,000
Fencing										
Repairs and Maintenance	% FC	10.0%		1	$ 1,900,000	$190,000	$ 1,900,000	$190,000	$ 1,900,000	$190,000

Notes:
1. Abbreviations: FC = Field Cost, kW-hr = kilowatt hours, I/O = inlet/outlet, O&M = Operation & Maintenance, R/R = Repair/Replacement.
2. Capital Costs are taken from Estimated Field Cost table for the appropriate site and are adjusted to include mobilization, unlisted items, contingency, and noncontract costs.

Table 4-1.3C
Estimated Net Present Values for Crab Creek Site and Operational Scenarios

Year	Operational Scenario 1						
	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (932,000,000)						
1 thru 24		$ (3,090,000)	$ 1,520,000	$ (3,620,000)			
25		$ (3,090,000)	$ 1,520,000	$ (3,620,000)	$ (45,120,000)		
26 thru 49		$ (3,090,000)	$ 1,520,000	$ (3,620,000)			
50		$ (3,090,000)	$ 1,520,000	$ (3,620,000)	$ (45,120,000)		
51 thru 74		$ (3,090,000)	$ 1,520,000	$ (3,620,000)			
75		$ (3,090,000)	$ 1,520,000	$ (3,620,000)	$ (45,120,000)		
76 thru 99		$ (3,090,000)	$ 1,520,000	$ (3,620,000)			
100		$ (3,090,000)	$ 1,520,000	$ (3,620,000)		$ -	
NPV	$ (932,000,000)	$ (62,800,000)	$ 30,900,000	$ (73,600,000)	$ (19,200,000)	$ -	$ (1,056,700,000)

Year	Operational Scenario 2						
	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (1,712,000,000)						
1 thru 24		$ (9,330,000)	$ 5,150,000	$ (6,300,000)			
25		$ (9,330,000)	$ 5,150,000	$ (6,300,000)	$ (94,560,000)		
26 thru 49		$ (9,330,000)	$ 5,150,000	$ (6,300,000)			
50		$ (9,330,000)	$ 5,150,000	$ (6,300,000)	$ (94,560,000)		
51 thru 74		$ (9,330,000)	$ 5,150,000	$ (6,300,000)			
75		$ (9,330,000)	$ 5,150,000	$ (6,300,000)	$ (94,560,000)		
76 thru 99		$ (9,330,000)	$ 5,150,000	$ (6,300,000)			
100		$ (9,330,000)	$ 5,150,000	$ (6,300,000)			
NPV	$ (1,712,000,000)	$ (189,800,000)	$ 104,700,000	$ (128,100,000)	$ (40,200,000)	$ -	$ (1,965,400,000)

Year	Operational Scenario 3						
	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (2,376,000,000)						
1 thru 24		$ (16,380,000)	$ 9,020,000	$ (8,790,000)			
25		$ (16,380,000)	$ 9,020,000	$ (8,790,000)	$ (143,250,000)		
26 thru 49		$ (16,380,000)	$ 9,020,000	$ (8,790,000)			
50		$ (16,380,000)	$ 9,020,000	$ (8,790,000)	$ (143,250,000)		
51 thru 74		$ (16,380,000)	$ 9,020,000	$ (8,790,000)			
75		$ (16,380,000)	$ 9,020,000	$ (8,790,000)	$ (143,250,000)		
76 thru 99		$ (16,380,000)	$ 9,020,000	$ (8,790,000)			
100		$ (16,380,000)	$ 9,020,000	$ (8,790,000)		$ -	
NPV	$ (2,376,000,000)	$ (333,100,000)	$ 183,400,000	$ (178,800,000)	$ (60,900,000)	$ -	$ (2,765,400,000)

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TABLE 4-1.4
Crab Creek Socioeconomic Impacts Summary

Factors	Criteria	Raw Data for Impacts				Impacts Normalized to Million Acre-Feet (MAF)			
		Units	OS1	OS2	OS3	Units	OS1	OS2	OS3
Land Use	Residential use	No. residences	18	18	18	No. residences/ MAF	18	9	6
	Irrigated Agriculture	Acres	4,989	6,768	8,650	Acres/MAF	4,989	3,384	2,883
Infrastructure	Highway (state, federal) impacts	Miles	2	3.5	5	Miles/MAF	2	2	2
	Local road impacts	Miles	33	43	48	Miles/MAF	33	22	16
	Railroad impacts	Miles	16	18	21	Miles/MAF	0	0	0
	Transmission line impacts	Miles	30	30	30	Miles/MAF	30	15	10

Land Use As shown on Table 4-1.4, residential and agricultural land uses would be impacted, with approximately 18 residences identified in the proposed footprint of the project and inundation of agricultural land.

Irrigated Agriculture The agricultural resources at Crab Creek consist mostly of low-value crops (pasture lands).

Infrastructure Major infrastructure that would be affected within the Crab Creek potential reservoir is listed below.

State and Federal Highways Under OS1, 2 miles of SR-26 would be inundated. This section could be abandoned, because an alternate route to Othello, Washington, via SR-262 could be used. Alternately, SR-26 could be re-routed to access Othello from the northwest. SR-26 would continue east within its existing route from Othello, Washington.

Local Roads A diffuse network of local roads is present within OS1. Approximately 33 miles of local roads (mainly Lower Crab Creek Road) would be inundated and abandoned.

Railroads An abandoned Chicago, Milwaukee, St. Paul, and Pacific Railroad track parallels Crab Creek; 16 miles of this track would be inundated by OS1. This railroad is currently abandoned, but is designated for recreational use. The rail line could also be re-activated by a railroad if an agreement were reached with the state.

Irrigation Facilities Although irrigation facilities are present on the private lands, data were not readily available to characterize the specific extent of irrigation facilities impacts. However, the nature of agricultural land use suggests that irrigation infrastructure is relatively moderate in the inundation area.

Transmission Lines Within the proposed footprint of OS1, 30 miles of transmission line follows Crab Creek and would need to be relocated.

Operational Scenario 2

Implementation of this alternative would result in the permanent conversion of 24,659 acres of uplands and wetlands to reservoir and associated facilities.

Land Ownership Land ownership data for the Crab Creek alternatives is lacking for several areas within the proposed footprint. However, the available data indicates that state-owned land is most prevalent (8,816 acres) with federally owned land at 2,791 acres. Although the existing data set is incomplete, it is assumed that agricultural lands are privately owned, which would indicate that at least 6,768 acres are privately owned.

Land Use The residential and agricultural land use effects are shows on Table 4-1.4. As described for OS1, approximately 18 residences have been identified within the proposed footprint of the project. The landscape surrounding and within the proposed project footprint is dominated by agricultural uses; 6,768 to acres of agriculture land would be inundated.

Irrigated Agriculture Same as described for OS1.

Infrastructure As described for OS1, roads, SR-26, and transmission lines would all be affected by OS2, but to a larger degree because of the larger footprint.

State and Federal Highways Although 3.5 miles of SR-26 would be inundated by OS2, an alternate route to Othello is available. As described for OS1, SR-26 could be either abandoned or re-routed.

Local Roads Approximately 43 miles of local roads (mainly Lower Crab Creek Road) would be inundated and abandoned under this alternative.

Railroads A railroad track would be more extensively inundated by OS2 than OS1 (approximately 18 miles).

Irrigation Facilities Same as described for OS1.

Transmission Lines Relocation of 30 miles of transmission line would be needed, as described for OS1.

Operational Scenario 3

Implementation of OS3 would result in the permanent conversion of 29,396 acres of uplands and wetlands to reservoir and associated facilities.

Land Ownership Land ownership data for the Crab Creek alternatives is lacking for several areas within the proposed footprint. However, the available data indicates that state-owned land is most prevalent (9,450 acres) with federally owned land at 3,701 acres. Although the existing data set is incomplete, it is assumed that agricultural lands are privately owned, which would indicate that at least 8,650 acres are privately owned.

Land Use The residential use is as described for OS1. Agricultural land use inundation is larger under OS3, at approximately 8,650 acres.

Irrigated Agriculture Same as described for OS1.

Infrastructure As described for OS1, roads, SR-26, and transmission lines would all be affected by OS2, but to a larger degree because of the larger footprint.

State and Federal Highways Although 5 miles of SR-26 would be inundated by OS2, an alternate route to Othello is available. As described for OS1, SR-26 could be either abandoned or re-routed.

Local Roads Approximately 48 miles of local roads (mainly Lower Crab Creek Road) would be inundated and abandoned.

Railroads Under OS3, 21 miles of this track would be inundated. The effects are the same as described for OS1.

Irrigation Facilities Same as described for OS1.

Transmission Lines Relocation of 30 miles of transmission line would be needed, as described for OS1.

4.1.6 Cultural Resource Effects

Impacts that can adversely affect heritage sites include anything that might significantly change the important features of a heritage site, and includes any kinds of ground-disturbing activities. Direct and indirect effects to cultural resources can result from human activities or natural events. Cultural sites are described in Section 4.1.1, *Site Characteristics*, under the heading, *Cultural Features and Developments*. As shown on Table 4-1.5, the probability that cultural resources are present is high. This ranking is based on the following assumptions:

- Lower Crab Creek is a primary drainage channel that empties into the Columbia River. Primary drainage channels generally contain larger numbers of pre-historic and historic sites or traditional cultural properties than do smaller drainage channels.
- A small amount of the study area has been inventoried for cultural resources. What cultural resource inventory information is available indicate that valley bottoms tend to have the greatest concentrations of archaeological sites and that site densities diminish as distance from the valley bottoms increases.

A description of known cultural resources is provided below for each Operational Scenario.

Operational Scenario 1

Direct Impacts This OS impacts 18,093 acres. Under this operational scenario, potential adverse effects to cultural resources may result from activities associated with the construction of the reservoir and dam, the inundation of water into the reservoir, sedimentation buildup from waters entering the reservoir and covering cultural resources, and the erosion of shorelines from seasonal water fluctuations.

Existing cultural resource information indicates there is a high potential for adverse effects to prehistoric and moderate potential to historic heritage sites within the footprint of the reservoir under OS1. The area with the highest potential for cultural resources is primarily along the valley floor of Lower Crab Creek. The cultural resources in most of the proposed project area have not been systematically inventoried. Current information indicates drainage bottoms and floodplains represent the greatest concentration of recorded archaeological sites, thus creating high-probability locations for areas that remain to be inventoried. This would be identified as part of the process of meeting the requirements of Section 106 of the NHPA and NEPA. In addition, there is a high potential for adverse effects to TCPs under this operational scenario. This would be addressed through consultation with the lead federal agency, associated Tribes, and SHPO.

TABLE 4-1.5
Crab Creek Cultural Impacts Summary

Factors	Criteria	Raw Data for Impacts				Impacts Normalized to Million Acre-Feet			
		Units	OS1	OS2	OS3	Units	OS1	OS2	OS3
National Register-eligible Resources and Traditional Cultural Properties	Potential resource impacts	Rating on 0-10 scale*	0	0	0	0-10 scale	0	0	0

* 0 = major conflict; 10 = none

When effects are analyzed as part of project planning, there may be some opportunities to redesign some components of the project to avoid some sites or adverse effects, or if necessary, mitigate them. Cultural resource sites would continue to be located and recorded in response to the proposed operational scenario. Mitigation and a management plan would be necessary to protect cultural resources from loss of integrity and physical damage.

Indirect Impacts Indirect impacts may include increased damage to prehistoric and historic sites because of increased public use or activities in the reservoir area of OS1. Under this scenario, there would be increased recreational activities and a seasonal fluctuation in the water levels along the shoreline. Both recreation and fluctuation of water levels may result in adverse effects to cultural resources.

Operational Scenario 2

Direct Impacts This OS impacts 24,659 acres. Direct impacts to cultural resources under OS2 would be the same as described for OS1.

Indirect Impacts Indirect impacts to cultural resources under OS2 would be the same as described for OS1.

Operational Scenario 3

Direct Impacts This OS impacts 29,396 acres. Direct impacts to cultural resources under OS3 would be the same as described for OS1.

Indirect Impacts Indirect impacts to cultural resources under OS3 would be the same as described for OS1.

Crab Creek Dam and Appurtenant Structures

Direct and indirect impacts to cultural resources associated with the Crab Creek Dam and appurtenant structures would be the same as described for OS1.

4.1.7 Environmental Resource Effects

Impacts to environmental resources for each operational scenario are summarized on Table 4-1.6. The environmental impacts discussion includes impacts of the reservoir, as well as the dam and all appurtenant structures.

Operational Scenario 1

Approximately 18,093 acres would be permanently disturbed by OS1.

Special Status Species For most special status species, impacts are measured by acreage. For aquatic species, impacts are measured in terms of miles of stream affected. Table 4-1.6 lists the acres or miles of stream of special status species habitat inundated or otherwise permanently disturbed through construction of OS1. In the table, habitat for each species is accumulated, which may mean that some acres for terrestrial species and miles for aquatic species are counted more than once. This approach accounts for the relative importance of a site if a variety of habitats and species are present. Four state threatened, state endangered, or state sensitive plant species would be impacted, for a total of 945 cumulative acres of habitat. Five state terrestrial priority species are found in the impact area, for a cumulative total of 5,453 acres.

Two anadromous species (summer steelhead, fall Chinook salmon) would be impacted for a total of 56 miles (28 miles each). This includes inundation of 28 miles of designated critical habitat for the Upper Columbia River Steelhead DPS, which is FT and an SC species of concern. Fall Chinook salmon are not federally or state listed for protection. Up to 112 miles of habitat for four aquatic state priority species would be impacted (28 miles each for rainbow trout, largemouth bass, smallmouth bass, and walleye; Table 4-1.6). This estimate is probably high because of the likely intermittent distribution of the basses and walleye in Lower Crab Creek. Approximately 6 miles of summer steelhead and fall Chinook habitat (3 miles each) downstream of the proposed Crab Creek Dam site could potentially be affected, either beneficially or adversely, by the project depending on future creek flows and effects on habitat (volume, water velocity and depth, temperature) compared to existing conditions (Table 4-1.6).

Special Status Habitats Four state priority habitats would be inundated at this site (Table 4-1.6). This includes 4,551 acres of wetlands, 416 acres of riparian habitat, 88 acres of cliff habitat, and 1,275 acres of shrub-steppe habitat. As noted above, 28 miles of designated critical habitat for Upper Columbia River steelhead would be inundated. The potential reservoir would inundate a portion of Nunnally Lake and completely inundate 28 miles of Crab Creek, Merry and Lenice Lakes, and multiple unnamed ponds. Approximately 227 acres of open water and riparian area are associated with Crab Creek and are located within the proposed footprint for OS1.

Conservation/Preservation Areas
Approximately 4,899 acres of the Columbia National Wildlife Refuge would be permanently impacted by OS1. Another 6,103 acres of the Crab Creek State Wildlife Refuge would be affected.

Operational Scenario 2
Under OS2, 24,659 acres would be permanently disturbed.

Special Status Species Table 4-1.6 lists the acres or miles of stream of special status species habitat inundated or otherwise permanently disturbed through construction of OS2. Four state-listed plant species would be impacted, for a total of 997 cumulative acres of habitat. Five state terrestrial priority species are found in the impact area, for a cumulative total of 5,137 acres.

Summer steelhead (FT, SC) and fall Chinook salmon would be impacted for a total of 64 miles (32 miles each). Thirty-two miles of designated summer steelhead critical habitat would be inundated. Up to a total of 128 miles of habitat for the four aquatic state priority species listed above (32 miles each) would be inundated. This estimate is probably high for the same reasons as given for OS1. Potential effects on anadromous habitat and species in Lower Crab Creek downstream of the proposed dam site may be beneficial or adverse, depending on the future flow regime in this creek reach (Table 4-1.6).

Special Status Habitats Four state priority habitats would be inundated at this site (Table 4-1.6). This includes 5,102 acres of wetlands, 418 acres of riparian habitat, 202 acres of cliff habitat, and 1,323 acres of shrub-steppe habitat. The potential reservoir would inundate 32 miles of Crab Creek, Merry and Lenice Lakes and multiple unnamed ponds, and a portion of the existing Nunnally Lake. Approximately 235 acres of open water and riparian area are associated with Crab Creek and are located within the proposed footprint for OS2. Thirty-two miles of designated critical habitat for Upper Columbia River steelhead would be inundated.

Conservation/Preservation Areas Approximately 8,941 acres of the Columbia National Wildlife Refuge would be permanently impacted with OS2. Another 6,830 acres of the Crab Creek State Wildlife Refuge would also be inundated.

Operational Scenario 3

Under OS3, 29,396 acres would be permanently disturbed.

Special Status Species Table 4-1.6 lists the acres or miles of stream of special status species habitat inundated or otherwise permanently impacted through construction of OS3. Five state-listed plant species would be impacted, for a total of 1,041 cumulative acres of habitat. Five state terrestrial priority species are found in the impact area, for a cumulative total of 5,547 acres.

Summer steelhead (FT, SC) and fall Chinook salmon would be impacted for a total of 72 miles (36 miles each). Thirty-six miles of designated summer steelhead critical habitat would be inundated. Up to a total of 144 miles of habitat for the four aquatic state priority species listed above (36 miles each) would be inundated. This estimate is probably high for the same reasons as given for OS1. Potential effects on anadromous habitat and species (3 miles each for summer steelhead and fall Chinook salmon) in Lower Crab Creek downstream of the proposed dam site may be beneficial or adverse, depending on the future flow regime in this creek reach.

Special Status Habitats Four state priority habitats would be inundated at this site (Table 4-1.6). This includes 5,550 acres of wetlands, 518 acres of riparian habitat, 306 acres of cliff habitat, and 1,335 acres of shrub-steppe habitat. The potential reservoir would inundate a portion of the existing Nunnally Lake and completely inundate 36 miles of Crab Creek, Merry and Lenice Lakes, and multiple unnamed ponds. Approximately 355 acres of open water and riparian area are associated with Crab Creek and are located within the proposed footprint for OS3. Thirty-six miles of designated critical habitat for Upper Columbia River steelhead would be inundated.

Conservation/Preservation Areas Approximately 11,918 acres of the Columbia National Wildlife Refuge would be permanently impacted with OS3. Another 7,311 acres of the Crab Creek State Wildlife Refuge would be affected.

4.1.8 Recommended Further Investigations Specific to this Site

Recommendations for further investigations specific to Crab Creek include the following:

- Refine the anticipated irrigation demand analysis for development of the second half of the Columbia River Basin project. Evaluate whether a water exchange with the Yakima Basin would occur.

TABLE 4-1.6
Crab Creek Environmental Impacts Summary

		Raw Data for Impacts				Impacts Normalized to Million Acre-Feet			
Factors	**Criteria**	**Units**	**OS1**	**OS2**	**OS3**	**Units**	**OS1**	**OS2**	**OS3**
Special Status Species	Anadromous Fish—Habitat Inundated	Miles	56	64	72	Miles/MAF	56	32	24
	Anadromous Fish—Downstream Habitat Affected	Miles	6	6	6	Miles/MAF	6	3	2
	Federal aquatic T & E species—Habitat Inundated	Miles	28	32	36	Miles/MAF	28	16	12
	Federal aquatic T & E species—Downstream Habitat Affected	Miles	3	3	3	Miles/MAF	3	2	1
	State aquatic Sensitive species—Habitat Inundated	Miles	28	32	36	Miles/MAF	28	16	12
	State aquatic Sensitive species—Downstream Habitat Affected	Miles	3	3	3	Miles/MAF	3	2	1
	State aquatic Priority Species	Miles	112	128	144	Miles/MAF	112	64	48
	Federal terrestrial T & E species impacts	Acres	0	0	0	Acres/MAF	0	0	0
	State terrestrial T & E and Sensitive species impacts	Acres	945	997	1,043	Acres/MAF	945	499	348
	State Terrestrial Priority Species	Acres	4,453	5,136	5,547	Acres/MAF	4,453	2,568	1,849
Special Status Habitat or Conservation/ Preservation Designation	Wetland habitat impacts	Acres	4,414	4,965	5,413	Acres/MAF	4,414	2,483	1,804
	Riparian habitat impacts	Acres	416	418	418	Acres/MAF	416	209	139
	Sand Dunes habitat impacts	Acres	119	119	119	Acres/MAF	119	60	40
	Cliffs/Bluffs habitat impacts	Acres	88	202	306	Acres/MAF	88	101	102
	Shrub-steppe habitat impacts	Acres	1,275	1,323	1,335	Acres/MAF	1,275	662	445
	Candidate Wild & Scenic rivers	Miles	0	0	0	Miles/MAF	0	0	0
	Wilderness Study Areas	Acres	0	0	0	Acres/MAF	0	0	0
	National wildlife refuges impacts	Acres	4,899	8,941	11,916	Acres/MAF	4,899	4,471	3,972
	State wildlife refuges impacts	Acres	6,103	6,930	7,311	Acres/MAF	6,103	3,465	2,437
	Other National or State conservation/preservation designation	Acres	0	0	0	Acres/MAF	0	0	0

- Feasibility of a potential gravity channel feed from Wanapum pool (above Wanapum Dam) instead of Priest Rapids pool. This would reduce pumping head approximately 80 feet, but would also reduce flow and power generation through the Wanapum Dam turbines.
- Feasibility of adding or modifying facilities along the Crab Creek system, from the Grand Coulee pumps into Banks Lake to the Columbia River at the Priest Rapids pool. This alternative could provide a more favorable balance of power consumption and power generation, while providing water supply to off-channel storage.
- Conduct additional geotechnical evaluations to determine facility structural needs, as follows:
  - Borings to determine the thickness and characteristic of alluvial sediments and eolian sand dunes under the proposed dam near Crab Creek
  - Borings to determine the thickness of the talus slopes at the south (left) abutment
  - Test pits to verify the depth and character of the basalt rock in shallow areas throughout the footprint area of the dam
  - Soil borings and rock cores along the proposed conveyance channel alignment. The excavation for the channel would be up to 100 feet deep and the proposed alignment would be underlain by shallow basalt rock, sandy and gravelly flood deposits, and gravelly alluvial deposits.
  - River bathymetry to facilitate more precise placement of the fish screen
  - Soil borings conducted from a barge to evaluate the subsurface conditions at the proposed fish screen to determine the thickness of alluvial deposits near the eastern side of the Columbia River
- Conduct additional geologic and seismotectonic mapping and investigation to establish seismic load parameters, as follows:
  - Core samples and rock samples to evaluate the durability of the bedrock and the suitability of the rock for aggregate for the RCC portion of the dam
  - Soil borings and rock cores in the vicinity of the bridge that would be constructed over the proposed conveyance channel alignment. This bridge is anticipated to be approximately 300 feet long and would likely be a single-span bridge.
- Conduct detailed geologic mapping of sites, including discontinuity mapping in rock outcrops, to accomplish the following research objectives:
  - Soil borings and rock cores to determine the thickness and characteristics of alluvial sediments, and shallow rock characteristics under the proposed dams and appurtenant facilities
  - Additional borings, test pits, and/or geophysical lines along the proposed axes of the dams to determine the basalt rock profile perpendicular to the existing streams

  - Down-hole hydraulic pressure testing to evaluate the permeability of the basalt bedrock
  - Rock quarry investigations to evaluate the volume and durability of the bedrock, and the suitability of the borrow area rock sources for dam embankment material. This investigation will consist of core samples, rock samples, and rock durability testing.
  - Borings to verify the depth and characteristics of soils and bedrock along proposed conveyance routes, outlet works, intake towers, fish screens, and pumping/powerhouse locations
- Conduct additional geotechnical evaluations to determine presence of groundwater.
  - Borings and test pits should carefully note the time of year and water level. Observation wells should be installed in borings that could be expected to penetrate below the water table.

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4.2 Sand Hollow Dam and Reservoir Site

The Sand Hollow Dam and Reservoir site is a potential new off-channel storage alternative. If constructed, the reservoir would be approximately 2.5 to 3 miles wide along most of it length and would extend to the east of the dam for a distance of about 8 miles. The surface area of the reservoir would be 12,500 acres. This site is only evaluated for one operational scenario, at 1 million acre-feet, because of topographic limitations. The project would include a rock fill dam, fish screen/diffuser structure, pump/power plant, penstocks, a tunnel, an energy dissipation structure, and power transmission facilities. The majority of the drainage basin ranges in elevation from about 1000 to 1500 feet.

The fish screen/diffuser structure would be constructed on the east bank of the Columbia River in bedrock that is covered with a veneer of talus, alluvium, or sand dunes. The pumping and power generation facilities would also be constructed on the east side of the Columbia River. Steep basalt cliffs and slopes exist in most of the area near the proposed site. An inflow/ outflow conveyance tunnel, about 25 feet in diameter, would extend from the Wanapum Reservoir east approximately 2.5 miles to the proposed Sand Hollow Reservoir. All activities would be located south (downriver) from the Vantage Bridge on the river.

4.2.1 Site Characteristics

Location

The Sand Hollow Dam and Reservoir site is a potential new off-channel reservoir near SR-26 east of the Columbia River. The general area showing the location of the Sand Hollow site is shown in Figure 1-7.1. The Sand Hollow drainage basin is relatively small at 50 square miles and is only slightly larger than the proposed reservoir surface itself. The drainage area for Sand Hollow is shown in Plate 4-2.1. All plates are presented in Volume II.

The drainage basin is bounded by the dam and the approximate alignment of SR-26 on the west and south sides, respectively, by a large saddle dam on the east end, and by the adjacent Frenchman Hills ridge that lies slightly north of the edge of the proposed reservoir.

The proposed dam site is located approximately 2.5 miles east of the Columbia River near the intersection of SR-243 and SR-26. The dam would cross SR-26 near S-SW Road. The reservoir would be approximately 2.5 to 3 miles wide along much of its length and would extend to the east of the dam a distance of approximately 8 miles to the saddle dam on the east end of the reservoir. The configuration of the proposed reservoir is shown in Plates 4-2.2A and 4-2.2B.

Topography

The drainage basin is generally characterized by gently undulating plains and upland plateaus. Elevations within the drainage basin generally vary from approximately 850 feet near the dam site to a high of approximately elevation 1700 feet along the Frenchman Hills ridge to the north. The majority of the drainage basin varies from approximately elevation 1000 to 1500 feet.

The topography of the drainage basin is controlled by a thick sequence of basalt flows. These basalt flows are well-exposed along the east side of the Columbia River, where they were scoured by ancient floodwater from the glacial Lake

Missoula. The topography at the dam site forms a relatively broad west-trending valley approximately 2 miles wide at the dam axis. The axis of the proposed dam is characterized by gentle slopes between 5 and 12 percent, with small plateau benches and slightly steeper slopes with basalt apparently within a few feet of the ground surface in nearly all areas.

Shallow bedrock formations form ridges at both abutments. The maximum elevation of the ridges where the dam would tie to is approximately elevation 1206 feet at both abutments. A small wasteway flows in the valley bottom with sand and gravel exposed in the stream bed. The area directly adjacent to both sides of the stream, for a width of 50 to 150 feet, is characterized by wetland conditions and seepage.

Socioeconomic Conditions

The dam and reservoir site at Sand Hollow is predominantly irrigated crop farmlands with a diffuse rural population. The site is adjacent to SR-26, and most of the area is accessed by local roads. A transmission line crosses the eastern end of the potential site. Sand Hollow contains several riparian corridors; however, relatively few areas of open water and wetlands have been identified within the project area. Section 3.5.1, *Socioeconomic Factors and Criteria*, lists the land ownership, uses, and infrastructure factors that are considered in the socioeconomic characterization and effects analysis.

Land Ownership The distribution of private, state, and federal land ownership within Sand Hollow is described below.

Private Ownership Within the Sand Hollow drainage, private land ownership is assumed to be predominant as a majority of the acreage is under agricultural management.

State Ownership Based on available data, state land ownership is minimal within the Sand Hollow watershed.

Federal Ownership Based on available data, the Sand Hollow drainage contains no federally held land.

Land Use All criteria land uses are present within the Sand Hollow site, except wetlands/marsh and conifer forest. The general characteristics of these land uses were described in the *Socioeconomic Conditions* section for Crab Creek.

Residential Use Within the Sand Hollow proposed project area, residential use is diffuse and rural. The proposed footprint of the project contains 32 residences.

Agriculture Agriculture is the primary source of employment in Grant County and within and around the Sand Hollow site. The predominant types of agriculture are irrigated cropland, pasture, and “other use” (USDA, 2007). Agriculture land use occupies nearly all of the 13,179 acres proposed for the Sand Hollow Reservoir. Agricultural values are rated as either high-value or moderate-value crops based only on land use maps.

Infrastructure The most prevalent structures in the area are farm buildings and diffuse residential homes associated with the agriculture community. A small portion of SR-26 is present within the proposed reservoir footprint, and 36 miles of local roadway are located within the proposed footprint. No railroad tracks are present within the Sand Hollow site. Extensive irrigation facilities are present in this high-value agricultural area. Approximately 3 miles of transmission line crosses the Sand Hollow site and would need to be relocated.

Cultural Features and Developments

The Sand Hollow Dam and Reservoir area includes known sites, as well as potential sites that could be located in the future as more of the Sand Hollow wasteway area is surveyed for cultural resources. The regulatory framework and ranking system (0 to 10) for cultural resource evaluation is presented in Section 3.5.2, *Cultural Resources.* Much of this area is privately owned farmland. Seven cultural resource survey reports are available and indicate that approximately 2,050 acres (16 percent) of the reservoir footprint has been investigated. Currently, one historic and three prehistoric archaeological sites have been documented within the reservoir footprint. Surveys and site documentations completed to date have been performed to evaluate the effect of other projects on heritage resources. The cultural resources in most of the Sand Hollow wasteway have not been systematically inventoried. Although information is limited, current information indicates drainage bottoms and floodplains represent the greatest concentration of recorded archaeological sites, thus creating a medium potential for areas that remain to be inventoried.

Seventy five percent (three) of the previously recorded sites date to the era of American Indian settlement that pre-dates European settlement (circa 10,000 B.C. to the mid-1800s). Prehistoric site types consist of open temporary camps containing lithic materials. Most of these sites are areas where people worked tool stone, or carried out other activities as part of their cycle of life. These sites probably represent activities by people who were otherwise based in nearby valleys. It is likely that many more American Indian sites exist in the Sand Hollow wasteway area. The assumption is that because of the distance from the Columbia River and that Sand Hollow wasteway is not a large primary drainage channel, there is a medium potential for prehistoric sites primarily along the drainage bottoms and low-lying deflated areas or dune “blow outs” with exposed sediments. Sites would diminish in numbers as the distance from the valley floor increases.

Information is not available related to TCP. Because of the distance from the Columbia River, and since Sand Hollow wasteway is not a primary drainage channel, the assumption is this area has a low potential for TCPs associated with the Sand Hollow wasteway option.

Twenty-five percent (one) of the sites documented in the Sand Hollow wasteway area (four sites) date from the historic European-American settlement era (after the mid-1800s), and include sites primarily related to ranching and farming from the twentieth century. Additional historic sites such as farms, homesteads, or other standing buildings are likely to be on private lands. The sites that may be present include debris scatters and/or rock or earthen structures associated with ranching activities or mineral prospecting likely dating from the 1880s to the present. The assumption is that because of the distance from the Columbia River and that there is developed farmland in the area, there is low potential for the Sand Hollow alternative to contain historic sites. Additional European-American sites would be documented in the future as more of the area is inventoried for cultural resources.

No NRHPs or Washington Heritage Register sites are currently recorded in the reservoir footprint of the Sand Hollow alternative. This can be somewhat misleading, as described previously for the Crab Creek site. Therefore, although no sites are currently listed on the NRHP or Washington Heritage Register, the assumption is that there may be sites that would be eligible once a full inventory is completed, sites recorded, and DOEs completed. A medium potential exists for eligible sites for the Sand Hollow operational scenario.

In addition, under the Sand Hollow alternative, the evaluation of lands that would be converted to agricultural production as the result of additional water storage would be conducted under a future phase of project implementation. Future development would be subject to separate environmental analysis.

The area where the tunnel entrance shaft and pump turbine structure are proposed for the east side of the Columbia River has a high potential to contain cultural resources. No information is available on TCPs, and the assumption is that there is a medium potential for TCPs in the area.

Within the footprint of the pump structure and tunnel entrance shaft, there is a high potential for adverse effects to heritage sites near the east side of the Columbia River. When effects are analyzed as part of project planning, there may be opportunities to redesign some components of the project to avoid some sites or those adverse effects, or if necessary, mitigate them.

Environmental Conditions

Few environmental resources are present at the potential Sand Hollow Reservoir site, according to data readily available in the literature. This site has not been surveyed with the intensity of the Crab Creek site. In general, the area falls within the shrub-steppe vegetation zone dominated by sagebrush and rabbitbrush with upland bunch grasses. There are scattered pockets of emergent wetland vegetation throughout the site, as well as irrigated fields. Section 3.5.3, *Environmental Factors and Criteria*, lists the habitats, species, and special areas that are considered in the environmental analysis.

Special Status Species This factor includes criteria for species that are unique to this habitat or are listed as imperiled by federal or state agencies.

Anadromous Species No anadromous species occupy the proposed Sand Hollow site (Ecology, 2002). However, the Upper Columbia River Steelhead DPS and the Upper Columbia River Fall Chinook Salmon DPS occur in the lower one mile of Sand Hollow wasteway (KWA Ecological Services, Inc., 2004). Adult steelhead have been caught by anglers in this reach, and spawning fall Chinook salmon have been observed here since 1987, with 33 fall Chinook redds documented by Reclamation in 1998 (WDFW, 1999). A culvert under SR-26, approximately 1 mile upstream of the creek mouth, is a barrier to further upstream fish movement (Ecology, 2002). The proposed Sand Hollow Dam site is approximately 1.2 miles upstream of the SR-26 culvert.

Aquatic FT Species No aquatic FT species are present at this proposed reservoir site. The Upper Columbia River Steelhead DPS (FT) occurs in the lower 1 mile of Sand Hollow wasteway (WDFW, 2004).

Aquatic SC Species No aquatic SC species occur at this proposed reservoir site. The Upper Columbia River Steelhead DPS (SC) occurs in the lower 1 mile of Sand Hollow wasteway (WDFW, 2004).

Terrestrial FT or FE Species No terrestrial FT or FE species or habitat are located at this site. However, habitat for gray cryptantha (FSOC) was once found throughout 1,296 acres of this area. However, this historical habitat has been converted to other plant community types.

Terrestrial ST or SE Species Although no terrestrial ST or SS species currently occupy habitat at this site, there were four terrestrial ST or SE species or habitat for those species was once found throughout 6,216 cumulative acres of this area. However, this historical habitat has been converted to other plant community types.

Palouse milk vetch (*Astragalus arrectus*) has a state rank of S2 and is listed as a ST species. Habitat was historically found over 1,520 acres of this site. Coyote tobacco (*Nicotiana attenuata)* is a SS species, with a state rank of S2. Habitat was historically found over 1,252 acres of this site. Gray cryptantha historically covered 1,520 acres at this site.

State Priority Species (SPS) No terrestrial or aquatic SPS are located at the proposed reservoir site (WDFW, 2004).

Special Status Habitats This factor includes criteria for habitats that have a high priority for either management or conservation.

Wetland Wetlands are the only special status habitat present at this proposed site. Wetland priority habitat is described in *Section 4.2.1, Environmental Conditions*.

Riparian Open water resources are not prevalent in the Sand Hollow drainage, and few open water resources are present within the area that would be affected by the Sand Hollow alternatives. The proposed reservoir would inundate about 9 miles of Sand Hollow wasteway and several small unnamed tributaries.

Conservation/Preservation Areas No federal or state conservation or preservation areas are found at Sand Hollow.

Geology

The general geologic setting of the Columbia River Basin is described in Section 3.5.4.

Local Geologic Setting The proposed reservoir area would be underlain by loess, Ringold Formation, and basalt flows of the Columbia River Basalt group. The floor of the proposed reservoir would be underlain primarily with loess and Ringold Formation sediments. There are thin alluvial deposits in Sand Hollow. Floodwaters from the Missoula Floods scoured much of the land surface in the area, removing overburden soils in many areas, and leaving a thin mantle of recessional alluvial soil consisting of sand, gravel, and silt overlying basalt bedrock in many areas.

The site is located within the Yakima Fold Belt subprovince. The Sand Hollow site is on the southern flank of the Frenchman Hills Structure, which is an east-west trending anticlinal warp. The basalt flows that underlie the Frenchman Hills structure dip generally to the south at a low angle (less than 5 or 10 degrees). It appears that the basalt in the vicinity of the dam site is relatively flat-lying or south-dipping at an angle between 1 and 6 degrees, based on geologic mapping. No other major faults or structures are mapped in the vicinity.

A geologic map of the area by WDNR is presented in Plate 4-2.3. Plate 4-2.4 shows a geologic map of the Sand Hollow Dam site prepared using information from existing geologic mapping and geologic reconnaissance conducted during the site visit. Topographic and geologic information is shown on the cross section on Plate 4-2.5.

Bedrock in the vicinity of the Sand Hollow site consists primarily of basalt bedrock of the Columbia River Basalt group, and is described in Appendix B. Surficial geologic units in the vicinity of the proposed Sand Hollow site, also described in Appendix B, include stream alluvium, eolian sand dunes, eolian loess deposits, and colluvium. In the immediate vicinity of the proposed dam footprint, it appears that little or no surficial deposits cover the basalt outcrops.

Project Facilities Geology The geologic setting for all project facilities consists primarily of the bedrock Columbia River basalts. Facility-specific geologic issues are described in detail in Appendix B and summarized below:

- **Reservoir Geology:** The southern side of the proposed reservoir would be underlain by loess, clay, and basalt flows. The northern parts of the proposed reservoir would be underlain by loess and shallow basalt that forms the southern side of Frenchman Hills.
- **Damsite, Spillway, and Outlet Works Geology:** The surficial materials at the proposed dam abutments and valley section beneath the proposed Sand Hollow Dam consists of Columbia River Basalt, alluvial deposits, sand dunes, and thin colluvial deposits. These would be removed, and the entire dam would be founded on basalt bedrock. A short segment in the valley bottom could have greater depths to bedrock where alluvial sediments have been deposited from a small perennial stream that flows in the valley bottom. The outlet works would be founded on basalt bedrock that underlies the valley floor. This bedrock would provide suitable foundation conditions.
- **Intake, Combined Pump/Turbine Facility, Conveyance, and Power Transmission Facilities Geology:**
  - The intake (fish screen/diffuser) structure, as well as the pumping and power generation facilities, would likely be constructed in basalt bedrock located on the east side of the Columbia River.
  - A combined inflow/outflow conveyance tunnel would extend from the pumping and generation facilities at Wanapum Reservoir at approximate elevation 575 feet to approximate elevation 900 feet at the upstream toe of the proposed dam site (distance of approximately 2.5 miles). This conveyance tunnel would likely begin at the downstream end in either shallow alluvial sediments, talus, or bedrock, depending on the proposed location of the pumping facilities near the Columbia River.

Groundwater

Groundwater in the vicinity of the Sand Hollow site is found primarily in the alluvial deposits that fill the lower valley of Sand Hollow, and within the basalt flows that form the plateau. The alluvial deposits consist of silts, sands, and gravels that transmit groundwater. The permeability of these deposits is anticipated to be low to moderate, depending on the material types and percent of fines (such as silts). The volume of groundwater in the alluvial deposits is anticipated to be small, based on the limited extent of alluvial deposits in Sand Hollow.

Localized, perched zones of groundwater appear to be present along the basalt flows that underlie the Sand Hollow valley in the vicinity of the proposed dam footprint. This groundwater discharges as springs and seeps along the valley walls, at the contact with the bedrock surface. Numerous springs and seeps were observed during the site visit, and locations of these are noted on the geologic map. The discharge from these springs and seeps was not measured. It appears that these springs and seeps are the result of agricultural return flows from irrigated fields on the flat plateau north and east of the proposed dam site. These springs contribute to a large percentage of the flow in Sand Hollow wasteway.

Water production wells in the vicinity of the proposed Sand Hollow site produce groundwater from fractured basalt flows and weathered, interbedded zones within the basalt flows. Wells drilled in the plateau northwest of the right abutment indicate that depth to water in this area is more than 250 feet bgs. Wells to the west of the left abutment indicate that the depth to groundwater is between 200 and 400 feet bgs in this area; these wells yield up to 3,000 gpm in basalt interbeds. It is possible that deep water-bearing zones in local wells are hydraulically connected to the Columbia River and thus produce large quantities of groundwater. Wells drilled in the floor of the proposed reservoir indicate the depth to groundwater is between 80 and 270 feet bgs; these wells yield up to 40 gpm.

Seismotectonics

This proposed dam would be located in an area of relatively high seismicity known as the Yakima Fold Belt. Several of the faults within the Yakima Fold Belt are considered to be potentially seismogenic. Potentially active faults (described as “Class A,” which is defined by the USGS as “geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features”) in the vicinity of the proposed Sand Hollow Dam site include the Frenchman Hills Fault and Saddle Mountains Fault. The closest mapped Class A fault is the Frenchman Hills Fault, which is mapped within approximately 3 miles north of the proposed dam site, along the northern flank of the Frenchman Hills anticline. This fault is a south-dipping thrust fault. The Frenchman Hills fault is estimated to have a recurrence interval between 1,220 and 61,100 years, with an average slip rate of less than 0.2 mm/year.

The next closest mapped Class A fault is the Saddle Mountains fault, which is mapped within 7 miles south of the proposed dam site, along the northern flank of the Saddle Mountains. This fault is a south-dipping thrust fault, and has a total length of approximately 150 miles. The Saddle Mountains fault is estimated to have a recurrence interval of “thousands to tens-of-thousands” of years, with an average slip rate between 0.2 and 1.0 mm/year.

Based on the USGS seismic hazard, the probabilistic ground motion at the proposed Sand Hollow Dam site is approximately 0.09 g for a 10 percent probability of exceedance in 50 years (500-year return period) and 0.2 g for a 2 percent probability of exceedance in 50 years (2,500-year return period). Design considerations for a rockfill dam would require special attention regarding seismic loading and potential dynamic displacements of the rockfill to be found. Active faults are not anticipated under the dam itself.

Probable Maximum Flood

The drainage basin area at the Sand Hollow Dam site is approximately 50 square miles. The PMF was very roughly estimated from the PMF reported by Reclamation for Conconully Dam (Reclamation, 2007a) based on the ratio of the drainage basin areas. The peak inflow volume and flowrate used for the conceptual spillway layout and design at Sand Hollow are 30,000 acre-feet and 20,000 cfs, respectively. This estimate is likely conservative given that the topography of Sand Hollow is lower than Conconully Dam. No flood routing was performed to estimate the spillway flow requirements (Reclamation, 2007a).

4.2.2 Project Facilities

Dam and Appurtenant Structures

Plate 4-2.6 shows the proposed layout for the dam and appurtenant structures, conveyance conduits, diversions, spillway, and channels, as well as existing structures and facilities along the proposed axis for the dam. The maximum storage for this reservoir site is limited to approximately 1 million acre-feet because of site topography. Additional storage is not possible without construction of substantial saddle dikes along the southeast side and possibly a portion of the northwest reservoir perimeter, to create a "bathtub" configuration that allows greater depth and contains water within the available basin reservoir area.

Analysis of wave run-up and overtopping protection indicates that approximately 15 feet would be required for minimum freeboard. Table 4.2-1 shows the storage volumes, surface area, estimated dam heights, estimated embankment volumes, and water surface elevations for OS1.

The crest of the dam would be at elevation 1206 feet. The valley floor at the dam axis varies more or less uniformly in elevation from approximately 900 feet at the stream to approximately 1210 feet at the top of the ridges along the axis of the dam.

Several design considerations are associated with the construction of a large embankment dam at the Sand Hollow site, none of which are considered to be "fatal flaws." It is believed that a safe dam can be constructed, and that no unusual measures or features beyond what is typical for a major embankment dam would be required.

A rockfill dam appears to be the most appropriate for a dam at this location. There is a relative lack of impervious soils or even unconsolidated pervious soils at or near the dam site in the quantities needed for earthfill dam construction. On the other hand, basalt rock is present throughout the dam and reservoir area, with relatively little soil cover in many areas. The basalt, through quarrying, would provide the required volumes of rockfill for the project. It is anticipated that the basalt rock would meet the gradation and durability requirements for rockfill dam construction.

A rockfill-type dam is also advantageous considering the location in a zone of relatively high seismicity. Strong ground motions and the potential for fault movement require a dam type that is seismically stable even under very large loadings. Rockfill dams are recognized to be one of the most earthquake-resistant dams, primarily because the design affords a large downstream portion that retains high-strength, possesses high permeability, and thereby remains unsaturated, while allowing seepage water to pass through in the event that the impervious element of the dam is cracked or damaged during a seismic event.

TABLE 4-2.1
Sand Hollow Dam and Reservoir Data

	Storage Volume (acre-feet)	Surface Area (acres)	Dam Height[1] (ft)	Dam Embankment Volume[2] (yd^3)	Maximum WSEL (ft)
Sand Hollow OS1	1,000,000	12,500	294	16,717,343	1191

[1]Height above the valley bottom to the maximum water surface elevation plus 15 feet freeboard.
[2]Based on 1.5H:1V upstream and downstream slopes.

As a result of the considerations listed previously, a zoned rockfill dam with continuously grouted foundations, abutments, and impervious water barrier is recommended at this stage of this project. Plate 4-2.7 shows two typical cross sections for proposed rockfill dams at this location. The sloping earthcore option is shown with 1.7H:1V upstream and downstream slopes, which are typical for many other rockfill dams of this type and configuration. The CFRD is shown with slopes of 1.5H:1V, which is also typical.

Two types of water barrier designs could be considered at this site, including either (1) a central impervious earth core or sloping upstream earth core; or (2) a rockfill dam having an upstream concrete facing. The central or sloping earth core dams would require a significant quantity of well-graded silty sand, or silty sand and gravel for the core. Processed filters would be required with either of these options, but carefully controlled processing and monitoring would be required to ensure that silty non-plastic earth core materials are controlled from piping for the earth core options. The remainder of the embankment should consist primarily of angular rockfill from required excavations and from selected quarry areas developed for that purpose.

For the rockfill dam having a sloping concrete water barrier membrane on the upstream face, 1.5H:1V upstream and downstream slopes are assumed at this stage of the project. As the design continues into more detailed phases following field and laboratory analyses, steeper slopes may be suitable and thus less material may be required. The slopes selected are a function of the size, durability of the rock, and rock quality of materials used for rockfill as well as seismic loading. Steeper slopes may be achievable as the design progresses to more detailed stages. However, the basalt rock throughout the vicinity of the reservoir is highly fractured and readily breaks down into sizes commonly ranging from 3 inches to approximately 18 inches. Less than 10 to 20 percent of the rock appears to be larger than approximately 18 inches after multiple handling including blasting, dumping, dozing, and compaction in the dam.

For purposes of the cost estimate and preliminary planning for a dam at this site, a rockfill dam having 1.5H:1V upstream and downstream slopes and an upstream sloping concrete membrane is assumed based on the types of potential borrow materials available for construction at locations near the site (potential lack of silty well-graded sand and gravel for a central or sloping core). A concrete grout curtain/cutoff with a drain would be required because of concern about seepage through the dam foundation. The crest of the proposed Sand Hollow Dam is assumed to be 40 feet wide.

The removal of sediments from the floor of the proposed reservoir area could lead to increased loss of water due to vertical seepage. It is recognized that removal of these natural soils and exposing fractured basalt bedrock is undesirable because, if left in place, these fine-grained soils help blanket and protect the bottom of the reservoir from future leakage.

Potential Borrow Sources Inspection of the dam site and reservoir area was made for potential borrow sources for construction materials. Surficial soils within the reservoir area consist of silt and sand with limited areas of silty sand and gravel. The thickness and distribution of these alluvial, colluvial, and eolian sediments is not well known and must be investigated to confirm the presence of adequate quantities and quality of borrow for use in a dam.

The upper Ringold Formation, which underlies portions of the proposed reservoir, consists of a thick sequence of interbedded fine sands, silts, and clays. In some areas, the upper Ringold is 400 feet thick and may provide a source for fine-grained, low-plasticity material. A well drillers' log in the vicinity of the floor of the proposed reservoir notes yellow clay and sand clay to a depth of 178 feet bgs; this appears to be fine-grained sediments of the upper Ringold Formation.

The concrete membrane liner would require well-draining filter zones under the concrete and a continuous rock foundation and plinth under the upstream toe of the dam. The filter materials can be constructed from basalt sources in the valley and abutment areas of the dam. For purposes of this evaluation, it is assumed that the basalt rock for rockfill in the dam and filters would be quarried from the base of the valley floor—or from the sidewalls of the valley—within the reservoir area. The filters would require processing to achieve the required gradations. However, the excavations must be monitored to ensure that poor-quality, fractured rock that may be subject to leakage is not left exposed in the quarry walls and floors, and also to ensure that the rock used for the fill material is of suitable quality.

Dam Alignments The proposed dam alignment is shown in Plate 4-2.2A. For purposes of this discussion, the primary axis is indicated as the preferred location, but additional studies would be required to verify suitable conditions and optimize the axis. Other locations could be considered during subsequent feasibility studies.

The primary dam axis is assumed to be a straight-line alignment between the two end points as noted in Plate 4-2.2A. The length of the axis along this line is approximately 8,660 feet. The advantage of this alignment is reduced area of the upstream concrete barrier and potentially reduced earthwork volume in the dam. Plate 4-2.5 shows a geologic and topographic cross section through the proposed dam axis.

Dam Foundation As noted previously, the valley floor consists primarily of hard basalt bedrock exposed at or near the ground surface throughout all of the dam axis alignment. Hard, competent basalt rock is exposed at or near the ground surface across nearly all parts of the valley floor. The depth to rock at the small stream in the valley bottom is not known; however, based on rock exposures and geomorphic interpretations of the site, rock is believed to be relatively shallow under the stream bed also. For preliminary evaluations, the depth to bedrock under the stream area is assumed to be less than 50 feet.

Since bedrock is at or near the ground surface in most areas of the valley, the size and extent of excavations is expected to be limited, and control of groundwater should not be a significant issue. The basalt bedrock is shallow in the vicinity of the dam where surficial materials have been stripped away on steeper slopes. Based on observations during the site reconnaissance, the depth to basalt rock varies from 1 foot to approximately 15 feet below existing grade.

It appears that alluvial sediments up to 50 feet thick could exist in the valley bottom. The groundwater is currently at or near the ground surface near the valley bottom, and these sediments would thus be saturated. Several areas in the vicinity of the proposed dam foundation displayed seepage, which is interpreted to be discharge from irrigation percolation from adjacent farmlands. The seepage generally appears to be occurring at or near the top of the rock surfaces.

Groundwater must be controlled during construction, and all water must be diverted around the work areas to achieve the required excavations. It is assumed that the water would be controlled by diversion around the work area, and all alluvial sediments in the valley bottom would be removed from under the footprint of the dam. It appears that the stream could be diverted by temporary pipeline, possibly by pumping around the work area during construction. Exploration would be required to determine the depth and degree of difficulty in removing alluvial sediments and controlling the groundwater at this site.

The natural rock foundation for the dam would require grouting and a drain downstream of the grout curtains. Dental concrete and concrete backfill would be required to create a foundation with smooth transitions. These elements should be constructed and the embankment materials placed to bring the constructed grade back up to the existing ground surface under the dam.

Reservoir Inlet/Outlet Facilities The inlet/outlet structure would be constructed in a massive rock cut. The rock cut would be carefully shaped to a near vertical configuration, lined with thick concrete facings, and reinforced with rock bolts as required for stability. A concrete tower structure would extend up above the rock cut as required to reach to an elevation above the maximum water surface of the proposed reservoir. A bridge would be provided from the top of dam (or from a point on shore) for access onto the top of the tower. Large roller gates are assumed for controlling the water to these inlet/outlets.

The tunnel leading from the pump/turbine facility to the inlet/outlet structure would pass around the end of the dam, likely by means of a vertical access shaft creating an angle point, as shown on Plates 4-2.6 and 4-2.8.

Spillway The concept layout in Plate 4-2.6 shows the spillway location at the proposed left abutment. The drainage area for the Sand Hollow site is very limited in size and is only slightly larger than the reservoir water surface area; consequently, it is anticipated that the spillway would be relatively small compared to other potential dam sites having much larger drainage basins. The crest of the spillway would be at approximately 1196 feet and the outlet would be approximate elevation 820, depending on the location. The spillway would be approximately 220 feet wide. The spillway would eventually discharge below the dam into the existing ravine that leads to Wanapum Reservoir.

The spillway would be excavated into fractured basalt bedrock and possible weak basalt interflow zones or sedimentary interbeds. Therefore, it is anticipated that portions of the spillway channel might have to be lined with concrete or other erosion protection measures to control scour. Rock generated from the required spillway excavation can be used as rock fill in the embankment for the dam.

The spillway should be designed to maintain velocities suitable for the quality and size of the fractured bedrock. Additional channelization may be required downstream of the dam to ensure that the flows from the spillway, if ever used, could flow to the discharge channel and out to Wanapum Reservoir with limited damage.

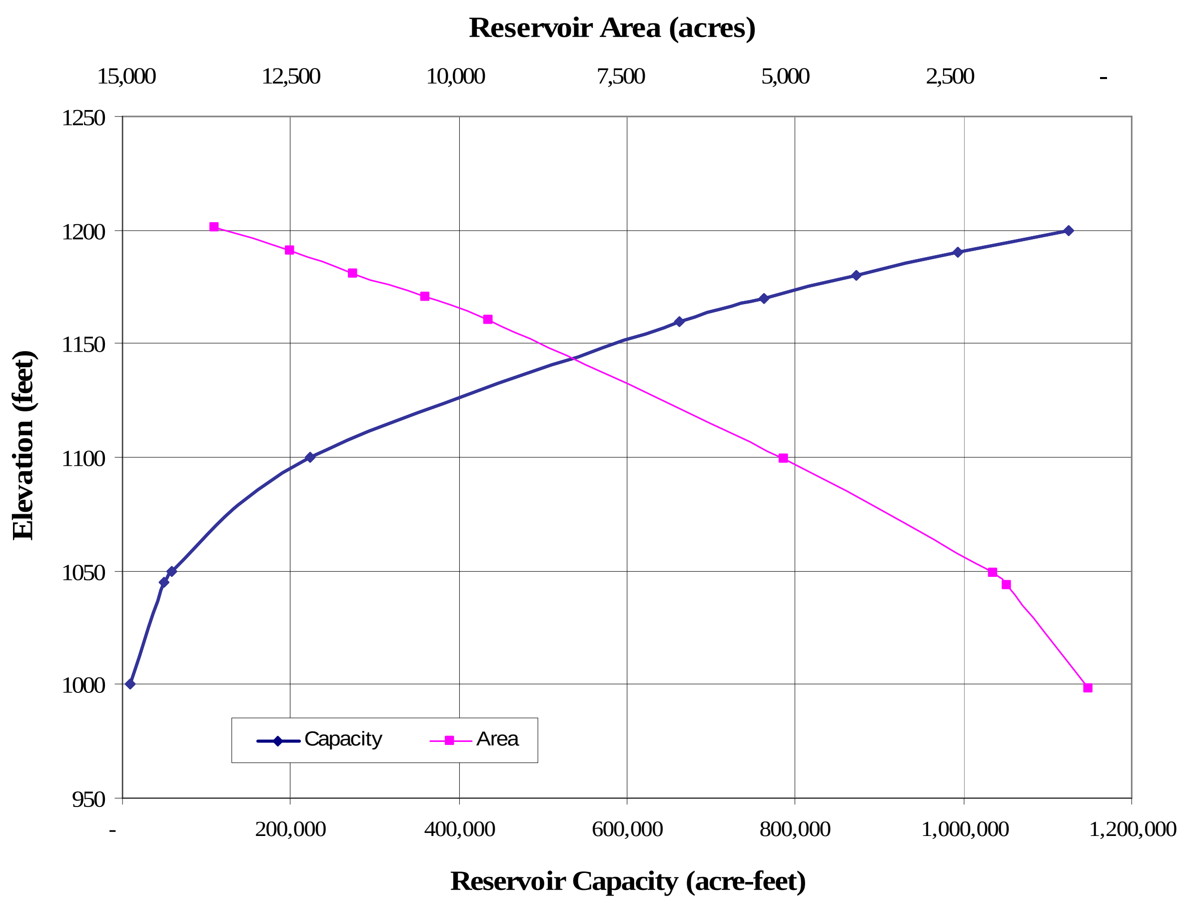
Reservoir

Plates 4-2.2A through 4-2.2B show the proposed reservoir configuration. The reservoir created by a dam as proposed for the Sand Hollow site would result in a lake that is approximately 9 miles long and approximately 2 to 3 miles wide. The area/storage curve for this reservoir compared to elevation is shown in Figure 4-2.1.

The water surface of the reservoir at storage elevation would be primarily in contact with silt and sand of the Palouse and upper Ringold Formations. The topography of the reservoir formed by these soils is gently to very gently sloping throughout most of the perimeter area of the proposed reservoir. These soils are highly erosive and development of significant erosion, turbidity, and wave-cut benches could be expected throughout many areas of the reservoir unless extensive slope protection is provided along the shorelines. Erosion and turbidity are expected within the reservoir, particularly along the north and eastern sides where the soils would be subject to predominant winds from the southwest. As the reservoir water levels are dropped, additional shallow water zones of alluvial sediments would be exposed to wave action and disturbance, which could lead to further increase in erosion and turbidity within the reservoir. Without extensive use of shoreline protection, it is expected that erosion would result at this site over a wide range of water levels. Shallow water zones could also lead to increased solar heat gain.

Because of the gentle side slopes that predominate throughout the reservoir area,

FIGURE 4-2.1
Sand Hollow Reservoir Elevation-Capacity-Area Curves



the reservoir is not expected to encounter unstable slopes associated with rapid drawdown of water levels during discharge periods to the Columbia River. The rate of drawdown during maximum withdrawal periods would be relatively low.

Little is known about the potential for reservoir leakage at this location through the abutments or floor of the reservoir. However, based on field observation of relatively shallow seepage from the slopes within the reservoir area and near the location of the proposed dam, it appears that the bedrock has a low coefficient of vertical permeability. Additionally, it is noted that significant areas of the reservoir bottom are currently blanketed with relatively fine-grained silt and sand material. The majority of the floor of the proposed reservoir is underlain by loess deposits that consist of fine-grained silty sands and the sandy silts, and upper Ringold Formation, which consists of laminated silts and clays. These soils are expected to form a natural barrier to vertical seepage and, therefore, it is anticipated that downward leakage through the floor of the reservoir would be minimal.

However, leakage through the abutments and underneath the dam is a possibility, and it is anticipated that grouting and/or a cutoff to less-permeable rock may be required. Fractured, high permeability zones in basalt bedrock may exist in the vicinity of the dam axis and may contribute to leakage and thus require treatment.

Overall, however, the relatively low hydraulic head at this dam site would reduce the potential for leakage that is associated with taller dams that produce greater hydraulic heads. For preliminary purposes, it is estimated that seepage through the reservoir floor and sides would be an average of 0.03 acre-ft/month/acre, or approximately 350 acre-ft/month for the reservoir at maximum pool level.

Additional information regarding leakage may be obtained by reviewing leakage history from other reservoirs in similar geologic conditions, and experience gained by Ecology's Dam Safety Division. These other dams may include, but not be limited to, Pinto Dam, O'Sullivan Dam, Dry Falls Dam, and numerous other dams in the area.

Columbia River Diversion Facilities

Plate 4-2.6 shows an overall layout of facilities for the potential Sand Hollow project, and Plates 4-2.9 and 4.2-10 show the conceptual layout and location of the proposed diversion/intake facility. Fish protection facilities would be needed on the Columbia River to prevent delay, false attraction, or stranding of fish. The combined fish screen/diffuser structure would be located in the river just beyond the pump/turbine facility. The fish screen/diffuser structure length would be approximately 385 feet, with access roads connecting from each end to SR-243 or other local roads for access by heavy maintenance equipment with limited maneuverability and large turning radii. Water diverted from the river would travel through fish screens and accelerate between converging sheetpile training walls toward the draft tubes leading to the pumps.

During reservoir releases, water would travel back out through the turbines and the draft tubes and decelerate between the training walls as it approached the screen/diffuser face. In this mode, the screen panels would be raised (as described for the Crab Creek site), and the diffuser panels would remain in place, preventing fish from entering the system and releasing water at low velocities in accordance with the criteria. At this site, because there is a closed system from the new reservoir back to the river, there is expected to be minimal (or no) debris in the water when it is released through the turbines and approaches the diffuser, so no trashrack would be needed to protect the diffuser panels.

As with the Crab Creek site, the required structure width for diversion is nearly identical to required width for discharge. However, the need for an emergency bypass system on the turbines dictates that a separate energy dissipation and discharge/diffuser system needs to be included at this site. As shown in Plate 4-2.9, water bypassing the turbines would be directed through a fixed cone valve structure (see Plate 4-2.11), reducing the extreme velocities and energy associated with the full reservoir head. Exiting this structure, it is believed that sufficient energy would remain to warrant the use of a baffled apron drop to discharge water to the Columbia River. It is assumed for the purposes of this study that the water exiting the baffled apron drop could be released to the river through an additional length of diffuser provided as an extension of the fish screen/diffuser structure. Because it is envisioned that the bypass system would only operate in emergency situations during temporary turbine shut-downs or similar circumstances, it was assumed that the additional diffuser would not be subject to the 1.0 fps velocity criteria—thus a shorter diffuser has been indicated in Plate 4-2.9.

It is assumed that no gates are needed as part of the diversion facilities. Diversion rates from the Columbia River would be controlled and measured by the pumping units near the river bank. Discharge rates from the new reservoir back to the river would be controlled by the units in the generating mode on the bypass valves.

The site would need to include an O&M building to house equipment, spare parts, and sensitive control equipment for the fish screen/diffuser structure. Alternatively, the pump/turbine facility building could be enlarged to house these items.

Conveyance Facilities

Plates 4-2.6 and 4-2.9 show the proposed layout and location of the conveyance facilities for the Sand Hollow project. Flows conveyed in both directions between the pump/turbine facility and the new reservoir would be carried in a combination of welded steel penstocks and a lined tunnel. Leaving the pumps next to the river, three 12-foot-diameter penstocks would cross under SR-243 and end approximately 1,200 feet upslope at a structure that provides the transition from three penstocks to a tunnel portal. Mapping is not adequate at this time to specify a precise vertical profile, but for the purposes of estimating construction cost, it is assumed that the average cover over the penstocks would be 10 feet. The highway crossing may require tunneling, but for the purposes of this evaluation it was assumed that a temporary detour could be developed to allow open-trench construction across the highway.

The tunnel (25 feet in diameter and mostly steel lined) would continue an additional 2.2 miles to the reservoir inlet/outlet works. Additional details about the penstocks, tunnels, and reservoir inlet/outlet works are provided under subsequent headings.

Combined Pump/Turbine Facilities

The units for pumping into the Sand Hollow Reservoir were selected to provide the target flows to the reservoir for the single operating scenario at the maximum pumping head. In addition, they were selected to be reversible units that can generate power when the flow from the reservoir is released back to the river. This allows energy recovery with most of the release flows with a minimum of incremental cost over the cost of the necessary pumping facilities. The selection and sizing of the units followed the procedures outlined in Reclamation Monograph No. 39. The minimum number of units was established as three to provide flexibility and limited reduction in capacity upon loss of use of one unit. Hence, three units were selected for the single operating scenario. The minimum pumping flow occurs at the maximum head; therefore, at pumping heads less than the maximum, the pumping capacity would be larger, up to about 2.1 times the target flow at the normal minimum head. Because the head variation for the operating scenario at Sand Hollow is within the normal range for reversible units of this type, single speed units were selected. At maximum generating head, the units can utilize almost all of the targeted release flows to produce power. At lower heads, the units cannot pass as much flow, and some of the releases would have to be released by the outlet valves when release demands are at their highest. The rated individual unit capacity for OS1 is 95 MW, resulting in a plant capacity of 285 MW. This is based on the maximum generating capacity at maximum head.

Plates 4-2.12 and 4-2.13 show the proposed combined pump/turbine facility, outlet works, and fish screen/diffuser structure location, and Plate 4-1.14 provides an overall system profile from the Columbia River to the new reservoir site. It is assumed that the combined pump/turbine facility would be located on competent bedrock. The combined pump/turbine facility would connect to the inlet/outlet works in the reservoir via penstock pipe(s) and a tunnel. A structure to allow water inlet and extraction from the reservoir would be required. The size and configuration of the structure would require hydraulic analysis to determine potential configurations and sizes.

Because the proposed Sand Hollow Reservoir would be long and relatively shallow, and the reservoir is located in a zone having significant solar heat gain, it is likely that provisions to draw water from multiple levels may be required to control the downstream water quality releases from the reservoir (that is, to regulate the temperature). The inlet/outlet works could be constructed with a floating fish screen/diffuser structure to allow withdrawal from variable surface elevations in the reservoir. Based on other projects in similar environments, it is likely that the solar heat gain can be expected to occur most significantly within the upper 40 to 50 feet of the reservoir.

Releases from the Sand Hollow Reservoir would discharge directly into the Columbia River via the pumping/generating station. A fixed cone valve structure has been provided to minimize water quality problems from erosion, aeration, dissolved oxygen, and nitrogen super-saturation. The fixed cone valve house would be set above maximum river stage because the valves do not operate well underwater.

Power Transmission Facilities

Power transmission facilities are required to provide energy to the large pump/turbines that lift water from the Columbia River into the Sand Hollow Reservoir. These same facilities then deliver the energy that is generated when water is released through the reversible pump/turbine units back into the Columbia River. The maximum power requirements for the reservoir hydraulic capacity operating scenario being considered at Sand Hollow are estimated on Table 4-2.2.

TABLE 4-2.2
Sand Hollow Pumping and Generating Power Requirements

Operating Scenario	Pumping Power Input Max (MW)	Generating Power Output Max (MW)
OS1	225	285

The proposed electric power substation and transmission facilities are shown on Plate 4-2.15. The new single-circuit 230 kV transmission line is approximately 5.6 miles and is proposed to connect the project substation to the existing transmission grid at BPA's Vantage Substation. The transmission line begins at the powerhouse substation and heads almost due east until it reaches the existing BPA Vantage-Columbia 230 kV transmission line, where it turns towards the south and parallels the line to the Vantage Substation. It is proposed that the new 230 kV line would terminate at Vantage in a new 230 kV breaker/bay.

The general requirements for selecting transmission voltage and for construction of power transmission facilities were described in Section 3.5.5, *General Requirements for Siting Power Transmission Facilities*. A typical single circuit 230 kV lattice steel transmission structure is shown in Plate 4-1.17. This type of structure closely resembles the existing lattice steel transmission structures near the Vantage/Wanapum Substation. When constructed, the new structures would be designed for placement adjacent to structures in the GCPUD Wanpum-Columbia 230 kV transmission line on a structure-to-structure basis for visual uniformity. The height of each structure would vary slightly by location as dictated by surrounding land features.

The ROW needed for the new transmission line and its structures is assumed to be 100 feet wide. However, this width may change depending upon the final conductor span lengths and selected and adjacent property uses.

The following structures would be needed at each substation:

- Sand Hollow Substation—A new bay would be constructed near the Sand Hollow powerhouse as indicated on Plate 4-2.15. New equipment within the substation would include a 230 kV-13.8 kV power transformer, power circuit breakers, switches, buswork, potential transformers, substation dead-end towers, buried grounding system, and perimeter fencing.
- Vantage Substation—A new bay would be constructed within the existing fenced yard of the Vantage Substation. New equipment within the substation would include power circuit breakers, switches, buswork, potential transformers, and substation dean-end towers.

Relocation Once filled to capacity, the reservoir would cover the GCPUD-owned Jericho Tap-Jericho 115 kV transmission line. The line would need to be relocated for 11 miles, via overhead line, above and away from the maximum fill elevation level of the new reservoir. The relocated transmission line is shown on Plate 4-2.15.

4.2.3 Alternative Operational Scenarios

OS1 is a 1 million acre-foot off-channel reservoir with a 2,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 6,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands. A detailed explanation of the development of OS1 is provided in *Operational Scenarios Development*, which is discussed in Section 3. In addition, numerical monthly results for OS1 are presented in Appendix C, *Water Balance Reports*.

Figures 4-2.2A and 4-2.2B show the minimum, maximum, median, first, and third quartiles for end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record, respectively. Quartiles divide a data set into quarters. The value that divides the lower half into halves is called the first quartile (q1). The value that divides the upper half into halves is called the third quartile (q3). These statistics are shown to provide insight into the results of the 50-year period of record and present outliers that can skew the average.

Figure 4-2.2C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS1.

FIGURE 4-2.2A

End-of-Month Off-Channel Reservoir Contents: Sand Hollow OS1

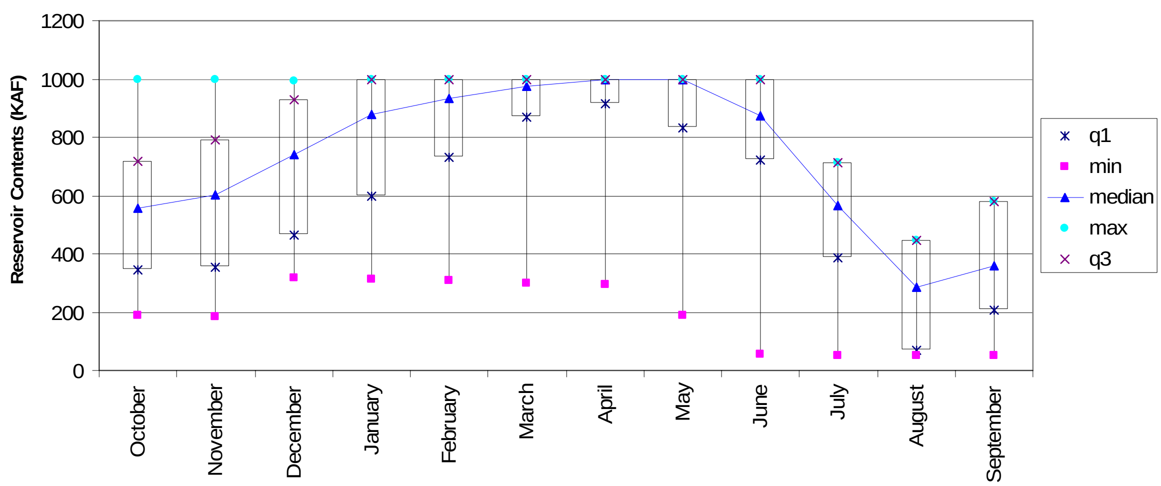


FIGURE 4-2.2B

Releases from Off-Channel Reservoir: Sand Hollow OS1

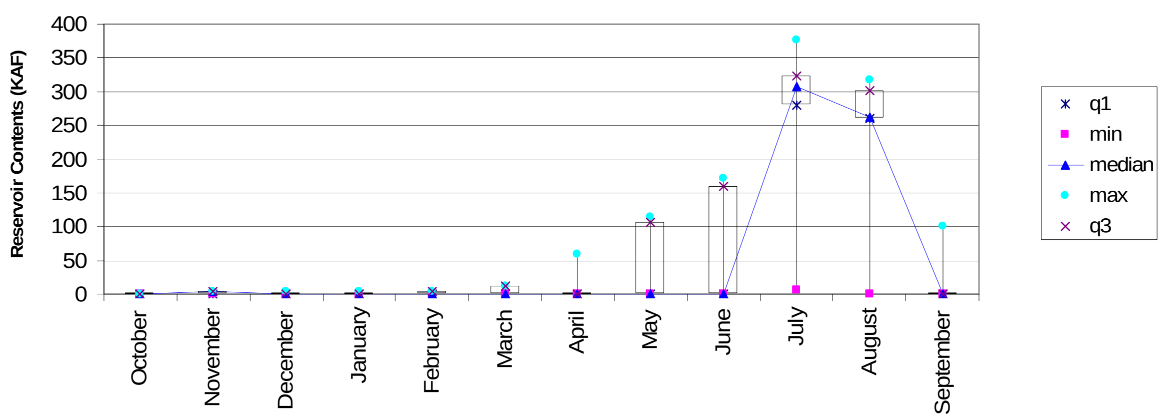
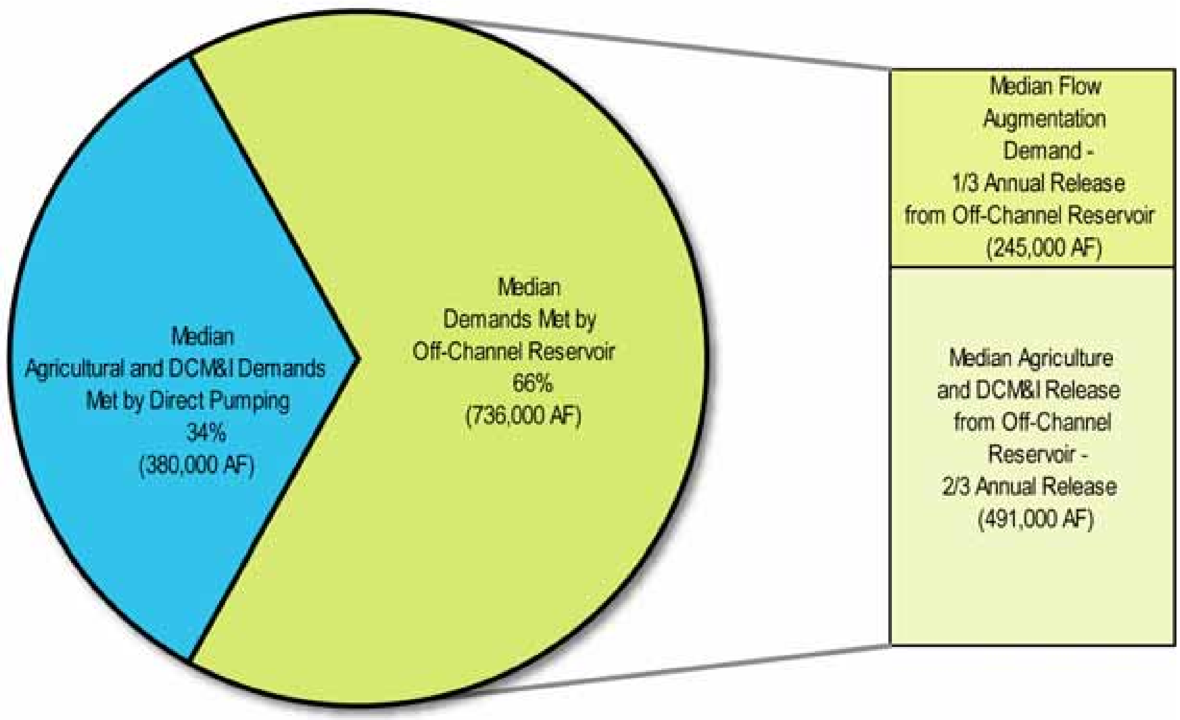


FIGURE 4-2.2C
Median Annual Demand Distribution: Sand Hollow OS1



OS1 allows for 1,116,000 acre-feet (380,000 acre-feet direct pumped and 736,000 acre-feet off-channel reservoir) of water to be delivered to agricultural, DCM&I, and flow augmentation demands either via direct pumping from the Columbia River mainstem or from the new off-channel reservoir based on median values for the 50-year period of record used in the water balance model. This value represents the "yield" or benefit to water users as a result of implementing this alternative. This yield is the basis of the cost/benefit analysis in the Decision Support Model.

4.2.4 Project Cost Estimates

Project cost estimates are shown in Tables 4-2.3A, *Estimated Capital Costs for Sand Hollow Site and Operational Scenarios*, 4-2.3B, *Estimated Annual Costs for Sand Hollow Site and Operational Scenarios*, and 4-2.3C, *Estimated Net Present Values for Sand Hollow Site and Operational Scenarios*.

4.2.5 Socioeconomic Resource Effects

Socioeconomic resource effects are summarized on Table 4-2.4.

Operational Scenario 1

Approximately 13,179 acres would be permanently converted to reservoir and associated facilities under OS1.

Table 4-2.3A

Estimated Capital Costs for Sand Hollow Site and Operational Scenarios

Facility or Cost Component	Type of Unit	Unit Cost	Reference Project Cost for Scale Ups or Scale Downs	Sand Hollow OS1 No. of Units or Scale Factor	Sand Hollow OS1 Extended $	Sand Hollow OS2 No. of Units or Scale Factor	Sand Hollow OS2 Extended $	Sand Hollow OS3 No. of Units or Scale Factor	Sand Hollow OS3 Extended $
Columbia River Intake Facilities					$ 21,800,000				
Fish Screen/Diffuser Structure			$ 9,750,000	2.24					
Penstocks and Tunnels									
Penstocks	LF x Dia Inch	$15		798,336	$ 12,000,000				
Tunnels					$ 130,700,000				
Access Shafts									
Total Depth of Shaft(s)	LF	equation		75					
Diameter of Shaft	Dia Ft	equation		40					
Tunnels (Concrete Lined Sections)									
Approx Total Tunnel Length	LF	equation		14,500					
Diameter of Tunnel	Dia Ft	equation		25					
Add on for Sections of Steel Lining									
Approx Length Required	LF	equation		1,200					
Assumed Thickness of Steel	Lining t (in)	equation		2.0					
Allowance for Stiffeners	Percentage			0.15					
Channels									
Pump/Turbine Facilities	LS	varies		204,600,000	$ 204,600,000				
Dams					$ 350,100,000				
Dam (rock fill portion with concrete face)	CY	$18.40		16,720,000					
Dam (RCC portion)	CY	$82		-					
Spillway	LS	varies		42,500,000					
Reservoir Inlet/Outlet Works (See Note 1)			$ 40,000,000	0.75	$ 30,000,000				
Additional Structures					$ 3,400,000				
Fixed Cone Valve Structure	LS	varies		1,100,000.0					
Bypass Pipes	LF x Dia Inch	$15		129,600					
Baffled Apron Drop	LS	varies		400,000.0					
Road Relocations	miles	$2,700,000		3	$ 8,100,000				
Bridges									
Power Transmission Facilities					$ 17,900,000				
Power Transmission Lines/Towers	mile	$540,000		26					
Substation Power Transformation	MVA	$11,000		150					
Substation Switchyards	Breakers, EA	$1,100,000		2					
Security/Safety Fencing	LF	$30		3,000	$ 100,000				
Mobilization		5%			$ 39,000,000				
Unlisted Items		15%			$ 117,000,000				
Subtotal					$ 935,000,000				
Contingency		30%			$ 281,000,000				
Field Cost (or Construction Contract Cost)					$ 1,216,000,000				
Noncontract Cost		35%			$ 426,000,000				
Total Capital Cost					$ 1,642,000,000				

Notes:

1. Captures costs for gates, concrete work, and miscellaneous civil works. Costs for tunnels under/around dam are included in Tunnels line items above.

Table 4-2.3B

Estimated Annual Costs for Sand Hollow Site and Operational Scenarios

Facility or Cost Component	Type of Unit[1]	Unit Cost[2]	Applicable Portion of Field Cost	Frequency of O&M or R&R (Years Between)	Sand Hollow OS1 No. of Units or Capital Cost[2]	Sand Hollow OS1 Extended Annual $	Sand Hollow OS2 No. of Units or Capital Cost[2]	Sand Hollow OS2 Extended Annual $	Sand Hollow OS3 No. of Units or Capital Cost[2]	Sand Hollow OS3 Extended Annual $
Average Annual Power Consumption Costs						$ 16,860,000				
Pump/Turbine Facility	kW-hr	$0.03			562,000,000					
Average Annual Power Generation Revenues						$ 8,340,000				
Pump/Turbine Facility	kW-hr	$0.025			333,620,000					
Operation & Maintenance										
Fish Screen/Diffuser Structure										
Structural/Civil Works, Annual	% FC	0.1%	40%	1	$ 45,910,000	$20,000				
Electrical/Mechanical Works, Annual	% FC	0.5%	60%	1	$ 45,910,000	$140,000				
Replacement	% FC	20.0%		25	$ 45,910,000	$9,180,000				
Pump/Turbine Facility										
Structural/Civil Works, Annual	% FC	0.1%	40%	1	$ 430,890,000	$170,000				
Electrical/Mechanical Works, Annual	% FC	1.0%	60%	1	$ 430,890,000	$2,590,000				
Replacement	% FC	20.0%		25	$ 430,890,000	$86,180,000				
Tunnels/Tunnel Lining										
Repairs and Maintenance	% FC	0.5%		1	$ 275,250,000	$1,380,000				
Penstocks										
Structural/Civil Works, Annual	% FC	0.5%		1	$ 25,270,000	$130,000				
Dams and Spillways										
Structural/Civil Works, Annual	% FC	0.1%	80%	1	$ 737,310,000	$590,000				
Electrical/Mechanical Works, Annual	% FC	1.0%	20%	1	$ 737,310,000	$1,470,000				
Additional Structures										
Structural/Civil Works, Annual	% FC	1.0%	40%	1	$ 7,160,000	$30,000				
Electrical/Mechanical Works, Annual	% FC	5.0%	60%	1	$ 7,160,000	$210,000				
Channels										
Dredging, Clearing, and Bank Repair										
Valving/Gates on I/O Facilities										
Electrical/Mechanical Works, Annual	% FC	0.1%		1	$ 63,180,000	$60,000				
Replacement	% FC	40.0%		25	$ 63,180,000	$25,270,000				
Power Transmission Facilities										
Clearing and Repairs	% FC	0.5%		1	$ 37,700,000	$190,000				
Fencing										
Repairs and Maintenance	% FC	10.0%		1	$ 210,000	$20,000				

Notes:

1. Abbreviations: FC = Field Cost, kW-hr = kilowatt hours, I/O = inlet/outlet, O&M = Operation & Maintenance, R/R = Repair/Replacement
2. Capital Costs are taken from Estimated Field Cost table for the appropriate site and are adjusted to include mobilization, unlisted items, contingency, and noncontract costs.

Table 4-2.3C
Estimated Net Present Values for Sand Hollow Site and Operational Scenarios

Year	Operational Scenario 1						
	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (1,642,000,000)						
1 thru 24		$ (16,860,000)	$ 8,340,000	$ (7,000,000)			
25		$ (16,860,000)	$ 8,340,000	$ (7,000,000)	$ (45,120,000)		
26 thru 49		$ (16,860,000)	$ 8,340,000	$ (7,000,000)			
50		$ (16,860,000)	$ 8,340,000	$ (7,000,000)	$ (45,120,000)		
51 thru 74		$ (16,860,000)	$ 8,340,000	$ (7,000,000)			
75		$ (16,860,000)	$ 8,340,000	$ (7,000,000)	$ (45,120,000)		
76 thru 99		$ (16,860,000)	$ 8,340,000	$ (7,000,000)			
100		$ (16,860,000)	$ 8,340,000	$ (7,000,000)		$ -	
NPV	$ (1,642,000,000)	$ (342,900,000)	$ 169,600,000	$ (142,400,000)	$ (51,300,000)	$ -	$ (2,009,000,000)

Year	Operational Scenario 2						
	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0							
1 thru 24							
25							
26 thru 49							
50							
51 thru 74							
75							
76 thru 99							
100							
NPV							

Year	Operational Scenario 3						
	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0							
1 thru 24							
25							
26 thru 49							
50							
51 thru 74							
75							
76 thru 99							
100							
NPV							

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TABLE 4-2.4
Sand Hollow Socioeconomic Impacts Summary

Factors	Criteria	Raw Data for Impacts		Impacts Normalized to Million Acre-Feet	
		Units	OS1	Units	OS1
Land Use	Residential use	No. residences	32	No. residences/MAF	32
	Irrigated Agriculture	Acres	12,441	Acres/MAF	12,441
Infrastructure	Highway (state, federal) impacts	Miles	1.5	Miles/MAF	1.5
	Local road impacts	Miles	36	Miles/MAF	36
	Railroad impacts	Miles	0	Miles/MAF	0
	Transmission line impacts	Miles	3	Miles/MAF	3

Land Ownership The existing GIS dataset for land ownership for the proposed Sand Hollow site is incomplete. Zoning information from Grant County and aerial photographs show that agriculture is the primary land use within the Sand Hollow footprint; as such, we assume that the majority of the land is owned privately. Based on agricultural land use data, it is assumed that private land ownership is dominant at the Sand Hollow site (12,441 acres).

Land Use As shown on Table 4-2.4, residential and agricultural land uses would be impacted, with approximately 32 residences identified in the proposed footprint of the project and inundation of 12,441 acres of agricultural land.

Irrigated Agriculture Except for seven farm units at its east end, all of Irrigation Block 82 lies under the footprint of the proposed reservoir with 10,310 assessed irrigated acres that would be removed from production. This area produces a variety of high value crops, including the following:

- Crop products: early and full-term potatoes, beans, peppermint, both feed and sweet corn, silage, and wheat
- Orchards: apples, cherries, nectarines, peaches, and pears
- Seed crops: onion, radish, and carrot
- Vineyards: wine grapes
- Hay: alfalfa and other types
- Pasture

Some of the farm units and Project facilities along the south side of Block 81 and along the north side of Block 83 would also be impacted.

Infrastructure Major infrastructure that would be affected within the Sand Hollow potential reservoir site includes farm buildings, local roads, SR-26, and transmission lines.

State and Federal Highways Under OS1, 1.5 of SR-26 would be inundated. This portion of the highway would need to be relocated to follow the southwest corner of the proposed reservoir.

Local Roads Along with existing agricultural infrastructure, 36 miles of local roads would likely be inundated. The roadways would be abandoned rather than relocated.

Irrigation Facilities Approximately 150 miles of buried pipe drains would have to be abandoned in place, and the buried pipe drains under the seven units at the east end of Irrigation Block 82 would require modification. Abandonment and removal of 56 miles of Project canals and laterals would occur.

Railroads No railroad tracks are present within the proposed footprint.

Transmission Lines Relocation of 3 miles of transmission line would be needed.

4.2.6 Cultural Resource Effects

Impacts that can adversely affect heritage sites include anything that might significantly change the important features of a heritage site, and any kind of ground-disturbing activities. Direct and indirect effects to cultural resources can result from human activities or natural events. Cultural sites are described in Section 4.2.1, *Site Characteristics*, under the heading, *Cultural Features and Developments*. As shown on Table 4-2.5, the probability that cultural resources are present is moderately low (8). This ranking is based on the following assumptions:

- Sand Hollow wasteway is not a large primary drainage channel. Primary drainage channels generally contain larger numbers of pre-historic and historic sites than do smaller drainage channels.
- Extensive irrigated agricultural development and ground disturbance that may have had an impact to unrecorded archaeological sites.
- Only a small amount has been inventoried for cultural resources.

A description of known cultural resources is provided below for each Operational Scenario.

Direct Impacts

This OS impacts 13,179 acres. Potential adverse effects to cultural resources may result from activities associated with the construction of the reservoir and dam, the inundation of water into the reservoir, sedimentation buildup from waters entering the reservoir covering cultural resources, and the erosion of shorelines from seasonal water fluctuations. Existing cultural resource information indicates there is a medium potential for adverse effects to heritage sites within the footprint of the reservoir under the Sand Hollow wasteway option. The area with the highest potential for cultural resources is primarily along the valley floor. The cultural resources in most of the proposed project area have not been systematically inventoried. Current information indicates drainage bottoms and floodplains represent the greatest potential for archaeological sites, thus creating medium-probability locations for areas that remain to be inventoried under this option. This would be identified as part of the process of meeting the requirements of Section 106 of the NHPA and NEPA. In addition, there is a low potential for Traditional Cultural Properties under this option. This would be addressed through consultation with the lead federal agency, associated Tribes, and SHPO.

When effects are analyzed as part of project planning, there may be opportunities to redesign some components of the project to avoid some sites or those adverse effects, or if necessary, mitigate them. Cultural resource sites would continue to be located and recorded in response to the proposed option. Mitigation and a management plan would be necessary to protect cultural resources from loss of integrity and physical damage.

TABLE 4-2.5
Sand Hollow Cultural Impacts Summary

Factors	Criteria	Raw Data for Impacts		Impacts Normalized to Million Acre-Feet	
		Units	OS1	Units	OS1
National Register-eligible Resources and Traditional Cultural Properties	Potential resource impacts	Rating on 0-10 scale*	8	0-10 scale	8

*0 = major conflict; 10 = none

Indirect Impacts

Indirect impacts may include increased damage to prehistoric and historic sites because of increased public use or activities in the reservoir area of the Sand Hollow alternative. Under this option, there may be recreational activities and a seasonal fluctuation in the water levels along the shoreline. Both recreation and fluctuation of water levels may result in adverse effects to cultural resources.

Sand Hollow Dam and Appurtenant Structures

Direct Impacts Potential adverse effects to cultural resources may result from activities associated with the construction of the pump structure and tunnel entrance and any ground-disturbing activities associated with this activity. Adverse effects would be identified as part of the process of meeting the requirements of Section 106 of the NHPA and NEPA. In addition, there is a low potential for Traditional Cultural Properties under this option. This would be addressed through consultation with the lead federal agency, associated Tribes, and SHPO.

When effects are analyzed as part of project planning, there may be opportunities to redesign some components of the project to avoid some sites or those adverse effects, or if necessary, mitigate them. Cultural resource sites would continue to be located and recorded in response to the proposed option. Mitigation and a management plan would be necessary to protect cultural resources from loss of integrity and physical damage. No direct impacts are anticipated for the 25-foot tunnel or tunnel exit shaft.

Indirect Impacts Indirect impacts may include increased damage to prehistoric and historic sites because of increased public use or activities in the pump structure and tunnel entrance area. Under this option, there may be increased recreational activities and a seasonal fluctuation in the water levels along the Wanapum Reservoir shoreline. Both recreation and fluctuation of water levels may result in adverse effects to cultural resources. This area currently receives recreational use primarily in the summer months. No indirect impacts are anticipated for the 25-foot tunnel or tunnel exit shaft.

4.2.7 Environmental Resource Effects

Impacts to environmental resources for each operational scenario are summarized on Table 4-2.6. The environmental impacts discussion includes impacts of the reservoir, as well as the dam and all appurtenant structures.

Operational Scenario 1

Under OS1, 13,199 acres would be permanently disturbed.

Special Status Species No federal or state special status species are currently found at this site (Table 4-2.6). Approximately 2 miles of summer steelhead and fall Chinook salmon habitat (1 mile each) downstream of the proposed Sand Hollow wasteway dam site could potentially be affected, either beneficially or adversely, by the project depending on future creek flows and effects on habitat (volume, water velocity and depth, temperature) compared to existing conditions (Table 4-2.6).

Special Status Habitats Approximately 112 acres of wetlands would be inundated (Table 4-2.6). No Open Water or Riparian resources have been identified within the proposed footprint for OS1.

TABLE 4-2.6
Sand Hollow Environmental Impacts Summary

Factors	Criteria	Raw Data for Impacts		Impacts Normalized to Million Acre-Feet	
		Units	OS1	Units	OS1
Special Status Species	Anadromous Fish—Habitat Inundated	Miles	0	Miles/MAF	0
	Anadromous Fish—Downstream Habitat Affected	Miles	2	Miles/MAF	2
	Federal aquatic T & E species—Habitat Inundated	Miles	0	Miles/MAF	0
	Federal aquatic T & E species—Downstream Habitat Affected	Miles	1	Miles/MAF	1
	State aquatic Sensitive species—Habitat Inundated	Miles	0	Miles/MAF	0
	State aquatic Sensitive species—Downstream Habitat Affected	Miles	1	Miles/MAF	1
	State aquatic Priority Species	Miles	0	Miles/MAF	0
	Federal terrestrial T & E species impacts	Acres	0	Acres/MAF	0
	State terrestrial T & E and Sensitive species impacts	Acres	52	Acres/MAF	52
	State terrestrial Priority Species	Acres	29	Acres/MAF	29
Special Status Habitat or Conservation/ Preservation Designation	Wetland habitat impacts	Acres	112	Acres/MAF	112
	Riparian habitat impacts	Acres	0	Acres/MAF	0
	Sand Dunes habitat impacts	Acres	0	Acres/MAF	0
	Cliffs/Bluffs habitat impacts	Acres	0	Acres/MAF	0
	Shrub-steppe habitat impacts	Acres	0	Acres/MAF	0
	Candidate Wild & Scenic rivers	Miles	0	Miles/MAF	0
	Wilderness Study Areas	Acres	0	Acres/MAF	0
	National wildlife refuges impacts	Acres	43	Acres/MAF	43
	State wildlife refuges impacts	Acres	0	Acres/MAF	0
	Other National or State conservation/preservation designation	Acres	0	Acres/MAF	0

Conservation/Preservation Areas No federal or state conservation or preservation areas are found at the Sand Hollow site.

4.2.8 Recommended Further Investigations Specific to this Site

Recommendations for further investigations specific to Sand Hollow include the following:

- Deep rock core borings to verify the rock mass quality and tunneling potential of basalt bedrock along the proposed conveyance tunnel alignment
- Borings upstream from the dam to evaluate the characteristics of the basalt bedrock in the vicinity of the proposed fish screen/diffuser structure cut. Rock cuts in interbedded basalt in this vicinity may be up to 200 feet high.
- Borings to determine the character and competency of the basalt rock and interbed zones and presence of sedimentary interbeds at the spillway location
- Soil borings conducted from a barge to evaluate the subsurface conditions at the proposed fish screen to determine the thickness of alluvial deposits near the eastern side of the Columbia River
- River bathymetry to facilitate more precise placement of the fish screen
- Detailed geologic mapping of sites, including discontinuity mapping in rock outcrops
- Soil borings and rock cores to determine the thickness and characteristics of alluvial sediments, and shallow rock characteristics under the proposed dams and appurtenant facilities
- Additional borings, test pits, and/or geophysical lines along the proposed axes of the dams to determine the basalt rock profile perpendicular to the existing streams
- Down-hole hydraulic pressure testing to evaluate the permeability of the basalt bedrock
- Rock quarry investigations to evaluate the volume and durability of the bedrock, and the suitability of the borrow area rock sources for dam embankment material. This investigation will consist of core samples, rock samples, and rock durability testing.
- Borings to verify the depth and characteristics of soils and bedrock along proposed conveyance routes, outlet works, intake towers, fish screens, and pumping/powerhouse locations
- Conduct cultural resources surveys

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4.3 Foster Creek Dam and Reservoir Site

The Foster Creek Dam and Reservoir site is a potential new off-channel storage alternative located on Foster Creek, near Chief Joseph Dam, adjacent to the Columbia River. Because this site has significant geotechnical concerns, in combination with a high downstream hazard condition, this proposed dam and reservoir site is believed to have “fatal flaws,” and therefore has been removed from further consideration.

The following is a summary of geotechnical issues associated with the construction of a large dam at the Foster Creek site:

1. **Settlement and Stability of Dam Foundation**: Because of the height (approximately 640 to 890 feet above the existing creek bed for 1 million to 3 million acre-feet reservoirs) and immense weight, this proposed dam should be constructed on a bedrock foundation to reduce settlement and stability issues and reduce risk of dam safety problems. Near the proposed left abutment, much of the bedrock is covered by stratified, fine-grained glaciolacustrine deposits, and also possibly landslides and glacial till. Based on available information and geologic interpretations, it is anticipated that depth to bedrock is possibly in the range of 200 feet bgs under much of the left side of the dam. The right abutment of the proposed dam would be underlain by stratified, fine-grained glaciolacustrine deposits, coarse-grained gravelly glacial outwash deposits, and landslides that consist of mixed rock and soil, and a few zones of shallow bedrock. It is anticipated, based on available information and geologic interpretations, that in the vicinity of the proposed right abutment the surficial materials may be more than 100 feet thick in some places. Therefore, very large excavations between 100 and 200 feet deep, and more than 0.5 mile wide, as well as extensive dewatering, would be required to build the dam on bedrock. The conceptual height of this dam above bedrock could be 855 to 1,105 feet in height to provide 1 million to 3 million acre-feet of storage. If constructed, Foster Creek Dam would be one of the largest dams ever constructed.
2. **Seismic Risk**: The proposed dam is located in a zone of relatively low seismicity from local faults. However, the general seismic hazard is relatively high, because of the possibility of large subduction zone earthquakes that may occur in the region. The failure of such a big dam during a seismic event poses enormous threat to Chief Joseph Dam and the town of Bridgeport, which are approximately 1 mile downstream from the proposed Foster Creek Dam site.
3. **Instability During Rapid Drawdown**: Because of the height of the proposed dam, draining the reservoir to meet water demands over a short time period would necessitate a rapid drawdown rate. Rapid drawdown would likely cause numerous slope failures in the saturated glaciolacustrine sediments that line much of the reservoir side slopes. The slides could result in severe water quality issues (that is, very turbid water releases), and plugging or damage to inlet and outlet facilities.

4. **Landslides**: Large landslides have been mapped at the proposed right abutment and immediately northwest of the proposed left abutment. The landslides consist primarily of mixed blocks of basalt, Ellensburg Formation sedimentary rocks, and glaciolacustrine sediments. Some of the mapped landslides are very large, and are up to 1 square mile in area. Observations of the materials included in the landslides (such as large blocks of basalt) suggest that the landslides possibly originated in interbedded materials within the basalt flows, such as Ellensburg Formation, and are deep-seated. Landslides tend to remain unstable throughout their history and may reactivate when physically altered, saturated, or surcharged. The presence of the large landslides raises serious stability concerns for the proposed Foster Creek Dam.
5. **Large Embankment Volume Required**: It is estimated that the volume of material required to build this dam would be between 100 and 250 million cubic yards. This volume would require extensive quarrying and borrow areas. The duration of construction could be on the order of a decade or more, based on the average rates of hauling, placement, and compaction of fill materials.
6. **Potential Leakage**: The estimated leakage around this dam (through the abutments) is estimated to be high because of the floor of the reservoir being partially lined with highly-permeable glacial outwash and stream alluvium; and the abutments that would be in part underlain by interbedded basalt flows that would likely have permeable interflow zones. Extensive foundation treatment to reduce potential seepage would be required.
7. **Spillway Limitations**: The spillway could not be routed around the left or right abutment because there is no safe location to route the flood. A spillway over the right abutment would cross a large landslide and discharge into the forebay of Chief Joseph Dam. A spillway over the left abutment would also cross a large landslide and discharge into the town of Bridgeport. A glory-hole type spillway tower and tunnel could be constructed, but the tower would have to be located on an abutment several hundred feet high above the valley. The tunnel and outlet channel would have to be lined with concrete.

Other special considerations for the Foster Creek site include the following:

1. **Downstream Hazard**: A large population downstream of the site, in combination with dam safety concerns, indicates unacceptable risk or excessive costs to reduce risk.
2. **Road and Transmission Line Relocation**: Numerous large transmission lines from the Chief Joseph Dam powerhouse are in the footprint of the dam and would be inundated by the reservoir. SR-17 and a county road provide travel routes. The highway, the road, and the transmission lines would have to be relocated at great expense.
3. **High Overall Cost**: Because of the large fill volume required for the proposed dam and relocating the existing infrastructure elements, the estimated cost of constructing a dam at the Foster Creek site would easily be the largest of any of the options. While a conceptual layout has not been

prepared and a formal estimate has not been made, our opinion is that the constructed cost and relocations would be significantly higher than other options.

4.3.1 Site Characteristics

Site characteristic information is provided below to provide background information relative to geotechnical concerns.

Because this site has fatal flaws, no layouts have been presented in the drawings (plates) for the dam, appurtenant structures, diversion facilities, or conveyance facilities. However, Section 4.3.2 does provide written material to describe general characteristics of a dam and reservoir at this site, to provide some additional context for the fatal flow designation. In addition, cultural resources and environmental impacts were not evaluated for this site.

Location

The general area showing the location of the Foster Creek site relative to other dam sites compared in this study is shown in Figure 1-7.1. The Foster Creek drainage basin has a drainage area of 452 square miles. The drainage basin area lies more or less west of Banks Lake and south of and east of the Columbia River as shown in Plate 4-3.1. All plates are presented in Volume II.

The proposed dam site is located approximately 1.5 miles south of the Columbia River near Bridgeport, Washington. SR-17 runs through the east fork of Foster Creek toward Bridgeport. A county road runs up the west fork of Foster Creek and a local paved road runs eastward along the shore of Rufus Woods Lake, the reservoir behind Chief Joseph Dam. The configuration of the proposed reservoir is shown in Plates 4-3.2A through 4-3.2C.

Topography

The Foster Creek drainage basin is generally characterized by gently undulating plains and upland basalt plateaus that were in part covered by glaciers during the late Pleistocene. Elevations within the drainage basin generally vary from approximately elevation 1000 feet near the proposed dam site to approximately elevation 2300 feet at the southern and eastern parts of the drainage basin.

The topography of the drainage basin is controlled by relatively flat-lying basalt flows that were overrun by glaciers and partially scoured by ancient floodwater from the glacial Lake Missoula. Much of the drainage basin is relatively flat with low relief, with the exception of the relatively steep-sided canyon that Foster Creek has eroded through the plateau on its course to the Columbia River.

The topography at the dam site consists of a north-trending valley approximately 10,000 feet wide and 1,000 feet deep. The eastern and western sides of the valley at the proposed dam site are irregular benches and hummocky slopes as steep as 15 percent. The valley bottom at the dam site is approximately 1,500 feet wide and slopes downward slightly to the north at approximately 2 to 3 percent.

Geology

Local Geologic Setting The geology at this proposed dam site is complex and includes a variety of surficial deposits and bedrock. The left (western) abutment of the proposed reservoir is underlain by mixed glacial deposits, landslides, Ellensburg Formation sedimentary rock, and basalt bedrock. The right (eastern) abutment of the proposed reservoir is underlain by glacial deposits, landslides, and bedrock including gneiss and basalt. The floor of the Foster Creek drainage is filled with various glacial deposits and stream alluvium.

A geologic map of the area by WDNR is presented in Plate 4-3.3. Plate 4-3.4 shows a geologic map of the Foster Creek Dam site prepared using information from existing geologic mapping and geologic reconnaissance conducted during the site visit. Topographic and geologic information is shown on the dam axis cross section on Plate 4-3.5. A general description of the geologic map units included in the Foster Creek site geologic map follows.

Surficial Geologic Units Surficial geologic units near the proposed Foster Creek site include stream alluvium, glaciolacustrine deposits, glacial outwash, glacial till (drift), and landslides, as follows:

- Qal: Stream alluvium was deposited by Foster Creek and is limited to the valley bottom. The alluvium consists primarily of interbedded, cross-bedded lenses of rounded sandy gravels to gravelly sand, with occasional clay layers. These deposits are described on local well logs as “sands and gravels” and “sand and gravel and clay,” which appear to be indicative of the mixed glacial and alluvial deposits. The thickness of the alluvium, based on well drillers’ logs of the area, is up to approximately 100 feet. It is anticipated this material is highly permeable.
- Qgo: Glacial outwash is deposited in the lower portions of Foster Creek. The outwash is exposed along the lower parts of Foster Creek and was deposited by glacial meltwater. The outwash consists primarily of weakly stratified, rounded sandy gravels to gravelly sands. The gravels observed in the vicinity were up to cobble and boulder sized. The thickness of the outwash is estimated to be up to 100 feet, but is difficult to estimate based on available information.
- Qgl: Glaciolacustrine deposits have been deposited in the Foster Creek valley. The top of these deposits forms somewhat distinctive benches that have been eroded by post-glacial stream activity and exhibit a relatively high drainage density. The uppermost elevation of these deposits is estimated to be approximately elevation 1800 feet, below the basalt cliffs that crop out on the upper valley walls. These deposits are described as interbedded, stratified, laminated, light tan silty sand, sandy silt, and clay. In addition, based on local exposures, these deposits include 10 percent subrounded to rounded gravels and cobbles. Based on interpretive cross sections, the maximum thickness of the glaciolacustrine deposits is estimated to be up to 200 feet. One well log in the vicinity indicates that these deposits are 236 feet thick. These deposits overlie gneiss and basalt bedrock, and in some areas, such as the east side of the Foster Creek valley, the underlying bedrock is exposed where the lacustrine beds have been stripped away.
- Ql: Landslides have been mapped and were observed in the vicinity of the Foster Creek site. The landslides consist primarily of mixed blocks of basalt, Ellensburg Formation sedimentary rocks, and glaciolacustrine sediments. Large landslides are mapped at the location

of the proposed right abutment, northeast of the right abutment in the valley of the Columbia River, and in the vicinity of the left abutment. Some of the mapped landslides are very large, and are up to 1 square mile in area. The landslides are characterized by irregular, hummocky topography, and a steep, arcuate headscarp. No analyses of the age or current movement rates on the landslides were made during this investigation.

It is not certain whether these large landslides originated in the glaciolacustrine deposits, or within the bedrock layers. However, the materials in the landslides suggest that they possibly originated in interbedded materials within the basalt flows, such as Ellensburg Formation. Large landslides such as this have been mapped in other areas throughout the Columbia Basin, where heavy, solid basalt flows slide on saturated, weaker interbedded layers. The landslides are also likely to be relatively thick and deep-seated, as opposed to shallow surficial slumps. In addition, other large landslides may be in the vicinity that have been completely buried and are covered by glaciolacustrine materials and therefore are not currently evident. It also appears that there may be numerous smaller slumps and landslides throughout the glaciolacustrine deposits.

- Qt: Glacial till and drift has been mapped in the vicinity of Foster Creek. Glacial moraines have been mapped in the Columbia River and Foster Creek valleys, and vast deposits of glacial till are mapped on the surface of the flat plateaus above Foster Creek. The glacial till consists primarily of an unsorted, unstratified mix of boulders, sand, silt, and clay. The thickness of the glacial till is highly variable and likely ranges up to hundreds of feet thick.

Other minor geologic units in the vicinity but not shown on the map include talus/colluvium deposits and alluvial fans. The talus and colluvium deposits form aprons along the basalt cliffs in some areas. These deposits consist primarily of angular basalt fragments mixed with sand and silt. Small alluvial fans exist where the glaciolacustrine sediments were eroded by intermittent flows and redeposited near the base of the glaciolacustrine sediments near the bottom of the Foster Creek valley.

Bedrock Geologic Units Bedrock geologic units near the proposed Foster Creek site include sedimentary deposits of the Ellensburg Formation, Columbia River Basalt, and metamorphic tonalite gneiss. Basalt flows in the vicinity include normal and reversed magnetic polarity flows of the upper Grande Ronde Formation, and the Priest Rapids Member of the Wanapum Basalt. The basalt flows form the upper canyon walls of the Foster Creek valley and define the edges of the surrounding plateau. The basalt flows are well-exposed above elevation 1800 feet, where they are not covered by glaciolacustrine deposits or glacial till. The basalt cliffs define the upper edges of the Foster Creek valley. The interbedded basalt flows form cliffs with flat benches between the basalt flows. Based on site observations, the basalt is typically brown to gray, hard, and moderately to highly fractured.

Gneiss bedrock underlies portions of the lower Foster Creek valley. The gneiss was partially exposed in the lower valley walls of East Foster Creek, and in both sides of the Foster Creek valley in the vicinity of the confluence of Foster Creek and the Columbia River. Based on field observations, the gneiss is typically gray, massive, foliated texture, and granitic composition. Structurally, the gneiss exhibited steeply dipping joints that divided the gneiss into massive blocks.

The Ellensburg Formation is mapped between the upper Grande Ronde and Priest Rapids Members of the Columbia River Basalt flows in the vicinity of the left abutment. Outcrops of the Ellensburg Formation were also observed approximately 8 miles upstream from the dam site in the east fork of Foster Creek. Based on observations of the outcrops, this formation in this vicinity appears to consist of tan to gray, weakly cemented, horizontally stratified, tuffaceous sandstone to siltstone.

Reservoir Geology The geology of the reservoir consists of unconsolidated geologic deposits including alluvial deposits, glacial deposits, and landslides; and bedrock including sedimentary rocks, gneiss, and basalt. Below a general elevation of 1800 feet, the reservoir would be predominantly underlain by unconsolidated deposits including sandy and gravelly alluvial and glacial outwash deposits, stratified sandy and silty glaciolacustrine deposits, and landslides that contain a mixture of rock and soil. The floor of the Foster Creek drainage is filled with gravelly glacial outwash deposits and stream alluvium. Outcrops of gneiss and basalt bedrock are exposed where the surficial unconsolidated materials have been eroded away. Ellensburg Formation sedimentary rocks are exposed in the vicinity of the left abutment, and several miles upstream from the dam in East Foster Creek.

Damsite, Spillway, and Outlet Works Geology The geology at the proposed dam site includes a variety of unconsolidated geologic deposits and sedimentary, igneous, and metamorphic bedrock. The left (western) abutment of the proposed reservoir would be underlain by stratified, fine-grained glaciolacustrine deposits, glacial till, and landslides that consist of mixed rock and soil. Basalt and sedimentary bedrock, and possibly gneiss, underlie these deposits but are not exposed in the vicinity of the left abutment because of the thickness of the surficial deposits. Basalt flows and interbedded Ellensburg Formation sedimentary rocks are exposed above an elevation of approximately 1800 feet. The thickness of the surficial materials, based on interpretive cross sections, may be 200 feet or more. Springs and seeps were also observed near the proposed left abutment, which indicates zones of perched water are present.

The right (eastern) abutment of the proposed reservoir is underlain by stratified, fine-grained glaciolacustrine deposits, coarse-grained gravelly glacial outwash deposits, and landslides that consist of mixed rock and soil. Outcrops of gneiss and basalt bedrock are exposed in the vicinity of the right abutment, which indicates that in some areas the surficial materials are thin and have been eroded away. However, in other areas near the proposed right abutment, the surficial materials are likely to be more than 100 feet thick, based on geologic observations and interpretations.

The floor of the Foster Creek drainage at the bottom of the proposed dam is filled with sandy and gravelly glacial outwash deposits, and sandy and gravelly stream alluvium. These deposits are estimated to be up to 100 feet or more thick in the vicinity of the dam footprint, based on water well logs in the vicinity. Gneiss bedrock is also exposed in some areas in the right side of the valley in the vicinity of the dam footprint.

The spillway would have to consist of a morning glory type of spillway, where the flood flows enter a fish screen/diffuser structure and are routed through a tunnel and/or conveyance pipeline under the dam and underground toward the Columbia River. The spillway tunnel alignment would cross through a variety of geologic materials, including gravelly glacial outwash deposits, glacial till, and hard, competent gneiss bedrock. The tower could be founded on gneiss bedrock.

The outlet works would be constructed in an area having deep glacial deposits, alluvial deposits, or possibly gneiss bedrock, depending on the preferred location.

Groundwater

Groundwater in the vicinity of the Foster Creek site is found primarily in the alluvial deposits that fill the bottom of Foster Creek, and in perched zones in the hillsides along the valley. The alluvial deposits consist of sands and gravels that readily transmit groundwater. The permeability of these deposits is anticipated to be high, based on coarse-grained material types.

Seven well logs were identified in the general vicinity of the proposed dam and lower part of the reservoir. Most of the wells were drilled in the lower part of the valley, either in glacial deposits or alluvium. The well logs indicate relatively thick alluvial and glacial sediments in the valley bottom underneath the proposed dam footprint. One of the well logs indicates a confining clay layer at 36 feet bgs, with artesian water pressure below the clay. In general, the sands and gravels appear to be loose and pervious. Depth to water in vicinity wells is between 15 and 70 feet bgs. Groundwater yields range from 20 to 60 gpm.

Localized, perched zones of groundwater appear to be present throughout the glaciolacustrine deposits and at the base of basalt flows or contact with the Ellensburg Formation. This groundwater discharges as springs and seeps along the valley walls. Numerous springs and seeps were observed during the site visit, and locations of these are noted on the geologic map. These springs and seeps likely discharge infiltrated snowmelt, precipitation, and irrigation percolation from the plateau above. The discharge from these springs and seeps was not measured. However, numerous large trees were observed in the vicinity of these seeps, which suggests that the springs and seeps may flow perennially.

Seismotectonics

The proposed Foster Creek Dam is located in an area of relatively low seismicity from local faults. However, the general seismic hazard is relatively high, presumably because of the possibility of large subduction zone earthquakes that may occur in the region. No potentially active faults (described as "Class A," which is defined by the USGS as "geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features") are mapped within 75 miles of the proposed Foster Creek Dam site.

Based on the USGS seismic hazard, the probabilistic ground motion at the proposed Foster Creek Dam site is approximately 0.1 g for a 10 percent probability of exceedance in 50 years (500-year return period) and 0.21 g for a 2 percent probability of exceedance in 50 years (2,500-year return period).

4.3.2 Project Facilities

Dam and Appurtenant Structures

Preliminary evaluations considered the possibility of developing the site with the goal of storing a minimum of 1 million acre-feet and as much as 3 million acre-feet of water in the proposed reservoir. Table 4-3.1 shows the storage volumes, surface area, estimated dam heights, estimated embankment volumes, and water surface elevations for the three operational scenarios.

The base footprint of the dam would cover a valley bottom width ranging from elevation 2360 to 2850 feet, measured perpendicular to the dam axis, depending on the height of the dam.

A dam of this height approaches the size of the largest rockfill dams ever constructed in the world, and only a small handful of dams have been constructed to heights greater than this. Many important design considerations are associated with the construction of an embankment dam this large. Initial evaluation of conditions at Foster Creek led to several significant issues that led to the fatal flaw determination.

Potential Borrow Sources Inspection of the dam site and reservoir area was made for potential borrow sources for construction materials. Surficial soils within the reservoir area consist primarily of silt, sand, and other well-graded mixtures of silt, sand, and gravel. The thickness and distribution of these alluvial and colluvial sediments is not well known and must be investigated to confirm the presence of adequate quantities and quality of borrow for use in the dam.

A rockfill dam at this site would require a very large amount of material (see Table 4-3.1). The rockfill embankment should consist primarily of angular rockfill from required excavations and from selected quarry areas developed for that purpose. The plateau that surrounds the reservoir site contains an abundance of hard basalt rock that could be quarried as borrow material for the dam and as a borrow material for filters and aggregate for the concrete barrier facing. The basalt, through quarrying, should provide the required volume of rockfill for the project. It is anticipated that the basalt rock would meet the gradation and durability requirements for rockfill dam construction.

A concrete membrane liner would require well-draining filter zones under the concrete and a continuous rock foundation and plinth under the upstream toe of the dam. The filter materials can be constructed from basalt sources in the valley and abutment areas of the dam. For purposes of this evaluation, it is assumed that the rock for rockfill in the dam and filters would be mined from rock from nearby exposure areas within the reservoir. The filters would require processing to achieve the required gradations. However, the excavations must be monitored to ensure that poor-quality, fractured rock that may be subject to leakage is not left exposed in the quarry walls and floors without removing and/or sealing.

TABLE 4-3.1
Foster Creek Dam and Reservoir Data

	Storage Volume (acre-feet)	Surface Area (acres)	Dam Height[1] (ft)	Dam Embankment Volume[2] (yd^3)	Maximum WSEL (ft)
Foster Creek	1,000,000	4,850	655	91,316,379	1635
Foster Creek	2,000,000	8,850	810	167,145,600	1790
Foster Creek	3,000,000	12,650	905	230,232,871	1885

[1]Height above the valley bottom to the maximum water surface elevation plus 15 feet freeboard.
[2]Based on 1.5H:1V upstream and downstream slopes.

Dam Alignments The dam alignment that was evaluated is shown in Plate 4-3.2A. This location was selected because portions of the valley abutments are slightly narrower at this location and the dam axis is closer to required conveyance and diversion facilities that would be located adjacent to the Columbia River. The length of the dam would be roughly 9,500 feet at crest elevation 1650 and 14,000 feet at crest elevation 1900 feet. SR-17 and the Bridgeport Hill Roads currently occupy a portion of the lower valley. Numerous electric transmission towers are currently located within the footprint of the proposed dam and in portions of the area that would be flooded by the proposed reservoir. These structures must be relocated to suitable locations.

Plate 4-3.5 shows geologic and topographic information. The section illustrates the locations and size of numerous terraced benches consisting of lacustrine sediments and the presence of steep exposures of basalt at higher elevations of the valley.

Dam Foundation As noted previously, the dam should be founded on competent bedrock. However, bedrock at this location in the valley is likely covered by 200 feet or more of alluvial and glacial sediments. The depth to the water table is estimated to be between 15 and 70 feet in the vicinity of the dam foundation. This depth to bedrock and variability of bedrock surfaces can only be roughly estimated from limited knowledge of geomorphic evidence unless borings are drilled to confirm the subsurface conditions.

The bedrock under the dam and in the abutments of the dam is expected to consist of gneiss and basalt. The majority of the abutment contact areas for the proposed dam are expected to consist of basalt flows. Some zones within the abutments are expected to encounter interbedded zones of soil such as the Ellensburg Formation or other weaker, interbedded sediments that could have caused landslides at both abutments.

Near the proposed left abutment, much of the bedrock is mostly covered by stratified glaciolacustrine deposits, and also possibly landslides and glacial till. The glaciolacustrine deposits consist of stratified fine sand, sandy silt, silt, and possibly clay. It is anticipated that the strength of these deposits is inadequate to support a dam foundation, and therefore would also need to be removed so the abutments could be built on rock.

The right abutment of the proposed dam is underlain by stratified, fine-grained glaciolacustrine deposits, coarse-grained gravelly glacial outwash deposits, and landslides that consist of mixed rock and soil. Outcrops of gneiss and basalt bedrock are also exposed in the vicinity of the right abutment, which indicates that in some areas the surficial materials are not as thick as under the proposed left abutment. Although the large landslides in the vicinity may not currently be active or subject to movement, landslides tend to remain unstable, and are likely to fail or start moving when disturbed or subjected to loading.

Water well logs show that the water table is expected to be well above the bedrock surface within the valley bottom areas. The stream, as well as groundwater, must be controlled before excavation to expose bedrock under the dam could proceed. This would include suitable diversion facilities to capture runoff from the existing streams. Foundation preparation would also include extensive dewatering and/or cutoff walls as required to contain and control groundwater within all excavation areas and under the entire footprint for the base of the dam foundation. The depth and size of the required excavations is expected to be extensive, and diversion of streams and control of groundwater within extensive pervious sediments under the dam is expected to be a significant issue for construction at the proposed dam site.

It is assumed that the natural rock foundation for the dam would require grouting and construction of a permanent seepage cutoff system. These elements should be constructed and the embankment materials placed to bring the constructed grade back up to the existing ground surface under the dam.

Spillway As discussed previously, the depth to bedrock foundations in many areas could be relatively deep on both abutments. Also, significant areas of both abutments could be affected by landslides. These factors combined with the difficult terrain make siting of a spillway difficult at this site. The town of Bridgeport is located directly downstream of the left abutment, and high, near-vertical basalt cliffs and areas containing landslides are located downstream of the right abutment. A spillway layout using an open-cut type spillway is not recommended based on these constraints. Extensive deep borings would be required to further evaluate suitable options for development of concepts for a spillway.

Reservoir

Plates 4-3.2A through 4-3.2C show the proposed reservoir configuration. The reservoir created by a dam as proposed for the Foster Creek site would result in a lake that is approximately 2 to 2.5 miles wide at the dam, approximately 7 miles long along the mainstem Foster Creek, and approximately 4 miles long along West Foster Creek. The reservoir is characterized by significant water depth and width near the dam, but steep existing stream gradients and narrow steep-sided canyons within both stream valleys limit the storage capacity of the site. This configuration results in a very high dam to achieve the required minimum water storage volume at this site.

Saturation during high reservoir water levels combined with rapid drawdown during water releases could lead to areas of instability in the glaciolacustrine sediments and existing landslides. Slope failures near the fish screen/diffuser structures could damage or clog the intakes. If landslides occur, the resulting steep-sided scarps and exposures could continue to erode and lead to turbidity within the reservoir in the vicinity of the unstable conditions.

Wave action and variable water levels within the reservoir would be expected to lead to erosion and turbidity along the shorelines in areas of alluvial, colluvium, and fine-grained lacustrine sediments. This erosion process may tend to stabilize over a period of time as the exposed slopes become reinforced with natural sand and gravel and talus rock on the exposed surfaces.

Where the water surface is in contact with erosion-resistant materials such as talus slopes and rocky colluvial deposits, waves may cause limited erosion and may form steep, wave-cut slopes. Conditions such as this have developed within the reservoir sideslopes along Lake Roosevelt, and provide a good example of expected conditions where the lake is in contact with similar material types.

Little is known about potential for reservoir leakage at this location through the abutments or floor of the reservoir. Leakage through interbeds and fractured zones of rock in the abutments is a possibility, and it is anticipated that grouting and/or cutoff to less-permeable rock would be required. Significant areas of the valley sediments near Foster Creek are currently blanketed with thick deposits of silt, sand, and other alluvial sediments that are expected to help form a natural barrier to vertical seepage in the base of the reservoir in these areas. These conditions, combined with foundation grouting are expected to lead to minimal seepage from most of the reservoir.

For preliminary purposes, it is estimated that seepage through the reservoir floor and side would be an average of 16 acre-feet/month/acre, or approximately 110,000 acre-feet/month for the reservoir at maximum pool level. This is a large amount of estimated potential seepage, and is due to the portions of the reservoir floor that would be underlain by the highly permeable glacial outwash and alluvial deposits, as well as potentially permeable basalts in the abutments. However, the amount of seepage would vary with water depth, and likely be greatest during the initial reservoir filling before the reservoir floor becomes coated with silty material. In addition, grouting and seepage control in the vicinity of the dam would be included in the dam design. Erosion and slumping of the glaciolacustrine deposits during reservoir drawdown would create a high concentration of suspended solids in the water, which would settle to the bottom of the reservoir and should eventually result in a fine-grained, low-permeability coating on the reservoir floor.

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4.4 Hawk Creek Dam and Reservoir Site

The Hawk Creek Dam and Reservoir site is a potential new off-channel storage alternative located on Hawk Creek, near Lake Roosevelt on the Columbia River. The Hawk Creek Dam and Reservoir site would be approximately 4,000 feet wide at the proposed dam site and extend approximately 3 miles to the north along Snook Creek, approximately 6 miles east along Indian Creek, and approximately 10 miles south along Hawk Creek. As described in Section 3.2, three operational scenarios are under consideration for the Hawk Creek site, and each would result in a different reservoir volume:

- **OS1:** 1 million acre-feet
- **OS2:** 2 million acre-feet
- **OS3:** 3 million acre-feet

Elevation ranges from 1400 near the proposed dam site to approximately 2500 feet at the eastern portion of the drainage basin. The project would include a lake tap from Lake Roosevelt, a supply tunnel system, a pumping plant and separate pump/turbine facility, additional fill/release tunnels, a smaller rockfill dam creating a forebay, and the large rockfill dam providing the off-channel storage that is the focus of this project.

4.4.1 Site Characteristics

Location

The general area showing the location of the Hawk Creek site relative to other dam sites compared in this study is shown in Figure 1-7.1. The Hawk Creek drainage basin has a drainage area of approximately 164 square miles in size. The drainage basin is relatively small, extending east and southeast from the southeast side of the Columbia River toward the small town of Davenport, Washington, as shown in Plate 4-4.1. All plates are presented in Volume II.

The proposed dam site is located approximately 3 miles southeast of the Columbia River, and approximately 1.5 miles east of the end of a small bay that extends east of the main body of Lake Roosevelt and would not need to be relocated. The site is located approximately 6 miles south of where the Spokane River enters Lake Roosevelt.

The new reservoir would be irregularly shaped and approximately 4,000 feet wide at the proposed dam site. The lake would extend approximately 3 miles to the north along Snook Creek, approximately 6 miles east along Indian Creek, and approximately 10 miles south along Hawk Creek. Snook Creek and Indian Creek are both tributaries of Hawk Creek. The reservoir width would become relatively narrow (0.25 mile or less) in portions of the narrow steep-sided canyons of the tributary basins. The configuration of the proposed reservoir is shown in Plates 4-4.2A through 4-4.2D.

The Miles-Creston Road runs north-south through the Hawk Creek Basin between the proposed dam and the bay at Lake Roosevelt, but is likely to be permanently affected by the project. However, other county gravel roads would be inundated by the reservoir including Indian Creek Road and Hawk Creek Road.

Topography

The Hawk Creek drainage basin is generally characterized by a flat, upland basalt plateau incised by Hawk Creek and its tributaries into a dendritic drainage pattern. Elevations within the drainage basin generally vary from approximately elevation 1400 feet near the proposed dam site to approximately elevation 2500 feet at the eastern part of the drainage basin.

The topography of the drainage basin is controlled by relatively flat-lying basalt flows. Much of drainage basin is relatively flat with low relief, with the exception of the relatively steep-sided canyons eroded by Hawk Creek and its tributaries. These steep-sided valleys are up to approximately 1,000 feet deep where Hawk Creek drains down to the Columbia River. The side slopes of the valley are relatively planar to benched, due to the layered basalt flows that underlie the valley walls.

The topography at the dam site consists of a west- to northwest-trending valley approximately 1,000 feet wide at the valley bottom. Valley side slopes are as steep as 60 percent at the proposed left abutment, and 25 to 40 percent at the proposed right abutment.

Numerous homes and limited utilities would be displaced near the dam and within the reservoir area of Hawk Creek and its tributary drainages. Gravel roads along Snook Creek, Indian Creek, and Hawk Creek would be inundated by the reservoir.

Socioeconomic Conditions

The Hawk Creek site is located south of SR-25 with most of the area accessed by local unimproved roads. It appears that land ownership of the Hawk Creek area is predominately private; however, ownership data is incomplete. The proposed reservoir site contains a mixed riparian community surrounded by open ponderosa pine forest on the slopes and a mosaic of dry grassland and dryland agriculture on hilltops. Because the area contains several tributaries to Hawk Creek, riparian and open water resources are common, which indicate that there is likely recreational use. The area contains several campgrounds and recreationists enjoy swimming, fishing, boating, hiking, and camping. No railroad tracks are located within the proposed reservoir footprint. A small section of transmission line is currently located within the proposed Hawk Creek site. Section 3.5.1, *Socioeconomic Factors and Criteria*, lists the land ownership, uses, and infrastructure factors that are considered in the socioeconomic characterization and effects analysis.

Land Ownership The distribution of private, state, and federal land ownership within the Hawk Creek site is described below.

Private Ownership Based on existing data, the Hawk Creek drainage appears to be dominated by private land ownership; however, ownership databases are incomplete.

State Ownership State owned lands are minimal within the Hawk Creek drainage, based on existing, limited data.

Federal Ownership Federally owned lands appear to be minimal within the Hawk Creek drainage.

Land Use The general characteristics of land uses are described in the *Socioeconomic Conditions* section for Crab Creek.

Residential Use Within the Hawk Creek proposed project, area homes are diffuse and relatively remote. No residential center or areas of commerce have been identified within the proposed site boundary. Approximately 40 residences are located throughout the Hawk Creek drainage.

Agriculture Based on the land use data set, no agricultural lands are located within the proposed alternative.

Infrastructure The most prevalent structures in the area are residences and associated outbuildings. No state or federal highways cross the proposed alternative. Local roadways are present within the proposed footprint and would be inundated by this alternative. No railroad tracks are present within the Hawk Creek site. The Hawk Creek site contains 1 mile of transmission line that would need to be relocated.

Cultural Features and Developments

Hawk Creek contains known cultural resource sites, as well as potential sites that could be located in the future as more of the area is surveyed for cultural resources. The regulatory framework and ranking system (0 to 10) for cultural resource evaluation is presented in Section 3.5.2, *Cultural Resources.* Currently, only five archaeological sites have been documented within the footprints of the three operational scenarios. The five sites are prehistoric and consist of rock cairns, talus pits, and a rock shelter. Surveys and site documentations completed to date have been performed to evaluate the effect of other projects on heritage resources. Inventoried areas are extremely limited and as a result, no site densities are available for the Hawk Creek area. Therefore, assumptions are made based on the Crab Creek and Sand Hollow information. This provides limited information to allow predictions about the effects on the Hawk Creek area.

One hundred percent (5) of the previously recorded sites date to the era of American Indian settlement that pre-dates European settlement (circa 10,000 B.C. to the mid-1800s). Prehistoric site types consist of a rock shelter, talus pits, and rock cairns. Most of these sites are relatively short-term locations or places where people processed plants, butchered animals, collected and worked tool stone, or carried out other activities as part of their cycle of life. These sites probably represent activities by people as part of their seasonal rounds who were otherwise based in nearby valleys. Many more American Indian sites probably exist along Hawk Creek. The cultural resources in most of the Hawk Creek area have not been systematically inventoried. Large drainage channels such as Hawk Creek routinely contain large quantities of cultural resources. Current information indicates drainage bottoms, floodplains, and talus slopes represent the greatest concentration for potential archaeological sites, thus creating high-probability locations for areas that remain to be inventoried. A high potential exists for prehistoric sites primarily along the valley floor between ridge tops and drainage bottoms. Sites would probably diminish in size and numbers as the distance from the valley floor increases.

Hawk Creek has also been identified as a TCP. The Spokane Tribe and other Native American groups continue to visit the area for spring root harvests and other traditional activities (Gough, 2006). Their identification and long-term protection depends primarily on consultation with the Colville, Coeur d’Alene, Spokane, and Yakama Tribes and the SHPO. A high potential for TCPs associated with each of the Hawk Creek options exists.

No historic European-American settlement era sites have been recorded in any of the three operational scenarios. Sites primarily related to ranching and farming from the twentieth century such as farms, homesteads, or other standing buildings are likely to be present. Such sites might also include debris scatters or rock or earthen structures associated with ranching activities or mineral prospecting, likely dating from the mid 1850s. Overall, there is only a moderate potential for the Hawk Creek options to contain historic sites.

No NHRP or Washington Heritage Register sites are currently recorded in the Hawk Creek project area. Once again, this is somewhat misleading. Although no sites are currently listed on the NRHP or Washington Heritage Register, there would be eligible sites once a full inventory is completed, sites recorded, and DOEs completed. A high potential exists for eligible sites for each of the operational scenarios.

In addition, under the Hawk Creek options, the evaluation of lands that would be converted to agricultural production as the result of additional water storage would be conducted under a future phase of project implementation. Future development would be subject to separate environmental analysis.

Archaeological sites are recorded in the general area of the dam and appurtenant structures. No information is available regarding TCPs. Therefore, the assumption is that the Hawk Creek Dam and appurtenant structures would have similar cultural resources as the reservoir operational scenarios.

Environmental Conditions

Similar to Sand Hollow, few environmental resources are present at the potential Hawk Creek site, according to data readily available in the literature. This site has not been surveyed with the intensity of the Crab Creek site. Section 3.5.3, *Environmental Factors and Criteria*, lists the habitats, species, and special areas that are considered in the environmental analysis.

Special Status Species This factor includes criteria for species that are unique to this habitat or are listed as imperiled by federal or state agencies.

Anadromous Species No anadromous species are present in Hawk Creek or at the proposed reservoir site because of blockage of fish movement downstream at Chief Joseph Dam on the mainstem Columbia River.

Aquatic FT Species No aquatic FT species are found at this proposed reservoir site (WDFW, 2004). However, bull trout (FT) occurs from approximately the lower 3 miles of Hawk Creek to near the base of a 30-foot high natural falls approximately 0.8 mile downstream of the proposed Hawk Creek Dam site (Ecology, 2007). The natural falls block all upstream fish movement (MWH, 2005). Bull trout spawn during the fall, eggs incubate over winter, and fry emerge the following spring.

Aquatic SC Species No aquatic SC species are found at this proposed reservoir site (Ecology, 2007). The bull trout (SC) occurs in the lower 3 miles of Hawk Creek, downstream of the proposed Hawk Creek Dam site.

Terrestrial FT or FE Species Spaulding’s silene (*Silene spaldingii*) is a FT plant species located at this site.

Terrestrial ST or SE Species As mentioned above, only one ST terrestrial species, Spaulding’s silene, currently occupies habitat at this site, which has a state rank of S2 and is ST. Least bladdery milk-vetch (*Astragalus microcystis*) was historically found here. It has a state rank of S2 and is state listed as Sensitive.

State Priority Species (SPS) Aquatic SPS reported to occur in Hawk Creek include largemouth bass, walleye, and rainbow trout (Ecology, 2007). It is likely that largemouth bass and walleye are associated with Lake Roosevelt populations, and occur in reservoir backwaters and lower Hawk Creek downstream of the 30-foot-high natural falls. Rainbow trout may occur upstream of the natural falls within the proposed Hawk Creek Reservoir site.

Special Status Habitats No special status habitats are present, except for riparian/open water.

Open Water or Riparian Open water resources are common throughout the Hawk Creek drainage area of the reservoir footprint.

Geology

The general geologic setting of the Columbia River Basin is described in Section 3.5.4.

Local Geologic Setting Hawk Creek flows through a plateau underlain by the CRBG. An intrusive plug of granite is also mapped upstream from the dam. The dam site and floor of the proposed reservoir would be underlain by alluvium of Hawk Creek and glaciolacustrine deposits. The basalt plateau surrounding the reservoir is largely mantled with silty loess deposits.

The basalt bedrock in the vicinity of the Hawk Creek site is flat-lying with little or no folding or warping. No faults, folds, or other major geologic structures are mapped in the vicinity.

A geologic map of the area by WDNR is presented in Plate 4-4.3. Plate 4-4.4 shows a geologic map of the Hawk Creek Dam site prepared using information from existing geologic mapping and geologic reconnaissance conducted during the site visit. Topographic and geologic information is shown on the dam axis cross section on Plate 4-4.5.

Bedrock geologic units in the vicinity of the proposed Hawk Creek site include Columbia River basalt flows and an intrusive granodiorite plug, and is described in Appendix B. Surficial geologic units in the vicinity of the proposed Hawk Creek site, also described in Appendix B, include stream alluvium and glaciolacustrine deposits in the valley bottom, and talus/colluvium along the valley walls.

Project Facilities Geology The geologic setting for all project facilities consists primarily of the bedrock Columbia River basalts. Facility-specific geologic issues are described in detail in Appendix B and summarized below:

- **Reservoir Geology.** The side walls of most of the proposed reservoir area would be underlain by relatively flat-lying basalts, and the granodiorite intrusion. The floor of the proposed reservoir would be underlain primarily by silty, sandy, and gravelly alluvium of Hawk Creek and fine silty sand and silty glaciolacustrine deposits.
- **Damsite, Spillway, and Outlet Works Geology.** The left abutment of the proposed Hawk Creek Dam would be underlain by relatively flat-lying basalts of the CRBG and glaciolacustrine deposits. The right (north) proposed abutment location is underlain by glaciolacustrine deposits between the floor of the valley and approximately elevation 1680 feet. The outlet works would be founded primarily on basalt bedrock or alluvium that underlies the valley floor.
- **Intake, Combined Pumping/Turbine Facility, Conveyance, and Power Transmission Facilities Geology.** Hawk Creek enters Lake Roosevelt and forms a somewhat narrow, steep, twisting inlet lined in part by basalt bedrock, and infilled with alluvium and glaciolacustrine sediments. The lower intake structure is anticipated to be a lake tap bored through basalt

bedrock on the south side of the Hawk Creek inlet of Lake Roosevelt. The combined pump/turbine facility would primarily be founded either on or deep within basalt bedrock on the south side of the Hawk Creek inlet.

Groundwater

Groundwater near the Hawk Creek site is found primarily in the alluvial deposits that fill the bottom of Hawk Creek, and in fractured zones within the basalt bedrock. The alluvial deposits consist of clays, silts, sands, and gravels that transmit groundwater. The permeability of these deposits is anticipated to be moderate to high, depending on the local material types.

Wells in the valley bottom closest to the location of the proposed dam footprint indicate more than 80 feet of unconsolidated materials that range from gray clay to wet sand. Depth to water in wells in the valley bottom ranges between 20 and 40 feet bgs. One of the well logs indicates artesian water, presumably the result of confinement by clay layers. Groundwater well yields in the vicinity range from 8 to 45 gpm.

Groundwater in fractured basalt interflow zones was also noted in well drillers' logs. Localized, perched zones of groundwater may be present between basalt flows that form the canyon walls and would discharge as springs and seeps along the canyon walls.

Seismotectonics

This proposed dam would be located in an area of relatively low seismicity. No potentially active faults (described as "Class A," which is defined by the USGS as "geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features") are mapped within 75 miles of the proposed Hawk Creek Dam site.

Based on the USGS seismic hazard, the probabilistic ground motion at the proposed Hawk Creek Dam site is approximately 0.06g for a 10 percent probability of exceedance in 50 years (500-year return period) and 0.13g for a 2 percent probability of exceedance in 50 years (2,500-year return period).

Probable Maximum Flood

The drainage basin area at the Hawk Creek Dam site is approximately 164 square miles. The PMF was very roughly estimated from the PMF reported by Reclamation for Cold Springs Dam and Conconully Dam (Reclamation, 2007a and 2007c) based on the ratio of the drainage basin areas. The peak inflow volume and flowrate used for the conceptual spillway layout and design at Hawk Creek are 60,000 acre-feet and 40,000 cfs, respectively. No flood routing was performed to estimate the spillway flow requirements (Reclamation, 2007a and 2007c).

4.4.2 Project Facilities

Main Off-Channel Dam and Appurtenant Structures

To achieve the required storage, the proposed dam at Hawk Creek would be one of the largest rockfill dams in the world. A rockfill dam appears to be the most appropriate type of dam for this site. Plate 4-4.6 shows the potential layout for the dam and appurtenant structures, pipelines, diversions, spillway, channels, as well as existing structures and facilities in the vicinity of the proposed dam.

Table 4-4.1 shows the storage volumes, surface area, estimated dam heights, estimated embankment volumes, and water surface elevations for the three operational scenarios.

Many important design considerations are associated with the construction of an embankment dam this large. However, an initial evaluation of the conditions at Hawk Creek led to the conclusion that a safe dam could be constructed at this site, and that no unusual measures or features beyond what is typical for a major embankment dams would be required.

A rockfill dam appears to be the most appropriate type of dam for this site. A dam of this height approaches the size of the largest rockfill dams ever constructed in the world, and only a small number of dams have been constructed to heights greater than this. The base footprint of the dam would cover a valley bottom width ranging from 1,950 to 2,530 feet, measured perpendicular to the dam axis, depending on the height of the dam. Plate 4-4.7 shows two typical cross sections for proposed rockfill dams at this location. The crest of the proposed dam is assumed to be 40 feet wide.

A rockfill-type dam is also advantageous considering the location in a zone of potential seismicity. High ground motions require a dam type that is seismically stable even under large loadings. Rockfill dams are recognized to be one of the most earthquake-resistant dams, primarily because the design affords a large downstream portion that retains high-strength, possesses high permeability, and thereby remains unsaturated, while allowing seepage water to pass through in the event that the impervious element of the dam is cracked or damaged during a seismic event.

As a result of the considerations listed previously, a zoned rockfill dam with continuously grouted foundations, abutments, and impervious water barrier is recommended at this stage of this project for this site. Two types of water barrier designs could be considered at this site including either a central impervious earth core or sloping upstream earth core, and a dam having an upstream concrete facing. The central or sloping earth core dam configurations would require a significant quantity of well-graded silty sand, or silty sand and gravel for the core. Processed filters would be required with either of these options, but carefully controlled processing and monitoring would be required to ensure that silty non-plastic earth core materials are controlled from piping if used for the earth core options. The remainder of the embankment should consist primarily of angular rockfill from required excavations and from selected quarry areas developed for that purpose.

TABLE 4-4.1

Hawk Creek Dam and Reservoir Data

	Storage Volume (acre-feet)	Surface Area (acres)	Dam Height[1] (ft)	Dam Embankment Volume[2] (yd^3)	Maximum WSEL (ft)
Hawk Creek OS1	1,000,000	5,200	537	38,108,290	1916
Hawk Creek OS2	2,000,000	8,500	687	71,147,884	2066
Hawk Creek OS3	3,000,000	11,750	780	99,384,104	2159

[1]Height above the valley bottom to the maximum water surface elevation plus 15 feet freeboard.
[2]Based on 1.5H:1V upstream and downstream slopes.

The rockfill dam at this location could be constructed using either type depending on the availability and quality of borrow materials. Well-graded filters would be required with either of these options. The embankment should consist primarily of angular rockfill from required excavations and from selected quarry areas developed for that purpose.

For the rockfill dam having a sloping concrete water barrier membrane on the upstream face, 1.5H:1V upstream and downstream slopes are assumed at this stage of the project. The slopes selected are a function of the size, durability of the rock, and rock quality of materials used for rockfill as well as seismic loading. Steeper slopes may be achievable as the design progresses to more detailed stages.

The basalt rock throughout the vicinity of the reservoir appears to be highly fractured and readily breaks down into sizes commonly ranging from 3 inches to approximately 18 inches. Less than 10 to 20 percent of the rock appears to be larger than approximately 18 inches after multiple handling including blasting, dumping, dozing, and compaction in the dam. Much of the rock is likely to average 6 inches to 10 inches in size.

It is assumed that a concrete grout curtain/cutoff would be required to limit seepage through the foundation although little is known about the foundation of the dam at this site at this stage of evaluation.

Assumptions and Issues for Deep Excavations The tunnel junction chamber and pump chamber for the Hawk Creek inlets are anticipated to include large underground rooms excavated into basalt bedrock or possibly granodiorite. The chances that granodiorite would be encountered in this area are judged to be very slim, based on available geologic mapping, and therefore it is anticipated that the chambers would be in bedded basalt flows. The tunnel junction chamber is anticipated to have dimensions on the order of 220 feet long by 100 feet wide with a height of 50 feet (dimensions based on OS3). The pump chamber is anticipated to have dimensions on the order of 210 long by 85 feet wide with a height of 100 feet. Assuming the underground chambers are excavated into basalt, it is likely that the stability of the underground chambers would be questionable. This is due to the fact that the horizontally-bedded basalt flows would have weak horizontal seams that would not have the strength to support the ceiling. The locations of the weak interflow zones or sedimentary interbeds in the basalt are not known and would have to be determined by deep rock core borings. In order to overcome the possibility of roof collapse, the roof would likely have to be arched and supported with shotcrete, mesh and rock anchors, or possibly steel supports. These support structures would add to the cost but would be necessary in order to ensure stability of these underground openings.

Potential Borrow Sources Inspection of the dam site and reservoir area was made for potential borrow sources for construction materials. Surficial soils within the reservoir area consist of primarily of silt, sand, and other well-graded mixtures of silt, sand, and gravel. The thickness and distribution of these alluvial and colluvial sediments is not well known and must be investigated to confirm the presence of adequate quantities and quality of borrow for use in the dam.

As previously noted, the dam could either be concrete-faced rockfill or a rockfill dam with a well-graded silty sand and gravel core as the water barrier. Well-graded filters would be required with either of these options. The rockfill shells should consist primarily of angular rockfill from required excavations and from selected quarry areas developed for that purpose.

The area throughout the reservoir site contains an abundance of hard basalt rock that could be quarried as borrow material for the dam and as a borrow material for filters and aggregate for the concrete barrier facing. The basalt, through quarrying, should provide an adequate volume of rockfill for the project. It is anticipated that the basalt rock would meet the gradation and durability requirements for rockfill dam construction.

A concrete membrane liner would require well-draining filter zones under the concrete and a continuous rock foundation and plinth under the upstream toe of the dam. The filter materials can be constructed from basalt sources in the valley and abutment areas of the dam. For purposes of this evaluation, it is assumed that the rock for rockfill in the dam and filters would be mined from rock from nearby exposure areas within the reservoir. The filters would require processing to achieve the required gradations. However, the excavations must be monitored to ensure that poor-quality, fractured rock that may be subject to leakage is not left exposed in the quarry walls and floors without removing and/or sealing.

Dam Alignments The proposed dam alignment is shown in Plate 4-4.2A. For purposes of this discussion, the primary axis is indicated at the preferred location, but additional studies would be required to verify suitable foundation conditions at this location. Secondary axis locations were not evaluated at this site for the following reasons:

- Local site topography limits the locations at which a dam could be built to minimize its embankment volume
- The primary alignment maximizes the storage at the proposed reservoir by including three separate drainage tributaries
- The primary alignment places the dam and facilities as close as possible to Lake Roosevelt
- The primary alignment appears to have reasonable foundation and abutment conditions

Dam Axis The dam axis is shown in Plate 4-4.2A. The dam is shown having a straight alignment. Because of the weight of the proposed dam, it should be founded on competent bedrock, which is estimated to be between 80 and 100 feet bgs. The depth to bedrock and variability of bedrock surfaces can only be roughly estimated from limited knowledge of geomorphic evidence without borings to confirm the subsurface conditions, but is estimated to be at greater depth in the center of the valley and is likely relatively shallow near the abutments where rock is exposed at or near the ground surface.

The lower portion of the valley is roughly 1,400 feet wide and currently forms the channel and floodplain for Hawk Creek. Remnant lacustrine and alluvial deposits have formed terraces in the lower portion of the valley during the last ice age. The geologic and topographic cross section (Plate 4-4.5) illustrates the locations and approximate thickness of lacustrine deposits and the presence of steep exposures of basalt at higher elevations of the valley. The length of the proposed dam would be roughly 4,500 feet at crest elevation 1931, and 7,500 feet at crest elevation 2174 feet.

Dam Foundation The walls of the valley are formed by basalt bedrock, and the floor of the valley is underlain by alluvial deposits and glaciolacustrine deposits.

Based on observations during the site reconnaissance, the depth to basalt bedrock is very shallow at nearly all of the left abutment and on the right abutment above approximately elevation 1680 feet. In these areas, the overburden over bedrock is estimated to be less than 10 feet in most areas. Below elevation 1680 feet on the right abutment, alluvial/lacustrine deposits cover portions of the valley floor. The alluvial deposits are up to 80-feet thick in the vicinity of the dam footprint, based on well drillers' logs. The glaciolacustrine deposits are estimated to be up to 300 feet thick.

As discussed previously, a large rockfill dam at this site would require that the embankment be founded on competent bedrock foundations. The depth to bedrock and variability of bedrock surfaces can only be roughly estimated from limited knowledge of geomorphic evidence unless borings are drilled to confirm the subsurface conditions. However, based on existing information, it is thought that the bedrock would be shallow, particularly near the left abutment and deepest nearer to the center of the valley.

Water well logs show that the water table is expected to be well above the bedrock surface within the valley bottom areas (that is, the alluvium is mostly saturated with groundwater). Alluvial sediments in the valley bottom consist of silt, sand, and gravel and are expected to be pervious. The stream, as well as groundwater, must be controlled before excavation to expose bedrock under the dam could proceed.

Diversion and control of water during construction would include suitable diversion facilities to capture and divert runoff from the existing streams. Foundation preparation would also include extensive dewatering or cutoff walls as required to contain and control groundwater within excavation areas and under the entire footprint for the base of the dam foundation. The geologic and topographic cross section (Plate 4-4.5) illustrates the depth of the foundation excavation required under the base and abutment zones of the dam. The depth and size of the required excavations is expected to be large (between 80 and 300 feet), and diversion of streams and control of groundwater within pervious sediments under the dam is expected to be an important construction consideration at the proposed dam site.

Foundation preparation would require diversion of the existing stream around the work areas. It is assumed that the stream could be diverted in a channel and/or pipeline, around the work areas. This diversion would likely be made around one side of the valley while foundation preparation proceeds on the opposite side of the valley. Once foundation work is completed on one side of the valley and the base of the dam is constructed, the stream could be diverted to the opposite of the valley, and foundation preparation and groundwater control would proceed in a similar manner.

It is assumed that the natural basalt rock foundation for the dam would require grouting and construction of a permanent seepage cutoff system. These elements should be constructed and the embankment materials placed to bring the constructed grade back up to the existing ground surface under the dam.

Reservoir Inlet/Outlet Facilities The inlet/outlet structure would be constructed in a massive rock cut. The rock cut would be carefully shaped to a near vertical configuration, lined with thick concrete facings, and reinforced with rock bolts as required for stability. A concrete tower structure would extend up above the rock cut as required to reach to an elevation above the maximum water surface of the proposed reservoir. A bridge would be provided from the top of the dam (or from a point on shore) for access onto the top of the tower. Large roller gates are assumed for controlling the water to these inlet/outlets.

The tunnel(s) leading from the pump/turbine facility to the inlet/outlet structure would pass around the end of the dam, likely by means of a vertical access shaft creating an angle point, as shown on Plates 4-2.6 and 4-2.8. Because of the great water depth associated with Hawk Creek Reservoir, it is assumed that two tunnel levels would be used for the inlet/outlet facilities. The tunnel from the pump/turbine facility would be extended at the same grade to exit into a rock cut slightly below the dead storage level in the reservoir. A large vertical shaft would be constructed to connect to a higher elevation (mid height) tunnel that would connect to the base of the inlet/outlet structure. Hydraulically controlled roller gates in the tower would control the inlets/outlets for the upper structure and tunnel. A gate house and hydraulic hoist and gate rods would extend down to the lower tunnel to a large inlet gate, controlling water flows in the lower tunnel. The vertical shaft would also serve at the inlet/outlet shaft to convey water from the upper tunnel to the pump/turbine tunnel.

Spillway The PMF is anticipated to be contained within the reservoir and a spillway is not required. The PMF flood volume is estimated to be 80,000 acre-feet. The rise in water level if the entire PMF is stored is approximately 7 feet. Therefore, the PMF could be stored in the reservoir and released through the outlet tunnels. A small morning glory type of shaft leading to the tunnel outlet could also be constructed, in order to ensure the water level of 2177 is not exceeded, except for big storms. Eliminating the spillway requirements for both of the Hawk Creek dams would save a large sum of money. In addition to the above considerations, the topography and geology of the proposed Hawk Creek would make construction of a spillway very difficult and expensive.

Hawk Creek Forebay Dam

The proposed improvements also require the use a smaller dam at the forebay near Lake Roosevelt. This dam is required to impound water for the combined pump/turbine facility located near this smaller impoundment.

The required dam is about 100 feet in height and would have variable foundation conditions. The left (south) abutment is underlain by basalt bedrock of the CRBG. Bedrock is exposed or estimated to be close to the existing ground surface in most areas of the left abutment and spillway on the left abutment.

The right (north) abutment location is underlain by a thick sequence of glaciolacustrine deposits between the low point of the valley to well above the top of the proposed forebay dam. Based on field observations, these deposits consist of interbedded, laminated, light tan silty sand, sandy silt, and clay.

Forebay Dam Alignments and Construction Several potential alignments were considered in this study for the forebay dam, including the layout for the alignment shown. Other alignments, located slightly downstream from the proposed location, were estimated to require substantially more excavation to provide a suitable foundation in the areas underlain by the glaciolacustrine deposits.

The foundation of the dam at the proposed location is estimated to extend about 30 feet below the water level of Lake Roosevelt. To build a conventional dam, a separate cofferdam would be required downstream of the proposed dam axis, and the stream flow through the valley and seepage into the work area would have to be continuously pumped around the work area during construction. Since the bottom of the valley (under Lake Roosevelt) drops significantly in elevation for potential cofferdam locations located downstream of the proposed dam axis, the cofferdam height at downstream locations would be about twice as high as the proposed dam location. For these reasons, the concept shown uses the cellular cofferdam as a cutoff for lowering the lake within the new impoundment area for construction, and it serves as the water barrier/cutoff for the proposed permanent forebay dam. This eliminates the requirement for a completely dewatered condition for construction of an impervious core and filters for the dam.

The design and construction of the forebay dam is complicated by the normally high water elevation associated with Lake Roosevelt. The foundation at the proposed dam location is about 30 feet below the normal lake level. To allow construction in these conditions, the concept drawings illustrate cofferdam cells and interconnecting arcs using steel sheet piles driven to bedrock and filled with suitable granular fill for stability. The cofferdam would be constructed to an elevation well above Lake Roosevelt water. Cutoff walls are required on each end of the cellular cofferdam to form the remainder of the cutoff, and a cutoff wall is shown extending to the maximum forebay elevation to form the upper portion of the cutoff barrier above the cellular cofferdam. For stability of the forebay dam, rock fill is shown on each side of the cofferdam and cutoff walls, extending to elevation 1340.

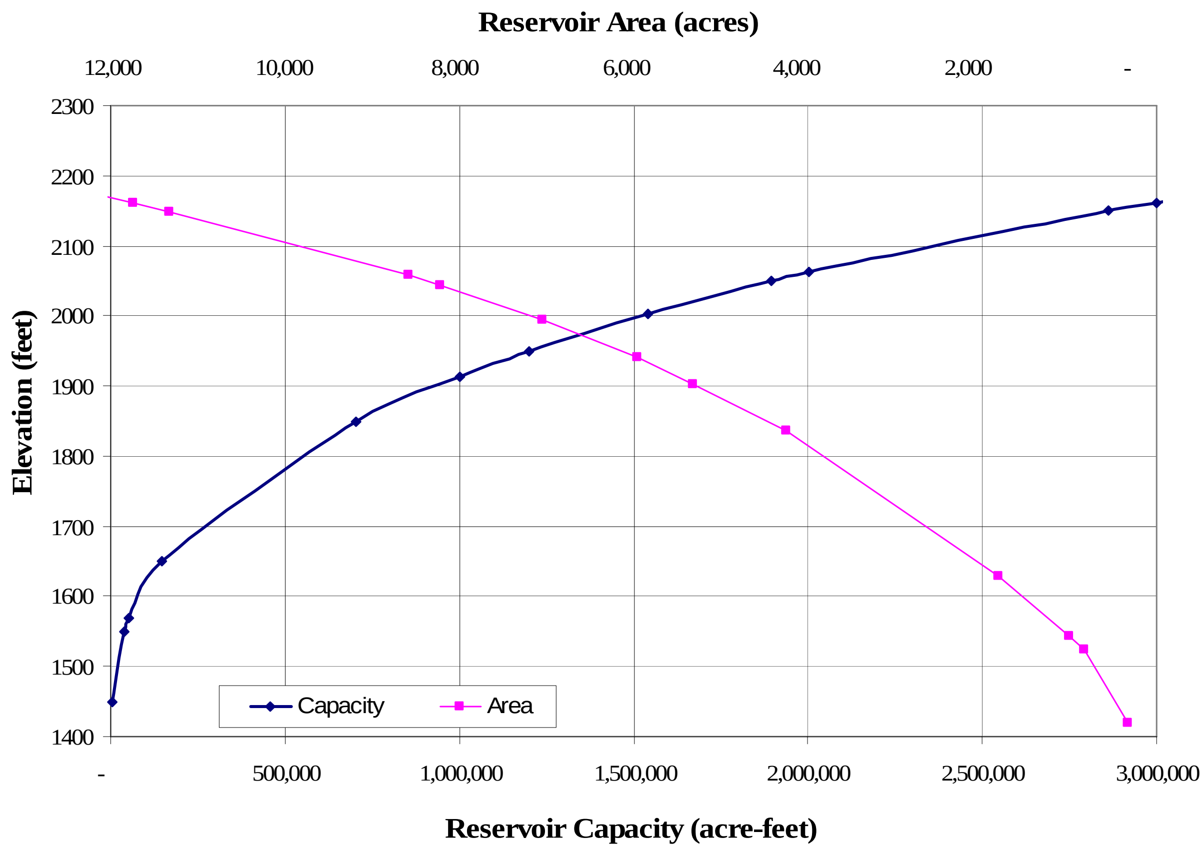
Spillway A rockcut spillway is provided on the left abutment to pass up to 25,000 cfs from the pump/turbine facility during release of water from the upper reservoir to the Columbia River. The spillway would also be used to pass any flood water released from the upper dam when necessary. For purposes of development of these concepts, it is estimated that the 25,000 cfs associated with the annual releases from the upper reservoir through the pump/turbine facility would control the design for the spillway.

The spillway would be 200 feet or more in width and water depths would be up to 12 feet deep. Rock from the spillway cut would be used for construction of the rock fill embankments associated with the forebay dam and other areas to be protected from scour. The quality of basalt rock for the spillway is not known. Therefore, it is assumed that the spillway would have to be concrete lined for protection from scour.

Reservoir

Plates 4-4.2A through 4-4.2D show the proposed reservoir configuration. The irregularly shaped reservoir created by a dam as proposed for the Hawk Creek site would result in a lake that is 1.5 to 3 miles wide near the dam and a dendritically shaped, branching reservoir with narrow bays that are 3 to 10 miles long along some of the Hawk Creek tributary drainages. This configuration results in a relatively high dam having a large rockfill volume to achieve the required minimum water storage volume at this site. The area/storage curve for this reservoir compared to elevation is shown in Figure 4-4.1.

FIGURE 4-4.1
Hawk Creek Reservoir Elevation-Capacity-Area Curves



The water surface of the reservoir at or near full reservoir would be in contact with exposed basalt rock, talus slopes, and colluvium. At lower elevations, the water surface would also be in contact with glaciolacustrine and alluvial sediments in the lower valleys. Saturation by the reservoir and rapid drawdown of reservoir levels during high discharge periods could result in instability of the glaciolacustrine sediments within the lower valley walls. Further evaluation and analysis would be required to determine the stability of these sediments. Flattening of some slopes and/or removal of sediments in some areas may be required to protect intake facilities. Reduced rates of drawdown would limit episodes of erosion and slumping, and could potentially lead to improved water quality.

Wave action and variable water levels within the reservoir would be expected to lead to erosion and turbidity along the shorelines in areas of alluvial, colluvial, and fine-grained lacustrine sediments. This erosion process may tend to stabilize over a period of time as the exposed slopes become reinforced with natural sand and gravel and talus rock on the exposed surfaces. If unstable conditions, such as landslides within the lacustrine sediments, continue to occur, steep-sided scarps and exposures could continue to erode and could lead to turbidity within the reservoir.

Where the water surface is in contact with erosion-resistant materials such as talus, rocky colluvial, and basalt bedrock slopes, waves may cause limited erosion and may form steep, wave-cut slopes. Conditions such as this have developed within the reservoir sideslopes along Lake Roosevelt, and provide a good example of expected conditions where the lake is in contact with similar material types.

As the reservoir water levels are dropped, additional shallow water zones of alluvial sediments would be exposed to wave action and disturbance, which could lead to some increase in turbidity at times although this condition is expected to be minimal because of the relatively steep rocky sideslopes throughout most of the reservoir area.

Little is known about potential for reservoir leakage at this location through the dam abutments or floor of the reservoir. Fractured, high-permeability zones in the vicinity of the dam abutments may contribute to leakage, and it is anticipated that grouting and/or cutoff to less-permeable rock may be required.

The majority of the floor of the proposed reservoir is underlain by glaciolacustrine deposits and alluvial deposits. It is anticipated that downward leakage through the glaciolacustrine deposits would be minimal because of their fine-grained, horizontally bedded character. However, the alluvial deposits include lenses of clays, silts, sands, sandy gravels, to gravelly sand. The thickness of the alluvium, based on well drillers' logs of the area, is more than 75 feet. Therefore, it appears that a cutoff would be required under the dam in order to prevent seepage under the dam. These conditions, combined with foundation grouting, are expected to lead to minimal seepage from the reservoir.

For preliminary purposes, it is estimated that seepage through the reservoir floor and side would be an average of 0.1 acre-feet/month/acre, or approximately 700 acre-feet/month for the reservoir at maximum pool level. The amount of seepage would vary with water depth, and likely be greatest during the initial reservoir filling before the reservoir floor becomes coated with silty material.

Additional information regarding leakage may be obtained by reviewing leakage history from other reservoirs in similar geologic conditions (that is, basalt underlying the dam abutments), and experience gained by the Washington Department of Ecology Dam Safety Division. These other dams may include but not be limited to Pinto Dam, O'Sullivan Dam, Dry Falls Dam, and numerous other dams in the area.

Columbia River Diversion Facilities

Plate 4-4.6 shows an overall layout of facilities for the potential Hawk Creek project, and Plate 4-4.9 shows the conceptual layout and location of the proposed diversion/intake facility specifically (see lake tap discussion below). Hydraulic conditions for the intake at this site are somewhat more complex because of the wide swing in the water surface elevation of Lake Roosevelt (the Columbia River impoundment behind Grand Coulee Dam). This 81-foot swing over the course of the year makes a surface diversion much more complex. In addition, operation records for Lake Roosevelt indicate that some of its lowest levels could coincide with times of the year that diversions to a new off-channel reservoir at Hawk Creek would be at a maximum. As a result, a deep lake intake (or "lake tap") has been the configuration selected for this evaluation of the Hawk Creek site.

Lake Tap As shown in Plate 4-4.9, the lake tap consists of a vertical shaft (one or more, depending on Operational Scenario) protruding from the bottom of the lake, connected to the pump station by a series of tunnels. At the lowest Lake Roosevelt levels, the Hawk Creek arm of the lake is actually fairly shallow for a significant distance out and away from the proposed new off-channel reservoir location, so to shorten the length and reduce the cost of the conveyance system, it is necessary to develop a configuration for the lake tap that is workable with relatively low depth and submergence. The size of the vertical shaft was established based on keeping the velocity under 6 feet per second, a rate at which hydraulic references suggest that 15-20 feet of submergence would be adequate to discourage vortexing. Additionally, it was assumed that 25 feet was a reasonable upper limit for the diameter of a single vertical steel pipe shaft, and that a vortex-breaker system should be included for cost estimating purposes at this level. The resulting layout consisted of one to three 25-foot vertical shafts (depending on the design flow rate tied to the various operational scenarios), located about two miles west of the proposed new dam axis.

The main tunnel to the pump station cannot reasonably be staged from a position within the lake, and the need for additional lake taps under higher flow scenarios also dictates the need to develop a main tunnel access shaft on land. From this point, tunnels can be completed in all directions. A location was selected on the adjacent hillside where the terrain is somewhat flatter, to provide a more reasonable location for construction of the main shaft. When multiple lake taps are needed for the larger flow scenarios, it is believed that a large underground chamber would be needed to connect in the multiple tunnels. The tunnel to the pump station would then be staged from the adjacent main shaft.

Fish Protection Considerations As noted in Table 3-2.10, it is assumed that for this site and the lake tap configuration no screening is needed. This rationale is based on the fact that the Hawk Creek site is above Grand Coulee Dam and the anadromous reach of the Columbia River, and this type of intake is generally thought to be less likely to divert or injure fish than a surface diversion.

The proposed layout for the Hawk Creek projects does not include a reverse flow function for the lake tap and its associated tunnels. Reservoir releases would not be routed through these facilities, so diffusers are not expected to be needed.

Access Issues The terrain surrounding the Hawk Creek arm of Lake Roosevelt is fairly steep and rugged, so roads that need to be constructed to provide construction (and later, maintenance) access to the tunnel access shaft area would be a significant cost consideration. The road would probably need to be benched into the sidehill along the 1600 foot contour.

Conveyance Facilities

As noted above, the lake tap system would connect to the pump station by means of a single main tunnel, varying in size based on the flow and operational scenario. The lake tap would fill the tunnel system by gravity using the head of the lake, and the main tunnel would serve as the supply conduit to the pumps, which in turn would lift the water to a stable forebay created by a small dam across the Hawk Creek channel (the Hawk Creek Forebay Dam as identified on Plates 4-4.6 and 4-4.10) about 0.5 mile east of the lake tap. It is expected that this tunnel would pass under the Hawk Creek Forebay Dam's spillway rather than the dam itself.

From the forebay, the much larger lift to the new off-channel storage reservoir would be made with pump/turbine units in a separate facility from the pump station described above. This water would be delivered to the large dam's inlet/outlet works through a single or dual tunnel (number and diameter based on flow and operational scenario) approximately 1.1 miles in length.

More information about the conveyance system can be found on Plates 4-4.11 and 4-4.12, which provide a profile of the entire system. Specifics of the pump station, pump/turbine facility, and the small dam creating the forebay are provided in subsequent sections of this report.

Lower Head Pumping Plant

Plates 4-4.6 and 4-4.13 through 4-4.16 show the proposed lower head pumping plant, which would take suction from the main body of Roosevelt Lake and pump the water to a the newly created forebay behind the Hawk Creek Forebay Dam proposed to facilitate the conveyance operation at Hawk Creek. This plant would not generate power when releases are made from off-channel storage. The reverse flow from the forebay back to Roosevelt Lake would go over a spillway at the Hawk Creek Forebay Dam. Three pumping scenarios were analyzed as shown in Table 4-4.2 and described below: 2,500 cfs, 5,500 cfs, and 8,500 cfs.

As described above, the three lake-bottom inlet tunnels would combine into one tunnel in a subterranean forebay, and this one combined tunnel would serve as the suction to the pumping plant. As shown in Table 4-4.2, the suction tunnels vary in diameter to ultimately achieve similar flow velocities, ranging from 10 fps to 12 fps. The subterranean forebay is also adjacent to the proposed location of an access shaft to be used for the tunnel construction.

The single suction tunnel would run 8,500 feet from the subterranean forebay to the lower head pumping plant. The pumping plant would be located underground, as the pumps would be located well below the 1209 feet low pool elevation to prevent cavitation. The pumping plant location must allow for an access tunnel off the service road that would lead to the Hawk Creek pump-turbine plant. Existing grade in the proposed location of the pumping plant is about 1500 feet, with the motor floor of the pumping plant at about 1212 feet. It is anticipated that much of the overlying earth would be removed to provide fill for the dam.

TABLE 4-4.2

Three Scenarios for Pumping Water from Roosevelt Lake to the Forebay of Hawk Creek

Pumping Scenarios	Suction Tunnel Diameter	Flow Velocity	Number of Pumps	Pump Size (each pump)	Pump Shaft Power Inputs (each pump)
2,500 cfs	18 feet	10 fps	3	833 cfs	13,860 horsepower
5,500 cfs	25 feet	11 fps	4	1,375 cfs	22,880 horsepower
8,500 cfs	30 feet	12 fps	4	2,125 cfs	35,350 horsepower

As shown on Table 4-4.2, three smaller pumps would be needed for the 2,500 cfs scenario, and four larger pumps for the 5,500 and 8,500 cfs scenarios. These numbers of pumps maintain 67 percent to 75 percent of plant capacity with one pump out of service, and result in pump sizes that are within the capabilities of manufacturers. The pumps would have some degree of variable flow capacity to allow the pumping rate to facilitate capture of the available water.

The pumps would discharge individually to the newly created forebay. The forebay would have a relatively constant water surface elevation of 1330 feet. Therefore, the pump static head would range from 40 feet at high pool in Roosevelt Lake to 121 feet at low pool in Roosevelt Lake. With an assumed 85 percent pump efficiency and allowing 5 feet for losses and velocity head, the pump shaft power inputs for the three scenarios range from 13,860 horsepower to 35,350 horsepower at 125 feet total head, as shown on Table 4-4.2.

A service access tunnel would be built off the pump-turbine plant access road and slope down at about a 7 percent grade to the low head pumping plant. This tunnel would provide access during construction, and continuing access for maintenance during operation.

Combined Pump/Turbine Facilities

As shown in Plates 4-4.6, 4-4.12, 4-4.13, 4-4.17, and 4-4.18, the lift from the Hawk Creek Forebay to the off channel storage reservoir would be provided by a combined pump/turbine facility that would also generate power during reservoir releases.

The units for pumping into the Hawk Creek Reservoir from the forebay were selected to provide the target flows to the reservoir for the three operating scenarios at the maximum pumping head. In addition, they were selected to be reversible units that can generate power when the flow from the reservoir is released back to the river. This allows energy recovery with most of the release flows with a minimum of incremental cost over the cost of the necessary pumping facilities. The selection and sizing of the units followed the procedures outlined in Reclamation Monograph No. 39. The minimum number of units was established as three to provide flexibility and limited reduction in capacity upon loss of use of one unit. Three units were selected for OS1 and four for OS2 and OS3. The minimum pumping flow occurs at the maximum head; therefore, at pumping heads less than the maximum, the pumping capacity would be larger, up to about 2.1 times the target flow at the normal minimum head for the main selected unit rotational speed. Because the head variation for all three operating scenarios exceeds the normal range for reversible units of this type, variable speed units were selected. By lowering the speed, the units can operate safely at heads down to the lowest that would exist when the reservoir is at its minimum level and still have pumping capacity in excess of the target flows. At maximum generating head, the units can utilize almost all of the targeted release flows to produce power. At lower heads, the units cannot pass as much flow, and some of the releases would have to be released by the outlet valves when release demands are at their highest. The rated individual unit capacities for OS1, OS2, and OS3 are 79, 163, and 284 MW respectively, resulting in plant capacities for the three operating scenarios of 237, 652, and 1,136 MW. These are based on the maximum generating capacities at maximum head.

The bypass release from the main reservoir into the forebay at Hawk Creek would not be governed by fish issues and, therefore, the valves can discharge directly into the forebay.

The fixed cone valve house would be set above the forebay water surface elevation because the valves do not operate well underwater.

Power Transmission Facilities

Power transmission facilities are required to provide energy to the low head pumping plant that lifts water from Lake Roosevelt to the new forebay and the large pump/turbines that lift water from the forebay into the Hawk Creek Reservoir. These same facilities then deliver the energy that is generated when water is released through the reversible pump/turbine units back into the forebay. The maximum power requirements for the three reservoirs hydraulic capacity operating scenarios being considered are estimated in Table 4-4.3.

TABLE 4-4.3
Hawk Creek Pumping and Generating Power Requirements

Operating Scenario	Lower Head Pumping Plant* (MW)	Combined Pump/ Turbine Facility* (MW)	Generating Power Output Max (MW)
OS1	33	198	237
OS2	57	544	652
OS3	113	948	1,136

*Pumping power input maximum

The proposed electric power substation and transmission facilities are shown on Plate 4-4.19. A new single-circuit 230 kV transmission line is approximately 7.5 miles long and is proposed to connect the project substation to the existing transmission grid at a new 230 kV Hawk Creek tap substation located near BPA's transmission corridor, intercepting one or more existing 230 kV transmission lines. This corridor has one 500 kV line; three 230 kV lines; and one 115 kV line. A system impact study, as described in Section 3.5.5, *General Requirements for Siting Power Transmission Facilities*, may determine that it would be best if this line were constructed to operate at 500 kV.

A single-circuit tower has three conductors and one circuit on one side of the structure. Three conductors and the other circuit are on the other side of the structure. Plate 4-1.17 shows a typical double circuit lattice steel 230 kV transmission tower. The proposed single-circuit 230 kV transmission line begins at the powerhouse substation and heads south until it reaches the BPA transmission corridor, where it terminates in a new 230 kV substation.

The general requirements for selecting transmission voltage and for construction of power transmission facilities were described in Section 3.5.5, *General Requirements for Siting Power Transmission Facilities*. The ROW needed for the new transmission line and its structures is assumed to be 100 feet wide. However, this width may change depending upon the final conductor span lengths and selected and adjacent property uses.

The following structures would be needed at each substation:

- Hawk Creek Substation—One new 230 kV bay would be constructed near the Hawk Creek powerhouse. New equipment within the substation would include 230 kV to 13.8 kV power transformers, power circuit breakers, switches, buswork, potential transformers, substation dead-end towers, control building, communications, buried grounding system, relaying, and perimeter fencing.

- Hawk Creek Tap Substation—Three new bays would be constructed as part of a new substation. New equipment within the substation would include power circuit breakers, switches, buswork, potential transformers, substation dead-end towers, control building, relaying, communications, buried grounding system, and perimeter fencing.

Relocation Once filled to capacity, the reservoir would cover a small portion of the BPA-owned Grand Coulee Bell 500 kV/230 kV/115 kV transmission line corridor, requiring relocation 1.7 miles via overhead lines to elevations above and away from the maximum fill elevation level. These transmission lines are shown on Plate 4-4.19.

4.4.3 Alternative Operational Scenarios

A detailed explanation of the development of all three operational scenarios is provided in *Operational Scenarios Development*, which is discussed in Section 3. Numerical monthly results for the three scenarios are presented in Appendix C, *Water Balance Reports*.

This sub-section describes the operational scenarios for the Hawk Creek Dam and Reservoir site. The same approach, and the same set of three figures, are used for each operational scenario, as follows:

- Figure A: End-of-Month Off-Channel Reservoir Contents
- Figure B: Releases from Off-Channel Reservoir
- Figure C: Median Annual Agricultural, DCM&I, and Flow Augmentation Demand Distribution

Figures A and B within each operational scenario show the minimum, maximum, median, first, and third quartiles for end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record, respectively. Quartiles divide a data set into quarters. The value that divides the lower half into halves is called the first quartile (q1). The value that divides the upper half into halves is called the third quartile (q3). These statistics are shown to provide insight into the results of the 50-year period of record and present outliers that can skew the average. Figure C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for each operational scenario.

For each of the operational scenarios, water would be delivered to agricultural, DCM&I, and flow augmentation demands either via direct pumping from the Columbia River mainstem or from the new off-channel reservoir based on median values for the 50-year period of record used in the water balance model. This value represents the “yield” or benefit to water users as a result of implementing this alternative. This yield is the basis of the cost/benefit analysis in the Decision Support Model.

Operational Scenario 1

OS1 is a 1 million acre-feet off-channel reservoir with a 2,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 6,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands. Figures 4-4.2A and 4-4.2B show the end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record for OS1.

Exhibit 4-4.2C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS1.

FIGURE 4-4.2A

End-of-Month Off-Channel Reservoir Contents: Hawk Creek OS1

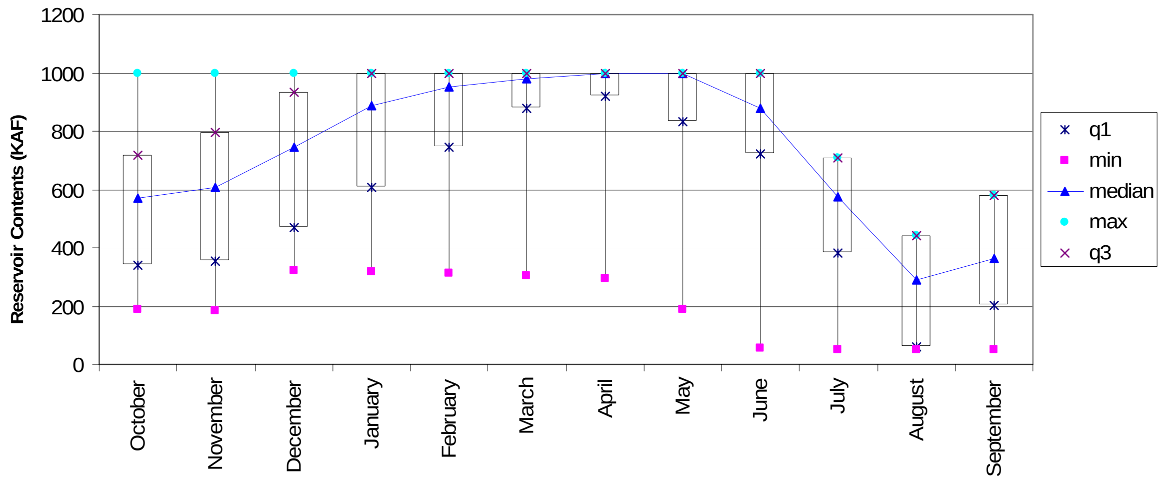


FIGURE 4-4.2B

Releases from Off-Channel Reservoir: Hawk Creek OS1

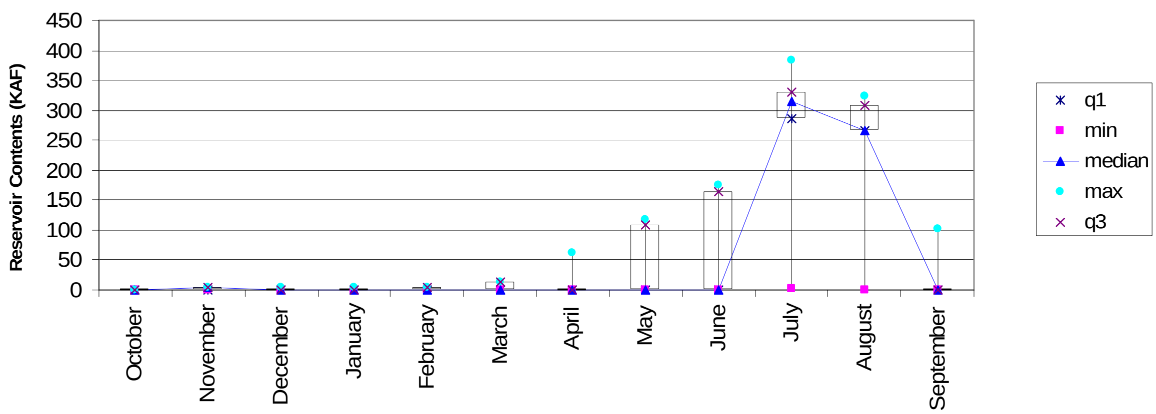
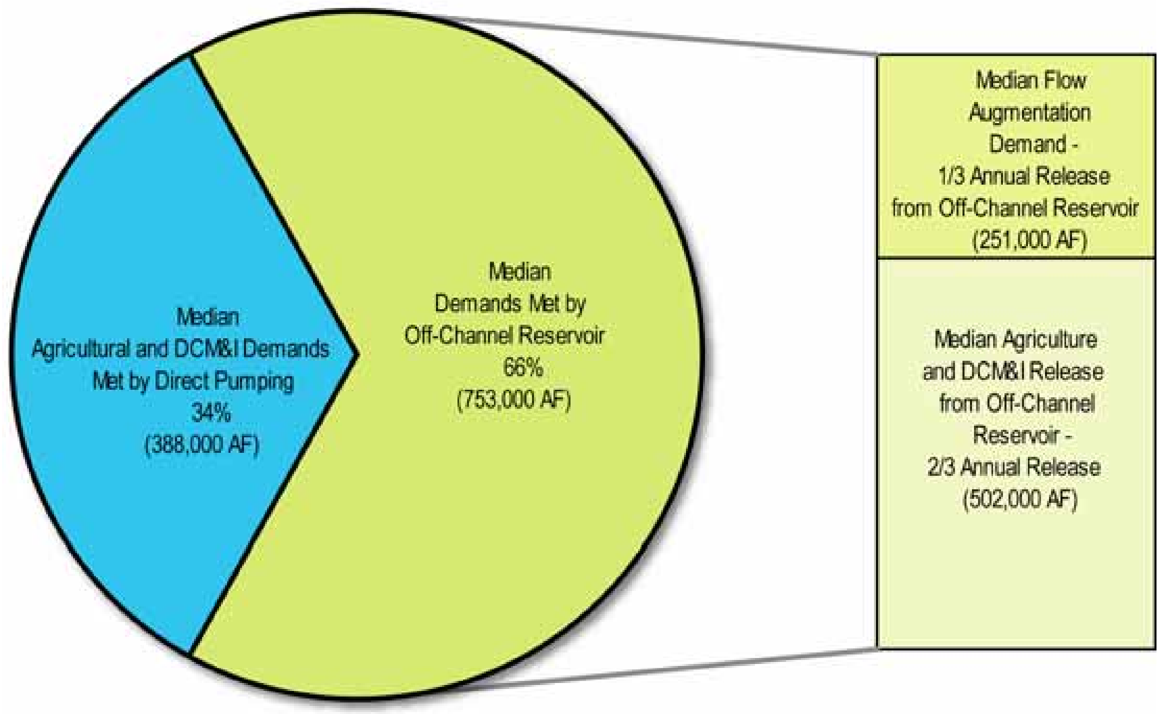


FIGURE 4-4.2C
Median Annual Demand Distribution: Hawk Creek OS1



OS1 allows for 1,141,000 acre-feet (388,000 acre-feet direct pumped and 753,000 acre-feet off-channel reservoir) of water to be delivered to agricultural, DCM&I, and flow augmentation demands; this yield is the basis of the cost/benefit analysis in the Decision Support Model.

Operational Scenario 2

OS2 is a 2 million acre-feet off-channel reservoir with a 5,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 13,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands. Figures 4-4.3A and 4-4.3B show the end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record for OS2.

Figure 4-4.3C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS2.

FIGURE 4-4.3A
End-of-Month Off-Channel Reservoir Contents: Hawk Creek OS2

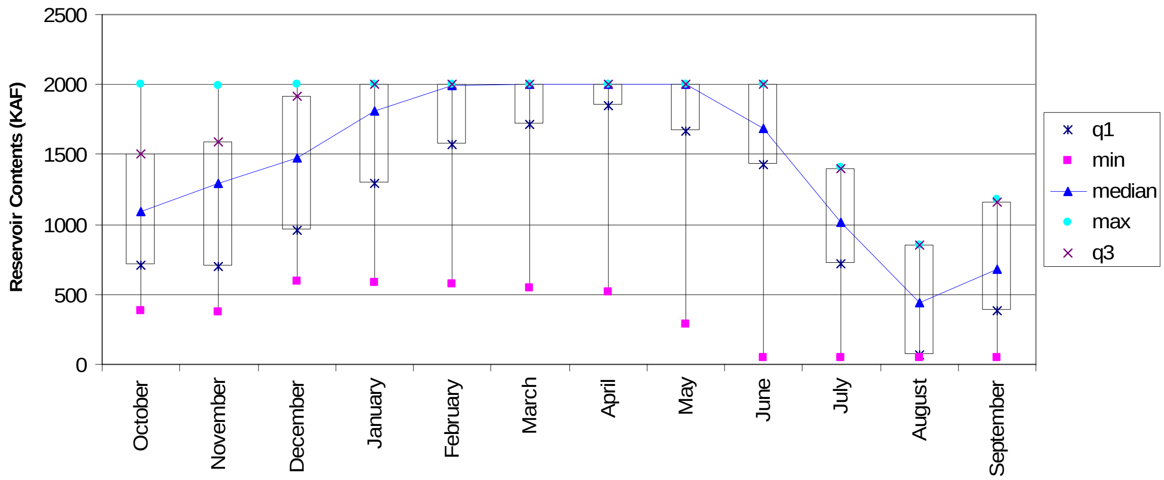


FIGURE 4-4.3B
Releases from Off-Channel Reservoir: Hawk Creek OS2

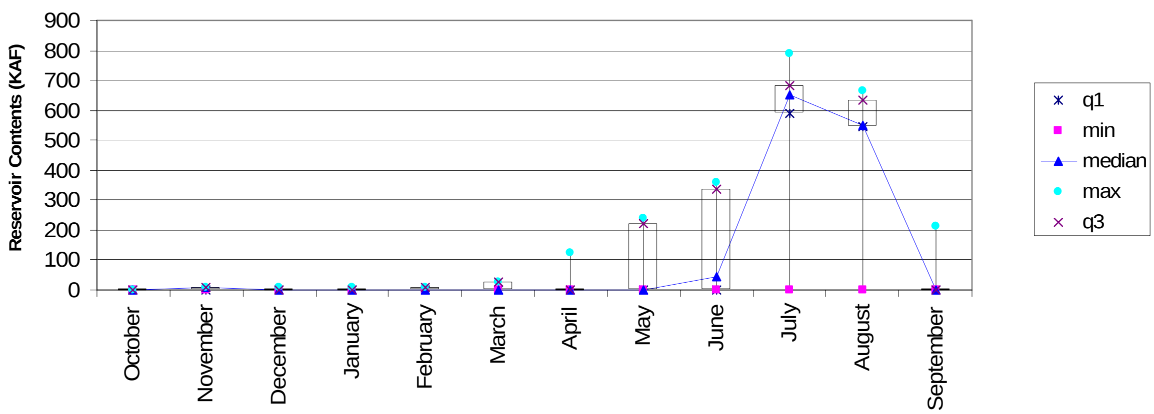
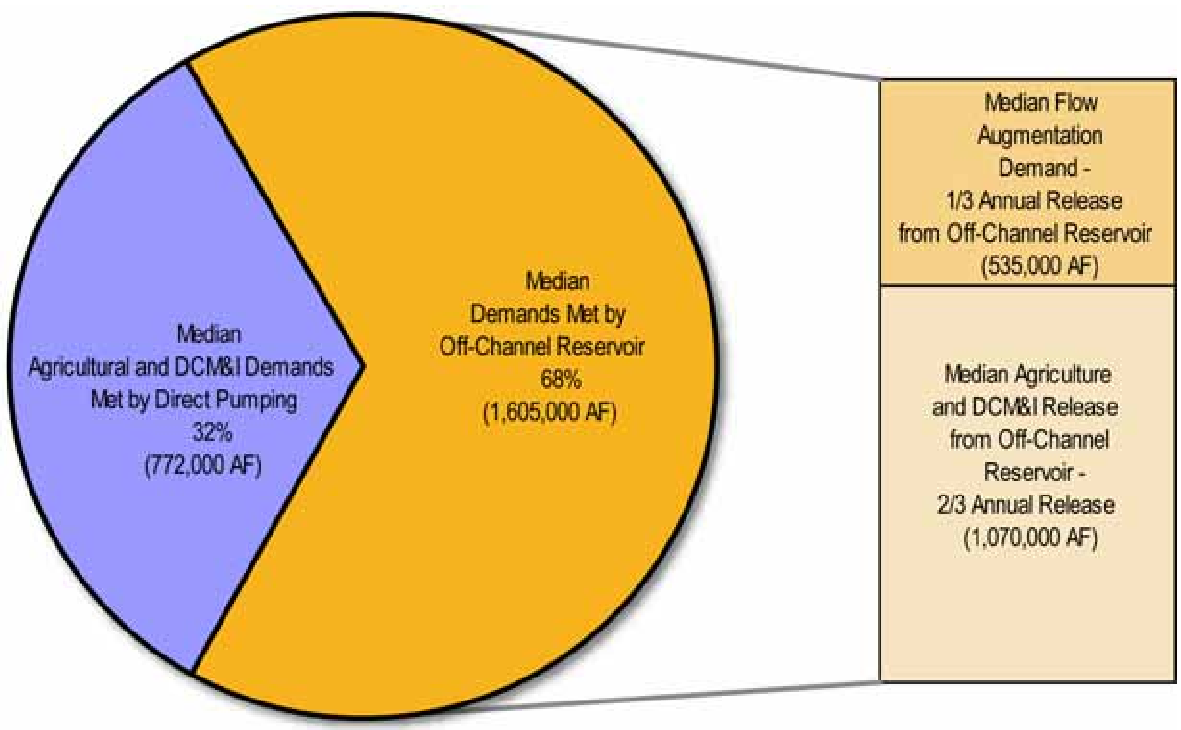


FIGURE 4-4.3C
Median Annual Demand Distribution: Hawk Creek OS2



OS2 allows for 2,377,000 acre-feet (772,000 acre-feet direct pumped and 1,605,000 acre-feet off-channel reservoir) of water to be delivered to agricultural, DCM&I, and flow augmentation demands; this yield is the basis of the cost/benefit analysis in the Decision Support Model.

Operational Scenario 3

Operational Scenario 3 is a 3 million acre-feet off-channel reservoir with an 8,500 cfs Columbia River mainstem diversion capacity. The dam and appurtenant structures are sized to release 18,500 cfs during peak demand periods to meet agricultural, DCM&I, and flow augmentation demands. Figures 4-4.4A and 4-4.4B show the end-of-month reservoir contents and releases from the off-channel reservoir for the 50-year period of record for OS3.

Figure 4-4.4C shows the median annual agricultural, DCM&I, and flow augmentation demand distribution for OS3.

FIGURE 4-4.4A
End-of-Month Off-Channel Reservoir Contents: Hawk Creek OS3

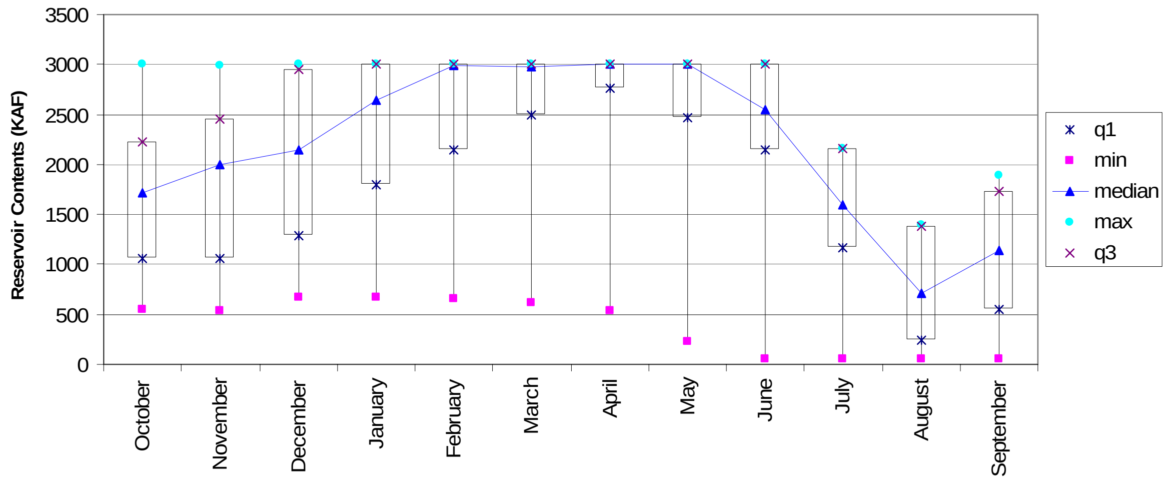


FIGURE 4-4.4B
Releases from Off-Channel Reservoir: Hawk Creek OS3

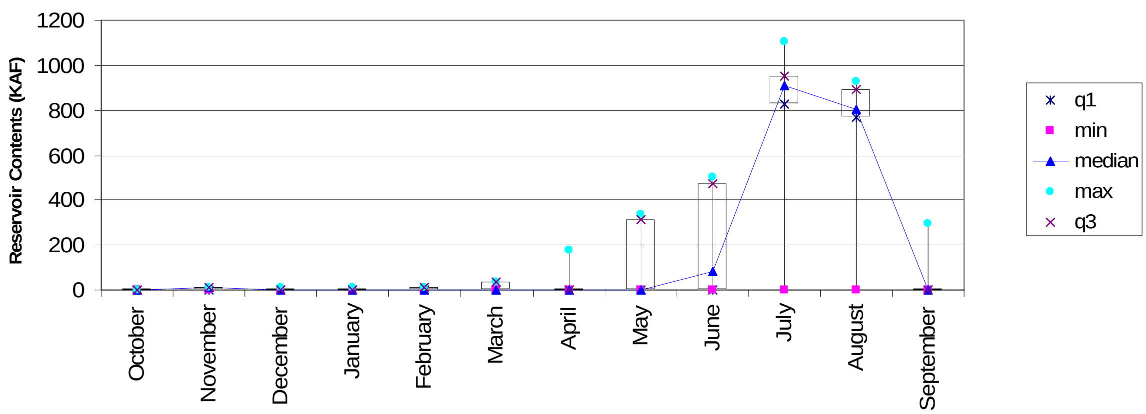
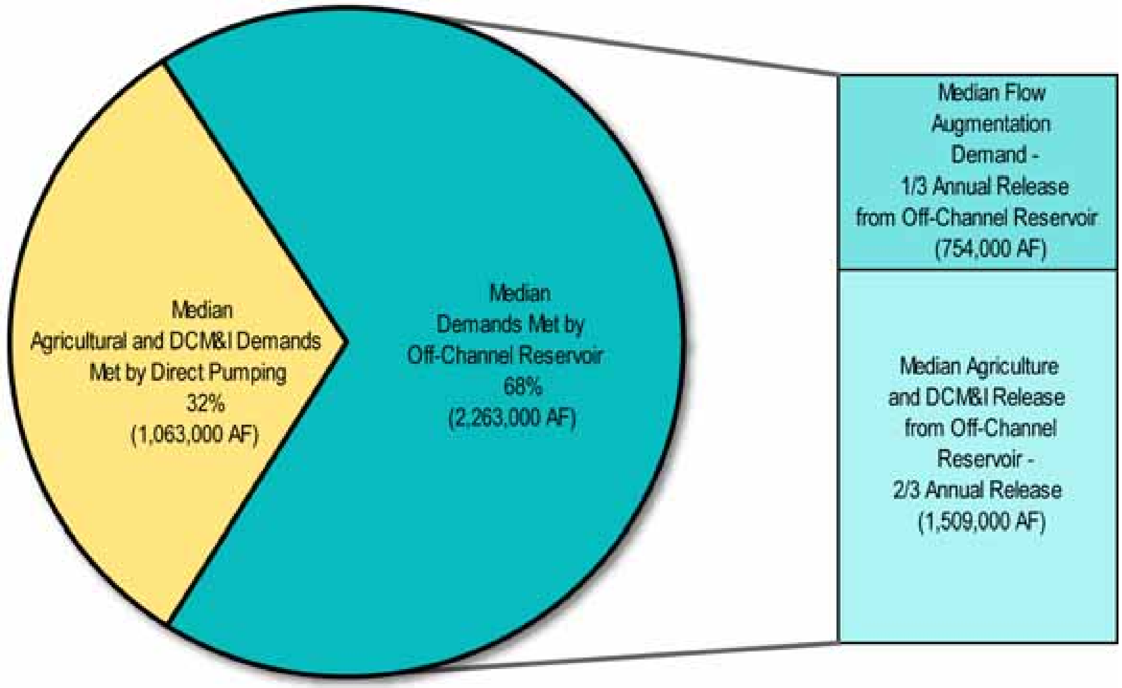


FIGURE 4-4.4C
Median Annual Demand Distribution: Hawk Creek OS3



OS3 allows for 3,326,000 acre-feet (1,063,000 acre-feet direct pumped and 2,263,000 acre-feet off-channel reservoir) of water to be delivered to agricultural, DCM&I, and flow augmentation demands; this yield is the basis of the cost/benefit analysis in the Decision Support Model.

4.4.4 Project Cost Estimates

Project cost estimates are shown in Tables 4-4.4A, *Estimated Capital Costs for Hawk Creek Site and Operational Scenarios*, 4-4.4B, *Estimated Annual Costs for Hawk Creek Site and Operational Scenarios,* and 4-4.4C, *Estimated Net Present Values for Hawk Creek Site and Operational Scenarios.*

4.4.5 Socioeconomic Resource Effects

Socioeconomic resource effects are summarized on Table 4-4.5.

TABLE 4-4.5
Hawk Creek Socioeconomic Impacts Summary

		Raw Data for Impacts				Impacts Normalized to Million Acre-Feet			
Factors	**Criteria**	**Units**	**OS1**	**OS2**	**OS3**	**Units**	**OS1**	**OS2**	**OS3**
Land Use	Residential use	No. residences	41	45	46	No. residences/ MAF	41	23	15
	Irrigated Agriculture	Acres	0	0	0	Acres/MAF	0	0	0
Infrastructure	Highway (state, federal) impacts	Miles	0	0	0	Miles/MAF	0	0	0
	Local road impacts	Miles	28	39	48	Miles/MAF	28	20	16
	Railroad impacts	Miles	0	0	0	Miles/MAF	0	0	0
	Transmission line impacts	Miles	1	1	1	Miles/MAF	1	0.5	0

Operational Scenario 1

Approximately 5,239 acres would be permanently converted to reservoir and associated facilities under OS1.

Land Ownership The existing land ownership data for the proposed Hawk Creek site is incomplete. According to the Major Public Lands of Washington database, WDFW owns 0.14 acres within the proposed alternative and manages this area for recreation. Reclamation owns 19 acres within the proposed footprint. No acreage information was provided or found indicating acres or proportion of privately owned land. The majority of the land, although unspecified, is assumed to be privately owned.

Land Use As shown on Table 4-4.5, residential land uses would be impacted, with approximately 41 residences identified in the proposed footprint of the project. The impacts to various land types, such as riparian resources, are more fully described in Section 4.4.7, *Environmental Resource Effects*, and in Table 4-4.7. Non-forested lands occupy 561 acres within the proposed footprint. Conifer forests dominate the vegetation community within and surrounding the Hawk Creek site. Over half (2,762 acres) of the 5,204 acres proposed for this site alternative are forested.

Irrigated Agriculture The agricultural resources at Hawk Creek consist of low-value crops on primarily private lands.

Infrastructure Major infrastructure that would be affected within the Hawk Creek potential reservoir site includes local roads and transmission lines.

State and Federal Highways No state or federal highways are located within the proposed alternative.

Local Roads Within the proposed reservoir footprint, 28 miles of local road would be inundated and abandoned.

Railroads No railroad tracks are present within the proposed footprint.

Irrigation Facilities Although irrigation facilities are present on the private lands, data were not readily available to characterize the specific extent of irrigation facilities impacts. However, the nature of agricultural land use suggests that irrigation infrastructure is relatively moderate in the inundation area.

Transmission Lines Only 1 mile of transmission line crosses the proposed Hawk Creek footprint and would need to be relocated.

Operational Scenario 2

Approximately 8,556 acres would be permanently converted to reservoir and associated facilities under OS2.

Land Ownership As described for OS1, the land ownership data for Hawk Creek is incomplete and the majority of land is assumed to be privately owned. WDFW owns 21.7 acres within the proposed alternative and manages this area for recreation, while Reclamation owns 28.1 acres within OS2.

Land Use Land use impacts are the same as described for OS1, except they are greater because OS2 has a larger footprint (Table 4.4-5). For OS2, approximately 45 residences would be impacted.

Irrigated Agriculture Same as described for OS1.

Infrastructure As described for OS1, local roads and 1 mile of transmission line would be impacted by the proposed Hawk Creek Reservoir. Under OS2, 39 miles of local roads would be inundated and abandoned.

Table 4-4.4A

Estimated Capital Costs for Hawk Creek Site and Operational Scenarios

Facility or Cost Component	Type of Unit	Unit Cost	Reference Project Cost for Scale Ups or Scale Downs	Hawk Creek OS1 No. of Units or Scale Factor	OS1 Extended $	OS2 No. of Units or Scale Factor	OS2 Extended $	OS3 No. of Units or Scale Factor	OS3 Extended $
Columbia River Intake Facilities					$ 62,000,000		$ 117,200,000		$ 172,400,000
Lake Tap (including Intake Shaft(s)			$ 62,000,000	1.00		1.89		2.78	
Penstocks and Tunnels									
Penstocks	LF x Dia Inch	$15							
Tunnel, Lake Tap to Access Shaft					$ 15,700,000		$ 35,000,000		$ 54,300,000
Access Shafts									
Total Depth of Shaft(s)	LF	equation		-		-		-	
Diameter of Shaft	Dia Ft	equation		-		-		-	
Tunnels (Concrete Lined Sections)									
Approx Total Tunnel Length	LF	equation		1,300		2,900		4,500	
Diameter of Tunnel	Dia Ft	equation		25		25		25	
Add on for Sections of Steel Lining									
Approx Length Required	LF	equation		325		725		1,125	
Assumed Thickness of Steel	Lining t (in)	equation		2.0		2.0		2.0	
Allowance for Stiffeners	Percentage			0.15		0.15		0.15	
Tunnel, Access Shaft to Lower Head PS					$ 62,200,000		$ 79,000,000		$ 101,000,000
Access Shafts									
Total Depth of Shaft(s)	LF	equation		500		500		500	
Diameter of Shaft	Dia Ft	equation		40		40		45	
Tunnels (Concrete Lined Sections)									
Approx Total Tunnel Length	LF	equation		6,300		6,300		6,300	
Diameter of Tunnel	Dia Ft	equation		18		24		30	
Add on for Sections of Steel Lining									
Approx Length Required	LF	equation		1,575		1,575		1,575	
Assumed Thickness of Steel	Lining t (in)	equation		2.0		2.0		2.0	
Allowance for Stiffeners	Percentage			0.15		0.15		0.15	
Tunnel, from P/T facility to I/O Structure					$ 78,200,000		$ 147,700,000		$ 229,300,000
Access Shafts									
Total Depth of Shaft(s)	LF	equation		550		700		800	
Diameter of Shaft	Dia Ft	equation		45		45		45	
Tunnels (Concrete Lined Sections)									
Approx Total Tunnel Length	LF	equation		7,400		14,800		14,800	
Diameter of Tunnel	Dia Ft	equation		25		25		30	
Add on for Sections of Steel Lining									
Approx Length Required	LF	equation		600		1,500		3,600	
Assumed Thickness of Steel	Lining t (in)	equation		2.0		2.0		2.0	
Allowance for Stiffeners	Percentage			0.15		0.15		0.15	
Channels									
Pump/Turbine Facilities					$ 291,500,000		$ 659,300,000		$ 993,000,000
Pump Station (L. Roosevelt to Forebay)	LS	varies		90,000,000		270,000,000		400,000,000	
P/T Facility (Forebay to New Reservoir)	LS	varies		179,500,000		367,300,000		571,000,000	
Rockcuts and Benching	CY	$20		1,100,000		1,100,000		1,100,000	
Dams					$ 1,137,200,000		$ 1,745,200,000		$ 2,264,600,000
Dam (rock fill portion with concrete face)	CY	$18.40		38,110,000		71,150,000		99,380,000	
Dam (RCC portion)	CY	$82							
Smaller Dam creating Forebay (RCC)	CY	$82		5,000,000		5,000,000		5,000,000	
Spillway for Smaller Dam	CY	$20		1,300,000		1,300,000		1,300,000	
Reservoir Inlet/Outlet Works (See Note 1)			$ 40,000,000	0.80	$ 32,000,000	0.90	$ 36,000,000	1.00	$ 40,000,000
Additional Structures					$ 2,800,000		$ 4,300,000		$ 4,800,000
Fixed Cone Valve Structure	LS	varies		1,100,000		1,700,000		1,900,000	
Bypass Pipes	LF x Dia Inch	$15		115,200		172,800		192,000	
Baffled Apron Drop	LS	varies							
Road Relocations	LF	varies							
Bridges									
Power Transmission Facilities					$ 14,200,000		$ 15,200,000		$ 16,600,000
Power Transmission Lines/Towers	mile	$540,000		17		17		17	
Substation Power Transformation	MVA	$11,000		85		175		300	
Substation Switchyards	Breakers, EA	$1,100,000		4		4		4	
Security/Safety Fencing	LF	$30		4,000	$ 100,000	4,000	$ 100,000	4,000	$ 100,000
Mobilization		5%			$ 85,000,000		$ 142,000,000		$ 194,000,000
Unlisted Items		15%			$ 254,000,000		$ 426,000,000		$ 581,000,000
Subtotal					$ 2,035,000,000		$ 3,407,000,000		$ 4,651,000,000
Contingency		30%			$ 611,000,000		$ 1,022,000,000		$ 1,395,000,000
Field Cost (or Construction Contract Cost)					$ 2,646,000,000		$ 4,429,000,000		$ 6,046,000,000
Noncontract Cost		35%			$ 926,000,000		$ 1,550,000,000		$ 2,116,000,000
Total Capital Cost					$ 3,572,000,000		$ 5,979,000,000		$ 8,162,000,000

Notes:

1. Captures costs for gates, concrete work, and miscellaneous civil works. Costs for tunnels under/around dam are included in Tunnels line items above.

Table 4-4.4B

Estimated Annual Costs for Hawk Creek Site and Operational Scenarios

Facility or Cost Component	Type of Unit[1]	Unit Cost	Applicable Portion of Field Cost	Frequency of O&M or R&R (Years Between)	Hawk Creek					
					OS1		OS2		OS3	
					No. of Units or Capital Cost[2]	Extended $	No. of Units or Capital Cost[2]	Extended $	No. of Units or Capital Cost[2]	Extended $
Average Annual Power Consumption Costs						$ 16,770,000		$ 42,480,000		$ 67,500,000
Pump Station (L. Roosevelt to Forebay)	kW-hr	$0.03			84,000,000		182,000,000		256,000,000	
P/T Facility (Forebay to New Reservoir)	kW-hr	$0.03			475,000,000		1,234,000,000		1,994,000,000	
Average Annual Power Generation Revenues						$ 6,280,000		$ 15,400,000		$ 25,220,000
P/T Facility (Forebay to New Reservoir)	kW-hr	$0.025			251,260,000		616,000,000		1,008,840,000	
Operation & Maintenance Labor and Expense										
Lake Tap(s)										
Structural/Civil Works, Annual	% FC	0.1%	100%	1	$ 130,570,000	$130,000	$ 246,820,000	$250,000	$ 363,070,000	$360,000
Electrical/Mechanical Works, Annual	% FC	0.5%	0%	1	$ 130,570,000	$0	$ 246,820,000	$0	$ 363,070,000	$0
Replacement	% FC				$ 130,570,000	$0	$ 246,820,000	$0	$ 363,070,000	$0
Pump/Turbine Facility (total of 2)										
Structural/Civil Works, Annual	% FC	0.1%	50%	1	$ 613,900,000	$310,000	$ 1,388,490,000	$690,000	$ 2,091,260,000	$1,050,000
Electrical/Mechanical Works, Annual	% FC	1.0%	50%	1	$ 613,900,000	$3,070,000	$ 1,388,490,000	$6,940,000	$ 2,091,260,000	$10,460,000
Replacement	% FC	40.0%		25	$ 613,900,000	$245,560,000	$ 1,388,490,000	$555,400,000	$ 2,091,260,000	$836,500,000
Tunnels/Tunnel Lining										
Repairs and Maintenance	% FC	0.5%		1	$ 328,750,000	$1,640,000	$ 551,140,000	$2,760,000	$ 809,970,000	$ 4,050,000
Penstocks										
Structural/Civil Works, Annual	% FC	0.5%		1	$ -	$0	$ -	$0	$ -	$0
Dams and Spillways										
Structural/Civil Works, Annual	% FC	0.1%	80%	1	$ 2,394,940,000	$1,920,000	$ 3,675,390,000	$2,940,000	$ 4,769,250,000	$3,820,000
Electrical/Mechanical Works, Annual	% FC	1.0%	20%	1	$ 2,394,940,000	$4,790,000	$ 3,675,390,000	$7,350,000	$ 4,769,250,000	$9,540,000
Additional Structures										
Structural/Civil Works, Annual	% FC	0.1%	40%	1	$ 5,900,000	$0	$ 9,060,000	$0	$ 10,110,000	$0
Electrical/Mechanical Works, Annual	% FC	0.5%	60%	1	$ 5,900,000	$20,000	$ 9,060,000	$30,000	$ 10,110,000	$30,000
Channels										
Dredging, Clearing, and Bank Repair										
Valving/Gates on I/O Facilities										
Electrical/Mechanical Works, Annual	% FC	0.1%		1	$ 67,390,000	$70,000	$ 75,820,000	$80,000	$ 84,240,000	$80,000
Replacement	% FC	20.0%		25	$ 67,390,000	$13,480,000	$ 75,820,000	$15,160,000	$ 84,240,000	$16,850,000
Power Transmission Facilities										
Clearing and Repairs	% FC	0.5%		1	$ 29,910,000	$150,000	$ 32,010,000	$160,000	$ 34,960,000	$170,000
Fencing										
Repairs and Maintenance	% FC	10.0%		1	$ 210,000	$20,000	$ 210,000	$20,000	$ 210,000	$20,000

Notes:

1. Abbreviations: FC = Field Cost, kW-hr = kilowatt hours, I/O = inlet/outlet, O&M = Operation & Maintenance, R/R = Repair/Replacement
2. Capital Costs are taken from Estimated Field Cost table for the appropriate site and are adjusted to include mobilization, unlisted items, contingency, and noncontract costs.

Table 4-4.4C

Estimated Net Present Values for Hawk Creek Site and Operational Scenarios

	Operational Scenario 1						
Year	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (3,572,000,000)						
1 thru 24		$ (16,770,000)	$ 6,280,000	$ (12,120,000)			
25		$ (16,770,000)	$ 6,280,000	$ (12,120,000)	$ (259,040,000)		
26 thru 49		$ (16,770,000)	$ 6,280,000	$ (12,120,000)			
50		$ (16,770,000)	$ 6,280,000	$ (12,120,000)	$ (259,040,000)		
51 thru 74		$ (16,770,000)	$ 6,280,000	$ (12,120,000)			
75		$ (16,770,000)	$ 6,280,000	$ (12,120,000)	$ (259,040,000)		
76 thru 99		$ (16,770,000)	$ 6,280,000	$ (12,120,000)			
100		$ (16,770,000)	$ 6,280,000	$ (12,120,000)		$ -	
NPV	$ (3,572,000,000)	$ (341,100,000)	$ 127,700,000	$ (246,500,000)	$ (110,100,000)	$ -	$ (4,142,000,000)

	Operational Scenario 2						
Year	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (5,979,000,000)						
1 thru 24		$ (42,480,000)	$ 15,400,000	$ (21,220,000)			
25		$ (42,480,000)	$ 15,400,000	$ (21,220,000)	$ (570,560,000)		
26 thru 49		$ (42,480,000)	$ 15,400,000	$ (21,220,000)			
50		$ (42,480,000)	$ 15,400,000	$ (21,220,000)	$ (570,560,000)		
51 thru 74		$ (42,480,000)	$ 15,400,000	$ (21,220,000)			
75		$ (42,480,000)	$ 15,400,000	$ (21,220,000)	$ (570,560,000)		
76 thru 99		$ (42,480,000)	$ 15,400,000	$ (21,220,000)			
100		$ (42,480,000)	$ 15,400,000	$ (21,220,000)			
NPV	$ (5,979,000,000)	$ (863,900,000)	$ 313,200,000	$ (431,600,000)	$ (242,500,000)	$ -	$ (7,203,800,000)

	Operational Scenario 3						
Year	Total Capital Cost	Annual Power Cost	Annual Power Revenue	Annual O&M Cost	Periodic Replacement Cost	Salvage Value	Total
0	$ (8,162,000,000)						
1 thru 24		$ (67,500,000)	$ 25,220,000	$ (29,580,000)			
25		$ (67,500,000)	$ 25,220,000	$ (29,580,000)	$ (853,350,000)		
26 thru 49		$ (67,500,000)	$ 25,220,000	$ (29,580,000)			
50		$ (67,500,000)	$ 25,220,000	$ (29,580,000)	$ (853,350,000)		
51 thru 74		$ (67,500,000)	$ 25,220,000	$ (29,580,000)			
75		$ (67,500,000)	$ 25,220,000	$ (29,580,000)	$ (853,350,000)		
76 thru 99		$ (67,500,000)	$ 25,220,000	$ (29,580,000)			
100		$ (67,500,000)	$ 25,220,000	$ (29,580,000)		$ -	
NPV	$ (8,162,000,000)	$ (1,372,800,000)	$ 512,900,000	$ (601,600,000)	$ (362,600,000)	$ -	$ (9,986,100,000)

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Irrigation Facilities Same as described for OS1.

Operational Scenario 3

Approximately 11,767 acres would be permanently converted to reservoir and associated facilities under OS3.

Land Ownership As described for OS1, the land ownership data for Hawk Creek is incomplete and the majority of land is assumed to be privately owned. WDFW owns 60 acres within the proposed alternative and manages this area for recreation, while Reclamation owns 55 acres within OS2.

Land Use Land use impacts are the same as described for OS1, except they are greater because OS3 has a larger footprint (Table 4.4-5). For OS3, approximately 46 residences would be impacted.

Irrigated Agriculture Same as described for OS1.

Infrastructure As described for OS1, local roads and 1 mile of transmission line would be impacted by the proposed Hawk Creek Reservoir. Under OS3, 48 miles of local roads would be inundated and abandoned.

Irrigation Facilities Same as described for OS1.

4.4.6 Cultural Resource Effects

Impacts that can adversely affect heritage sites include anything that might significantly change the important features of a heritage site, and includes any kinds of ground-disturbing activities. Direct and indirect effects to cultural resources can result from human activities or natural events. Cultural sites are described in Section 4.4.1, *Site Characteristics*, under the heading, *Cultural Features and Developments*. As shown on Table 4-4.6, the probability that cultural resources are present is high. This ranking is based on the following assumptions:

- Hawk Creek is a primary drainage channel that empties into the Columbia River. Primary drainage channels generally contain larger numbers of pre-historic and historic sites than do smaller drainage channels.
- Only a very small amount of the study area has been inventoried for cultural resources; it is anticipated that when surveys are conducted there is a high probability that cultural resources will be present.

Hawk Creek and Crab Creek have been assigned an equal ranking. This is based primarily on the similarities of being primary drainage channels that generally contain large numbers of cultural resources.

A description of known cultural resources is provided below for each Operational Scenario.

Hawk Creek Reservoir Site

Operational Scenario 1

Direct Impacts This OS impacts 5,239 acres. Under this operational scenario, potential adverse effects to cultural resources may result from activities associated with the construction of the reservoir and dam, the inundation of water into the reservoir, sedimentation buildup from waters entering the reservoir covering cultural resources, and the erosion of shorelines from seasonal water fluctuations.

TABLE 4-4.6
Hawk Creek Cultural Impacts Summary

Factors	Criteria	Raw Data for Impacts				Impacts Normalized to Million Acre-Feet			
		Units	OS1	OS2	OS3	Units	OS1	OS2	OS3
National Register-eligible Resources and Traditional Cultural Properties	Potential resource impacts	Rating on 0-10 scale*	0	0	0	0-10 scale	0	0	0

* 0 = major conflict; 10 = none

Existing cultural resource information indicates there is a high potential for adverse effects to heritage sites within the footprint of the reservoir under OS1. The area with the highest potential for cultural resources is primarily along the valley floor. The cultural resources in most of the proposed project area have not been systematically inventoried. Current information indicates drainage bottoms and floodplains represent the greatest concentration of recorded archaeological sites, thus creating high-probability locations for areas that remain to be inventoried. This would be identified as part of the process of meeting the requirements of Section 106 of the NHPA and NEPA. In addition, there is a high potential for TCPs under this operational scenario. This would be addressed through consultation with the lead federal agency, associated Tribes, and SHPO.

When effects are analyzed as part of project planning, there may be opportunities to redesign some components of the project to avoid some sites or those adverse effects, or if necessary, mitigate them. Cultural resource sites would continue to be located and recorded in response to the proposed operational scenario. Mitigation and a management plan would be necessary to protect cultural resources from loss of integrity and physical damage.

Indirect Impacts Indirect impacts may include increased damage to prehistoric and historic sites because of increased public use or activities in the reservoir area of OS1. Under this scenario there would be increased recreational activities and a seasonal fluctuation in the water levels along the shoreline. Both recreation and fluctuation of water levels may result in indirect impacts to cultural resources.

Operational Scenario 2

Direct Impacts This OS impacts 8,556 acres Direct impacts on cultural resources under OS2 would be the same as described for OS1.

Indirect Impacts Indirect impacts on cultural resources under OS2 would be the same as described for OS1.

Operational Scenario 3

Direct Impacts This OS impacts 11,767 acres Direct impacts on cultural resources under OS3 would be the same as described for OS1.

Indirect Impacts Indirect impacts on cultural resources under OS3 would be the same as described for OS1.

Hawk Creek Dam and Appurtenant Structures

Although archaeological sites are recorded in the general area, no information is available regarding TCPs. Therefore, the assumption is that the Hawk Creek Dam and appurtenant structures would have similar cultural resources as the reservoir operational scenarios.

Direct Impacts Direct impacts to cultural resources under the Hawk Creek Dam and appurtenant structures would be the same as described for OS1.

Indirect Impacts Indirect impacts to cultural resources under the Hawk Creek Dam and appurtenant structures would be the same as described for OS1.

4.4.7 Environmental Resource Effects

Impacts to environmental resources for each operational scenario are summarized on Table 4-4.7. The environmental impacts discussion includes impacts of the reservoir, as well as the dam and all appurtenant structures.

Operational Scenario 1

Under OS1, 5,239 acres would be permanently disturbed.

Special Status Species As shown in Table 4-4.7, there are no terrestrial special status species present within the proposed Hawk Creek Reservoir site under OS1. Least bladdery milk-vetch was historically found on 57 acres at this site, but is no longer known to inhabit the site. Up to 10 miles of habitat for rainbow trout, an aquatic SPS, would be inundated by the proposed reservoir (Table 4-4.7). Approximately 3 miles of bull trout (FT and SC species) habitat in lower Hawk Creek downstream of the proposed Hawk Creek Dam site could potentially be affected, either beneficially or adversely, by the project depending on future creek flows and effects on habitat compared to existing conditions in the backwaters of Lake Roosevelt (Table 4-4.7).

Special Status Habitats Two state priority habitats would be inundated at this site (Table 4-4.7). This includes 50 acres of wetlands and 1,713 acres of riparian habitat. Open water resources are common within the Hawk Creek drainage, and the proposed site is at the confluence of several tributaries supporting 1,916 acres of riparian or open water habitat. The potential reservoir would inundate the existing Hawk Creek and its tributaries.

Conservation/Preservation Areas No federal or state conservation or preservation areas are found at the Hawk Creek site**.**

Operational Scenario 2

Under OS2, 8,556 acres would be permanently disturbed.

Special Status Species As shown in Table 4-4.7, no terrestrial special status species are present under OS2. Least bladdery milk-vetch was historically found on 62 acres at this site, but is no longer known to inhabit the site. Up to 12 miles of rainbow trout habitat would be inundated by the proposed reservoir. Potential effects on bull trout habitat in lower Hawk Creek downstream of the proposed dam site may be beneficial or adverse, depending on the future flow regime in this creek reach (Table 4-4.7).

Special Status Habitats Two state priority habitats would be inundated at this site (Table 4-4.7). This includes 50 acres of wetlands and 2,721 acres of riparian habitat.

Conservation/Preservation Areas No federal or state conservation or preservation areas are found at the Hawk Creek site**.**

Operational Scenario 3

Under OS3, 11,767 acres would be permanently disturbed.

Special Status Species Spaulding's silene is found to occupy approximately 9 acres under OS3 (Table 4-4.7). Least bladdery milk-vetch was historically found on 63 acres at this site by OS3, but is no longer known to inhabit the site. Up to 14 miles of rainbow trout habitat would be inundated by the proposed reservoir. Potential effects on bull trout habitat in lower Hawk Creek downstream of the proposed dam site may be beneficial or adverse, depending on the future flow regime in this creek reach (Table 4-4.7). The proposed site supports 2,407 acres of riparian and/or open water habitat.

Special Status Habitats Two state priority habitats would be inundated at this site (Table 4-4.7). This includes 53 acres of wetlands and 3,430 acres of riparian habitat.

Conservation/Preservation Areas No federal or state conservation or preservation areas are found at the Hawk Creek site.

4.4.8 Recommended Further Investigations Specific to this Site

Recommendations for further investigations specific to the proposed Hawk Creek site include the following:

- A large rockfill dam would be required at this site, having a height of 600 to 800 feet. A dam of this size (537 to 780 feet) should be founded on bedrock to avoid settlement and stability issues. Deep borings would be required to determine the thickness, distribution, strength, and permeability characteristics of the alluvium and particularly the glaciolacustrine materials that underlie the northern side of the valley.
- The lake taps, intake tunnels, tunnel junction chamber, and underground pump chamber would require deep borings in order to characterize the bedrock and design the tunnel access shaft, support for the tunnels, and structural support for the underground pump chambers.
- The outlet works would be constructed near the left (abutment). The outlet tunnel would be set back into the steep hillside upstream from the south abutment and require high, steep rock cuts in layered basalt flows with possible interbeds. Deep borings and geologic mapping would be required in order to evaluate the stability and construction considerations of the high rock cuts.
- Borings and possibly geophysical lines would be required to verify the subsurface conditions and variations in bedrock and groundwater along conveyance facilities, penstock, and combined pump/turbine facility locations.
- Bathymetric mapping in Hawk Creek bay in order to accurately map the underwater areas. In addition, sediment cores should be conducted in order to estimate how much sediment accumulation has occurred that may alter the design and elevations of the intakes, lake taps, etc.
- A subsurface investigation must be conducted in the vicinity of the small rock fill dam in the Hawk Creek inlet; this investigation would include borings and tests pits to characterize the subsurface conditions at this site and search for appropriate fill materials.

- Deep borings and geologic mapping at the spillway near the smaller Hawk Creek inlet dam in order to evaluate the stability of the proposed rock cut. The rock cut on the south side of the spillway channel is anticipated to be up to 250 feet high.
- Detailed geologic mapping of sites, including discontinuity mapping in rock outcrops
- Soil borings and rock cores to determine the thickness and characteristics of alluvial sediments, and shallow rock characteristics under the proposed dams and appurtenant facilities
- Additional borings, test pits, and/or geophysical lines along the proposed axes of the dams to determine the basalt rock profile perpendicular to the existing streams
- Down-hole hydraulic pressure testing to evaluate the permeability of the basalt bedrock.
- Conduct cultural resources surveys
- Rock quarry investigations to evaluate the volume and durability of the bedrock, and the suitability of the borrow area rock sources for dam embankment material. This investigation will consist of core samples, rock samples, and rock durability testing.
- Borings to verify the depth and characteristics of soils and bedrock along proposed conveyance routes, outlet works, intake towers, fish screens, and pumping/powerhouse locations.

TABLE 4-4.7
Hawk Creek Environmental Impacts Summary

Factors	Criteria	Raw Data for Impacts				Impacts Normalized to Million Acre-Feet			
		Units	OS1	OS2	OS3	Units	OS1	OS2	OS3
Special Status Species	Anadromous Fish—Habitat Inundated	Miles	0	0	0	Miles/MAF	0	0	0
	Anadromous Fish—Downstream Habitat Affected	Miles	0	0	0	Miles/MAF	0	0	0
	Federal aquatic T & E species—Habitat Inundated	Miles	0	0	0	Miles/MAF	0	0	0
	Federal aquatic T & E species—Downstream Habitat Affected	Miles	3	3	3	Miles/MAF	3	2	1
	State aquatic Sensitive species—Habitat Inundated	Miles	0	0	0	Miles/MAF	0	0	0
	State aquatic Sensitive species—Downstream Habitat Affected	Miles	3	3	3	Miles/MAF	3	2	1
	State aquatic Priority Species	Miles	10	12	14	Miles/MAF	10	6	5
	Federal terrestrial T & E species impacts	Acres	0	0	0	Acres/MAF	0	0	0
	State terrestrial T & E and Sensitive species impacts	Acres	0	0	9	Acres/MAF	0	0	3
	State terrestrial Priority Species	Acres	9,701	14,069	17,816	Acres/MAF	9,701	7,035	5,939
Special Status Habitat or Conservation/ Preservation Designation	Wetland habitat impacts	Acres	51	51	54	Acres/MAF	51	26	18
	Riparian habitat impacts	Acres	1,767	2,775	3,484	Acres/MAF	1,767	1,388	1,161
	Sand Dunes habitat impacts	Acres	0	0	0	Acres/MAF	0	0	0
	Cliffs/Bluffs habitat impacts	Acres	0	0	0	Acres/MAF	0	0	0
	Shrub-steppe habitat impacts	Acres	70	89	229	Acres/MAF	70	45	76
	Candidate Wild & Scenic rivers	Miles	0	0	0	Miles/MAF	0	0	0
	Wilderness Study Areas	Acres	0	0	0	Acres/MAF	0	0	0
	National wildlife refuges impacts	Acres	0	0	0	Acres/MAF	0	0	0
	State wildlife refuges impacts	Acres	0	0	0	Acres/MAF	0	0	0
	Other National or State conservation/preservation designation	Acres	0	22	61	Acres/MAF	0	11	20

5 Decision Support Model Summary

This section summarizes the results of applying a decision support modeling tool to compare storage alternatives objectively. The full decision support model results are provided in Appendix D.

5.1 Basis for Comparison—Evaluation Criteria

As presented on a site-by-site and scenario-by-scenario basis in Section 4, the off-channel storage site and scenario alternatives are assessed from three different perspectives, each of which is important to decision-making:

- Implementation/Technical Feasibility
- Benefits/Objectives Achievement
- Impacts (potential environmental, cultural, or socioeconomic impacts)

These **perspectives** provide the big-picture overview of the costs, benefits, and impacts of each of the sites. For analysis purposes, each of these perspectives is divided into **categories**, such as time to build or socioeconomic resources. These categories are further divided into **factors**, which identify the specific item being measured, such as land ownership or irrigation supply needs. To get to measurable units, the factors are subdivided to **criteria**, such as stream miles inundated or the ratio of hydroelectric revenue to power cost.

Table 5-1.1 presents the base data for all alternatives for each of these perspectives. The data shown on this table—and its organization into evaluation perspectives, categories, factors, and criteria—form the basis for comparative analysis and are the starting point for development of the decision support model. This analysis process was introduced in Section 3.4, *Evaluation/Screening Criteria*. Additionally, some of the criteria that were applied to analyze impacts were presented for socioeconomic, cultural, and environmental resources in Section 3.5, *Regional Context and Similarities among Alternatives*.

Overview of Comparison and Screening Process

To compare the alternatives, it was necessary to convert the objective criteria in Table 5-1.1 (for example, miles, acres, and dollars) to a common language or normalized scoring system, called a **criteria score**. To reach the criteria score, all values were converted to a common scale of 0 to 10, with 0 being the worst, or least desirable condition, and 10 being the best, or most desirable condition.

For example, in a hypothetical situation, imagine four alternatives: one that impacts 10 residences, another impacting 32 residences, a third impacting 67 residences, and the fourth impacting 110 residences. The alternatives would be ranked according to the percent difference between best and worst. The first alternative would receive a criteria score of 10, because it is the best (least impact). The fourth alternative, with the most impact to homes, would be rated a 0. The second and third alternatives would be rated 7.8 and 4.3, respectively, based on the percent difference. A detailed description of this process is provided in Appendix D, *Decision Support Model*.

Objective Data and Professional Judgment

Most of the data presented use objective measurements for each factor, such as acres, dollars, numbers of residences, or miles. Some of the data used in the decision model relies upon professional judgment to estimate results. For example, relative risk or hazard of potential dam sites is influenced by a number of considerations, including proximity to populated areas and geotechnical issues that are not yet completely explored (through drilling or other site-specific investigations). Professional judgment must be applied when reviewing available data to assist in making a decision. Similarly, more extensive cultural resource investigations have been conducted at the Crab Creek Dam and Reservoir site than at the Sand Hollow or Hawk Creek sites. Because there are varying levels of existing studies at the three sites, assumptions were made to compare the probability that cultural resources are present (as described in Sections 3 and 4). These assumptions were based on information collected from the Washington State Historic Preservation Office and professional experience.

For all of the factors requiring professional judgment, the 0 to 10 rating system was used from the outset to be compatible with the criteria scores calculated for the objective factors.

Comparing the Three Perspectives

Comparing Implementation/Technical Feasibility, Objectives/Benefits Achievement, and Impacts to each other required another level of normalizing the criteria scores. Once a criteria score is reached for each factor, then those must be rolled up into one score for each of the perspectives. Since each perspective has a different number of factors, the scores from all of the factors were simply averaged to come up with one score for the perspective. For example, as shown on Table 5-1.1, the Objectives/Benefits perspective contains two categories with five factors. A criteria score was calculated for each factor, added together, then divided by five to come up with a criteria score for the entire perspective.

For this Appraisal Evaluation, all of the data are considered equally, and two analyses were performed. One analysis considered the data as presented without additional manipulation. For example, Crab Creek OS3 data were ranked the same as Hawk Creek OS1. In the second analysis, the data were adjusted to reflect the per-million-acre-foot yield expected from each project alternative. This allowed the costs, benefits, and impacts to be adjusted for the scale of the operational scenario considered for each potential reservoir site. This is achieved by dividing the base units (for example, miles or acres) by the number of million acre-feet for the reservoir alternative (that is, 1 million acre-feet in OS1, or 3 million acre-feet in OS3). For example, Crab Creek OS3 has 30 miles of transmission line impact; for Crab Creek OS2, that impact is divided by 2 million acre-feet to result in 15 miles of impact per million acre-feet.

In Appendix D, both sets of results are presented. For this summary, the Implementation/Technical Feasibility and Objectives/Benefits Achievement are shown **with** the million-acre-foot adjustment, which provides a better evaluation in terms of costs and yield. The Impacts perspective is presented **without** adjusting for reservoir size, because the level of impact is not directly tied to storage volume. The largest amount of impact occurs with the introduction of reservoirs at the three sites; as the reservoir footprint increases to the 2 million and 3 million acre-foot levels, many impacts increase in magnitude but do not double or triple when compared with the 1 million acre-foot scenario.

Table 5-1.1
Alternatives Comparison/Screening Criteria and Base Data

Perspective	Categories	Factors	Criteria	Units of Measure (base data/score)	Crab Creek			Sand Hollow	Hawk Creek		
					OS1 (1 MAF)	OS2 (2 MAF)	OS3 (3 MAF)	OS1 (1 MAF)	OS1 (1 MAF)	OS2 (2 MAF)	OS3 (3 MAF)
A. Implementation/ Technical Feasibility											
	Cost & Time to Build		Net Present Value	$	$ 1,056,700,000	$ 1,965,400,000	$ 2,765,400,000	$ 2,009,000,000	$ 4,142,000,000	$ 7,203,800,000	$ 9,986,100,000
			Net Present Value/50 yrs yield	$/AF of yield	$ 19	$ 17	$ 17	$ 36	$ 73	$ 61	$ 60
			Construction duration	Years	4	5	6	4	6	7	8
	Risk Factors	Safety & integrity	Relative risk/hazard	Rating on 0-10 scale (0=highest, 10=lowest risk)	9	8	8	7	6	5	4
		Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	Rating on 0-10 scale (0=highest, 10=lowest risk)	6	7	8	0	4	5	6
B. Objectives/ Benefits Achievement											
	Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	acre-feet/year	845,000	1,764,000	2,463,000	834,000	852,000	1,764,000	2,463,000
		DCM&I Supply	Meeting projected demand (yield)	acre-feet/year	38,000	78,000	109,000	37,000	38,000	78,000	109,000
		Flow augmentation	Meeting projected demand (yield)	acre-feet/year	249,000	535,000	754,000	245,000	251,000	535,000	754,000
	Secondary Benefits	Power generation	Power balance	Revenue/Cost	0.49	0.55	0.55	0.49	0.37	0.36	0.37
		Expandibility	Potential for expansion to increase storage volume in the future	Rating on 0-10 scale (10=highest, 0=lowest potential)	8	7	6	0	0	0	0
C. Impacts											
	Socio-economic	Land Ownership	Private land acquisition requirement	Acres	5,000	7,000	9,000	12,500	5,000	8,000	11,000
			Federal & State land acquisition requirement	Acres	11000	16000	19000	50	100	100	100
		Land Use	Residential use	No. residences	18	18	18	32	41	45	46
			Irrigated Agriculture--High value crops (e.g. orchards, seed)	Acres	0	0	0	12,441	0	0	0
			Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	Acres	4,989	6,768	8,650	0	0	0	0
		Infrastructure	Highway (State, federal) impacts	Miles	2	3.5	5	1.5	0	0	0
			Local road impacts	Miles	33	43	48	36	28	39	48
			Railroad impacts	Miles	16	18	21	0	0	0	0
			Irrigation Infrastructure	Rating on 0-10 scale (0=major conflict, 10=none)	7	6	5	1	10	10	10
			Transmission line impacts	Miles	30	30	30	3	1	1	1
	Cultural	National Register-eligible resources and Traditional Cultural Properties	Potential for resource impacts	Rating on 0-10 scale (0=major potential, 10=none)	0	0	0	8	0	0	0
	BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	Miles	56	64	72	0	0	0	0
			Anadromous Fish--Downstream Habitat Affected	Miles	6	6	6	2	0	0	0
			Federal aquatic T & E species--Habitat Inundated	Miles	28	32	36	0	0	0	0
			Federal aquatic T & E species--Downstream Habitat Affected	Miles	3	3	3	1	3	3	3
			State aquatic Sensitive species--Habitat Inundated	Miles	28	32	36	0	0	0	0
			State aquatic Sensitive species--Downstream Habitat Affected	Miles	3	3	3	1	3	3	3
			State aquatic Priority Species	Miles	112	128	144	0	10	12	14
			Federal terrestrial T & E species impacts	Acres	0	0	0	0	0	0	0
			State terrestrial T & E and Sensitive species impacts	Acres	945	997	1,043	52	0	0	9
			State terrestrial Priority Species	Acres	4,453	5,136	5,547	29	9,701	14,069	17,816
		Special Status habitat or conservation/preservation designation	Wetland habitat impacts	Acres	4,414	4,965	5,413	112	51	51	54
			Riparian habitat impacts	Acres	416	418	418	0	1,767	2,775	3,484
			Sand Dunes habitat impacts	Acres	119	119	119	0	0	0	0
			Cliffs/Bluffs habitat impacts	Acres	88	202	306	0	0	0	0
			Steppe-Shrub habitat impacts	Acres	1,275	1,323	1,335	0	70	89	229
			Candidate Wild & Scenic rivers	Miles	0	0	0	0	0	0	0
			Wilderness Study Areas	Acres	0	0	0	0	0	0	0
			National wildlife refuges impacts	Acres	4,899	8,941	11,916	43	0	0	0
			State wildlife refuges impacts	Acres	6,103	6,930	7,311	0	0	0	0
			Other National or State conservation/preservation designation	Acres	0	0	0	0	0	22	61
		Water & Air Quality	Downstream temperature impacts	Rating on 0-10 scale (0=major conflict, 10=none)	7	8	9	2	9	10	10
			Windblown dust/particulates (from annual reservoir drawdown)	Rating on 0-10 scale (0=major conflict, 10=none)	8	7	6	2	10	10	10

5.2 Results of Project Alternatives Comparison/ Screening

Implementation/Technical Feasibility

Site/scenario rankings from the perspective of Implementation and Technical Feasibility are illustrated on Figure 5-2.1. As shown, The Crab Creek site performs best among the three candidate sites in all Implementation/ Technical Feasibility categories. It offers the lowest cost and lowest risk options and best time-to-build ratings. The closest any site/scenario comes to approximating the Implementation/Technical Feasibility ratings of the Crab Creek scenarios is Sand Hollow, where the 1 million acre-foot Sand Hollow option rates comparably to the 3 million acre-foot Crab Creek OS3.

The Sand Hollow site option represents a "middle ground" (only related to OS1 options), primarily because its cost is double that of Crab Creek but half that of Hawk Creek, and because it would take the shortest time to build.

The Hawk Creek site, in all scenarios, is clearly shown to be the lowest ranking from the Implementation/Technical Feasibility perspective. This is due to having by far the highest cost, relatively high risk factors, and the longest time to build.

Objectives/Benefits Achievement

Site/scenario ranking from the perspective of Objectives/Benefits Achievement are illustrated on Figure 5-2.2. The largest reservoir scenarios and the Crab Creek site in general rank the highest from this perspective. Basically, this result demonstrates that more water storage better meets primary project objectives. The Crab Creek site generally ranks higher than other comparable sites because it has the best performance on secondary benefits. That is, Crab Creek has the best power balance (revenue/cost ratio) and is the only site judged to offer future expansion potential.

FIGURE 5-2.1

Alternatives Comparison: Implementation/Technical Feasibility

→ Total NPV costs adjusted to per million acre-feet

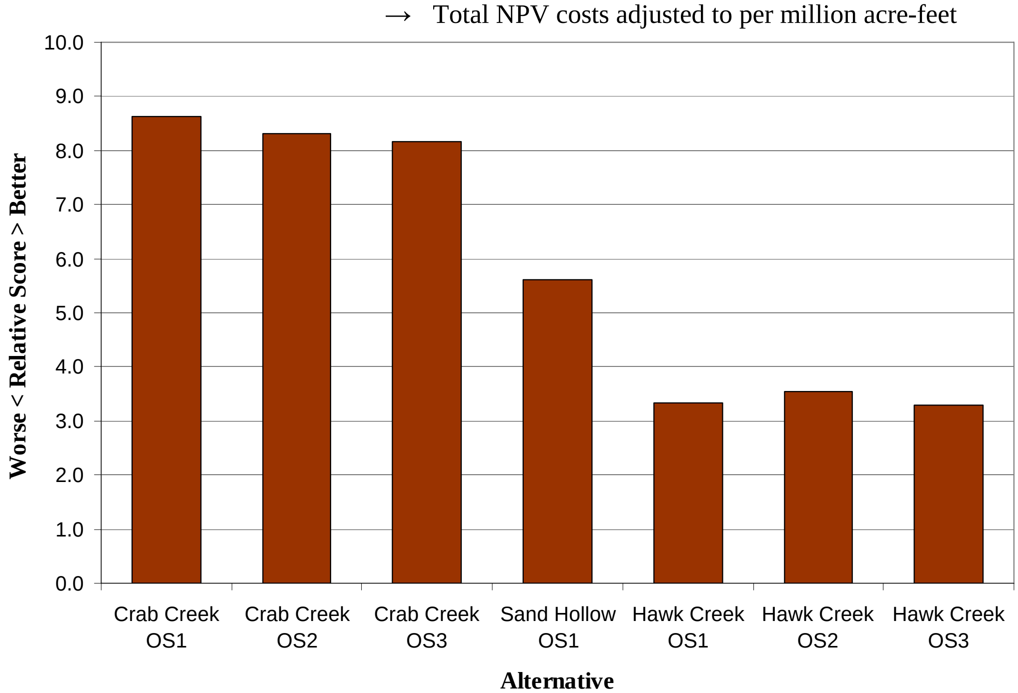
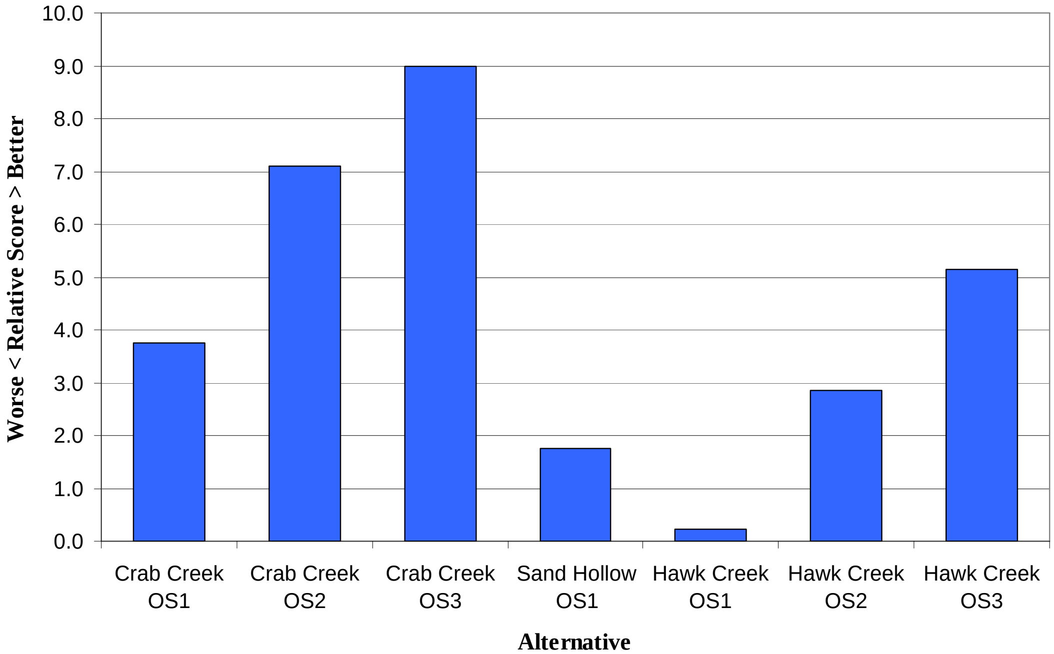


FIGURE 5-2.2

Alternatives Comparison: Objectives/Benefits Achievement

→ Total NPV costs adjusted to per million acre-feet



Combination of Implementation/ Technical Feasibility and Objectives/Benefits Achievement

Figure 5-2.3 combines the Implementation/ Technical Feasibility and Objectives/ Benefits Achievement perspectives. When taken together, these two perspectives reinforce the superiority of the Crab Creek site, centering on cost, ability to construct and maintain, and flexibility for expansion. These site/scenario ratings also show a preference for the larger reservoir sizes; specifically, a higher capacity available to meet future water supply needs.

Impacts

Site/scenario rankings from the perspective of Impacts are illustrated on Figure 5-2.4. As shown, the Crab Creek site, in all operational scenarios, rates lowest (or least desirable) in terms of impacts. Crab Creek has high impacts in all three categories of socioeconomic, cultural, and biophysical (environmental). Impacts include acquisition of high acreages of private and public lands, as well as presence of endangered and sensitive species, including wetlands and wildlife refuges.

FIGURE 5-2.3

Alternatives Comparison: Combined Implementation/Technical Feasibility and Objectives/Benefits Achievement Perspectives

→ Total NPV costs adjusted to per million acre-feet

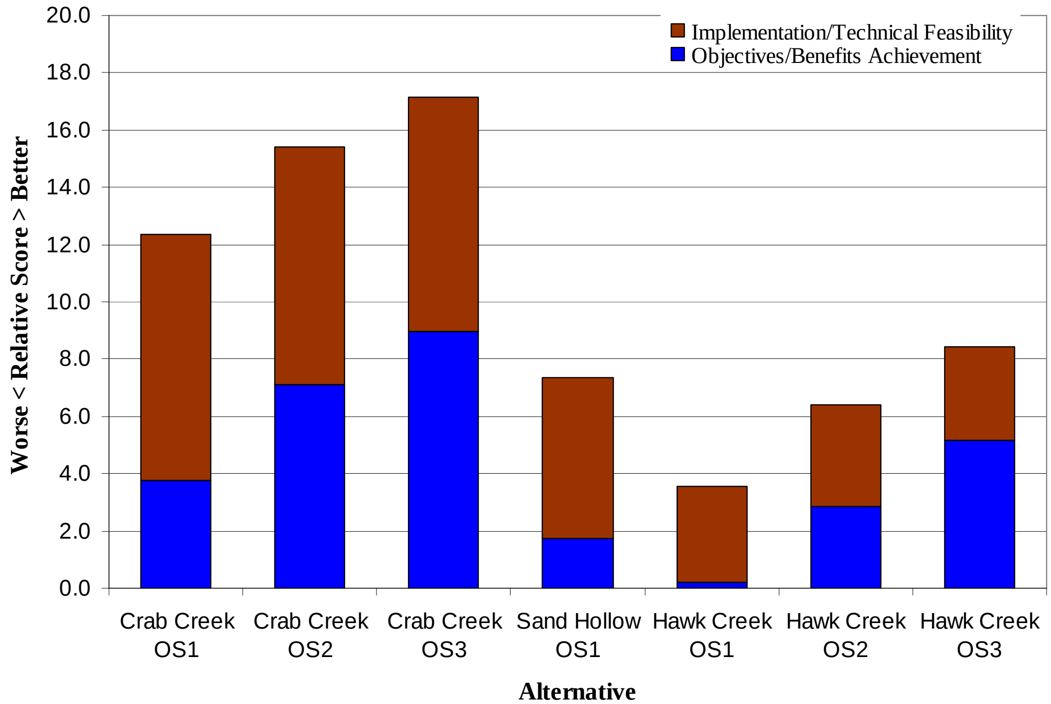
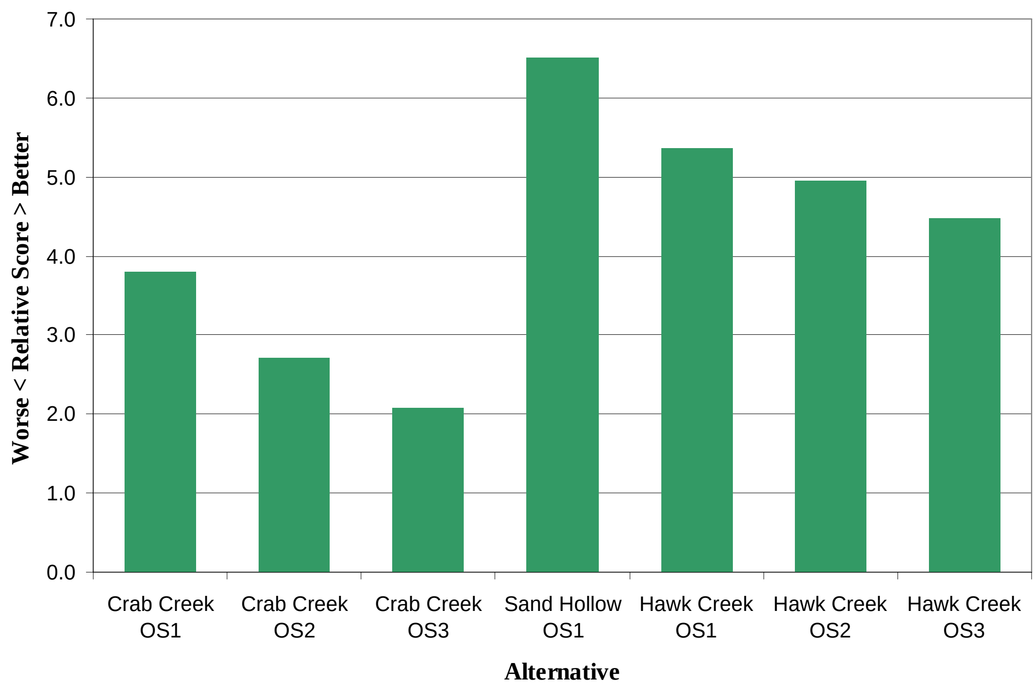


FIGURE 5-2.4

Alternatives Comparison: Impacts

→ Overall rankings; no consideration of reservoir size



The Sand Hollow site rates as the most desirable, with the lowest potential for impacts, primarily because of its score in the cultural category. While Crab Creek and Hawk Creek are primary drainage channels that could be expected to have a high probability of cultural resource sites, the Sand Hollow wasteway does not and, therefore, scores much better in the cultural category. Sand Hollow is constrained by potential air and water quality impacts, and has a moderate score in the environmental and socioeconomic impacts. Negative socioeconomic impacts include a high level of impact to existing irrigation infrastructure.

The Hawk Creek site has the highest overall scores in both socioeconomic and environmental categories; however, it involves the most residential displacements among the three alternatives. If the cultural impacts scores were excluded, it would rank more highly than Sand Hollow.

5.3 Decision Model Findings

Based on the decision support model analysis, the Crab Creek site, in aggregate, appears most favorable among the candidate sites being considered. This is because the Crab Creek site offers the best response to Implementation/Technical Feasibility and Objectives/Benefits Achievement criteria. Specifically, this site has significantly lower costs than the other sites and offers the potential for future expansion.

However, the Crab Creek site also presents the highest potential for adverse impacts in many evaluation categories and factors (socioeconomic, cultural, and environmental).

From the standpoint of Impacts, the Sand Hollow and Hawk Creek sites present substantially fewer issues than the Crab Creek site. However, the Hawk Creek site in particular presents significantly greater cost and other technical challenges. Although Sand Hollow ranks about the same as Hawk Creek OS2 and OS3 when Implementation/Technical Feasibility and Objectives/Benefits Achievement are combined, the storage capacity of 1 million acre-feet, combined with the fact that the site could not be expanded, may present a significant obstacle.

6 Findings and Conclusions

This section summarizes the findings of the analysis that was performed for each of the sites in Section 4, and recommends one site for evaluation in subsequent studies. The conclusions from the decision support model are provided in Section 5.

6.1 Findings

As a baseline for comparison, the relative sizes and characteristics of major project facilities are provided in Table 6-1.1. As shown, the alternatives vary significantly in size, which influences project costs and feasibility. The differences among the dam sizes are shown graphically in Figure 6-1.1.

6.1.1 Technical Viability

Based on the information available at this time, three of the Columbia River off-channel storage options appear to be technically viable:

- Crab Creek
- Sand Hollow
- Hawk Creek

Foster Creek was found to have fatal flaws, because of significant geotechnical concerns in combination with a high downstream hazard condition.

Of the three technically viable sites, Crab Creek is the most viable and has the least risk from a technical standpoint. In particular, Hawk Creek has technical challenges beyond the other two sites because of the extensive infrastructure and subterranean earthworks required.

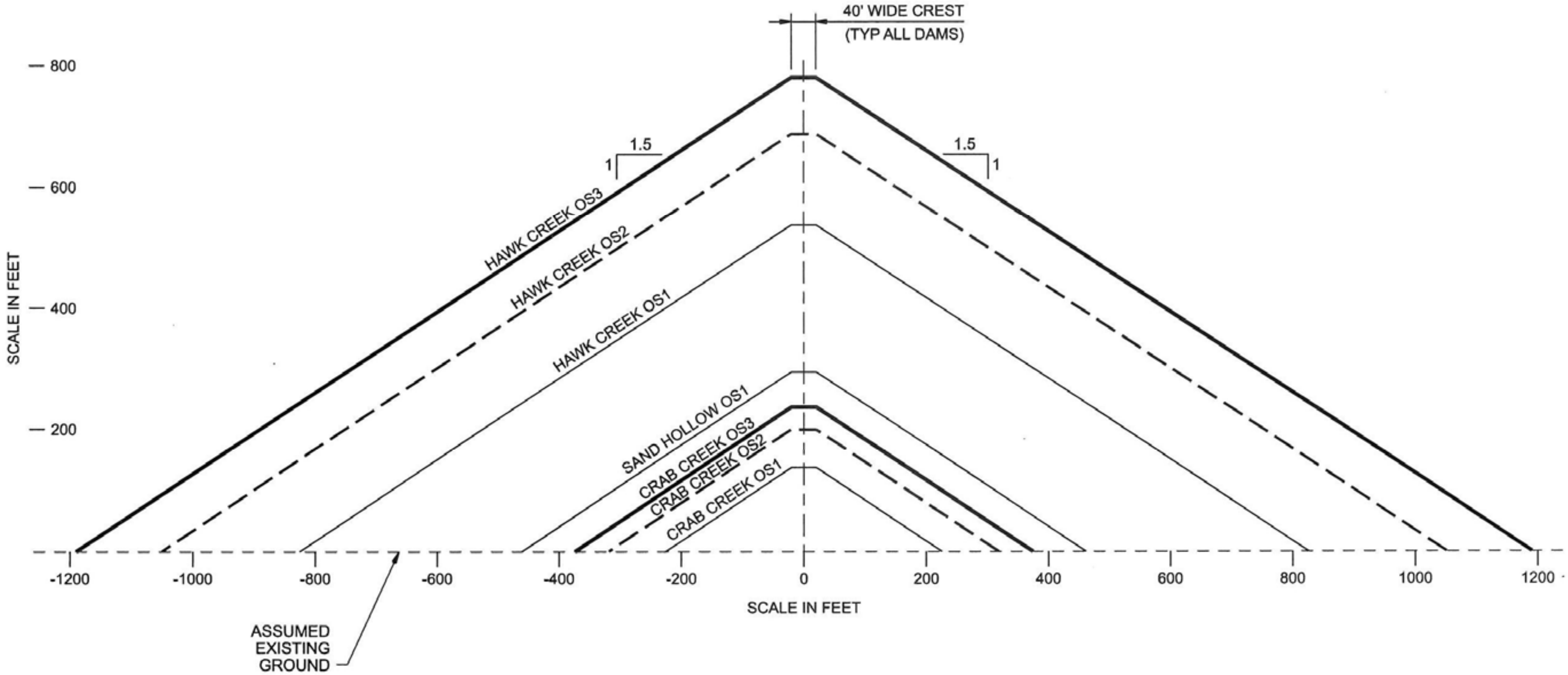
Technical viability does not, however, consider economic, financial, environmental, cultural, and social aspects of the four storage alternatives.

TABLE 6-1.1

Comparison of Key Parameters for Dam, Reservoir, and Pump/Turbine Facilities

Dam Site	Storage Volume (acre-feet)	Reservoir Surface Area (acres)	Dam Height (ft)	Dam Embankment Volume (yd^3)	Maximum Total Pumping Horsepower Required (hp)	Maximum Power Generating Output from Turbines (MW)
Crab Creek OS1	1,000,000	16,950	137	4.3 million	56,300	69
Crab Creek OS2	2,000,000	23,500	199	10.9 million	172,000	216
Crab Creek OS3	3,000,000	29,400	236	16.6 million	316,000	392
Sand Hollow OS1	1,000,000	12,500	294	16.7 million	302,000	285
Hawk Creek OS1	1,000,000	5,200	537	38.1 million	310,000	237
Hawk Creek OS2	2,000,000	8,500	687	71.1 million	806,000	652
Hawk Creek OS3	3,000,000	11,750	780	99.3 million	1,422,000	1,136

FIGURE 6-1.1
Graphic Comparison of Dam Sizes: Concrete-Faced Rock Fill Dams



6.1.2 Storage Study Goals

The three technically viable alternatives—Crab Creek, Sand Hollow, and Hawk Creek—meet all three storage study goals:

- Provide water supply for irrigation in dry years and the future
- Improve anadromous fish habitat through flow augmentation
- Meet future DCM&I supply needs for population growth to the year 2050

The Foster Creek Dam and Reservoir site was not studied in detail for its ability to meet project goals because it was eliminated early in the Appraisal Evaluation.

Crab Creek and Hawk Creek could be developed to 1 million, 2 million, or 3 million acre-feet of storage and are able to provide significantly larger storage volumes than Sand Hollow. Sand Hollow could only be feasibly developed to provide 1 million acre-feet of storage because of topographic constraints. All three sites provide comparable anadromous fish flow benefits at each of the operational scenarios, increasing the flow by roughly the same percentage at Priest Rapids Dam.

6.2 Cost Effectiveness

Figures 6-2.1 and 6-2.2 illustrate the differences in cost among the alternative

FIGURE 6-2.1
Cost Comparison Based on Median Reservoir Yield for Anticipated Uses

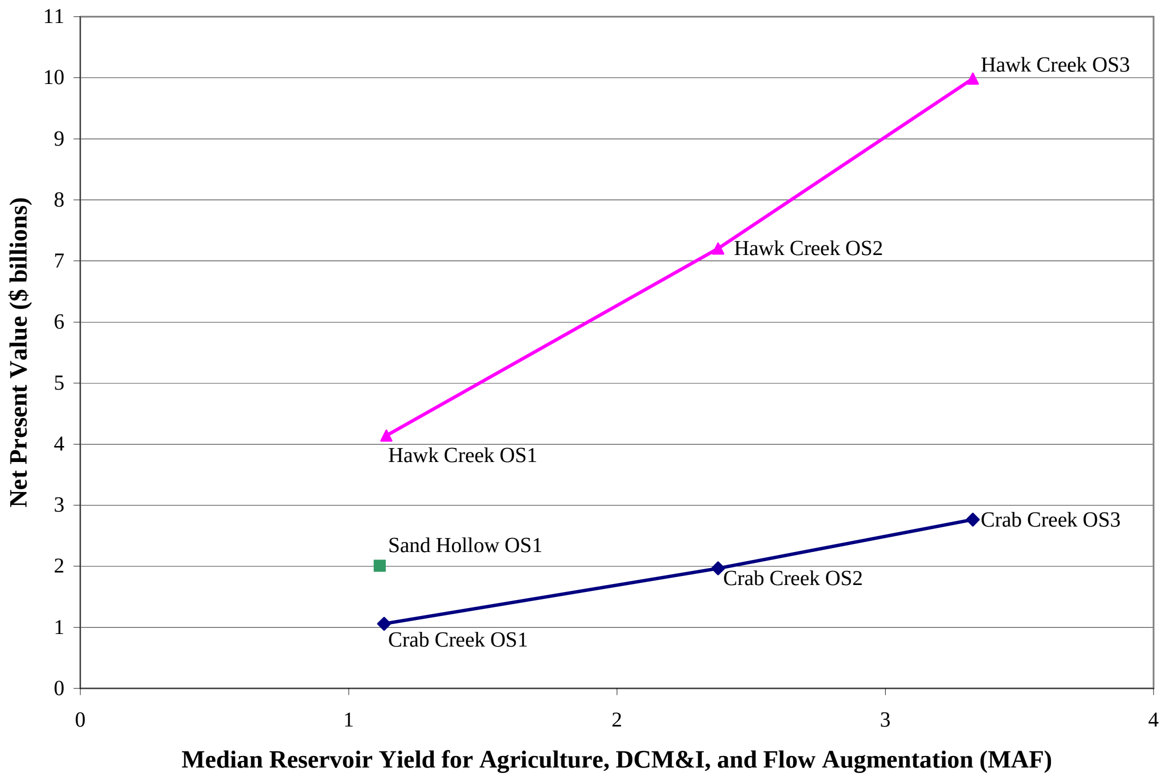
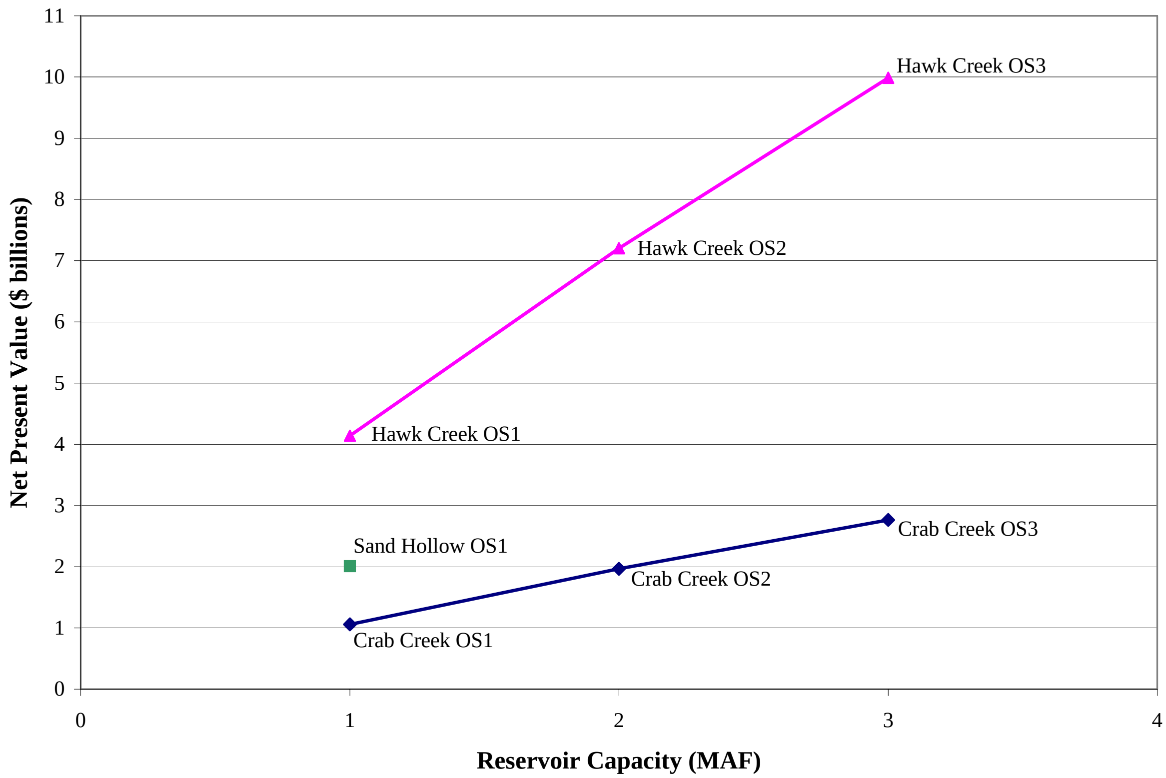


FIGURE 6-2.2
Cost Comparison Based on Reservoir Capacity



scenarios. Figure 6-2.1 illustrates the difference in cost in terms of the median reservoir yield for agriculture, DCM&I, and flow augmentation, while Figure 6-2.2 shows the costs in terms of reservoir capacity. Tables 6-2.1, *Summary of Capital Costs and Net Present Values for All Sites and Operational Scenarios*, and 6-2.2, *Summary of Annual Costs and Net Present Values for All Sites and Operational Scenarios*, are provided at the end of this section. As the figures and tables indicate, the operational scenarios at the Crab Creek site are significantly less expensive from a capital cost, annual cost, and net present value perspective than the comparably sized projects at Sand Hollow and Hawk Creek. Costs for the Crab Creek site range from $900 million to $2.4 billion for total capital costs, and from $1 billion to $2.8 billion in net present value.

6.3 Conclusions and Recommendations

Based on this Appraisal Evaluation, Crab Creek is the recommended site to carry forward if a Feasibility Study is conducted. The Crab Creek site scores higher for technical viability and cost-effectiveness than either the Sand Hollow or Hawk Creek sites. As described in Section 5, *Decision Support Model*, Crab Creek also has the most environmental, socioeconomic, and cultural impacts. However, the difference in cost and other elements of viability between Crab Creek and the other two alternatives is significant, particularly for the Hawk Creek site, which has far greater cost and technical challenges.

Another key factor in the recommendation for Crab Creek is that it offers flexibility that the other sites cannot. Sand Hollow can only feasibly be developed to 1 million acre-feet. The characteristics and technical challenges of the Hawk Creek site are such that increasing that prospective project's capacity in the future would be difficult, eliminating all or most financial benefits to any sort of staging approach. By contrast, Crab Creek could be developed for a lower capacity now and upgraded in the future with additional equipment and structures to increase capacity.

During the Feasibility Study, the tradeoffs between constructing more capacity now versus the cost of rebuilding or upgrading in the future must be carefully considered. For example, the cost analysis may demonstrate that it is more economical to build the largest facility from the start. However, since much of the cost is tied to the size of the dam, pump/turbine units, and other equipment, it might be desirable to build the structure with future expansion in mind (for example, tunnels and channels and concrete structures sized for full buildout), but with dam height, inundation area mitigation, and pump/turbine equipment constructed or installed only as needed for smaller capacities and yield at initial construction.

The demand analysis recommended as a future investigation would assist Reclamation and Ecology in determining the desired starting size for the reservoir. Regardless of the initial size selected, the concept of future flexibility is an important and highly desired trait in selecting an off-channel storage option. The Crab Creek Dam and Reservoir site best meets these characteristics.

6.3.1 Further Technical Investigations

If the Crab Creek site is carried forward into a Feasibility Study, additional investigations should be conducted. Specific studies from this Appraisal Evaluation are listed in Section 4.1.8, *Recommended Further Investigations Specific to this Site*. Briefly, potential investigations could include the following:

- Refining the anticipated irrigation demand analysis for development of the second half of the Columbia Basin project, and refining the optimal flow augmentation release timing for target fish species.
- Investigating the feasibility of bringing water supply for the proposed Crab Creek reservoir from upstream sources (rather than the Priest Rapids Pool), thereby reducing pumping needs.
- Conducting numerous geotechnical investigations, including test pits, soil borings, rock cores, river bathymetry, and additional geologic and seismotectonic mapping to better establish facility structural needs.
- Following this study or during the Feasibility Study, consideration could be given to expanding the decision model work to apply Relative Importance criteria to the analysis. This would confirm site selection of Crab Creek. Based on the decision model analyis to date, Crab Creek appears to rank the highest by a moderate margin, if the benefits of volume are ignored. When these

benefits are considered, the expandability of the Crab Creek site to 3 million acre-feet represents a substantial improvement over other alternative sites. Applying Relative Importance criteria may serve to confirm the recommendation to futher evaluate Crab Creek.

Table 6-2.1

Summary of Capital Costs for All Sites and Operational Scenarios

Facility or Cost Component	Crab Creek			Sand Hollow	Hawk Creek		
	OS1	OS2	OS3	OS1	OS1	OS2	OS3
Columbia River Intake Facilities	$ 20,200,000	$ 40,200,000	$ 60,200,000	$ 21,800,000	$ 62,000,000	$ 117,200,000	$ 172,400,000
Penstocks and Tunnels	$ 2,900,000	$ 4,900,000	$ 5,500,000	$ 142,700,000	$ 156,100,000	$ 261,700,000	$ 384,600,000
Channels	$ 41,500,000	$ 50,400,000	$ 59,300,000	$ -	$ -	$ -	$ -
Pump/Turbine Facilities	$ 56,900,000	$ 144,300,000	$ 229,900,000	$ 204,600,000	$ 291,500,000	$ 659,300,000	$ 993,000,000
Dams and Spillways	$ 148,000,000	$ 373,400,000	$ 568,200,000	$ 350,100,000	$ 1,137,200,000	$ 1,745,200,000	$ 2,264,600,000
Reservoir Inlet/Outlet Works	$ 15,000,000	$ 20,000,000	$ 25,000,000	$ 30,000,000	$ 32,000,000	$ 36,000,000	$ 40,000,000
Additional Structures	$ 4,000,000	$ 6,100,000	$ 6,600,000	$ 3,400,000	$ 2,800,000	$ 4,300,000	$ 4,800,000
Road Relocations	$ 8,900,000	$ 25,700,000	$ 27,000,000	$ 8,100,000	$ -	$ -	$ -
Bridges	$ 7,100,000	$ 7,700,000	$ 8,200,000	$ -	$ -	$ -	$ -
Power Transmission Facilities	$ 137,500,000	$ 137,900,000	$ 138,500,000	$ 17,900,000	$ 14,200,000	$ 15,200,000	$ 16,600,000
Security/Safety Fencing	$ 900,000	$ 900,000	$ 900,000	$ 100,000	$ 100,000	$ 100,000	$ 100,000
Mobilization (5%)	$ 22,000,000	$ 41,000,000	$ 56,000,000	$ 39,000,000	$ 85,000,000	$ 142,000,000	$ 194,000,000
Unlisted Items (15%)	$ 66,000,000	$ 122,000,000	$ 169,000,000	$ 117,000,000	$ 254,000,000	$ 426,000,000	$ 581,000,000
Subtotal	$ 531,000,000	$ 975,000,000	$ 1,354,000,000	$ 935,000,000	$ 2,035,000,000	$ 3,407,000,000	$ 4,651,000,000
Contingency (30%)	$ 159,000,000	$ 293,000,000	$ 406,000,000	$ 281,000,000	$ 611,000,000	$ 1,022,000,000	$ 1,395,000,000
Field Cost (or Construction Contract Cost)	$ 690,000,000	$ 1,268,000,000	$ 1,760,000,000	$ 1,216,000,000	$ 2,646,000,000	$ 4,429,000,000	$ 6,046,000,000
Noncontract Cost (35%)	$ 242,000,000	$ 444,000,000	$ 616,000,000	$ 426,000,000	$ 926,000,000	$ 1,550,000,000	$ 2,116,000,000
Total Capital Cost	$ 932,000,000	$ 1,712,000,000	$ 2,376,000,000	$ 1,642,000,000	$ 3,572,000,000	$ 5,979,000,000	$ 8,162,000,000

Table 6-2.2

Summary of Annual Costs and Net Present Values for All Sites and Operational Scenarios

Facility or Cost Component	Crab Creek			Sand Hollow	Hawk Creek		
	OS1	OS2	OS3	OS1	OS1	OS2	OS3
Power Consumptions Costs	$ 3,090,000	$ 9,330,000	$ 16,380,000	$ 16,860,000	$ 16,770,000	$ 42,480,000	$ 67,500,000
Power Generation Revenues	$ 1,520,000	$ 5,150,000	$ 9,020,000	$ 8,340,000	$ 6,280,000	$ 15,400,000	$ 25,220,000
Operation & Maintenance Labor and Expense	$ 3,620,000	$ 6,300,000	$ 8,790,000	$ 7,000,000	$ 12,120,000	$ 21,220,000	$ 29,580,000
Total Annual Power and O&M Costs	$ 5,190,000	$ 10,480,000	$ 16,150,000	$ 15,520,000	$ 22,610,000	$ 48,300,000	$ 71,860,000
Total Capital Costs	$ 932,000,000	$ 1,712,000,000	$ 2,376,000,000	$ 1,642,000,000	$ 3,572,000,000	$ 5,979,000,000	$ 8,162,000,000
Net Present Value	$ (1,056,700,000)	$ (1,965,400,000)	$ (2,765,400,000)	$ (2,009,000,000)	$ (4,142,000,000)	$ (7,203,800,000)	$ (9,986,100,000)

Note: NPV accounts for initial field costs, power consumption and generation, annual O&M, replacement, and salvage as described in Section 3.3.2.

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8 Glossary

Acre-foot. The quantity of water that would cover 1 acre, 1 foot deep (1 hectare, 13.6 centimeters deep). One acre-foot contains 43,560 cubic feet (1,233 cubic meters).

Alternatives. Courses of action that may meet the objectives of a proposal at varying levels of accomplishment, including the most likely future conditions without the project or action.

Appraisal-level of detail. The level of detail necessary to facilitate making decisions on whether or not to proceed with a detailed study and evaluation of any alternative.

Appraisal study (appraisal report). A study incorporating an appraisal-level of detail.

Authorization. An act by the Congress of the United States which authorizes use of public funds to carry out a prescribed action.

Authorized Reclamation project. A congressionally approved Bureau of Reclamation project that has been authorized for specific purposes.

Average. The arithmetic mean. The sum of the values divided by the number of values.

Baseline (condition or alternative). Conditions that would prevail if no actions were taken.

Candidate species. Plant or animal species that are candidates for designation as endangered (in danger of becoming extinct) or threatened (likely to become endangered), but is undergoing status review by the U.S. Fish and Wildlife Service.

Channel. Natural or artificial watercourse of perceptible extent, with a definite bed and banks to confine and conduct continuously or periodically flowing water. Rivers and streams. A general term.

Combined Pump/Turbine Facility. A reversible unit that pumps water into a reservoir from the river, and then generate power when the flow from the reservoir is released back to the river. This allows energy recovery with most of the release flows.

Conservation. Increasing the efficiency of energy use, water use, production, or distribution.

Critical habitat. Defined in Section 3(5)(A) of the ESA as:

> (1) The specific areas within the geographical area occupied by the species at the time it is listed, on which are found those physical and biological features essential to the conservation of the listed species and which may require special management considerations for protection; and
>
> (2) Specific areas outside the geographical area occupied by a species at the time it is listed upon a determination by the Secretary of the Department of Interior that such areas are essential for the conservation of the species. These areas have been legally designated via Federal Register notices.

Cubic feet per second (cfs). A unit of discharge for measurement of a flowing liquid equal to a flow of 1 cfs (448.8 gallons per minute (gpm), 7.48 gallons per second, or 1.98 acre-feet per day). A rate of streamflow; the volume, in cubic feet, of water passing a reference point in 1 second.

Dam. A barrier built across a watercourse to impound or divert water. A barrier that obstructs, directs, retards, or stores the flow of water. Usually built across a stream. A structure built to hold back a flow of water.

Delivery. The amount of water delivered to the point of use. The difference between delivery and release is usually the same as consumptive use.

Demand. Water needs for irrigated agriculture, domestic, commercial, municipal, and industrial (DCM&I) use, and flow augmentation. These demands are the purpose and need for evaluating new off-channel storage options.

Dewatering As opposed to unwatering, dewatering is the removal and control of ground water from pores or other open spaces in soil or rock formations to the extent that allows construction activities to proceed as intended, including the relief of ground water pressure. Removing water by pumping, drainage, or evaporation. The removal of ground water and seepage from below the surface of the ground or other surfaces through the use of deep wells and wellpoints.

Diffuser. Lowers the velocity of released water from the reservoir back to the river.

Discharge. Volume of water that passes a given point within a given period of time. Any spilling, leaking, pumping, pouring, emitting, emptying, or dumping not including permitted activities in compliance with section 402 of the CWA.

District. An entity that has a contract with the Bureau of Reclamation for the delivery of irrigation water. Such entities include, but are not limited to: canal companies, conservancy districts, ditch companies, irrigation and drainage districts, irrigation companies, irrigation districts, reclamation districts, service districts, storage districts, water districts, and water users associations.

Diversion. A process which, having return flow and consumptive use elements, turns water from a given path. Removal of water from its natural channel for human use. Use of part of a stream flow as a water supply. Channel constructed across the slope for the purpose of intercepting surface runoff, changing the accustomed course of all or part of a stream. A structural conveyance (or ditch) constructed across a slope to intercept runoff flowing down a hillside, and divert it to some convenient discharge point.

Diversion channel (canal or tunnel). A waterway used to divert water from its natural course. The term generally applies to a temporary arrangement (e.g., to bypass water around a damsite during construction). Channel is normally used instead of canal when the waterway is short. Occasionally the term is applied to a permanent arrangement (diversion canal, diversion tunnel, diversion aqueducts).

Diversion dam. A dam built to divert water from a waterway or stream into a different watercourse.

Diversion inlet. A conduit or tunnel upstream from an intake structure. Diversion inlet may be integral with the outlet works or be part of a separate conveyance structure that will only be used during construction.

Drainage. Process of removing surface or subsurface water from a soil or area. A technique to improve the productivity of some agricultural land by removing excess water from the soil; surface drainage is accomplished with open ditches; subsurface drainage uses porous conduits (drain tile) buried beneath the soil surface.

Drainage area. The area which drains to a particular point on a river or stream. The drainage area of a stream at a specified location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

Drainage basin. All of the area drained by a river system. The drainage basin is a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water. The area of land that drains its water into a river.

Drainage system. Collection of surface and/or subsurface drains, together with structures and pumps, used to remove surface or ground water.

Drawdown. Lowering of a reservoir's water level; process of depleting a reservoir or ground water storage. The drop in the water table or level of water in the ground when water is being pumped from a well. Vertical distance the free water surface elevation is lowered or the reduction of the pressure head due to the removal of free water. The difference between a water level and a lower water level in a reservoir within a particular time. The amount of water used from a reservoir.

Drought. Climatic condition in which there is insufficient soil moisture available for normal vegetative growth. A prolonged period of below-average precipitation.

Elevation. The height of a point above a plane of reference. Generally refers to the height above sea level.

Endangered species. A species or subspecies whose survival is in danger of extinction throughout all or a significant portion of its range.

Endangered species act (ESA). This act provides a framework for the protection of endangered and threatened species.

Environment. All biological, chemical, social, and physical factors to which organisms are exposed. The surroundings that affect the growth and development of an organism.

Facilities. Structures associated with Reclamation irrigation projects, municipal and industrial water systems, power generation facilities, including all storage, conveyance, distribution, and drainage systems.

Federal organizations. Agencies, departments, or their components of the Federal Government that have a role in dam safety emergency planning and preparedness (i.e., Reclamation, U.S. Army Corps of Engineers, National Weather Service, etc.).

Fill. Manmade deposits of natural soils or the process of the depositing. Manmade deposits of natural soils or rock products and waste materials designed and installed in such a manner as to provide drainage, yet prevent the movement of soil particles due to flowing water. An earth or broken rock structure or embankment. Soil or loose rock used to raise a grade. Soil that has no value except as bulk.

Fish Screen. A barrier designed to prevent fish from swimming or being drawn into an aqueduct, dam, or other diversion on a river, lake, or other waterway where water is taken for human use. Fish screens are typically installed to protect threatened or endandered species of fishes.

Flood. A temporary rise in water levels resulting in inundation of areas not normally covered by water. May be expressed in terms of probability of exceedance per year such as 1-percent chance flood or expressed as a fraction of the probable maximum flood or other reference flood.

Floodplain. Nearly level land, susceptible to floods, that forms the bottom of a valley. An area, adjoining a body of water or natural stream, that has been or may be covered by floodwater.

Flow. Volume of water that passes a given point within a given period of time.

Flow augmentation. The release of water stored in a reservoir or other impoundment to increase the natural flow of a stream.

Foundation. Lower part of a structure that transmits loads directly to the soil. The excavated surface upon which a dam is placed.

Full pool. Volume of water in a reservoir at normal water surface. The reservoir level that would be attained when the reservoir is fully utilized for all project purposes, including flood control.

Gauge (gage). Device for registering water level, discharge, velocity, pressure, etc. Thickness of wire or sheet metal. A number that defines the thickness of the sheet used to make steel pipe. The larger the number, the thinner the pipe wall.

Groundwater. Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper level of the saturated zone is called the water table. Water stored underground in rock crevices and in the pores of geologic materials that make up the earth’s crust. That part of the subsurface water which is in the zone of saturation; phreatic water. Water found underground in porous rock strata and soils, as in a spring. Water under ground, such as in wells, springs and aquifers. Generally, all subsurface water as distinct from surface water; specifically, that part of the subsurface water in the saturated zone where the water is under pressure greater than atmospheric.

Groundwater table. The upper boundary of ground water where water pressure is equal to atmospheric pressure, i.e., water level in a bore hole after equilibrium when ground water can freely enter the hole from the sides and bottom.

Habitat. The area or type of environment in which a plant or animal normally lives or occurs.

Hydrology. Scientific study of water in nature: its properties, distribution, and behavior. The science that treats the occurrence, circulation properties, and distribution of the waters of the earth and their reaction to the environment. Science dealing with the properties, distribution and flow of water on or in the earth.

Impoundment. Body of water created by a dam.

Improvement. Structural measures for the betterment, modernization, or enhancement of an existing facility or system to improve the social, economic, and environmental benefits of the project.

Inflow. Water that flows into a body of water. The amount of water entering a reservoir expressed in acre-feet per day or cfs.

Inlet channel (inlet structure). Concrete lined portion of spillway between approach channel and gate or crest structure.

Inlet/Outlet Works. Structures through which water is pumped to the reservoir and then released back to the river. See definitions for **combined pumping/turbine facility**, **pumping plant**, **fish screen**, and **diffuser**.

Instream flow requirements. Amount of water flowing through a defined stream channel needed to sustain instream values, e.g. flows designated for fish and wildlife.

Inundate. To cover with impounded waters or floodwaters.

Irrigation. Act of supplying dry land with water in order to grow crops or other plants. Application of water to lands for agricultural purposes.

Irrigation district. A cooperative, self-governing public corporation set up as a subdivision of the State government, with definite geographic boundaries, organized and having taxing power to obtain and distribute water for irrigation of lands within the district; created under the authority of a State legislature with the consent of a designated fraction of the landowners or citizens.

Juvenile. Young fish older than 1 year but not capable of reproduction.

Levee. A natural or man-made barrier that helps keep rivers from overflowing their banks.

Mainstream (mainstem). The main course of a stream where the current is the strongest.

Maintenance. All routine and extraordinary work necessary to keep the facilities in good repair and reliable working order to fulfill the intended designed project purposes. Maintaining structures and equipment in intended operating condition, equipment repair, and minor structure repair.

Maximum water surface (maximum pool). The highest acceptable water surface elevation with all factors affecting the safety of the structure considered. It is the highest water surface elevation resulting from a computed routing of the inflow design flood through the reservoir under established operating criteria. This surface elevation is also the top of the surcharge capacity.

Median. The median is the value halfway through the ordered data set, below and above which there lies an equal number of data values.

Mitigation (measures). Methods or plans to reduce, offset, or eliminate adverse project impacts. Action taken to avoid, reduce the severity of, or eliminate an adverse impact. Mitigation can include one or more of the following:

- Avoiding impacts.
- Minimizing impacts by limiting the degree or magnitude of an action.
- Rectifying impacts by restoration, rehabilitation, or repair of the affected environment.
- Reducing or eliminating impacts over time.

- Compensating for the impact by replacing or providing substitute resources or environments to offset the loss.

Modeling. Use of mathematical equations to simulate and predict real events and processes.

National Environmental Policy Act (NEPA). An act requiring analysis, public comment, and reporting for environmental impacts of Federal actions.

Net Present Value. The current value of an investment, as determined by combining the initial cost of project implementation with annual costs, intermittent replacement costs, and salvage values over the life of the project. The net present value calculation relies on the establishment of the duration of the project's useful life, as well as the use of a discount rate, which converts future costs or benefits to their present value.

Outlet. An opening through which water can be freely discharged from a reservoir to the river for a particular purpose.

Outlet Works. A combination of structures and equipment required for the safe operation and control of water released from a reservoir to serve various purposes, i.e., regulate stream flow and quality; release floodwater; and provide irrigation, municipal, and/or industrial water. Included in the outlet works are the intake structure, conduit, control house-gates, regulating gate or valve, gate chamber, and stilling basin. A series of components located in a dam through which normal releases from the reservoir are made. A device to provide controlled releases from a reservoir. A pipe that lets water out of a reservoir, mainly to supply downstream demands.

Precipitation. The total measurable amount of water received in the form of snow, rain, drizzle, hail, and sleet. The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, or other forms of moisture.

Project. A single financial entity which can be composed of several units or divisions, integrated projects, or participating projects.

Pumping plant. Facility that lifts water up and over hills.

Q1, Q3. See **quartile.**

Quartile. The value of the boundary at the 25th (q1), 50th (median), or 75th (q3) percentiles of a frequency distribution divided into four parts, each containing a quarter of the population.

Reach. Any specified length of stream, channel, or other water conveyance. A portion of a stream or a river. The area of a canal or lateral between check structures. Sometimes also used to describe a contiguous stretch of river.

Release. The amount of water released after use. The difference between delivery and release is usually the same as consumptive use.

Reservoir. A body of water impounded by a dam and in which water can be stored. Artificially impounded body of water. Any natural or artificial holding area used to store, regulate, or control water. Body of water, such as a natural or constructed lake, in which water is collected and stored for use. Dam design and reservoir operation utilize reservoir capacity and water surface elevation data. To ensure uniformity in the establishment, use, and publication of these data, the following standard definitions of water surface elevations shall be used.

Reservoir capacity. The capacity of the reservoir, usually in acre-feet. Dam design and reservoir operation utilize reservoir capacity and water surface elevation data. To ensure uniformity in the establishment, use, and publication of these data, the following standard definitions of reservoir capacities shall be used. Reservoir capacity as used here is exclusive of bank storage capacity.

Reservoir inflow. The amount of water entering a reservoir expressed in acre-feet per day or cfs.

Reservoir regulation (or operating) procedure. Operating procedures that govern reservoir storage and releases.

Reservoir surface area. The area covered by a reservoir when filled to a specified level.

Return flow. Drainage water from irrigated farmlands that re-enters the water system to be used further downstream. May contain dissolved salts or other materials that have been leached out of the upper layers of the soil. That portion of the water previously diverted from a stream which finds its way back to that stream or to another body of ground or surface water. The water that reaches a ground or surface water source after release from the point of use and thus becomes available for further use.

Riparian. Living on or adjacent to a water supply such as a riverbank, lake, or pond. Of, on, or pertaining to the bank of a river, pond, or lake.

Run. Seasonal upstream migration of anadromous fish. One or more lengths of pipe that continue in a straight line.

Runoff. The portion of precipitation, snow melt, or irrigation that flows over the soil, eventually making its way to surface water supplies. Liquid water that travels over the surface of the Earth, moving downward due to the law of gravity; runoff is one way in which water that falls as precipitation returns to the ocean.

Rural area. Predominantly agricultural, prairie, forest, range, or undeveloped land where the population is small.

Sediment. Any finely divided organic and/or mineral matter deposited by air or water in nonturbulent areas. Unconsolidated solid material that comes from weathering of rock and is carried by, suspended in, or deposited by water or wind.

Sensitive species. Species not yet officially listed but undergoing status review for listing on the USFWS official threatened and endangered list; species whose populations are small and widely dispersed or restricted to a few localities; and species whose numbers are declining so rapidly that official listing may be necessary. Redefine to match definition in table.

Spawn. To lay eggs, refers mostly to fish.

Spawning beds. Places in which eggs of aquatic animals lodge or are placed during or after fertilization.

Storage. The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel.

Stream. Natural water course containing water at least part of the year. The type of runoff where water flows in a channel.

Streamflow. Discharge that occurs in a natural channel.

Surface water. Water on the surface of the earth. An open body of water, such as a river, stream or lake. All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors which are directly influenced by surface water.

Threatened. A legal classification for a species which is likely to become endangered within the foreseeable future.

Threatened species. Any species which has potential of becoming endangered in the near future.

Tributary. River or stream flowing into a larger river or stream.

Tunnel. Covered portion of spillway between the gate or crest structure and the terminal structure, where open channel flow and/or pressure flow conditions may exist. Portion of an outlet works between upstream and downstream portals, excluding the gate chamber. Tunnels are generally located in the dam abutments, and are concrete lined or concrete/steel lined. An enclosed channel that is constructed by excavating through natural ground. A tunnel can convey water or house conduits or pipes. A long underground excavation with two or more openings to the surface, usually having a uniform cross section used for access, conveying flows, etc.

Uncertainty. Describes situations where potential outcomes cannot be estimated based on historical events.

Urban area. Predominantly cities, towns or developed areas where the population is significant.

Valve house. A small building housing a valve which controls the flow of water from a reservoir via a canal feeder channel to a canal.

Wasteway. An open canal or ditch that discharges excess water associated with irrigation.

Water demand. Water requirements for a particular purpose, as for irrigation, power, municipal supply, plant transpiration or storage.

Water user. Any individual, district, association, government agency, or other entity that uses water supplied from a Reclamation project.

Watershed (drainage area). Surface drainage area above a specified point on a stream. Area which drains into or past a point. A geographical portion of the Earth's surface from which water drains or runs off to a single place like a river. The area of land that drains its water into a stream or river. All the land and water within the confines of a certain drainage area. Vertically, it extends from the top of the vegetation to the underlying rock layers that confine water movement. An area of land that contributes runoff to one specific delivery point.

Watershed divide. The divide or boundary between catchment areas (or drainage areas).

Wetlands. Lands including swamps, marshes, bogs, and similar areas such as wet meadows, river overflows, mudflats, and natural ponds. An area characterized by periodic inundation or saturation, hydric soils, and vegetation adapted for life in saturated soil conditions. Any number of tidal and nontidal areas characterized by saturated or nearly saturated soils most of the year that form an interface between terrestrial and aquatic environments; including freshwater marshes around ponds and channels, and brackish and salt marshes. A jurisdictional wetland is subject to regulation under the Clean Water Act. A nonjurisdictional is subject to consideration under the Fish and Wildlife Coordination Act.

Withdrawal. Water removed from the ground or diverted from a surface-water source for use. The process of taking water from a source and conveying it to a place for a particular type of use.

Yield. The quantity of water that can be collected for a given use from surface or ground water sources.

Appendix A: Comparative Assessment of Anadromous Fish Benefits

Appendix A: Comparative Assessment of Anadromous Fish Benefits

General Anadromous Fish Benefits

The flow augmentation water that would be made available via storage and release at the three alternative storage sites is intended to benefit the survival of anadromous salmon and steelhead trout in the Columbia River. Currently, for these proposed alternatives it is assumed that Columbia River streamflows would be augmented in July and August. At this time of year most benefits are anticipated for the juvenile salmonid smolts that outmigrate during these months. These fish include summer Chinook salmon originating from the upper Columbia River tributaries (mostly Methow and Wenatchee Rivers) and fall Chinook salmon, most of which originate downstream of Priest Rapids Dam. Included are the ESA-listed Snake River fall Chinook, which enter the Columbia River upstream of McNary Dam. Most of these Snake River fall Chinook juveniles outmigrate in the summer while others overwinter in the system and migrate out the following spring as yearling smolts. This fall Chinook yearling “reservoir type” lifestage appears to have developed in recent years in response to augmentation of cold water to the Snake River from releases at Dworshak Dam on the Clearwater River.

Benefits for upstream migrating adults are not expected to be significant because this has not been identified as a concern in the mid- and lower-Columbia River (it is a concern in the Snake River where low flows and associated warm water temperatures can impede upstream fish migration during the late summer).

Flow augmentation from the proposed alternatives in July and August would not be expected to benefit spring-migrating smolts, which include mid- and upper-Columbia spring Chinook salmon (ESA-listed), sockeye salmon, coho salmon, Snake River spring/summer Chinook salmon (ESA-listed), upper- and mid-Columbia steelhead trout (ESA-listed), and Snake River steelhead trout. Considerable water storage in the upper Columbia system (above Grand Coulee Dam) already has been dedicated to these spring-migrant species. Although it is assumed that the flow augmentation from the proposed alternatives would occur in the summer, the water could potentially be availed for release during the spring months if the fish resource agencies conclude that additional water in the spring months would better benefit the species of concern. As briefly discussed below, there is considerable scientific uncertainty and debate regarding if, when, and how much flow augmentation actually benefits the various anadromous salmonids in the Columbia River system. Therefore, it is likely that flow augmentation and its timing and location priorities in the Columbia River Basin will continue to evolve as more information is obtained about effectiveness.

Comparison of Alternative Storage Locations

In comparing the relative benefits of the three alternative storage sites it is important to understand the status of current research findings and differences of opinion regarding the flow/survival hypothesis. In the past it was assumed that greater flows during the smolt outmigration increased in-river survival presumably by hastening the smolt downstream migration, thus exposing them to less risk of predation. This premise has been the basis for flow management in the Columbia River since 1983. A positive relationship between flow during the smolt migration period and subsequent adult return rates, when compared among years, has been the foundation of the flow augmentation emphasis (Sims and Ossiander, 1981). Recent research, however, has questioned this premise for in-river survival (Anderson, 2003). Evaluation of extensive in-river survival data appears to indicate that there is no direct relationship between flow and survival that cannot be explained by other factors such as water temperature, distance traveled, spill volumes, water velocity, or turbidity. In light of these more recent findings it has been suggested that the link between flow and ocean survival for anadromous fish is associated with a delayed or latent effect below Bonneville Dam rather than in the river migration corridor (Williams et al., 2005). The importance of smolt entry time to the estuary, condition of the smolts when they reach the estuary, and conditions in the estuary associated with river discharge have been suggested as factors potentially linking river flow to the smolt-to-adult survival.

If the benefits of river flow augmentation are manifested below Bonneville dam, the effects of the three alternative storage/release sites should be similar, where they provide a similar amount of water. Potential benefits would be expected to be greater where more water is provided.

If flow augmentation benefits are manifested within the river migration corridor, the Hawk Creek alternative would be slightly more beneficial than the two downstream sites at Sand Hollow and Crab Creek in terms of the most upstream point where flow augmentation would occur. Under the in-river survival hypothesis, increased flows from the Hawk Creek site (entering Lake Roosevelt) would benefit those smolts entering the Columbia River between the Okanogan River and the Wenatchee River (river miles [RM] 540 and 465, respectively). These smolt inputs include those from the Okanogan, Methow, Entiat, and Wenatchee Rivers as well as from several hatcheries. The benefits would continue downstream to Bonneville Dam (RM 146) for these fish as well as for the large numbers of additional fish entering the river between Priest Rapids Dam (RM 397) and Bonneville. Flow augmentation from the Sand Hollow and Crab Creek sites would occur near Wanapum Dam at RM 416, which lies between Rock Island and Priest Rapids Dams. Therefore, flow augmentation from these lower-site alternatives would benefit the upper Columbia smolts only from that that point downstream to Bonneville. Similar to the Hawk Creek alternative, the two lower site alternatives would benefit all smolts entering the system below Priest Rapids Dam.

In terms of migratory river miles affected by the three alternatives, the Hawk Creek alternative would affect salmonid smolt migration for between 394 miles (Okanogan to Bonneville) to 319 miles

(Wenatchee to Bonneville). The two downriver alternatives would affect smolts for approximately 270 mile (Wanapum to Bonneville).

As a means to roughly quantify the comparative benefits between the Hawk Creek alternative and the two downstream alternatives (with similar effects due to their close proximity) it is useful to compare the production of anadromous fish above Priest Rapids Dam to that which occurs below Priest Rapids to Bonneville Dam. Reasonably accurate estimates of smolt production are not available for all reaches. Therefore, we present average adult returns at Bonneville Dam and Priest Rapids Dam (years 1996 to 2005) as a surrogates for smolt production (Fish Passage Center, 2006). For the combined all-species adult returns, the area above Priest Rapids Dam produces approximately 15 percent of the fish entering the Columbia River at Bonneville Dam (Table A-1). On the basis of this ratio, and assuming the in-river survival hypothesis, one can conclude that the Hawk Creek alternative would benefit 15 percent of the system's fish production for its entire downstream migration route (319 to 394 river miles) whereas the Sand Hollow and Crab Creek alternatives would benefit these same 15 percent only for the 270 miles between Wanapum Dam and Bonneville.

TABLE A-1

Comparison of Adult Salmon and Steelhead Trout Returns to Bonneville Dam and Priest Rapids Dam, 10-Year Average 1996-2005

Salmonid Species	Bonneville	Priest Rapids	Percent of Bonneville Entering Mid-Columbia
Spring Chinook	145,297	15,454	10.6
Summer Chinook	54,750	39,202	71.6
Fall Chinook	325,277	24,001	7.4
Coho	76,516	1,482	1.9
Sockeye	53,716	52,082	97.0
Steelhead	308,826	12,590	4.1
Total All Salmonids	**964,382**	**144,811**	**15.0**

Source: PFC 2005 Annual Report.

The proportion of Columbia River anadromous salmonids produced upstream of Priest Rapids Dam varies considerably among species. The area above Priest Rapids produces approximately 72 percent of the Columbia system summer Chinook salmon and 97 percent of the sockeye salmon. Neither of these species/populations is listed under the ESA. The two listed anadromous salmonids in the mid-Columbia River are spring Chinook salmon and steelhead trout. Compared to the Columbia system total, the upper Columbia produces a small percentage of the spring Chinook salmon (10.6 percent) and steelhead trout (4.1 percent). However, both of these mid-Columbia stocks are considered ESA populations distinct from the other similar species found elsewhere in the Columbia system. Smolts of these two ESA-listed species migrate during the spring and, therefore, would benefit from flow augmentation at that time of year.

Augmentation of Columbia River flow from the Hawk Creek alternative would not be expected to significantly affect water temperatures in the mid- and lower-Columbia River because of the overwhelming attenuation effect of Lake Roosevelt. For the two lower river alternatives, however, the augmented flow potentially could affect water temperatures in the Columbia River depending on the season of operation and ability to selectively release water from different reservoir elevations. Generally, a lower water temperature is believed to be more favorable to migrating smolts (to a point) because the cold water reduces the metabolic and feeding rate of predatory fish such as northern pikeminnow. Concerns over water temperatures in the Columbia River system have been focused primarily in the lower Snake River, especially in the summer. However, reduced water temperatures in the lower Columbia River also would be viewed as beneficial for the Snake River fall Chinook salmon summer migrants when they pass through this reach and for other subyearling Chinook migrating in the summer.

Comparison of Alternative Storage Volumes

Of the three alternative storage sites, one, Sand Hollow, has only one storage volume alternative while the other two sites each have three size alternatives, as shown on Table A-2. The Sand Hollow site would be sized for a total storage capacity of 1 million acre-feet, of which 245,000 acre-feet would be made available for streamflow augmentation. Assuming a constant release of this volume of water over 62 days (July and August), flow in the Columbia River would increase by 2,062 cfs. At Priest Rapids Dam, where July-August flows now average approximately 140,000 cfs, the 2,062 cfs additional flow would equate to about a 1.5 percent increase. At McNary Dam, the additional flow of 2,062 cfs would represent an increase of about 1.0 percent over its average July-August flow of 200,000 cfs.

The Hawk Creek and Crab Creek sites both have alternative size components of approximately 1 million, 2 million, and 3 million acre-feet, thus making available for flow augmentation approximately 250,000, 535,000, and 754,000 acre-feet, respectively. In terms of flow released constantly to the Columbia River over the 62 days of July and August, these three storage volumes equate to flow increases on 2,062 cfs, 4,400 cfs, and 6,250 cfs, respectively In terms of percentage increases over average flows at Priest Rapids Dam during July-August, these additional flows equate to 1.5 percent, 3.1 percent, and 4.5 percent, respectively. At McNary Dam, the flow increases would be 1.0 percent, 2.2 percent, and 3.1 percent, respectively, for the three storage alternatives.

The above quoted percent increases in Columbia River flow were based on average-year water conditions. In drier years, however, flow augmentation would result in a greater percent increase in flow (assuming the stored water volume of the alternatives would be available in all years). This is significant because a number of studies have shown a stronger relationship between flow and survival (and fish travel time) when river flows are below average (Williams et al., 2005). Increasing flows in low-flow years have a greater effect on reducing fish travel time than when flows are high, and reduced travel time is believed to benefit fish survival.

TABLE A-2

Alternative Storage Volumes and Resulting Flow Increase

	Storage Volume (acre-feet)	Median Annual Flow Augmentation Volume (acre-feet)	Additional Flow in July/August from Flow Augmentation (cfs)	Percentage increase in flows at Priest Rapids Dam in July/August*
Crab Creek OS1	1,000,000	249,000	2,062	1.5%
Crab Creek OS2	2,000,000	535,000	4,400	3.1%
Crab Creek OS3	3,000,000	754,000	6,250	4.5%
Sand Hollow OS1	1,000,000	245,000	2,062	1.5%
Hawk Creek OS1	1,000,000	251,000	2,062	1.5%
Hawk Creek OS2	2,000,000	535,000	4,400	3.1%
Hawk Creek OS3	3,000,000	754,000	6,250	4.5%

*Flows at Priest Rapids Dam in July/August average approximately 140,000 cfs

Appendix B:
Geologic Setting of the Crab Creek, Sand Hollow, and Hawk Creek Project Alternatives

Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options

Appendix B: Geologic Setting of the Crab Creek, Sand Hollow, and Hawk Creek Project Alternatives

Crab Creek Dam and Reservoir Site

Bedrock Geologic Units

Columbia River Basalt formations in the vicinity of the proposed Crab Creek site include the upper Grande Ronde Formation, and the Frenchman Springs, Roza, Priest Rapids, and Elephant Mountain members of the Wanapum Basalt. The basalt outcrops observed at the site could typically be described as brown to gray, moderately to highly fractured, vesicular to non-vesicular, fresh to slightly weathered.

The Ellensburg Formation consists primarily of sedimentary rocks deposited between basalt flows, and is mapped near the top of the Saddle Mountains, and is also mapped along the Columbia River east of Wanapum Dam, northwest of the proposed Crab Creek site. Exposures of this formation could be seen up on the Saddle Mountains. It appeared this formation consists of cemented gray sandstone to siltstone.

The Ringold Formation consists primarily of basin-filling sediments, and is mapped in the upper valley of Lower Crab Creek, near the upper end of the proposed reservoir, and on the bench north of the proposed reservoir. This formation likely has characteristics of both unconsolidated materials and weak rock. The upper part of this formation (which is exposed in the Crab Creek area) is described primarily as well-sorted sand, silt, and clay with minor pebble lenses.

Surficial Geologic Units

Surficial geologic units in the area consist of the following:

- Qa: Stream alluvium deposited by Lower Crab Creek. The alluvium consists primarily of stratified, interbedded, cross-bedded lenses of silty sand, sandy silt, with lenses of poorly graded rounded gravels. The thickness of the alluvium ranges from less than 5 feet up to possibly more than 100 feet based on visual observations and local water well logs. The alluvium is located in the valley of Lower Crab Creek. Stream alluvium is also deposited along the Columbia River, and consists of sands and gravels in this vicinity.
- Qf: Missoula Flood deposits are found along the Columbia River, primarily downstream from the proposed dam axis. Based on visual observations, these flood deposits consist of sandy gravel to large boulders. Published geologic mapping indicates that interbedded sandy and silty touchet beds have been deposited in the vicinity on the bench north of the right abutment.
- Qda: Eolian sand dunes have been deposited in the vicinity of the proposed dam axis. The sand dunes consist of fine-grained, poorly graded sand. The dunes are estimated to be up to 30 or more feet in height and cover

an area of approximately 1 square mile.

- Ql: Loess deposits and the Palouse Formation have been mapped in the vicinity; primarily on the flat benches north of the Crab Creek coulee and on the crest of the Saddle Mountains. The loess deposits and Palouse Formation consist primarily of tan to light brown, massive to weakly stratified, windblown fine silty sand to sandy silt deposits with interbedded ash layers.
- Qc/Qtf: Conical-shaped talus fans and colluvial deposits mantle the northern slope of the Saddle Mountains. Colluvium is primarily restricted to the slopes, and the talus fans grade out onto the valley floor. Based on field observations, these deposits consist primarily of weakly stratified, sandy to silty angular gravel, with sizes primarily 12-inch minus.
- Qta: Talus deposits also mantle the northern flank of the Saddle Mountains and form a nearly continuous apron. These deposits are described as clean to sandy and silty, weakly stratified angular gravels and cobbles. The slopes (angle of repose) of the talus deposits are approximately 35 degrees. The thickness of the talus deposits is estimated to range from less than 1 foot up to approximately 30 or more feet.

Project Facilities Geology

Reservoir Geology

Basalt flows of the Columbia River basalts are exposed along much of the length of the proposed reservoir on the northern side of Lower Crab Creek Road. The south side of the reservoir would be underlain by talus and scattered exposures of basalt along the northern flank of the Saddle Mountains. The basalt flows exposed north of Crab Creek Road, dip south at an angle of 5 degrees or less.

Damsite, Spillway, and Outlet Works Geology

The bedrock underlying the proposed dam abutments and valley section beneath the proposed Crab Creek Dam consists of Columbia River basalt, alluvial deposits, and sand dunes. A large part of the proposed dam would be founded on bedrock of the valley floor. A thin mantle of alluvial and lacustrine silt and sand deposits and sand dunes exist near the southern side of the valley for a width of approximately 2,000 feet near the proposed dam site and along the present Lower Crab Creek channel. The thickness of these alluvial and lacustrine sediments are known to be up to 120 feet thick at a distance of approximately 8,000 feet west of the proposed dam site, based on existing water well logs. However, during the site visit, exposures of basalt rock were observed along Crab Creek a distance of 7,500 feet east of the proposed dam site. Therefore, it is anticipated that the alluvial deposits are very thin to absent east of the proposed dam site. It appears that the bedrock surface drops in elevation toward the Columbia River, and thus the alluvial deposits in the Crab Creek drainage are thicker closer to the Columbia River.

A small coulee is formed in basalt near the northern edge of the lower valley. This coulee is filled with water forming Nunnally Lake and is fed by springs and seepage that emerge from the basalt rock along the north side of the valley within the proposed reservoir. The exposed basalt bedrock throughout the entire valley floor was severely scoured by the glacial Missoula Floodwaters approximately 13,000 years ago, leaving hard durable basalt rock exposed at the ground surface in many areas.

The proposed spillway would be located on the roller-compacted concrete (RCC) portion of the proposed dam. The spillway would discharge into Crab Creek. The western portion of the spillway channel would eventually cross from basalt into Missoula Flood sands/silts/gravels and Columbia River alluvial deposits. It is anticipated that much of the spillway channel must be lined with concrete or other erosion protection measures.

The outlet works would be founded primarily on basalt bedrock that underlies the valley floor. This bedrock would provide suitable foundation conditions.

Intake, Combined Pump/Turbine Facility, Conveyance, and Power Transmission Facilities Geology

The intake (fish screen/diffuser) structure would likely be constructed in river alluvium and flood gravels on the east side of Priest Rapids reservoir. These deposits consist primarily of interbedded sands and gravels, with interbedded clay layers. Based on water well logs in the vicinity, the depth to bedrock in this vicinity ranges from approximately 80 to 140 feet below ground surface (bgs).

The combined pump/turbine facility would be built on basalt bedrock near the north abutment of the proposed dam, at the end of the intake channel. This combined inlet and outlet channel would be constructed in basalt bedrock between the proposed dam site and the east side of Beverly.

Between the east side of Beverly and the Columbia River, the subsurface is underlain by thick alluvial and flood deposits. The depth to bedrock in this vicinity ranges from approximately 80 to 140 feet bgs.

Sand Hollow Dam and Reservoir Site

Bedrock Geologic Units

Bedrock in the vicinity of the Sand Hollow site consists primarily of basalt bedrock of the Columbia River Basalt group. The basalt bedrock in the vicinity of the Sand Hollow site includes the Frenchman Springs, Roza, Priest Rapids, and Elephant Mountain members of the Wanapum Basalt. The basalt outcrops observed at the site could typically be described as brown to gray, moderately to highly fractured, vesicular to non-vesicular, fresh to slightly weathered. Based on observations from the wasteway and gravel pit, it appeared that in some areas the uppermost 10 feet of basalt was highly weathered and fractured.

A sedimentary interbed of the Ellensburg Formation is mapped in the hills and cliffs on the east side of the Columbia River, southwest of the proposed dam site. This formation was not exposed in the vicinity of the proposed dam site, but based on previous geologic mapping, this formation typically consists of cemented, gray, tuffaceous sandstone to siltstone.

The Ringold Formation is mapped in the flat area east of the proposed Sand Hollow site and would underlie much of the proposed reservoir. This formation likely has characteristics of both unconsolidated materials and weak rock. This formation is described primarily as well-sorted sand, silt, and clay with minor pebble lenses. The clay layers are finely laminated. Water well logs in the vicinity indicate that the Ringold Formation in this vicinity consists of yellow clay to sandy clay up to 170 feet thick.

Surficial Geologic Units

Surficial geologic units in the vicinity of the proposed Sand Hollow site include stream alluvium, eolian sand dunes, eolian loess deposits, and colluvium. In the immediate vicinity of the proposed dam footprint; it appears that little or no surficial deposits cover the basalt outcrops. A description of the surficial geologic units shown in Plate 4-2.4 follows:

- Qal: Stream alluvium was deposited by Sand Hollow Creek and is limited to the immediate vicinity of the lower Sand Hollow valley. The alluvium was poorly exposed, but appears to consist primarily of stratified, interbedded, cross-bedded lenses of silty sand, sandy silt, and poorly graded rounded gravels. The thickness of the alluvium could not be determined but is estimated to be thin, probably less than 10 to 20 feet, based on the limited flow of Sand Hollow (primarily agricultural return flows) and the fact that the creek is down-cutting toward the Columbia River.
- Qe: Eolian sand dunes have been deposited in the vicinity of the left (south) abutment of the proposed dam. The sand dunes consist of tan, fine-grained, poorly graded sand. The dunes are estimated to be up to 20 feet in height and cover an area of approximately 0.5-mi^2.
- Ql: Loess deposits and the Palouse Formation have been mapped in the vicinity; primarily on the flat benches north, south, and east of the proposed dam site. The loess deposits and Palouse Formation consist primarily of tan to light brown, massive to weakly stratified, windblown fine silty sand to sandy silt deposits with interbedded ash layers. Based on well drillers' logs, the thickness of the loess is estimated to be less than 30 feet in the vicinity.
- Qc: Colluvial deposits cover slopes and overlie the bedrock in the vicinity of the proposed dam axis. These deposits are described as weakly stratified, sand to silt with angular gravel clasts. Gravel appeared to be primarily less than 12 inches in diameter. Based on site observations and well drillers' logs, the colluvial deposits ranged from less than 2 to 30 feet thick.

Reservoir Geology

The southern side of the proposed reservoir would be underlain by loess, Ringold Formation, and basalt flows. The northern parts of the proposed reservoir would be underlain by loess and shallow basalt that forms the southern side of Frenchman Hills. The floor of the proposed reservoir would be underlain primarily by loess and Ringold Formation sediments. Thin sandy to gravelly alluvial deposits are deposited in Sand Hollow near the bottom of the drainage.

Damsite, Spillway, and Outlet Works Geology

The surficial materials at the proposed dam abutments and valley section beneath the proposed Sand Hollow Dam consists of Columbia River Basalt, alluvial deposits, sand dunes, and thin colluvial deposits. These would be removed and the entire dam would be founded on basalt bedrock. The depth to rock is expected to be very shallow (generally less than approximately 5 to 10 feet) throughout most of the foundation area for the dam. Basalt is exposed in the vicinity of the proposed dam and spillway site and downstream in the Sand Hollow drainage. A continuous exposure of the surface of the basalt underneath the northern part of the dam axis was evident during field visits since it was exposed underneath an existing south-trending wasteway. The wasteway had been excavated down to the basalt surface in order for drainage flows from a channel north of the right abutment. This wasteway provided a nearly continuous exposure of the top of the basalt flow. The depth to basalt rock varies from 1 to 15 feet below most of the existing grade. An existing gravel pit also showed exposed basalt rock in the vicinity of the proposed left abutment. The gravel pit was operated by Washington Department of Transportation (WSDOT) and provided primarily crushed rock base course.

A short segment in the valley bottom could have greater depths to bedrock where alluvial sediments have been deposited from a small perennial stream that flows in the valley bottom. The depth to rock in this area is estimated to be 50 feet or less.

The outlet works would be founded on basalt bedrock that underlies the valley floor. This bedrock would provide suitable foundation conditions.

Intake, Combined Pump/Turbine Facility, Conveyance, and Power Transmission Facilities Geology

The intake (fish screen/diffuser) structure would likely be constructed in a basalt bedrock shelf located on the east side of the Columbia River. The basalt bedrock may be overlain by a veneer of talus, alluvium, or sand dunes.

The pumping and power generation facilities would be constructed on the east side of the Columbia River. Steep basalt cliffs and steep basalt slopes exist in most areas near the proposed site. Talus rock slopes and talus-filled slopes are likely present but are now inundated by Wanapum Reservoir. It is assumed that the pumping facilities would be constructed by extending a short channel and deep excavation from the Wanapum Reservoir to the pumping site.

A combined inflow/outflow conveyance tunnel would extend from the pumping and generation facilities at Wanapum Reservoir at approximate elevation 575 feet to approximately elevation 900 feet at the upstream toe of the proposed dam site (distance of approximately 2.5 miles). This conveyance tunnel would likely begin at the downstream end in either shallow alluvial sediments, talus, or bedrock, depending on the proposed location of the pumping facilities near the Columbia River. The tunnel can be expected to be constructed in relatively flat-lying basalt flows that would likely have weak, fractured interflow zones, and possibly interbedded, weakly indurated sedimentary rocks.

Hawk Creek Dam and Reservoir Site

Bedrock Geologic Units

Bedrock geologic units in the vicinity of the proposed Hawk Creek site include Columbia River basalt flows and an intrusive granodiorite plug. Basalt flows including normal and reversed magnetic polarity flows of the upper Grande Ronde Formation, and the Priest Rapids Member of the Wanapum Basalt form the canyon walls of the Hawk Creek valley. The basalt flows form planar to stepped slopes with occasional cliffs and flat benches between basalt flows. Based on site observations, the basalt is typically brown to gray, hard, and moderately to highly fractured. The fractured basalt breaks into angular talus deposits that mantle portions of the slopes.

A granodiorite intrusion (Hawk Creek granodiorite) is mapped approximately 4 miles south (upstream) from the proposed Hawk Creek Dam site. This granodiorite is exposed in hillsides and road cuts along Hawk Creek. Based on field observations, the granodiorite is described as gray and fresh to slightly weathered. Structurally, the granodiorite outcrops exhibited dipping joints that separate the granodiorite into massive blocks.

Surficial Geologic Units

Surficial geologic units in the vicinity of the proposed Hawk Creek site include stream alluvium and glaciolacustrine deposits in the valley bottom, and talus/colluvium along the valley walls, as follows:

- Qal: Stream alluvium deposited by Hawk Creek and limited to the valley bottom. The alluvium consists primarily of interbedded, cross-bedded lenses of clays, silts, sands, sandy gravels, to gravelly sand. The thickness of the alluvium, based on well drillers' logs of the area, is more than 75 feet. It is anticipated this material is moderately to highly permeable.
- Qgl: Glaciolacustrine deposits have been deposited in the Hawk Creek valley and fill in portions of the existing canyon. These deposits form distinctive benches that have been eroded by post-glacial stream activity and exhibit a relatively high drainage density. These deposits are described as interbedded, laminated, light tan silty sand, sandy silt, and clay. The uppermost elevation of these deposits is estimated to be approximately 1680 feet. Based on interpretive cross sections, the maximum thickness of the glaciolacustrine deposits is estimated to be between 200 and 300 feet.
- Qt/Qc: Talus and colluvial deposits mantle portions of the basalt canyon walls. These deposits consist primarily of weakly stratified, angular, clean to sandy and silty gravels and cobbles. The angle of repose of the talus is approximately 35 degrees. The thickness of the talus and colluvial deposits is estimated to range from less than 1 foot up to between 10 and 20 feet. It appears that the talus and colluvial deposits are thin in the vicinity of the proposed dam site.

Reservoir Geology

The side walls of most of the proposed reservoir area would be underlain by relatively flat-lying basalts of the CRBG. An intrusive plug of gray, fresh to slightly weathered granodiorite is mapped approximately 4 miles south of the proposed Hawk Creek Dam site. The floor of the proposed reservoir would be underlain primarily by silty, sandy, and gravelly alluvium of Hawk Creek and fine silty sand and silty glaciolacustrine deposits.

Damsite, Spillway, and Outlet Works Geology

The abutments of the proposed Hawk Creek Dam would be underlain by relatively flat-lying basalts of the CRBG and glaciolacustrine deposits. The left abutment would be underlain by shallow, horizontally-bedded basalt flows with a minimal surficial cover of talus and colluvium.

The right (north) proposed abutment location is underlain by glaciolacustrine deposits between the floor of the valley and approximately elevation 1680 feet. Based on field observations, these deposits consist of interbedded, laminated, light tan silty sand, sandy silt, and clay. Based on interpretive cross sections, the maximum thickness of the glaciolacustrine deposits is estimated to be between 200 and 300 feet.

The dam foundation would be underlain by alluvium of Hawk Creek and glaciolacustrine deposits. The alluvium consists primarily of interbedded, cross-bedded lenses of clays, silts, sands, sandy gravels, to gravelly sand. The thickness of the alluvium, based on well drillers' logs of the area, is more than 75 feet but thinner closer to the edges of the valley where it pinches out against the basalt slopes that form the sides of the valley.

The outlet works would be founded primarily on basalt bedrock or alluvium that underlies the valley floor.

Intake, Combined Pumping/Turbine Facility, Conveyance, and Power Transmission Facilities Geology

Hawk Creek enters Lake Roosevelt and forms a somewhat narrow, steep, twisting inlet lined in part by basalt bedrock, and infilled with alluvium and glaciolacustrine sediments.

The lower intake structure is anticipated to be a lake tap, and would be bored through basalt bedrock on the south side of the Hawk Creek inlet of Lake Roosevelt.

The combined pump/turbine facility would primarily be founded either on or deep within basalt bedrock on the south side of the Hawk Creek inlet. The conveyance route would consist of a tunnel bored through near-horizontally bedded basalt flows along the south side of the Hawk Creek inlet. The basalt flows are anticipated to include weak, fractured, poor-quality interflow zones and possibly weak, poorly indurated sedimentary interbeds.

Appendix C
Water Balance Reports

Appendix C: Water Balance Reports

A CD-ROM containing the water balance technical memorandum and results for each operational scenario is provided. The CD contains separate files for each of the project alternatives and operational scenarios, as follows:

- Water-Balance_Technical-Memo.pdf
- FINAL_Crab_Creek_OS1.pdf
- FINAL_Crab_Creek_OS2.pdf
- FINAL_Crab_Creek_OS3.pdf
- FINAL_Sand_Hollow_OS1.pdf
- FINAL_Hawk_Creek_OS1.pdf
- FINAL_Hawk_Creek_OS2.pdf
- FINAL_Hawk_Creek_OS3.pdf

Appendix D
Decision Support Model

Appendix D: Decision Support Model

D.1 Basis for Comparison—Evaluation Criteria

As presented on a site-by-site and scenario-by-scenario basis in Section 4 and summarized in Section 5, the off-channel storage site and scenario alternatives are assessed from three different perspectives, each of which is important to decision-making:

- Implementation/Technical Feasibility
- Benefits/Objectives Achievement
- Impacts (potential environmental, cultural, or socioeconomic impacts)

Table D-1.1 presents the base data for all alternatives for each of these perspectives. The data shown on this table—and its organization into evaluation perspectives, categories, factors, and criteria—form the basis for comparative analysis and are the starting point for development of the decision support model.

Section D.2 describes the comparison and screening process, including the numerical construct of the decision support model. Section D.3 presents the results of the comparative analysis. Section D.4 describes the findings and conclusions emerging from the comparative analysis.

D.2 Comparison/Screening Process

The comparison and screening process of the Decision Support Model follows four basic steps:

Step 1. Reviewing base data—simple “best and worst” indications

Step 2. Translating diverse criteria data into a common scale and unit of measure (normalization to a common scoring scheme) to enable comparisons among all evaluation criteria on an equal basis

Step 3. Comparing the alternatives with all criteria scores equal in importance (that is, no criterion rated as more or less important than any other)

Step 4. Comparing the alternatives using judgments about which criteria are most or least important to decision-making (a relative importance analysis)

Steps 1, 3, and 4 each can provide important insight regarding which alternatives warrant further study, or which option should be selected as the preferred alternative.

For this Appraisal Evaluation, only Steps 1 through 3 have been conducted. The Decision Support Model has been developed to enable Step 4, Relative Importance (RI) analysis. However, such an exploration inherently involves a wide range of opinions from multiple constituencies, and thus is only appropriate in later phases of planning, with involvement from stakeholders.

Because the alternatives being considered for Columbia River off-channel storage vary by site conditions and reservoir size at each site, the comparison analysis is conducted from two points of view at each step in the process:

- No adjustments for reservoir size (that is, total cost or total impact for each alternative and scenario considered without regard to water supply yield)

- Reservoir size-related criteria values (such as cost and impacts) reported on a per million acre-foot of yield basis

These two points of view are presented to provide a complete analysis. Certainly, in some cases (particularly total cost), it is relevant to consider alternatives on a "per unit of yield" basis. For other criteria that vary according to reservoir size (for example, biological resource impacts), it may be misleading to consider such a translation of site and scenario results.

D.2.1 Step 1: Base Data Review—Simple "Best and Worst" Indications

It is valuable to compare alternatives to the extent possible based on the fundamental (base) data prior to moving away from "real world" values such as dollars, acre-feet, and miles, to abstracted "criteria scores" used in decision support models.

Although little can be done to quantify differences among alternatives on this basis, simple patterns of best and worst performance among alternatives can be informative. As noted above, two viewpoints are included: one with no adjustment for reservoir size, and one with adjustments made per million acre-feet of value.

D.2.2 Step 2: Normalization of Base Data to a Common Scoring System

As can be seen on Table D-1.1, the array of criteria used to evaluate the alternative sites and scenarios involves reporting in diverse units of measure and scales, including the following:

- Professional judgment of relative risk, hazard, permitting constraint, potential for expansion, and other factors
- Cost (NPV in dollars)
- Cost per acre-foot of yield
- Miles of impact
- Acres of impact
- Instances of impact

To enable valid comparisons among these criteria, these units of measure must be translated into common language or normalized scoring system. The method used for this translation is described below.

Criteria-Level Normalization

The technique chosen to normalize the diverse criteria data for alternative sites and scenarios is a conversion of all values to scores on a common scale of 0 to 10, with 0 being the worst/least desirable and 10 being the best/most desirable condition. The score orientation of "lowest is worst, highest is best," is selected primarily because it facilitates application of relative importance values in Step 4, if desired in a future analysis.

For those criteria relying on professional judgment (for example, risk, hazard, or potential for expansion), this construct was set up from the outset and all scores for the alternatives are reported in this fashion.

Remaining criteria data (that is, cost, power balance, and all other impacts) were normalized by determining the range of values among all sites for each criterion, and interpreting this range for each site as shown in Table D-2.1.

TABLE D-2.1

Range of Values for Normalized Criteria

Base Data Value	Criterion Score
Worst/least desirable value in the range	0
All other values	Score from 0.1 to 9.9, where higher is better and lower is worse
Best/most desirable value in the range	10

Table D-1.1
Alternatives Comparison/Screening Criteria and Base Data

Perspective	Categories	Factors	Criteria	Units of Measure (base data/score)	Crab Creek OS1 (1 MAF)	Crab Creek OS2 (2 MAF)	Crab Creek OS3 (3 MAF)	Sand Hollow OS1 (1 MAF)	Hawk Creek OS1 (1 MAF)	Hawk Creek OS2 (2 MAF)	Hawk Creek OS3 (3 MAF)
A. Implementation/ Technical Feasibility											
	Cost & Time to Build		Net Present Value	$	$ 1,056,700,000	$ 1,965,400,000	$ 2,765,400,000	$ 2,009,000,000	$ 4,142,000,000	$ 7,203,800,000	$ 9,986,100,000
			Net Present Value/50 yrs yield	$/AF of yield	$ 19	$ 17	$ 17	$ 36	$ 73	$ 61	$ 60
			Construction duration	Years	4	5	6	4	6	7	8
	Risk Factors	Safety & integrity	Relative risk/hazard	Rating on 0-10 scale (0=highest, 10=lowest risk)	9	8	8	7	6	5	4
		Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	Rating on 0-10 scale (0=highest, 10=lowest risk)	6	7	8	0	4	5	6
B. Objectives/ Benefits Achievement											
	Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	acre-feet/year	845,000	1,764,000	2,463,000	834,000	852,000	1,764,000	2,463,000
		DCM&I Supply	Meeting projected demand (yield)	acre-feet/year	38,000	78,000	109,000	37,000	38,000	78,000	109,000
		Flow augmentation	Meeting projected demand (yield)	acre-feet/year	249,000	535,000	754,000	245,000	251,000	535,000	754,000
	Secondary Benefits	Power generation	Power balance	Revenue/Cost	0.49	0.55	0.55	0.49	0.37	0.36	0.37
		Expandibility	Potential for expansion to increase storage volume in the future	Rating on 0-10 scale (10=highest, 0=lowest potential)	8	7	6	0	0	0	0
C. Impacts											
	Socio-economic	Land Ownership	Private land acquisition requirement	Acres	5,000	7,000	9,000	12,500	5,000	8,000	11,000
			Federal & State land acquisition requirement	Acres	11000	16000	19000	50	100	100	100
		Land Use	Residential use	No. residences	18	18	18	32	41	45	46
			Irrigated Agriculture--High value crops (e.g. orchards, seed)	Acres	0	0	0	12,441	0	0	0
			Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	Acres	4,989	6,768	8,650	0	0	0	0
		Infrastructure	Highway (State, federal) impacts	Miles	2	3.5	5	1.5	0	0	0
			Local road impacts	Miles	33	43	48	36	28	39	48
			Railroad impacts	Miles	16	18	21	0	0	0	0
			Irrigation Infrastructure	Rating on 0-10 scale (0=major conflict, 10=none)	7	6	5	1	10	10	10
			Transmission line impacts	Miles	30	30	30	3	1	1	1
	Cultural	National Register-eligible resources and Traditional Cultural Properties	Potential for resource impacts	Rating on 0-10 scale (0=major potential, 10=none)	0	0	0	8	0	0	0
	BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	Miles	56	64	72	0	0	0	0
			Anadromous Fish--Downstream Habitat Affected	Miles	6	6	6	2	0	0	0
			Federal aquatic T & E species--Habitat Inundated	Miles	28	32	36	0	0	0	0
			Federal aquatic T & E species--Downstream Habitat Affected	Miles	3	3	3	1	3	3	3
			State aquatic Sensitive species--Habitat Inundated	Miles	28	32	36	0	0	0	0
			State aquatic Sensitive species--Downstream Habitat Affected	Miles	3	3	3	1	3	3	3
			State aquatic Priority Species	Miles	112	128	144	0	10	12	14
			Federal terrestrial T & E species impacts	Acres	0	0	0	0	0	0	0
			State terrestrial T & E and Sensitive species impacts	Acres	945	997	1,043	52	0	0	9
			State terrestrial Priority Species	Acres	4,453	5,136	5,547	29	9,701	14,069	17,816
		Special Status habitat or conservation/preservation designation	Wetland habitat impacts	Acres	4,414	4,965	5,413	112	51	51	54
			Riparian habitat impacts	Acres	416	418	418	0	1,767	2,775	3,484
			Sand Dunes habitat impacts	Acres	119	119	119	0	0	0	0
			Cliffs/Bluffs habitat impacts	Acres	88	202	306	0	0	0	0
			Steppe-Shrub habitat impacts	Acres	1,275	1,323	1,335	0	70	89	229
			Candidate Wild & Scenic rivers	Miles	0	0	0	0	0	0	0
			Wilderness Study Areas	Acres	0	0	0	0	0	0	0
			National wildlife refuges impacts	Acres	4,899	8,941	11,916	43	0	0	0
			State wildlife refuges impacts	Acres	6,103	6,930	7,311	0	0	0	0
			Other National or State conservation/preservation designation	Acres	0	0	0	0	0	22	61
		Water & Air Quality	Downstream temperature impacts	Rating on 0-10 scale (0=major conflict, 10=none)	7	8	9	2	9	10	10
			Windblown dust/particulates (from annual reservoir drawdown)	Rating on 0-10 scale (0=major conflict, 10=none)	8	7	6	2	10	10	10

The following example illustrates how this translation is achieved. Assuming the range of impacts on residential land use (among all candidate reservoir options) is a minimum of 10 to a maximum of 110 residences (or residences/million acre-feet), the impact score for this criterion would be derived as shown in Table D-2.2.

Factor, Category, and Perspective Normalization

Since it is often informative to be able to compare alternatives at one of the levels of criteria aggregation (that is, factors, categories, or perspectives, as shown on the data tables), the criteria scores must be normalized again at each level to maintain a common scale. This is because the number of criteria within a factor varies considerably (for example, three criteria comprise the Land Use factor, while ten criteria comprise the Special Status Species factor). Simply summing the criteria scores within the factors and comparing results is not valid for a basic score comparison or when relative importance values are added later in the process. The same is true when moving through the other levels—from factors to categories and then from categories to perspectives.

The method used to normalize the criteria scores through increasing levels of aggregation is simple averaging. This process is illustrated on Figure D-2.1; an extract from one of the normalized score tables presented later in this Appendix. Referring to the Land Use factor, the scores for the three criteria (Residential use at 6.1, Irrigated agriculture—High value at 10, and Irrigated agriculture—Moderate value at 4.2) are summed and divided by three (the total number of criteria), yielding a factor score of 6.8. The same process is used to obtain a score for the Socioeconomic Impact category: the scores for the three Socioeconomic factors (Land ownership at 7.1, Land use at 6.8 and Infrastructure at 4.6) are summed and divided by three to obtain the Socioeconomic score of 6.2 (all scores are rounded to the nearest tenth of a point).

TABLE D-2.2
Example Impact Score Resulting from Normalized Criteria

Residential Impact Range = Difference between best and worst = 100				
Alternative	**Number of Residences Impacted**	**% of Range**	**Score Calculation**	**Criteria Score**
A	10	0%	(1-0.00)*10	10.0
B	32	22%	(1-0.22)*10	7.8
C	67	57%	(1-0.57)*10	4.3
D	110	100%	(1-1.00)*10	0.0

FIGURE D-2.1

Example of Normalized Score Table (reference Tables D-3.3 and D-3.4 later in this Appendix)

Perspective	Categories	Factors	Criteria	Criteria Scores	Factor Scores	Category Scores	Perspective Scores
C. Impacts							
	Socio-economic	Land Ownership	Private land acquisition requirement	10.0	7.1	6.2	3.8
			Federal & State land acquisition requirement	4.2			
		Land Use	Residential use	6.1	6.8		
			Irrigated Agriculture--High value crops (e.g. orchards, seed)	10.0			
			Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	4.2			
		Infrastructure	Highway (State, federal) impacts	6.0	4.6		
			Local road impacts	7.5			
			Railroad impacts	2.4			
			Irrigation Infrastructure	7.0			
			Transmission line impacts	0.0			
	Cultural	National Register-eligible resources and Traditional Cultural Properties	Potential for resource impacts	0.0	0.0	0.0	
	BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	2.2	2.7	5.3	
			Anadromous Fish--Downstream Habitat Affected	0.0			
			Federal aquatic T & E species--Habitat Inundated	2.2			
			Federal aquatic T & E species--Downstream Habitat Affected	0.0			
			State aquatic Sensitive species--Habitat Inundated	2.2			
			State aquatic Sensitive species--Downstream Habitat Affected	0.0			
			State aquatic Priority Species	2.2			
			Federal terrestrial T & E species impacts	10.0			
			State terrestrial T & E and Sensitive species impacts	0.9			
			State terrestrial Priority Species	7.5			
		Special Status habitat or conservation/preservation designation	Wetland habitat impacts	1.9	5.6		
			Riparian habitat impacts	8.8			
			Sand Dunes habitat impacts	0.0			
			Cliffs/Bluffs habitat impacts	7.1			
			Steppe-Shrub habitat impacts	0.4			
			Candidate Wild & Scenic rivers	10.0			
			Wilderness Study Areas	10.0			
			National wildlife refuges impacts	5.9			
			State wildlife refuges impacts	1.7			
			Other National or State conservation/preservation designation	10.0			
		Water & Air Quality	Downstream temperature impacts	7.0	7.5		
			Windblown dust/particulates (from annual reservoir drawdown)	8.0			

D.2.3 Step 3: Alternatives Comparison—All Data/Values Equal in Importance

Before relative importance can be assigned in Step 4 (that is, ranking one criterion, factor, category, or perspective higher in importance than another), it is important to review site comparisons with all being equal in importance (Step 3). Relative importance analysis necessarily adds the dimension of individual or constituency points of view on what is important to a decision and what is not. For example, one point of view might be that cost is the most important consideration; another point of view might stress that impacts to endangered species are much more important than any other factor.

Step 3 compares the alternatives using the normalized scores derived from Step 2. While all reporting levels can be used, review of the data in this study suggests that the Category and Perspective levels are most informative and straightforward.

D.2.4 Step 4: Alternatives Comparison—With Relative Importance (RI) Values

The Relative Importance (RI) capability of the decision support model is designed to be applied at two levels; either or both of these levels can be used in exploring RI influence on alternatives rankings:

1. Criteria—Express differences in importance among the criteria within each of the three perspectives
2. Perspectives—Test how differences in points of view on the importance of each perspective influences which site(s) or scenario(s) rank highest or lowest

At the criteria level, within each perspective, each criterion would be assigned a RI value from 1 to 5, with 1 being least important and 5 being most important. The assigned RI value for each criterion would then be multiplied by its base criterion score to yield a weighted value. The influence of this weighted value carries through the normalization process to correspondingly influence the perspective score.

At the perspective level, the technique is to distribute 100 points among the three perspectives, with the perspective(s) seen as most important receiving higher proportions. The weighted perspective score derived from the criteria-level RI application (or simply the base perspective score if the criteria level RI rating is not used) would then be multiplied by the assigned points for each perspective. This would yield weighted perspective scores for each alternative.

RI analysis was not conducted in this Appraisal Evaluation (that is, without additional stakeholder input, analysis of RI values is not appropriate at this stage of planning. However, the groundwork is laid for use of this tool, as desired, in a future Feasibility Study.

D.3 Results of Project Alternatives Comparison/ Screening

D.3.1 Step 1: Base Data—Simple Best and Worst Review

Tables D-3.1 and D-3.2 illustrate the base criteria data table with color coding, showing the best/most desirable conditions in green and worst/least desirable conditions in orange highlighting. Table D-3.1 uses base data with no adjustment for reservoir size. Table D-3.2 adjusts total NPV cost data and the Impacts data to per million acre-foot values; all other values are the same as shown on Table D-3.1.

From a review of these tables, the following observations can be made:

- **Implementation/Technical Feasibility:**
  - The Crab Creek site performs best among the three candidate sites in all Implementation/Technical Feasibility categories. It offers the lowest cost and lowest risk options and best time-to-build ratings.
  - The Hawk Creek site involves by far the highest cost and longest time to build, and the highest risks of the three sites.
  - Economies of scale are apparent between OS1 and OS2 at both Crab Creek and Hawk Creek. At Crab Creek, the cost per acre-foot of yield (NPV/50 years yield) is reduced by 11 percent for OS2 compared with OS1. At Hawk Creek, this reduction is 16 percent. Neither site shows further significant reduction in cost per acre-foot of yield between OS2 and OS3.

  - The Sand Hollow site falls between the Crab Creek and Hawk Creek sites in terms of cost (roughly double the cost of Crab Creek and half the cost of Hawk Creek). The same is true of relative risk. However, the Sand Hollow site shows the highest potential of all three sites for storage volume reduction over time because of sedimentation.
- **Objectives/Benefits Achievement:**
  - Since response to project objectives related to irrigation, DCM&I, and flow augmentation is expressed as acre-feet of yield provided each year, it is obvious that the larger reservoirs (with Crab Creek OS3 and Hawk Creek OS3 being the largest) would rank highest in terms of primary benefits.
  - The Crab Creek site generally performs best in terms of the secondary objectives/benefits assessed (that is, offering potential for future expansion and the best power balance). Neither the Sand Hollow nor the Hawk Creek site offers expansion potential, and the Hawk Creek site has a substantially poorer power balance (that is, revenue to cost ratio).
- **Impacts:**
  - With some exceptions, Sand Hollow generally involves the least impacts of the three sites. This is particularly true in the cultural and biophysical resource categories, where potential for impacts appears low.

    Exceptions to this general observation center on the socioeconomic category, where Sand Hollow would involve the largest extent of private land acquisition, and the highest impacts to high-value agricultural land and associated irrigation infrastructure. The site would also involve displacement of approximately 32 residences, compared with 41 to 46 at Hawk Creek and 18 at Crab Creek.

    Within the biophysical impact category, Sand Hollow would have the highest potential for air and water quality impacts—in the criteria reported.
  - The Hawk Creek site has relatively low biophysical impacts, involving few apparent conflicts with endangered or sensitive species. (This site does, however, involve the highest impact on state terrestrial priority species and on riparian habitat.)

    However, Hawk Creek involves displacement of the highest number of residences, substantial private land acquisition, and a high potential for impact to cultural resources.
  - The Crab Creek site involves generally the highest aggregate potential for impacts among the three sites, facing substantial constraints in all three impact categories. It has by far the highest levels of potential for biophysical impacts, particularly related to federal and state endangered and sensitive species, wetland habitat, and established federal and state wildlife refuges.

Table D-3.1

Alternatives Comparison: Raw Data--Simple Best/Worst Response to Criteria
- No Adjustment For Reservoir Size

Relative Response to Criteria: = Best = Worst

Perspective / Categories	Factors	Criteria	Units of Measure (base data/score)	Crab Creek OS1 (1 MAF)	Crab Creek OS2 (2 MAF)	Crab Creek OS3 (3 MAF)	Sand Hollow OS1 (1 MAF)	Hawk Creek OS1 (1 MAF)	Hawk Creek OS2 (2 MAF)	Hawk Creek OS3 (3 MAF)
A. Implementation/ Technical Feasibility										
Cost & Time to Build		Net Present Value	$	$ 1,056,700,000	$ 1,965,400,000	$ 2,765,400,000	$ 2,009,000,000	$ 4,142,000,000	$ 7,203,800,000	$ 9,986,100,000
		Net Present Value/50 yrs yield	$/AF of yield	$ 19	$ 17	$ 17	$ 36	$ 73	$ 61	$ 60
		Construction duration	Years	4	5	6	4	6	7	8
Risk Factors	Safety & integrity	Relative risk/hazard	Rating on 0-10 scale (0=highest, 10=lowest risk)	9	8	8	7	6	5	4
	Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	Rating on 0-10 scale (0=highest, 10=lowest risk)	6	7	8	0	4	5	6
B. Objectives/ Benefits Achievement										
Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	acre-feet/year	845,000	1,764,000	2,463,000	834,000	852,000	1,764,000	2,463,000
	DCM&I Supply	Meeting projected demand (yield)	acre-feet/year	38,000	78,000	109,000	37,000	38,000	78,000	109,000
	Flow augmentation	Meeting projected demand (yield)	acre-feet/year	249,000	535,000	754,000	245,000	251,000	535,000	754,000
Secondary Benefits	Power generation	Power balance	Revenue/Cost	0.49	0.55	0.55	0.49	0.37	0.36	0.37
	Expandibility	Potential for expansion to increase storage volume in the future	Rating on 0-10 scale (10=highest, 0=lowest potential)	8	7	6	0	0	0	0
C. Impacts										
Socio-economic	Land Ownership	Private land acquisition requirement	Acres	5,000	7,000	9,000	12,500	5,000	8,000	11,000
		Federal & State land acquisition requirement	Acres	11000	16000	19000	50	100	100	100
	Land Use	Residential use	No. residences	18	18	18	32	41	45	46
		Irrigated Agriculture--High value crops (e.g. orchards, seed)	Acres	0	0	0	12,441	0	0	0
		Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	Acres	4,989	6,768	8,650	0	0	0	0
	Infrastructure	Highway (State, federal) impacts	Miles	2	3.5	5	1.5	0	0	0
		Local road impacts	Miles	33	43	48	36	28	39	48
		Railroad impacts	Miles	16	18	21	0	0	0	0
		Irrigation infrastructure impacts	Rating on 0-10 scale (0=major conflict, 10=none)	7	6	5	1	10	10	10
		Transmission line impacts	Miles	30	30	30	3	1	1	1
Cultural	National Register-eligible resources and Traditional Cultural Properties	Potential for resource impacts	Rating on 0-10 scale (0=major potential, 10=none)	0	0	0	8	0	0	0
BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	Miles	56	64	72	0	0	0	0
		Anadromous Fish--Downstream Habitat Affected	Miles	6	6	6	2	0	0	0
		Federal aquatic T & E species--Habitat Inundated	Miles	28	32	36	0	0	0	0
		Federal aquatic T & E species--Downstream Habitat Affected	Miles	3	3	3	1	3	3	3
		State aquatic Sensitive species--Habitat Inundated	Miles	28	32	36	0	0	0	0
		State aquatic Sensitive species--Downstream Habitat Affected	Miles	3	3	3	1	3	3	3
		State aquatic Priority Species	Miles	112	128	144	0	10	12	14
		Federal terrestrial T & E species impacts	Acres	0	0	0	0	0	0	0
		State terrestrial T & E and Sensitive species impacts	Acres	945	997	1,043	52	0	0	9
		State terrestrial Priority Species	Acres	4,453	5,136	5,547	29	9,701	14,069	17,816
	Special Status habitat or conservation/preservation designation	Wetland habitat impacts	Acres	4,414	4,965	5,413	112	51	51	54
		Riparian habitat impacts	Acres	416	418	418	0	1,767	2,775	3,484
		Sand Dunes habitat impacts	Acres	119	119	119	0	0	0	0
		Cliffs/Bluffs habitat impacts	Acres	88	202	306	0	0	0	0
		Steppe-Shrub habitat impacts	Acres	1,275	1,323	1,335	0	70	89	229
		Candidate Wild & Scenic rivers	Miles	0	0	0	0	0	0	0
		Wilderness Study Areas	Acres	0	0	0	0	0	0	0
		National wildlife refuges impacts	Acres	4,899	8,941	11,916	43	0	0	0
		State wildlife refuges impacts	Acres	6,103	6,930	7,311	0	0	0	0
		Other National or State conservation/preservation designation	Acres	0	0	0	0	0	22	61
	Water & Air Quality	Downstream temperature impacts	Rating on 0-10 scale (0=major conflict, 10=none)	7	8	9	2	9	10	10
		Windblown dust/particulates (from annual reservoir drawdown)	Rating on 0-10 scale (0=major conflict, 10=none)	8	7	6	2	10	10	10

Table D-3.2
Alternatives Comparison: Raw Data--Simple Best/Worst Response to Criteria
- Total NPV Costs and Impacts Converted to /MAF Values

Relative Response to Criteria: = Best = Worst

Categories	Factors	Criteria	Units of Measure (base data/score)	Crab Creek (CC) OS1 (1 MAF)	Crab Creek (CC) OS2 (2 MAF)	Crab Creek (CC) OS3 (3 MAF)	Sand Hollow OS1 (1 MAF)	Hawk Creek (HC) OS1 (1 MAF)	Hawk Creek (HC) OS2 (2 MAF)	Hawk Creek (HC) OS3 (3 MAF)
A. Implementation/ Technical Feasibility										
Cost & Time to Build		Net Present Value	$	$ 1,056,700,000	$ 982,700,000	$ 921,800,000	$ 2,009,000,000	$ 4,142,000,000	$ 3,601,900,000	$ 3,328,700,000
		Net Present Value/50 yrs yield	$/AF of yield	$ 19	$ 17	$ 17	$ 36	$ 73	$ 61	$ 60
		Construction duration	Years	4	5	6	4	6	7	8
Risk Factors	Safety & integrity	Relative risk/hazard	Rating on 0-10 scale (0=highest, 10=lowest risk)	9	8	8	7	6	5	4
	Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	Rating on 0-10 scale (0=highest, 10=lowest risk)	6	7	8	0	4	5	6
B. Objectives/ Benefits Achievement										
Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	acre-feet/year	845,000	1,764,000	2,463,000	834,000	852,000	1,764,000	2,463,000
	DCM&I Supply	Meeting projected demand (yield)	acre-feet/year	38,000	78,000	109,000	37,000	38,000	78,000	109,000
	Flow augmentation	Meeting projected demand (yield)	acre-feet/year	249,000	535,000	754,000	245,000	251,000	535,000	754,000
Secondary Benefits	Power generation	Power balance	Revenue/Cost	0.49	0.55	0.55	0.49	0.37	0.36	0.37
	Expandibility	Potential for expansion to increase storage volume in the future	Rating on 0-10 scale (10=highest, 0=lowest potential)	8	7	6	0	0	0	0
C. Impacts										
Socio-economic	Land Ownership	Private land acquisition requirement	Acres	5000.0	3500.0	3000.0	12500.0	5000.0	4000.0	3666.7
		Federal & State land acquisition requirement	Acres	11000.0	8000.0	6333.3	50.0	100.0	50.0	33.3
	Land Use	Residential use	No. residences	18.0	9.0	6.0	32.0	41.0	22.5	15.3
		Irrigated Agriculture--High value crops (e.g. orchards, seed)	Acres	0.0	0.0	0.0	12441.0	0.0	0.0	0.0
		Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	Acres	4989.0	3384.0	2883.3	0.0	0.0	0.0	0.0
	Infrastructure	Highway (State, federal) impacts	Miles	2.0	1.8	1.7	1.5	0.0	0.0	0.0
		Local road impacts	Miles	33.0	21.5	16.0	36.0	28.0	19.5	16.0
		Railroad impacts	Miles	16.0	9.0	7.0	0.0	0.0	0.0	0.0
		Irrigation infrastructure impacts	Rating on 0-10 scale (0=major conflict, 10=none)	7	6	5	1	10	10	10
		Transmission line impacts	Miles	30.0	15.0	10.0	3.0	1.0	0.5	0.3
Cultural	National Register-eligible resources and Traditional Cultural Properties	Potential for resource impacts	Rating on 0-10 scale (0=major potential, 10=none)	0	0	0	8	0	0	0
BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	Miles	56.0	32.0	24.0	0.0	0.0	0.0	0.0
		Anadromous Fish--Downstream Habitat Affected	Miles	6.0	3.0	2.0	2.0	0.0	0.0	0.0
		Federal aquatic T & E species--Habitat Inundated	Miles	28.0	16.0	12.0	0.0	0.0	0.0	0.0
		Federal aquatic T & E species--Downstream Habitat Affected	Miles	3.0	1.5	1.0	1.0	3.0	1.5	1.0
		State aquatic Sensitive species--Habitat Inundated	Miles	28.0	16.0	12.0	0.0	0.0	0.0	0.0
		State aquatic Sensitive species--Downstream Habitat Affected	Miles	3.0	1.5	1.0	1.0	3.0	1.5	1.0
		State aquatic Priority Species	Miles	112.0	64.0	48.0	0.0	10.0	6.0	4.7
		Federal terrestrial T & E species impacts	Acres	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		State terrestrial T & E and Sensitive species impacts	Acres	945.0	498.5	347.7	52.0	0.0	0.0	3.0
		State terrestrial Priority Species	Acres	4453.0	2568.0	1849.0	29.0	9701.0	7034.5	5938.7
	Special Status habitat or conservation/preservation designation	Wetland habitat impacts	Acres	4414.0	2482.5	1804.3	112.0	51.0	25.5	18.0
		Riparian habitat impacts	Acres	416.0	209.0	139.3	0.0	1767.0	1387.5	1161.3
		Sand Dunes habitat impacts	Acres	119.0	59.5	39.7	0.0	0.0	0.0	0.0
		Cliffs/Bluffs habitat impacts	Acres	88.0	101.0	102.0	0.0	0.0	0.0	0.0
		Steppe-Shrub habitat impacts	Acres	1275.0	661.5	445.0	0.0	70.0	44.5	76.3
		Candidate Wild & Scenic rivers	Miles	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Wilderness Study Areas	Acres	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		National wildlife refuges impacts	Acres	4899.0	4470.5	3972.0	43.2	0.0	0.0	0.0
		State wildlife refuges impacts	Acres	6102.9	3464.8	2437.0	0.0	0.1	0.0	0.0
		Other National or State conservation/preservation designation	Acres	0.0	0.0	0.0	0.0	0.1	10.9	20.3
	Water & Air Quality	Downstream temperature impacts	Rating on 0-10 scale (0=major conflict, 10=none)	7	8	9	2	9	10	10
		Windblown dust/particulates (from annual reservoir drawdown)	Rating on 0-10 scale (0=major conflict, 10=none)	8	7	6	2	10	10	10

Crab Creek is the only site that involves significant federal and state lands (much of which is currently within wildlife refuges), and would require substantial private land acquisition, mostly irrigated agricultural land. The site would also generally involve the most impact on infrastructure, primarily because of required relocations of local roads, state highway, railroad, and electric transmission lines.

These conditions at Crab Creek are due at least partially to the fact that this site would involve significantly larger inundation areas than either of the other two sites (that is, nearly 40 percent larger than Sand Hollow and roughly three times larger than Hawk Creek at comparable storage volumes).

- **Overall:**
  - From the perspectives of Implementation/Technical Feasibility and Objectives/Benefits Achievement, the Crab Creek site appears clearly to be the most attractive among the three sites. However, this site generally faces the highest levels of Impacts constraints.
  - Sand Hollow generally faces the least impact challenges (with the exception of private land acquisition and agricultural use and infrastructure). From the standpoint of Implementation/ Technical Feasibility criteria, Sand Hollow shows a moderately good response, but is limited to the smallest reservoir size being considered and has no potential for expansion.
  - The Hawk Creek site presents the most severe Implementation/ Technical Feasibility challenges and, while generally lower in impact potential than Crab Creek, still involves important challenges (particularly cultural resources, private land acquisition, residential land use, and some forms of wildlife habitat).

D.3.2 Step 2: Normalized Data/Scores

Normalized scores for all alternatives are shown in Tables D-3.3 (no consideration for reservoir size) and D-3.4 (with per million acre-foot adjustments). Comparative analysis of the alternatives presented in the following section is based primarily on the Perspective levels of the normalized scores shown on these tables.

D.3.3 Step 3: Alternatives Comparison—All Data/Values Equal in Importance

The review of base data presented in Section D.3.1 allows general observations on and comparisons of the alternative sites and scenarios. The decision support model, starting with normalization of base data to a common scoring system, allows more rigorous analysis and comparison, tests (and presumably confirms) the validity of these general observations, and provides further insight toward identifying the most feasible and attractive site or scenario.

The comparative analysis with all criteria, factors, categories, and perspectives equal in importance is presented below [1] for each Perspective individually (Implementation/Technical Feasibility, Objectives/Benefits Achievement, and Impacts), [2] for the combination of Implementation and Benefits perspectives, and [3] overall, summing scores for all three perspectives.

Implementation/Technical Feasibility

Site/scenario rankings from the perspective of Implementation and Technical Feasibility (with all criteria rated equally) are illustrated on Figures D-3.1 and D-3.2. Figure D-3.1 reflects no per million acre-foot adjustment in total NPV cost; Figure D-3.2 makes this adjustment.

As shown on these figures, the Crab Creek site rates highest among the three sites under consideration. All three scenarios at Crab Creek rate higher than any scenario at the other two sites.

This finding is consistent with the data review observations reported earlier. The Crab Creek site achieves the highest Implementation/Technical Feasibility scores as a result of having the best performance in all Implementation/ Technical Feasibility evaluation factors.

The Sand Hollow site option represents a “middle ground” (only related to OS1 options), primarily because its cost is double that of Crab Creek but half that of Hawk Creek, and because it would take the shortest time to build.

The Hawk Creek site, in all scenarios, is clearly shown to be the lowest ranking from the Implementation/Technical Feasibility perspective. This is due to having by far the highest cost, relatively high risk factors, and the longest time to build.

Objectives/Benefits Achievement

Site/scenario ranking from the perspective of Objectives/Benefits Achievement (with all criteria rated equally) is illustrated on Figure D-3.3. (This perspective has no criteria for which a per million acre-foot viewpoint is relevant.)

The largest reservoir scenarios and the Crab Creek site in general rank the highest from this perspective. In the former regard, the result is simply due to provision of more water storage to meet primary project objectives. In the latter regard, the Crab Creek site generally ranks higher because it has the best performance on secondary benefits (that is, the best power balance [revenue/cost ratio] and being the only site judged to offer future expansion potential). Also in this latter regard, the much higher ratings shown for the Crab Creek scenarios are due to the equal importance assigned to primary and secondary benefits. If, for example, secondary benefits were rated as less important, the difference in scores among the 1 million acre-foot scenarios and between the 2 million acre-foot or 3 million acre-foot scenarios would be smaller.

Combination of Implementation/Technical Feasibility and Objectives/Benefits Achievement

Figures D-3.4 and D-3.5 show site and scenario rankings when both the Implementation/Technical Feasibility and Objectives/Benefits Achievement perspectives are combined. Figure D-3.4 reflects no per million acre-foot adjustment in total NPV cost; Figure D-3.5 makes this adjustment.

When taken together, these two perspectives reinforce the superiority of the Crab Creek site, centering on cost, ability to construct and maintain, and flexibility for expansion. These site/scenario ratings also show a preference for the larger reservoir sizes; specifically, a higher capacity available to meet future water supply needs.

Table D-3.3
Alternatives Comparison: Normalized Scores
- All Criteria Equal--No Relative Importance Distinctions
- No Adjustment For Reservoir Size

Perspective	Categories	Factors	Criteria	Crab Creek (CC) OS1 (1 MAF)				Crab Creek (CC) OS2 (2 MAF)				Crab Creek (CC) OS3 (3 MAF)				Sand Hollow OS1 (1 MAF)				Hawk Creek (HC) OS1 (1 MAF)				Hawk Creek (HC) OS2 (2 MAF)				Hawk Creek (HC) OS3 (3 MAF)			
				Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level
A. Implementation/ Technical Feasibility																															
	Cost & Time to Build		Net Present Value	10.0	10.0			9.0	9.0	9.5	8.2	8.1	8.1			8.9	8.9			6.5	6.5			3.1	3.1			0.0	0.0		
			Net Present Value/50 yrs yield	9.6	9.6	9.9		10.0	10.0			10.0	10.0	7.7		6.5	6.5	8.5		0.0	0.0	3.8		2.1	2.1	2.6		2.2	2.2	0.7	
			Construction duration	10.0	10.0			7.5	7.5	7.5		5.0	5.0			10.0	10.0			5.0	5.0			2.5	2.5			0.0	0.0		
	Risk Factors	Safety & integrity	Relative risk/hazard	9.0	9.0		8.7	8.0	8.0	7.5		8.0	8.0		7.8	7.0	7.0		6.0	6.0	6.0		4.4	5.0	5.0		3.8	4.0	4.0		2.9
		Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	6.0	6.0	7.5		7.0	7.0			8.0	8.0	8.0		0.0	0.0	3.5		4.0	4.0	5.0		5.0	5.0	5.0		6.0	6.0	5.0	
			Totals	**44.6**	**44.6**	**17.4**	**8.7**	**41.5**	**41.5**	**24.5**	**8.2**	**39.1**	**39.1**	**15.7**	**7.8**	**32.5**	**32.5**	**12.0**	**6.0**	**21.5**	**21.5**	**8.8**	**4.4**	**17.8**	**17.8**	**7.6**	**3.8**	**12.2**	**12.2**	**5.7**	**2.9**
B. Objectives/ Benefits Achievement																															
	Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	0.1	0.1			5.7	5.7			10.0	10.0			0.0	0.0			0.1	0.1			5.7	5.7			10.0	10.0		
		DCM&I Supply	Meeting projected demand (yield)	0.1	0.1	0.1		5.7	5.7	5.7		10.0	10.0	10.0		0.0	0.0	0.0		0.1	0.1	0.1		5.7	5.7	5.7		10.0	10.0	10.0	
		Flow augmentation	Meeting projected demand (yield)	0.1	0.1		3.8	5.7	5.7		7.1	10.0	10.0		9.0	0.0	0.0		1.7	0.1	0.1		0.2	5.7	5.7		2.9	10.0	10.0		5.1
	Secondary Benefits	Power generation	Power balance	6.8	6.8			10.0	10.0			9.9	9.9			7.0	7.0			0.6	0.6			0.0	0.0			0.6	0.6		
		Expandibility	Potential for expansion to increase storage volume in the future	8.0	8.0	7.4		7.0	7.0	8.5		6.0	6.0	8.0		0.0	0.0	3.5		0.0	0.0	0.3		0.0	0.0	0.0		0.0	0.0	0.3	
			Totals	**15.1**	**15.1**	**7.5**	**3.8**	**34.1**	**34.1**	**14.2**	**7.1**	**45.9**	**45.9**	**18.0**	**9.0**	**7.0**	**7.0**	**3.5**	**1.7**	**1.0**	**1.0**	**0.4**	**0.2**	**17.1**	**17.1**	**5.7**	**2.9**	**30.6**	**30.6**	**10.3**	**5.1**
C. Impacts																															
	Socio-economic	Land Ownership	Private land acquisition requirement	10.0	7.1			7.3	4.5			4.7	2.3			0.0	5.0			10.0	10.0			6.0	8.0			2.0	6.0		
			Federal & State land acquisition requirement	4.2				1.6				0.0				10.0				10.0				10.0				10.0			
		Land Use	Residential use	6.1				6.1				6.1				3.0				1.1				0.2				0.0			
			Irrigated Agriculture--High value crops (e.g. orchards, seed)	10.0	6.8			10.0	6.1			10.0	5.4			0.0	4.3			10.0	7.0			10.0	6.7			10.0	6.7		
			Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	4.2				2.2				0.0				10.0				10.0				10.0				10.0			
		Infrastructure	Highway (State, federal) impacts	6.0		6.2		3.0		4.4		0.0		2.9		7.0		5.3		10.0		8.3		10.0		7.2		10.0		6.2	
			Local road impacts	7.5				2.5				0.0				6.0				10.0				4.5				0.0			
			Railroad impacts	2.4	4.6			1.4	2.6			0.0	1.0			10.0	6.7			10.0	8.0			10.0	6.9			10.0	6.0		
			Irrigation Infrastructure	7.0				6.0				5.0				1.0				0.0				0.0				0.0			
			Transmission line impacts	0.0				0.0				0.0				9.3				10.0				10.0				10.0			
	Cultural	National Register-eligible resources and Traditional Cultural Properties	Potential for resource impacts	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0		8.0	8.0	8.0		0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0	
	BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	2.2				1.1				0.0				10.0				10.0				10.0				10.0			
			Anadromous Fish--Downstream Habitat Affected	0.0				0.0				0.0				6.7				10.0				10.0				10.0			
			Federal aquatic T & E species--Habitat Inundated	2.2				1.1				0.0				10.0				10.0				10.0				10.0			
			Federal aquatic T & E species--Downstream Habitat Affected	0.0				0.0				0.0				10.0				0.0				0.0				0.0			
			State aquatic Sensitive species--Habitat Inundated	2.2	2.7			1.1	1.2			0.0	0.7			10.0	8.6			10.0	6.4			10.0	6.1			10.0	5.9		
			State aquatic Sensitive species--Downstream Habitat Affected	0.0			3.8	0.0			2.7	0.0			2.1	10.0			6.5	0.0			5.4	0.0			4.9	0.0			4.5
			State aquatic Priority Species	2.2				1.1				0.0				10.0				9.3				9.2				9.0			
			Federal terrestrial T & E species impacts	10.0				0				0				0				0				0				0			
			State terrestrial T & E and Sensitive species impacts	0.9				0.4				0.0				9.5				10.0				10.0				9.9			
			State terrestrial Priority Species	7.5				7.1				6.9				10.0				4.6				2.1				0.0			
		Special Status habitat or conservation/preservation designation	Wetland habitat impacts	1.9				0.8				0.0				9.9				10.0				10.0				10.0			
			Riparian habitat impacts	8.8				8.8				8.8				10.0				4.9				2.0				0.0			
			Sand Dunes habitat impacts	0.0		5.3		0.0		3.8		0.0		3.4		10.0		6.2		10.0		7.8		10.0		7.6		10.0		7.2	
			Cliffs/Bluffs habitat impacts	7.1				3.4				0.0				10.0				10.0				10.0				10.0			
			Steppe-Shrub habitat impacts	0.4	5.6			0.1	2.6			0.0	1.9			10.0	8.0			9.5	7.4			9.3	6.8			8.3	5.8		
			Candidate Wild & Scenic rivers	10.0				0				0				0				0				0				0			
			Wilderness Study Areas	10.0				0				0				0				0				0				0			
			National wildlife refuges impacts	5.9				2.5				0.0				10.0				10.0				10.0				10.0			
			State wildlife refuges impacts	1.7				0.5				0.0				10.0				10.0				10.0				10.0			
			Other National or State conservation/preservation designation	10.0				10.0				10.0				10.0				10.0				6.4				0.0			
		Water & Air Quality	Downstream temperature impacts	7.0				8.0				9.0				2.0				9.0				10.0				10.0			
			Windblown dust/particulates (from annual reservoir drawdown)	8.0	7.5			7.0	7.5			6.0	7.5			2.0	2.0			10.0	9.5			10.0	10.0			10.0	10.0		
			Totals	**155.5**	**34.3**	**11.4**	**3.8**	**103.3**	**24.4**	**8.1**	**2.7**	**76.5**	**18.8**	**6.3**	**2.1**	**252.4**	**42.6**	**19.5**	**6.5**	**248.3**	**48.3**	**16.1**	**5.4**	**229.8**	**44.5**	**14.8**	**4.9**	**209.2**	**40.4**	**13.5**	**4.5**

Table D-3.4
Alternatives Comparison: Normalized Scores
- All Criteria Equal--No Relative Importance Distinctions
- Total NPV Costs and Impacts Converted to /MAF Values

Categories	Factors	Criteria	Crab Creek												Sand Hollow				Hawk Creek											
			OS1 (1 MAF)				OS2 (2 MAF)				OS3 (3 MAF)				OS1 (1 MAF)				OS1 (1 MAF)				OS2 (2 MAF)				OS3 (3 MAF)			
			Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level	Criteria Level	Factor Level	Category Level	Perspective Level
A. Implementation/ Technical Feasibility																														
Cost & Time to Build		Net Present Value	9.6	9.6	9.7	8.6	9.8	9.8	9.1	8.3	10.0	10.0	8.3	8.2	6.6	6.6	7.7	5.6	0.0	0.0	1.7	3.3	1.7	1.7	2.1	3.6	2.5	2.5	1.6	3.3
		Net Present Value/50 yrs yield	9.6	9.6			10.0	10.0			10.0	10.0			6.5	6.5			0.0	0.0			2.1	2.1			2.2	2.2		
		Construction duration	10.0	10.0			7.5	7.5			5.0	5.0			10.0	10.0			5.0	5.0			2.5	2.5			0.0	0.0		
Risk Factors	Safety & integrity	Relative risk/hazard	9.0	9.0	7.5		8.0	8.0	7.5		8.0	8.0	8.0		7.0	7.0	3.5		6.0	6.0	5.0		5.0	5.0	5.0		4.0	4.0	5.0	
	Reservoir storage yield/volume	Volume reduction potential due to erosion/sedimentation	6.0	6.0			7.0	7.0			8.0	8.0			0.0	0.0			4.0	4.0			5.0	5.0			6.0	6.0		
		Totals	**44.2**	**44.2**	**17.2**	**8.6**	**42.3**	**42.3**	**16.6**	**8.3**	**41.0**	**41.0**	**16.3**	**8.2**	**30.2**	**30.2**	**11.2**	**5.6**	**15.0**	**15.0**	**6.7**	**3.3**	**16.3**	**16.3**	**7.1**	**3.6**	**14.8**	**14.8**	**6.6**	**3.3**
B. Objectives/ Benefits Achievement																														
Primary Benefits	Irrigation Supply	Meeting projected demand (yield)	0.1	0.1	0.1	3.8	5.7	5.7	5.7	7.1	10.0	10.0	10.0	9.0	0.0	0.0	0.0	1.7	0.1	0.1	0.1	0.2	5.7	5.7	5.7	2.9	10.0	10.0	10.0	5.1
	DCM&I Supply	Meeting projected demand (yield)	0.1	0.1			5.7	5.7			10.0	10.0			0.0	0.0			0.1	0.1			5.7	5.7			10.0	10.0		
	Flow augmentation	Meeting projected demand (yield)	0.1	0.1			5.7	5.7			10.0	10.0			0.0	0.0			0.1	0.1			5.7	5.7			10.0	10.0		
Secondary Benefits	Power generation	Power balance	6.8	6.8	7.4		10.0	10.0	8.5		9.9	9.9	8.0		7.0	7.0	3.5		0.6	0.6	0.3		0.0	0.0	0.0		0.6	0.6	0.3	
	Expandibility	Potential for expansion to increase storage volume in the future	8.0	8.0			7.0	7.0			6.0	6.0			0.0	0.0			0.0	0.0			0.0	0.0			0.0	0.0		
		Totals	**15.1**	**15.1**	**7.5**	**3.8**	**34.1**	**34.1**	**14.2**	**7.1**	**45.9**	**45.9**	**18.0**	**9.0**	**7.0**	**7.0**	**3.5**	**1.7**	**1.0**	**1.0**	**0.4**	**0.2**	**17.1**	**17.1**	**5.7**	**2.9**	**30.6**	**30.6**	**10.3**	**5.1**
C. Impacts																														
Socio-economic	Land Ownership	Private land acquisition requirement	7.9	3.9	3.7	2.5	9.5	6.1	6.1	4.0	10.0	7.1	7.0	4.5	0.0	5.0	4.6	6.4	7.9	8.9	8.1	5.3	8.9	9.5	9.2	5.9	9.3	9.6	9.6	6.0
		Federal & State land acquisition requirement	0.0				2.7				4.3				10.0				9.9				10.0				10.0			
	Land Use	Residential use	6.6	5.5			9.1	7.5			10.0	8.1			2.6	4.2			0.0	6.7			5.3	8.4			7.3	9.1		
		Irrigated Agriculture--High value crops (e.g. orchards, seed)	10.0				10.0				10.0				0.0				10.0				10.0				10.0			
		Irrigated Agriculture--Moderate value crops (e.g. pasture, grain)	0.0				3.2				4.2				10.0				10.0				10.0				10.0			
	Infrastructure	Highway (State, federal) impacts	0.0	1.7			1.3	4.8			1.7	5.8			2.5	4.5			10.0	8.8			10.0	9.6			10.0	10.0		
		Local road impacts	1.5				7.3				10.0				0.0				4.0				8.3				10.0			
		Railroad impacts	0.0				4.4				5.6				10.0				10.0				10.0				10.0			
		Irrigation Infrastructure	7.0				6.0				5.0				1.0				10.0				10.0				10.0			
		Transmission line impacts	0.0				5.1				6.7				9.1				9.8				9.9				10.0			
Cultural	Archaeological/National Register-eligible resources	Potential impact to Prehistoric and Historic sites	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0		8.0	8.0	8.0		0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0	
BioPhysical	Special Status Species	Anadromous Fish--Habitat Inundated	0.0	1.5	3.6		4.3	5.9	5.8		5.7	7.4	6.5		10.0	9.6	6.5		10.0	6.9	7.8		10.0	8.7	8.5		10.0	9.3	8.5	
		Anadromous Fish--Downstream Habitat Affected	0.0				5.0				6.7				6.7				10.0				10.0				10.0			
		Federal aquatic T & E species--Habitat Inundated	0.0				4.3				5.7				10.0				10.0				10.0				10.0			
		Federal aquatic T & E species--Downstream Habitat Affected	0.0				7.5				10.0				10.0				0.0				7.5				10.0			
		State aquatic Sensitive species--Habitat Inundated	0.0				4.3				5.7				10.0				10.0				10.0				10.0			
		State aquatic Sensitive species--Downstream Habitat Affected	0.0				7.5				10.0				10.0				0.0				7.5				10.0			
		State aquatic Priority Species	0.0				4.3				5.7				10.0				9.1				9.5				9.6			
		Federal terrestrial T & E species impacts	10.0				10.0				10.0				10.0				10.0				10.0				10.0			
		State terrestrial T & E and Sensitive species impacts	0.0				4.7				6.3				9.4				10.0				10.0				10.0			
		State terrestrial Priority Species	5.4				7.4				8.1				10.0				0.0				2.8				3.9			
	Special Status habitat or conservation/preservation designation	Wetland habitat impacts	0.0	1.9			4.4	3.8			5.9	4.6			9.8	8.0			9.9	6.9			10.0	6.6			10.0	6.3		
		Riparian habitat impacts	7.6				8.8				9.2				10.0				0.0				2.1				3.4			
		Sand Dunes habitat impacts	0.0				5.0				6.7				10.0				10.0				10.0				10.0			
		Cliffs/Bluffs habitat impacts	1.4				0.1				0.0				10.0				10.0				10.0				10.0			
		Steppe-Shrub habitat impacts	0.0				4.8				6.5				10.0				9.5				9.7				9.4			
		Candidate Wild & Scenic rivers	0				0				0				0				0				0				0			
		Wilderness Study Areas	0				0				0				0				0				0				0			
		National wildlife refuges impacts	0.0				0.9				1.9				9.9				10.0				10.0				10.0			
		State wildlife refuges impacts	0.0				4.3				6.0				10.0				10.0				10.0				10.0			
		Other National or State conservation/preservation designation	10.0				10.0				10.0				10.0				9.9				4.6				0.0			
	Water & Air Quality	Downstream temperature impacts	7.0	7.5			8.0	7.5			9.0	7.5			2.0	2.0			9.0	9.5			10.0	10.0			10.0	10.0		
		Windblown dust/particulates (from annual reservoir drawdown)	8.0				7.0				6.0				2.0				10.0				10.0				10.0			
		Totals	**77.4**	**14.6**	**7.4**	**2.5**	**166.1**	**28.1**	**11.9**	**4.0**	**197.7**	**33.0**	**13.5**	**4.5**	**247.0**	**39.3**	**19.1**	**6.4**	**230.0**	**38.2**	**15.9**	**5.3**	**256.1**	**42.9**	**17.6**	**5.9**	**262.9**	**44.4**	**18.1**	**6.0**

FIGURE D-3.1

Alternatives Comparison: Implementation/Technical Feasibility

→ Overall rankings

→ No consideration of reservoir size

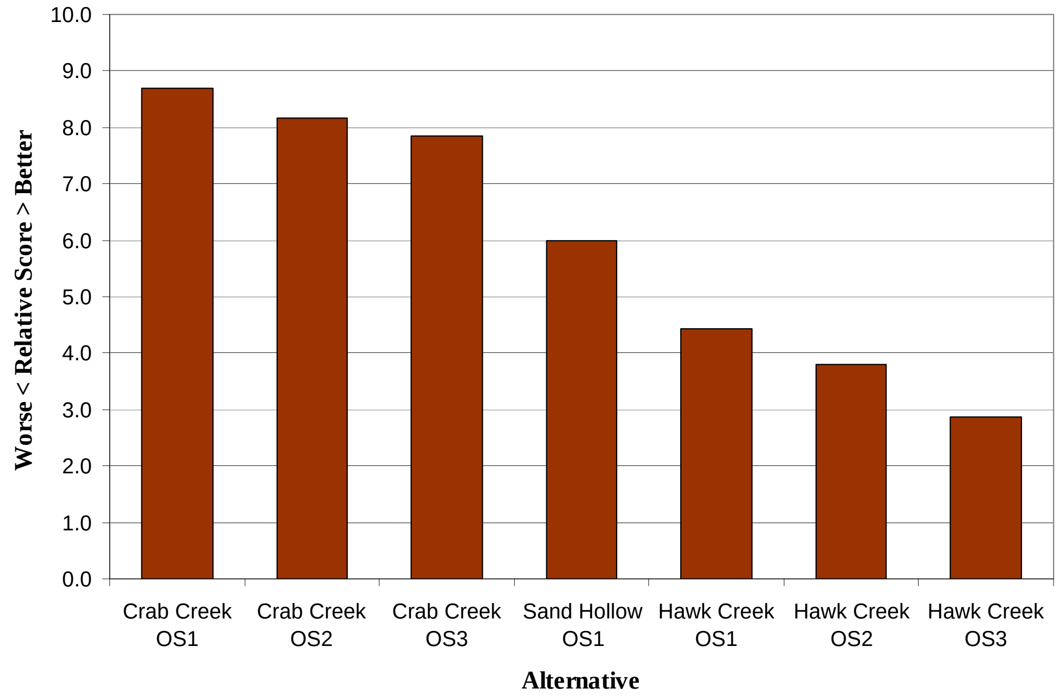


FIGURE D-3.2

Alternatives Comparison: Implementation/Technical Feasibility

→ Total NPV costs adjusted to per million acre-foot

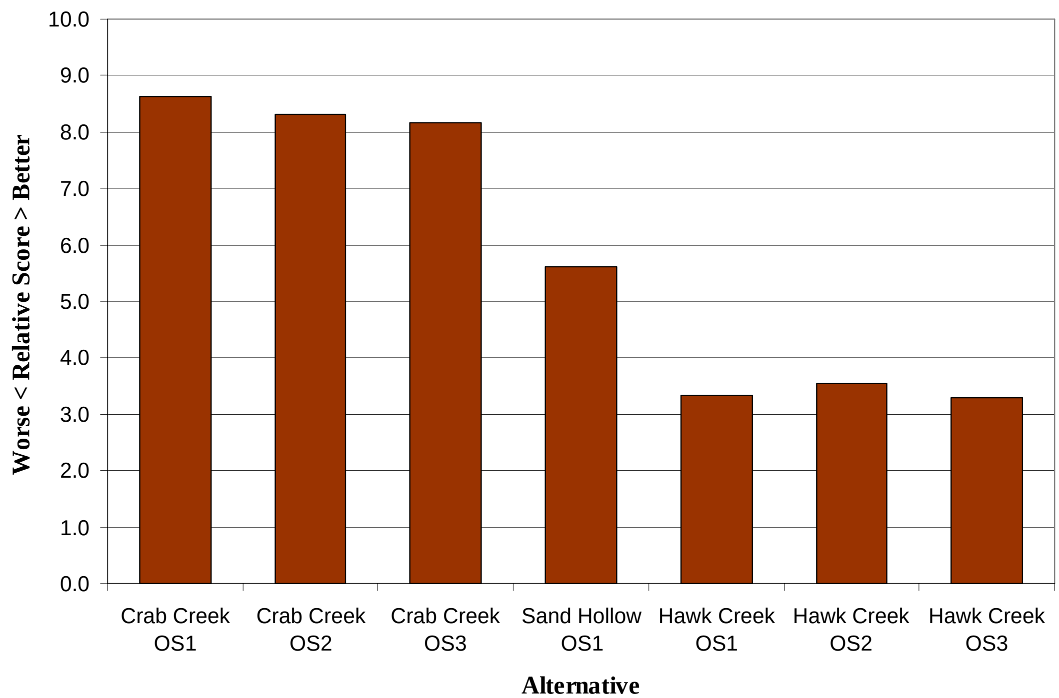


FIGURE D-3.3

Alternatives Comparison: Objectives/Benefits Achievement

→ Total NPV costs adjusted to per million acre-foot

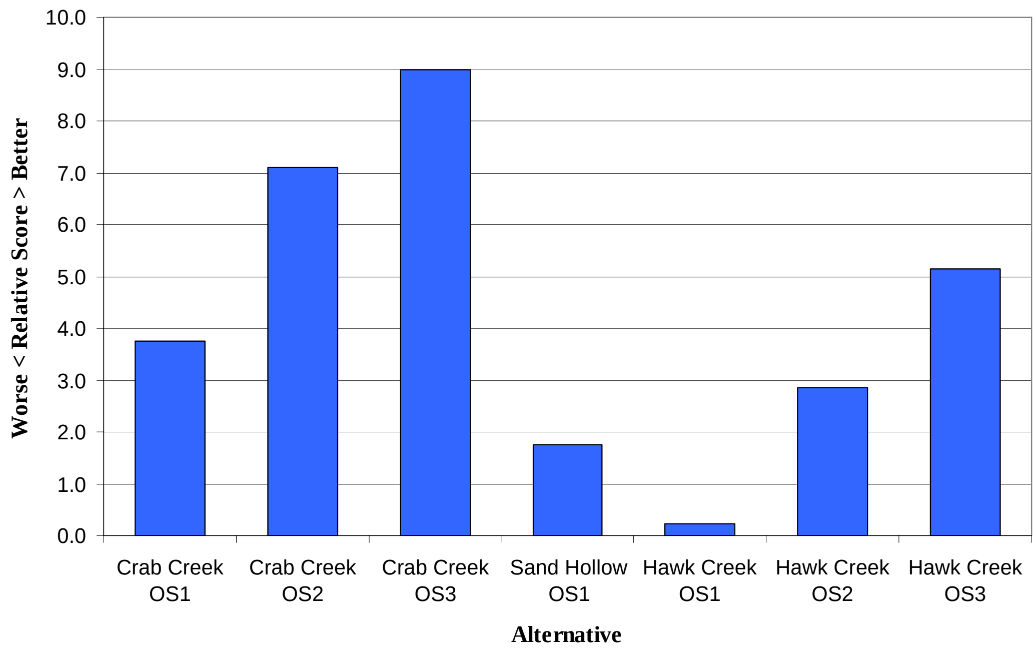


FIGURE D-3.4

Alternatives Comparison: Combined Implementation/Technical Feasibility and Objectives/Benefits Achievement Perspectives

→ No consideration of reservoir size

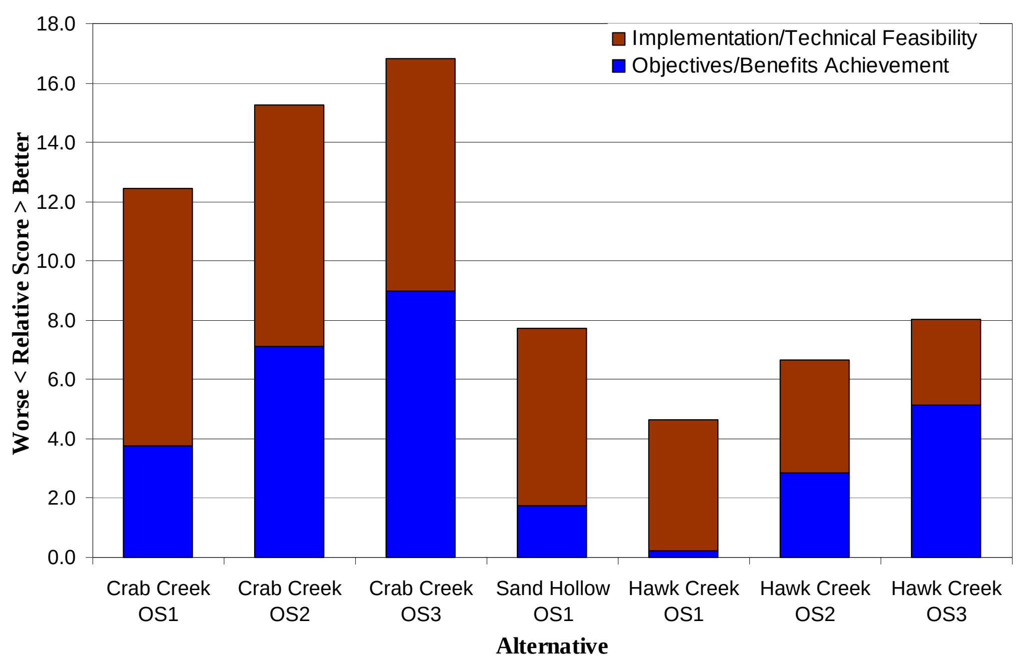
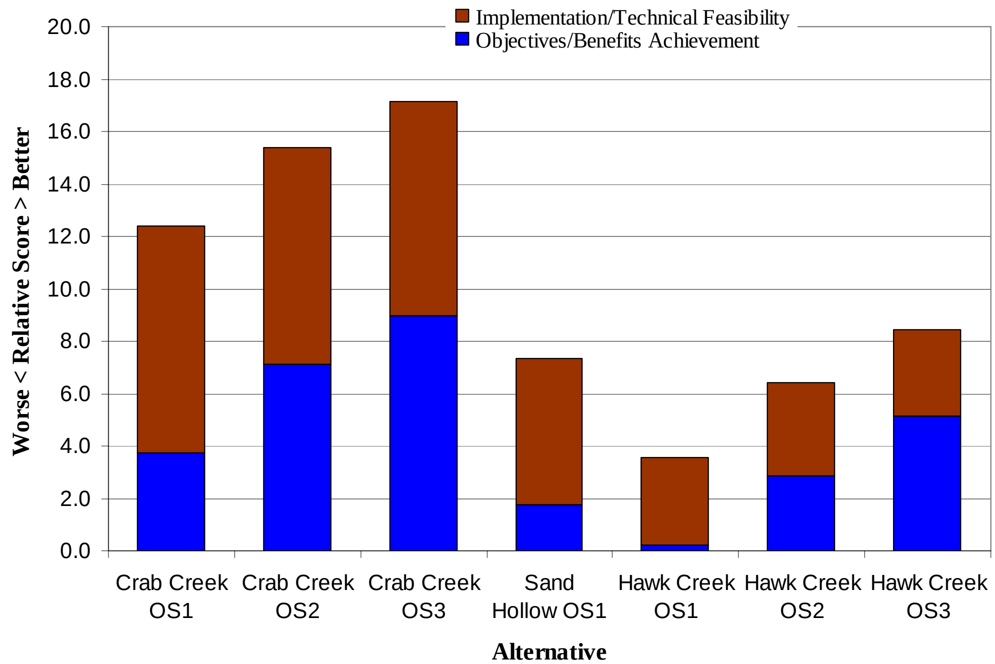


FIGURE D-3.5

Alternatives Comparison: Combined Implementation/Technical Feasibility and Objectives/Benefits Achievement Perspectives

→ Total NPV costs adjusted to per million acre-foot



Impacts

Site/scenario rankings from the perspective of Impacts are illustrated on Figures D-3.6 through D-3.9. Figures D-3.6 and D-3.7 reflect total impact (no adjustment for reservoir size), while Figures D-3.8 and D-3.9 reflect impacts on a per million acre-foot basis. In each of these pairs of figures, the first illustrates the overall normalized Perspective-level scores for the alternatives; the second is derived from the Category-level scores, illustrating the proportional role played by each evaluation category in the overall result.

The first pair of figures (D-3.6 and D-3.7), with no per million acre-foot adjustment, clearly shows that the Crab Creek site, in all scenarios, rates the lowest in terms of impact score (that is, has the highest levels of impact).

This result is due to the fact that Crab Creek has the highest potential impacts in terms of the following:

- Aggregate land acquisition requirements (combining relatively high acreages of private agricultural land and the only significant use of public land)
- Infrastructure
- Cultural resources (tied with Hawk Creek)
- Endangered and sensitive species (particularly anadromous fish and other aquatic species)
- Wetlands
- Wildlife refuges

FIGURE D-3.6
Alternatives Comparison: Impacts
→ Overall rankings
→ No consideration of reservoir size

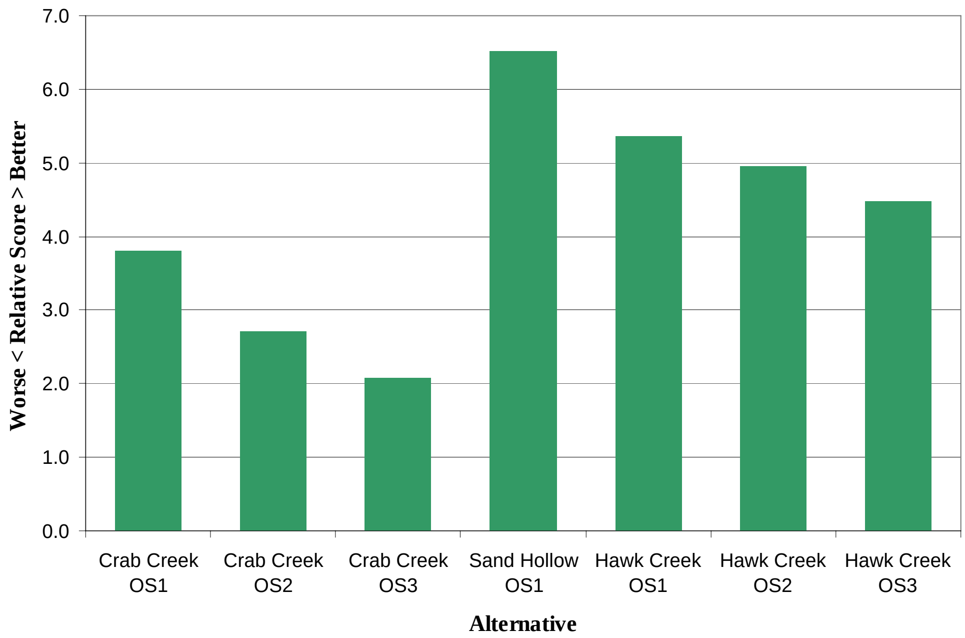


FIGURE D-3.7
Alternatives Comparison: Impacts
→ Showing relative role of evaluation categories
→ No consideration of reservoir size

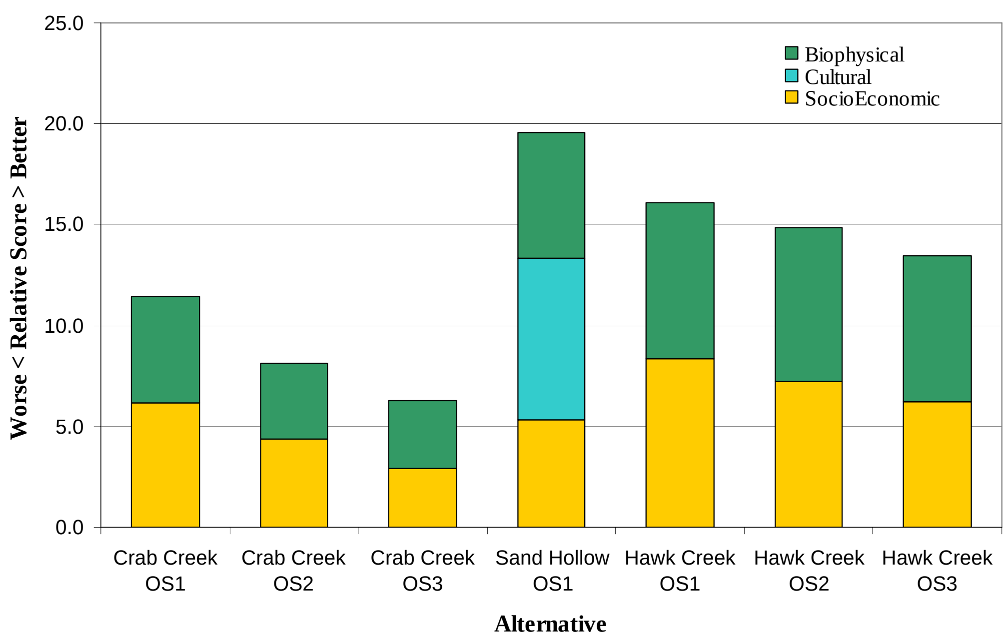


FIGURE D-3.8

Alternatives Comparison: Impacts

→ Overall rankings
→ Impacts adjusted to per million acre-foot

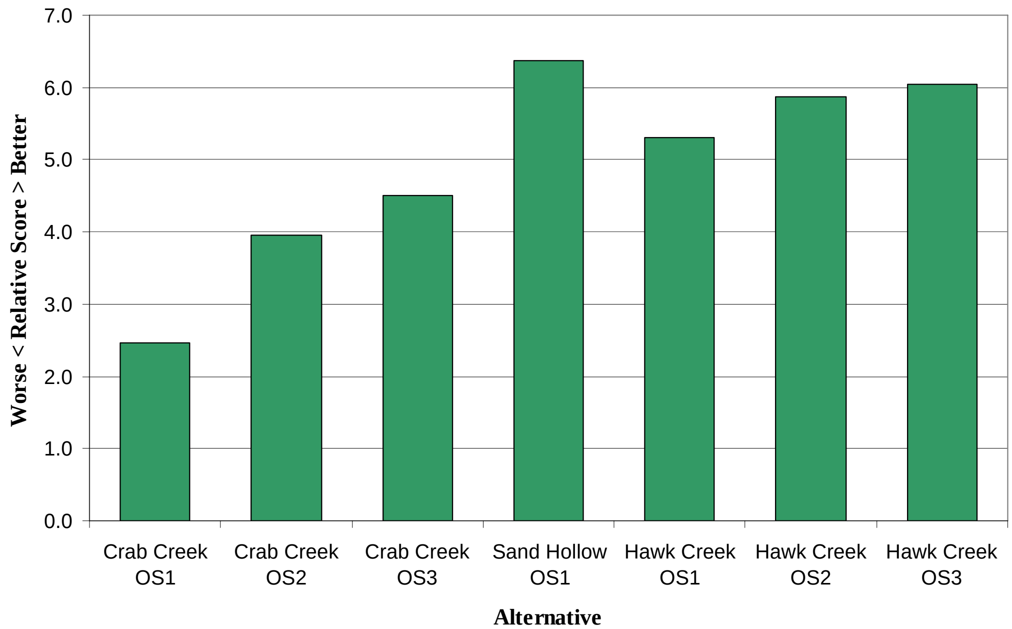
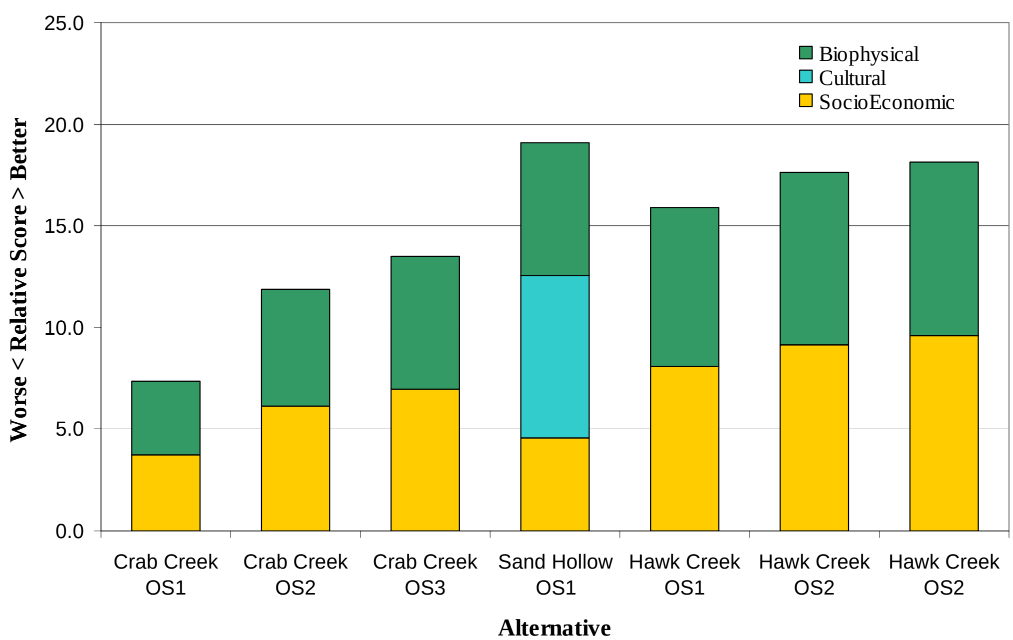


FIGURE D-3.9

Alternatives Comparison: Impacts

→ Showing relative role of evaluation categories
→ Impacts adjusted to per million acre-foot



The Sand Hollow site rates the highest (that is, has the lowest potential for impacts) overall, primarily due to its high score in the cultural category (that is, expected to have low potential for impact while the other two sites face equally high potential for cultural resource impacts). Its score on socioeconomic impacts is moderate (actually lower than the Crab Creek OS1 and lower than all scenarios at Hawk Creek) because this site has the highest levels of impact to private land, irrigated agriculture, and agricultural infrastructure. Its score in the biophysical category is also moderate (constrained by potential air and water quality impacts).

The Hawk Creek site also rates relatively high due to having the highest overall scores in both socioeconomic and biophysical categories. (The site does, however, involve the most residential displacements among the three sites.)

Referring to Figures D-3.8 and D-3.9, it is debatable whether adjustment of impacts to per million acre-foot values provides valid insight. Nevertheless, a review of the results of this adjustment highlights the following.

The per million acre-foot adjustment favors the larger reservoir sizes. For most impact criteria, the level of impact does not rise proportionately with reservoir size (that is, impact does not double with a doubling of storage volume). For the most part, the largest proportional amount of impact occurs with introduction of the 1 million acre-foot (OS1) reservoirs at the three sites; as the reservoir size increases to the 2 million acre-foot and 3 million acre-foot levels, many impacts increase in magnitude but in no case do they double or triple when compared with the 1 million acre-foot scenario. In some cases, impacts do not increase at all with increases in reservoir size (for example, downstream habitat impacts). Because of this, the larger reservoir sizes (OS2 and OS3) achieve progressively higher impact scores when impacts are adjusted to per million acre-foot values, and result in the patterns shown on Figures D-3.8 and D-3.9.

Overall—All Perspectives Combined

Site rankings combining the scores for all three Perspectives are shown on Figures D-3.10 (no per million acre-foot adjustments) and D-3.11 (with per million acre-foot adjustments).

Referring to Figure D-3.10, with no adjustment for reservoir size, the Crab Creek site generally rates the highest, followed by Sand Hollow, with Hawk Creek rating the lowest. In terms of scenarios, all three Crab Creek options rate higher than Sand Hollow, and all three Hawk Creek options rate lower than Sand Hollow.

This result is largely due to the high ranking of the Crab Creek site from both the Implementation/Technical Feasibility and Objectives/Benefits Achievement perspectives. Since the analysis is structured around three perspectives (the two noted above and Impacts), and each of these perspectives is scored on an equal scale with equal importance, clear superiority on two out of three perspectives overcomes low rankings on the third perspective. Thus, even though the Crab Creek scenarios rate the lowest in terms of potential impacts, their superiority in the other two perspectives outweighs this condition.

FIGURE D-3.10

Alternatives Comparison: All Perspectives Combined

→ Showing relative role of each Perspective

→ No consideration of reservoir size

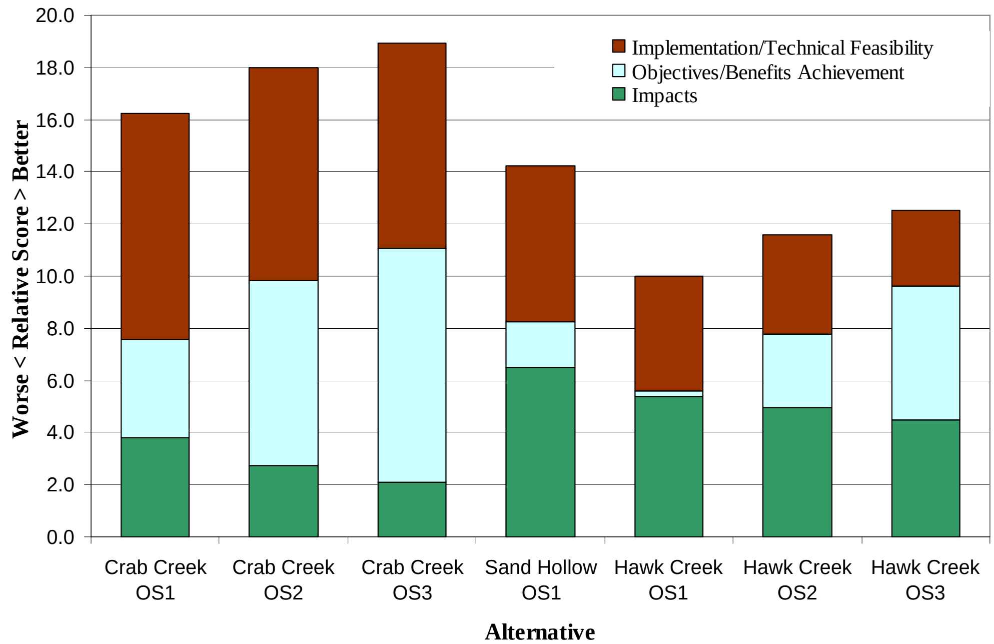
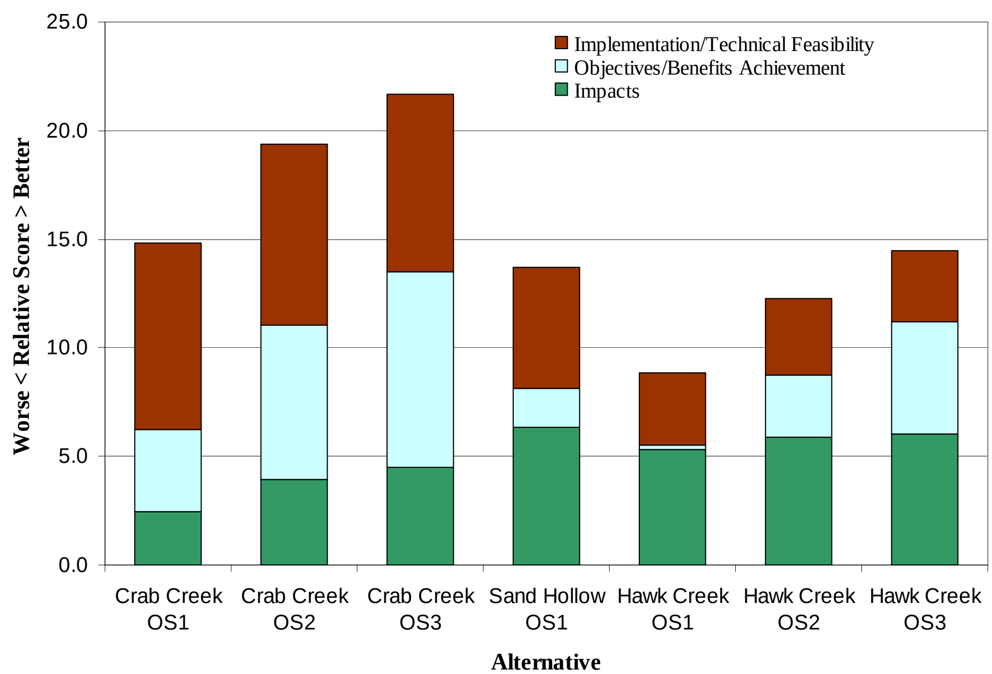


FIGURE D-3.11

Alternatives Comparison: All Perspectives Combined

→ Showing relative role of each Perspective

→ Total NPV costs and impacts adjusted to per million acre-foot



The Sand Hollow scenario achieves a relatively high rating (compared with Crab Creek OS1) because it has the highest rating on Impacts (that is, lowest potential for impacts overall) and a moderately high score for Implementation/Technical Feasibility; these ratings somewhat compensate for a low Objectives/Benefits Achievement score.

The Hawk Creek site (all scenarios) rates lowest overall because of poor performance on both Implementation/Technical Feasibility and Objectives/Benefits Achievement (even though it has relatively good Impacts rating).

Referring to Figure D-3.11, with NPV costs and impacts converted to per million acre-foot values, the picture remains essentially the same as described above. With the million acre-foot adjustments, the larger storage volume scenarios (Crab Creek OS2 and OS3; Hawk Creek OS2 and OS3) show higher rankings somewhat because of economies of scale, but largely because of the moderating effect of the million acre-foot adjustment on Impacts scores (see earlier discussion of Figures D-3.8 and D-3.9 under the Impacts heading).

D.4 Decision Model Findings

Based on the analysis presented in Section D.3, the Crab Creek site, in aggregate, appears most favorable among the candidate sites being considered. This is because the Crab Creek site offers the best response to Implementation/Technical Feasibility and Objectives/Benefits Achievement criteria. For example, this site has significantly lower costs than the other sites and offers the potential for future expansion.

However, the Crab Creek site presents the highest potential for adverse impacts in many evaluation categories and factors (socioeconomic, cultural, and biophysical).

From the standpoint of Impacts, the Sand Hollow and Hawk Creek sites present substantially fewer issues than Crab Creek. However, the Hawk Creek site in particular presents significantly greater cost and other technical challenges.

Overall, based on analysis to date, it appears that a decision on a preferred site will have to address a fundamental tradeoff between different perspectives.




Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options

Volume II of II: Plates

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region

Washington State Department of Ecology

May 2007

Cover Photos:
Left to right: Crab Creek, Sand Hollow,
Foster Creek, and Hawk Creek

Appraisal Evaluation of Columbia River Mainstem Off-Channel Storage Options

Volume II of II: Plates

U.S. Department of the Interior
Bureau of Reclamation
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Washington State Department of Ecology

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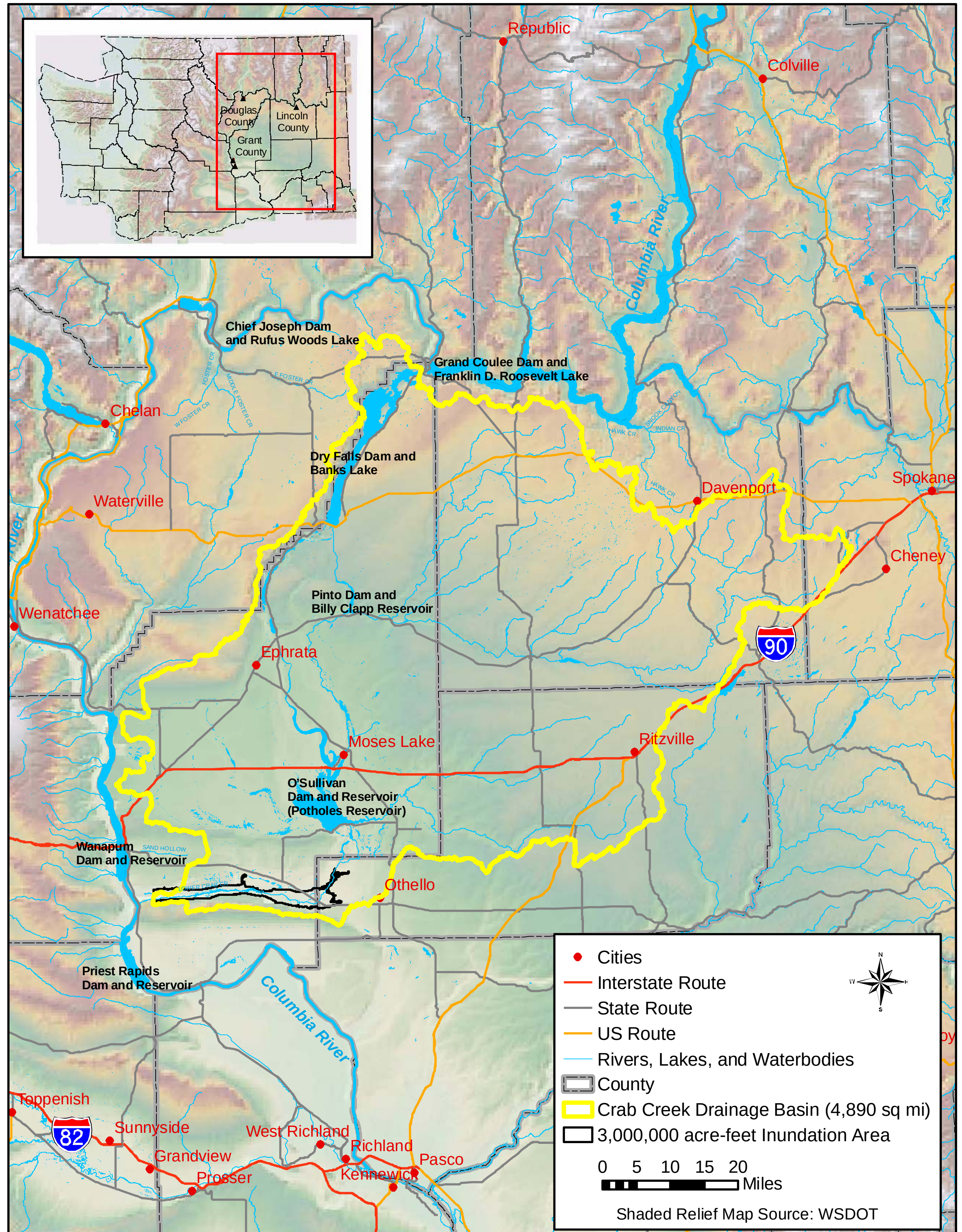


Plate 4-1.1
Crab Creek Drainage Basin

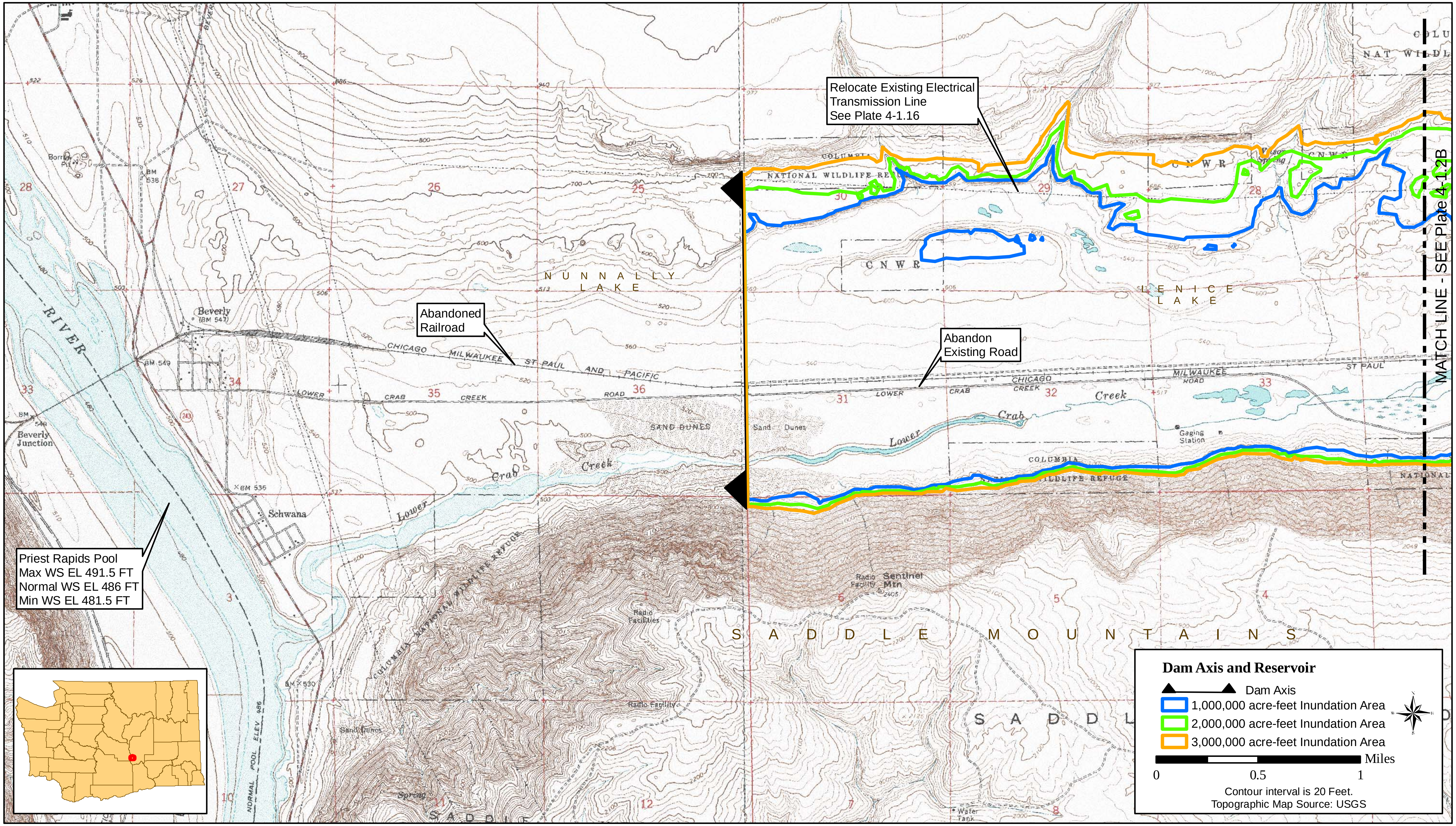


Plate 4-1.2A
Crab Creek Dam Axis and Reservoir

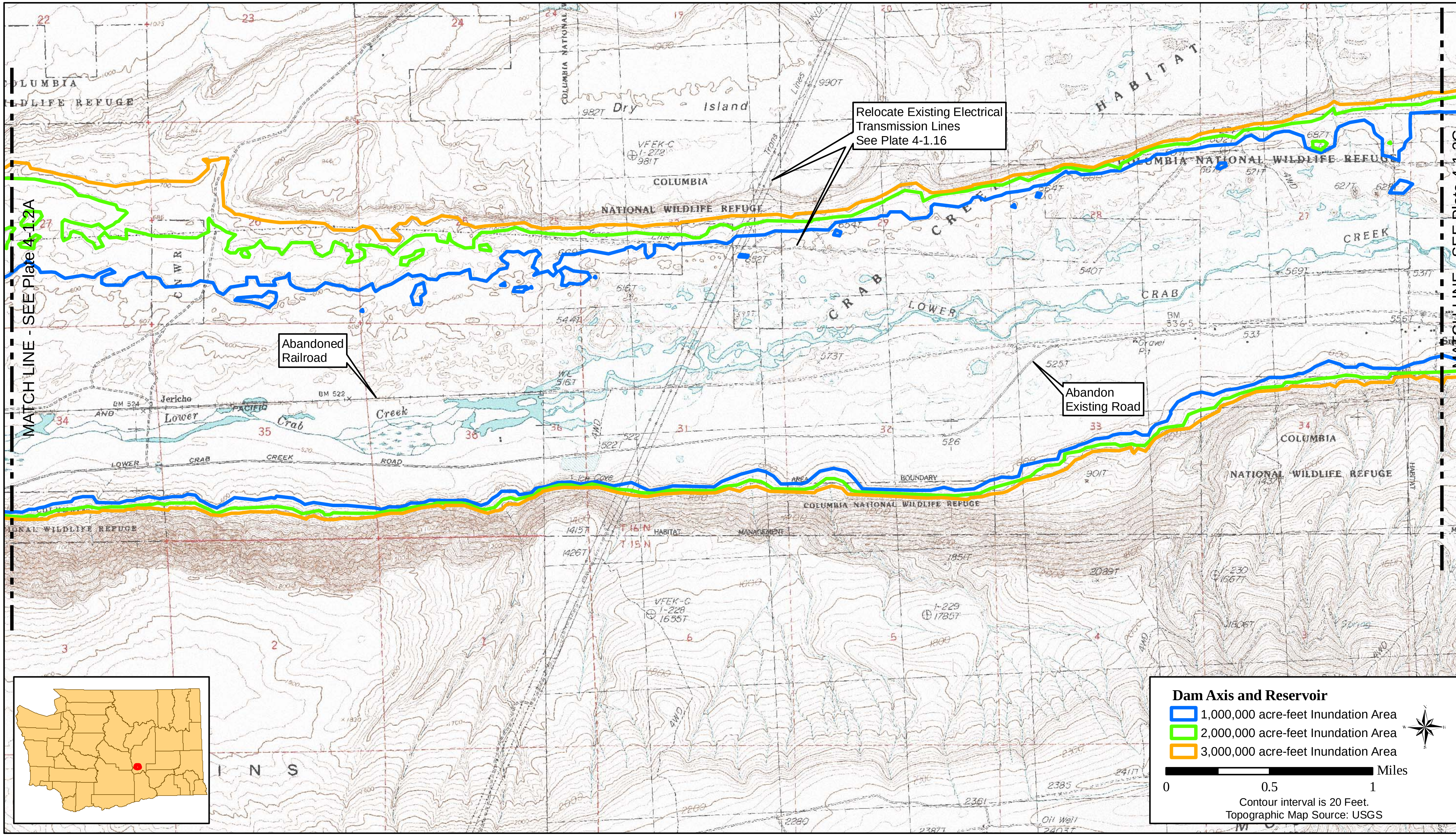


Plate 4-1.2B
Crab Creek Dam Axis and Reservoir, Cont.

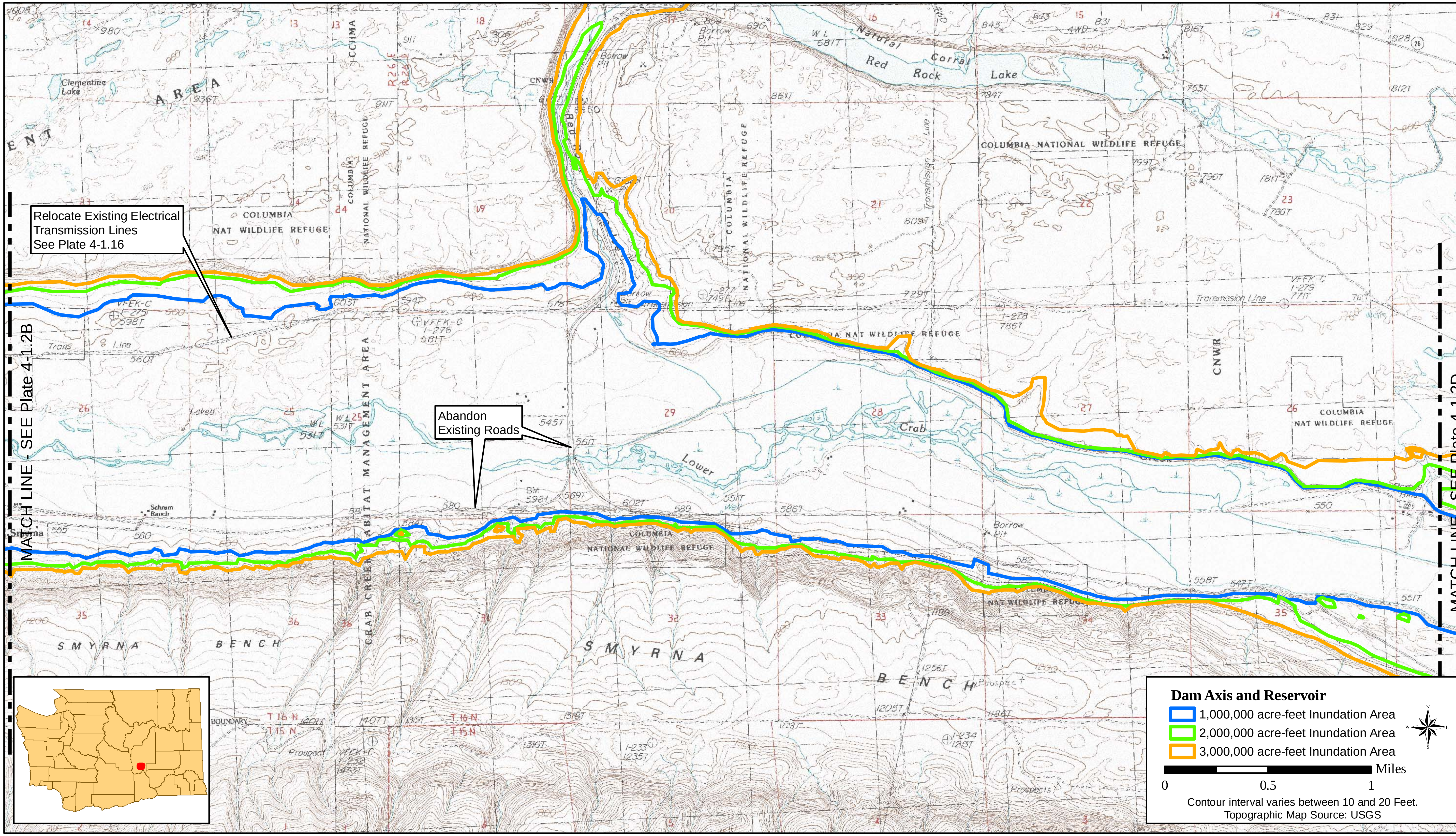


Plate 4-1.2C
Crab Creek Dam Axis and Reservoir, Cont.

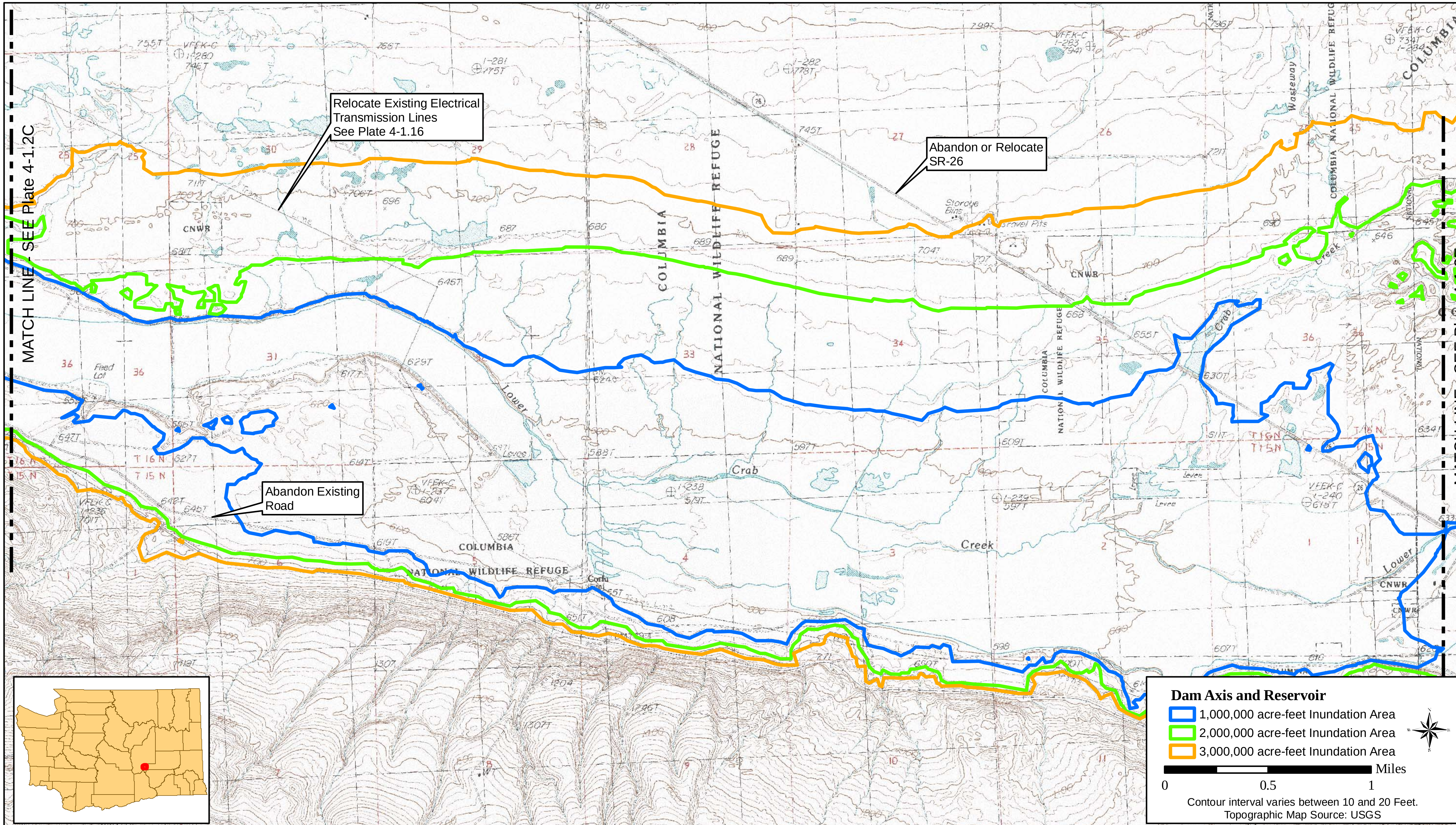


Plate 4-1.2D
Crab Creek Dam Axis and Reservoir, Cont.

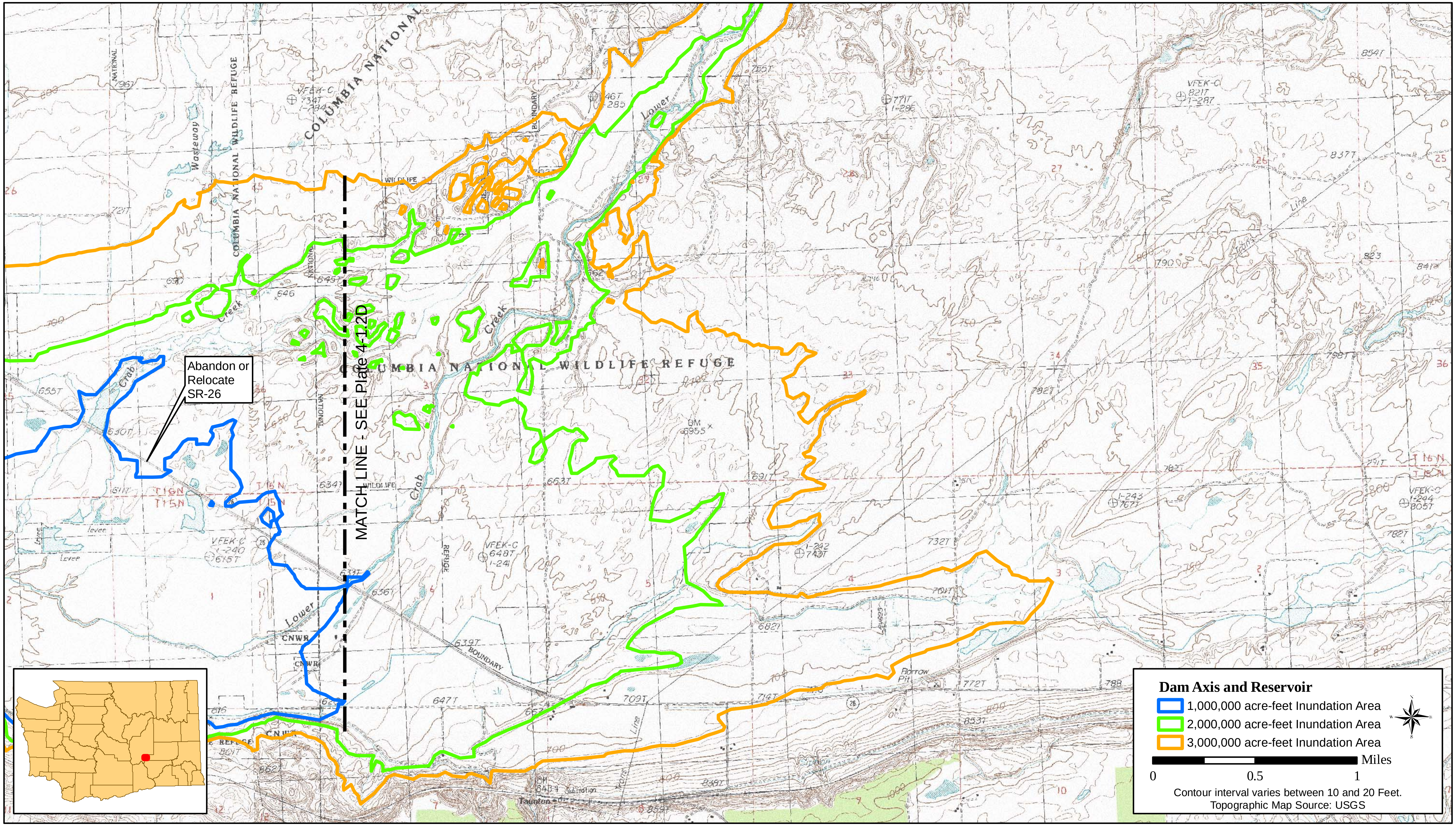


Plate 4-1.2E
Crab Creek Dam Axis and Reservoir, Cont.

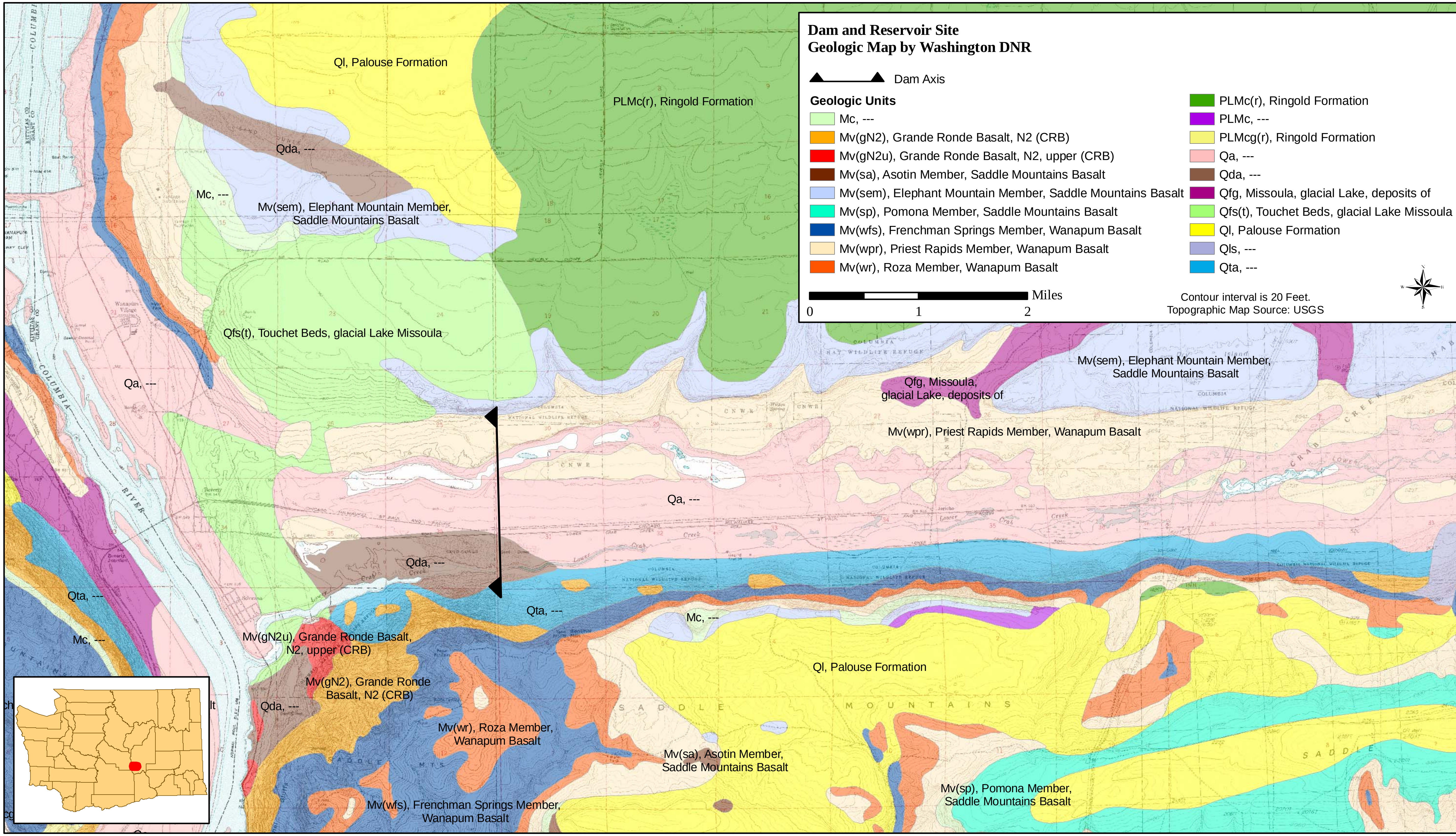


Plate 4-1.3
Crab Creek Dam and Reservoir Site Map

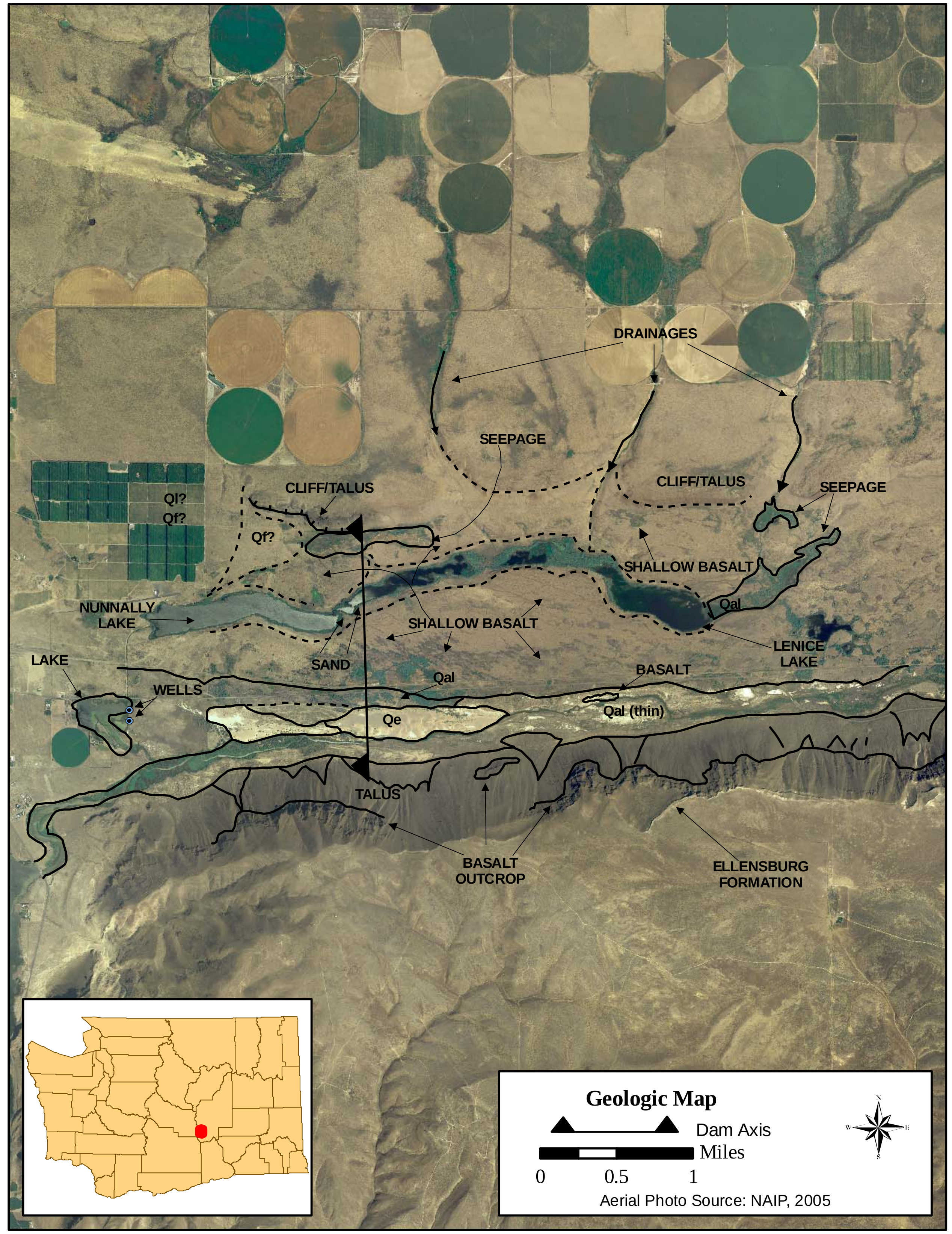


Plate 4-1.4
Crab Creek Geologic Map

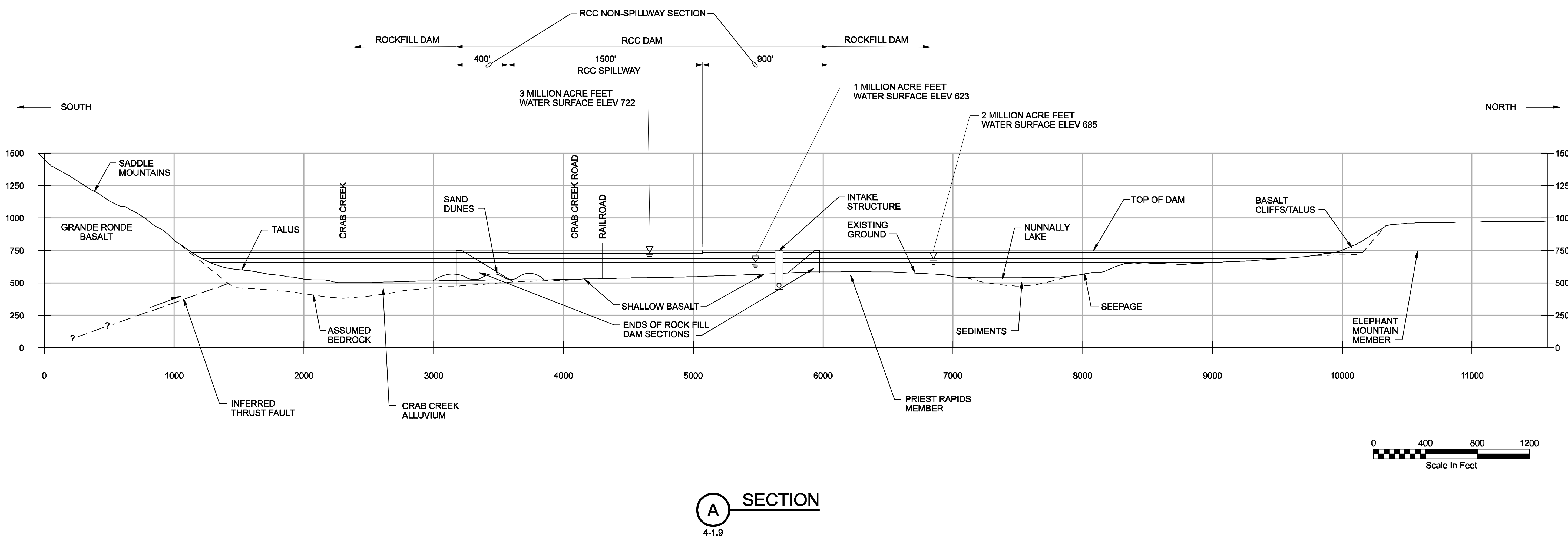


Plate 4-1.5
Crab Creek Dam Axis Cross Section

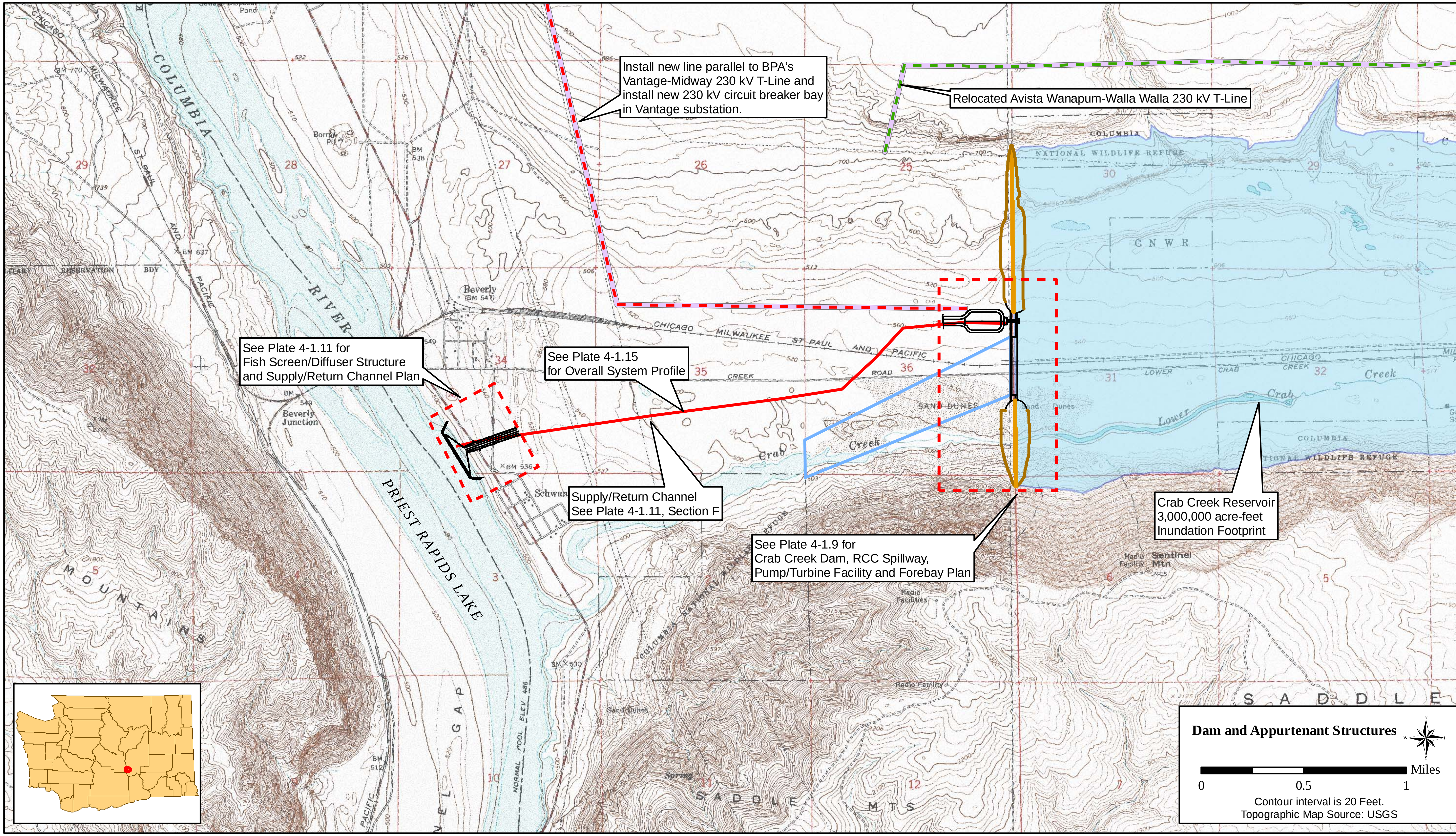
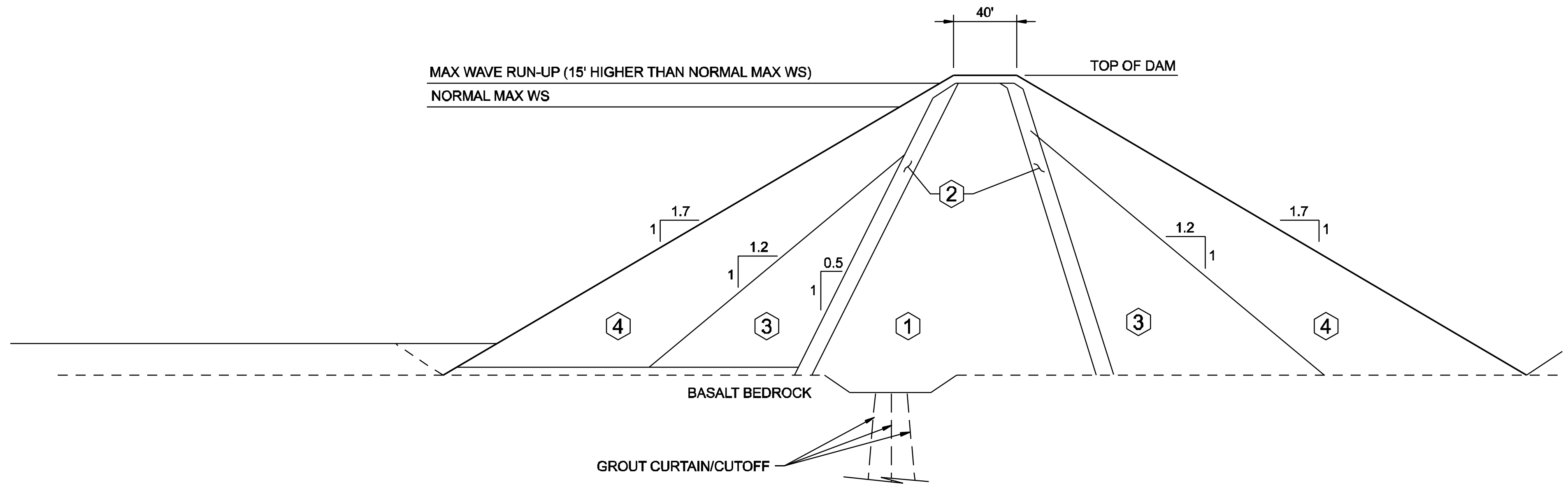


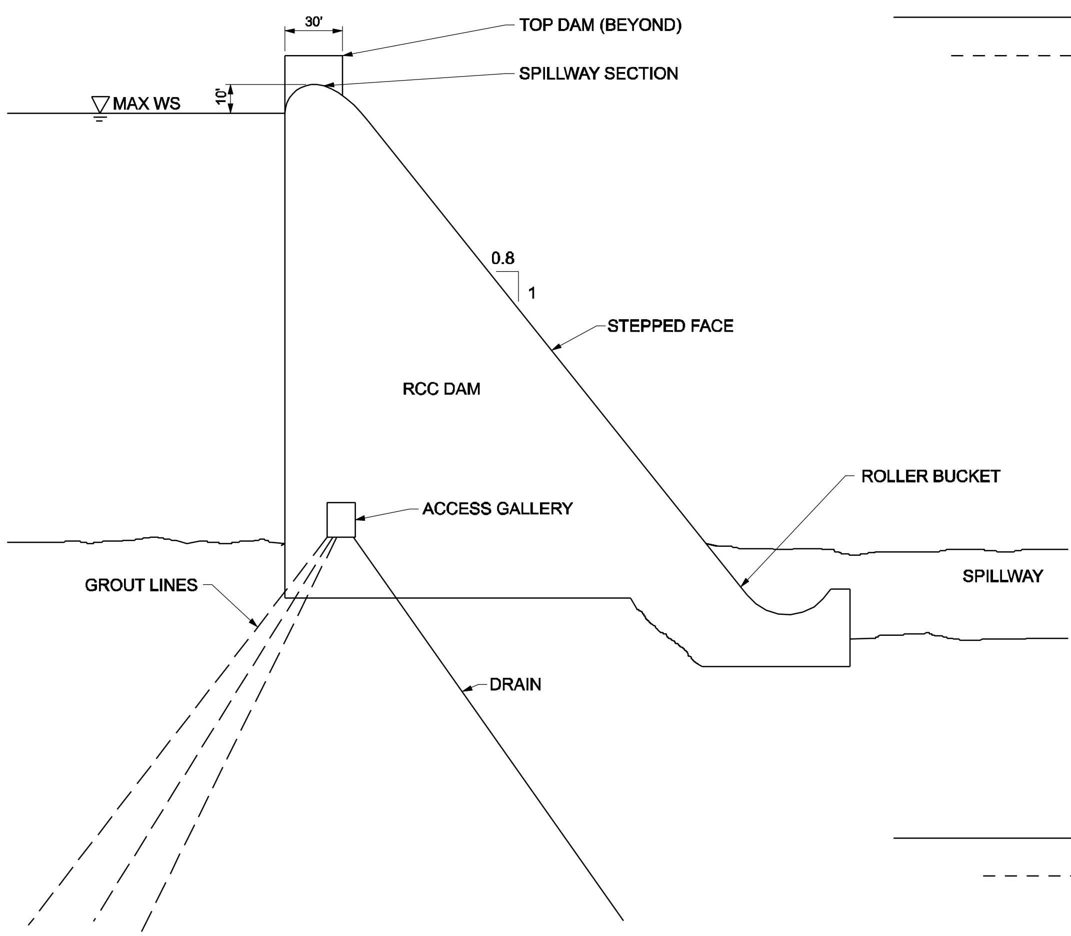
Plate 4-1.6
Crab Creek Dam and Appurtenant Structures



ROCKFILL DAM WITH EARTH CORE

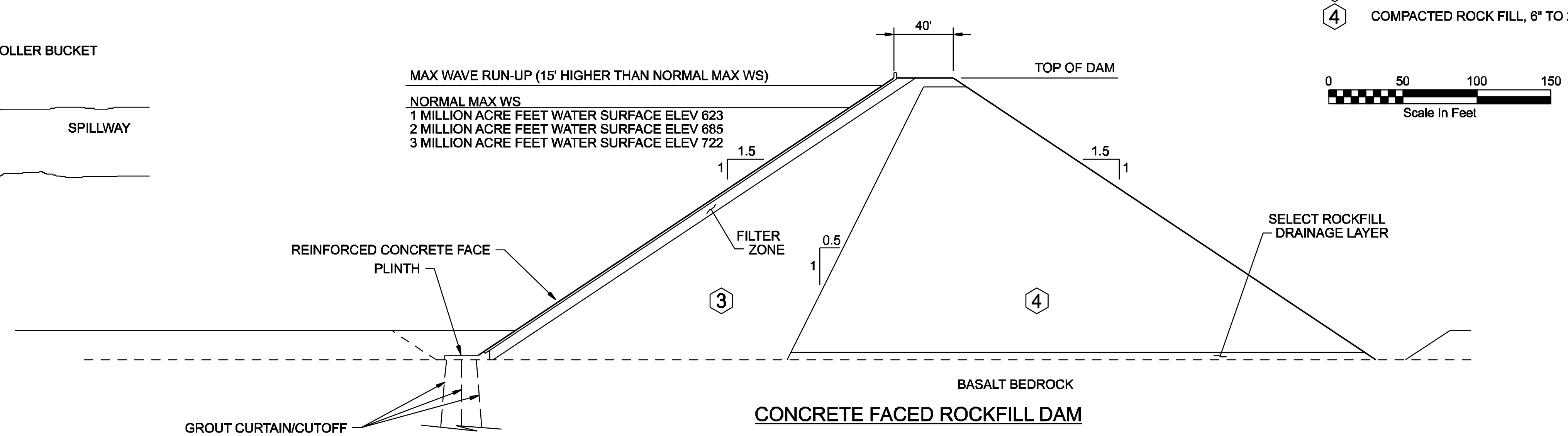
C SECTION
4-1.9

ZONE	DESCRIPTION
1	WELL GRADED SILTY SAND AND GRAVEL
2	SAND/GRAVEL FILTER, LESS THAN 3"
3	CRUSHED ROCK, LESS THAN 6" DIA
4	COMPACTED ROCK FILL, 6" TO 24"



RCC SPILLWAY SECTION

B SECTION
4-1.9



CONCRETE FACED ROCKFILL DAM

C SECTION
4-1.9

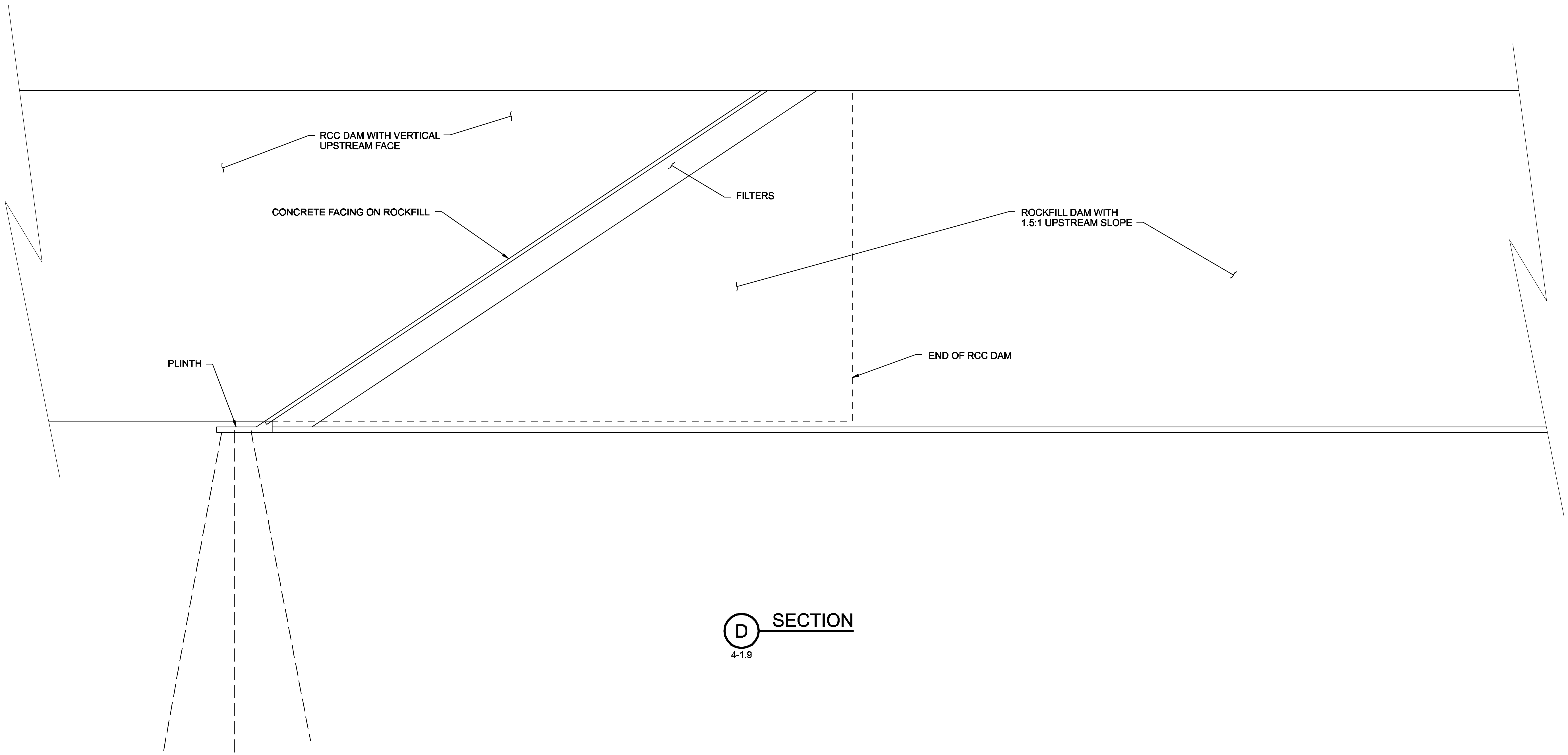


Plate 4-1.8
Crab Creek Additional Dam Section

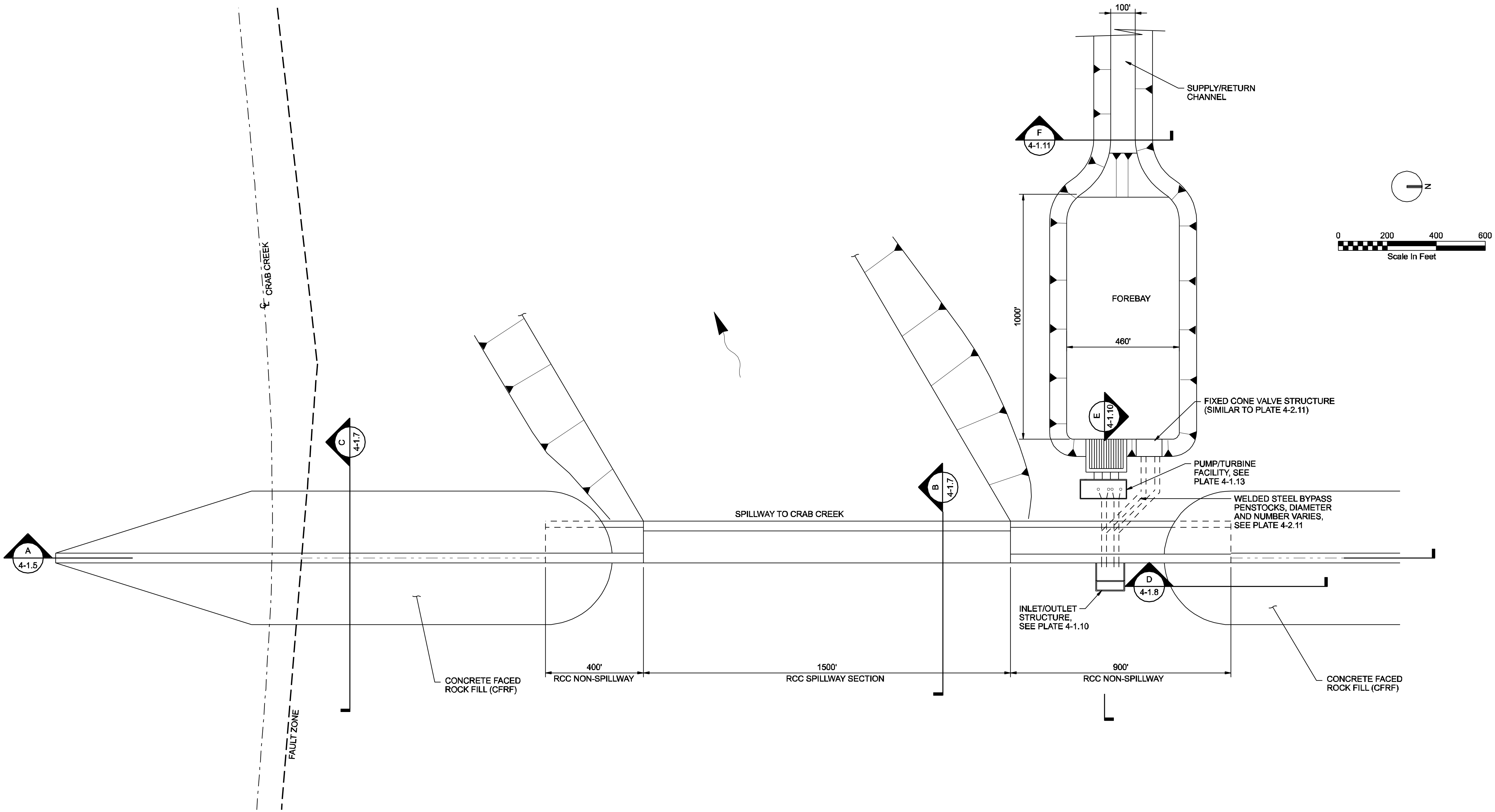


Plate 4-1.9
Crab Creek RCC Spillway and Forebay Plan

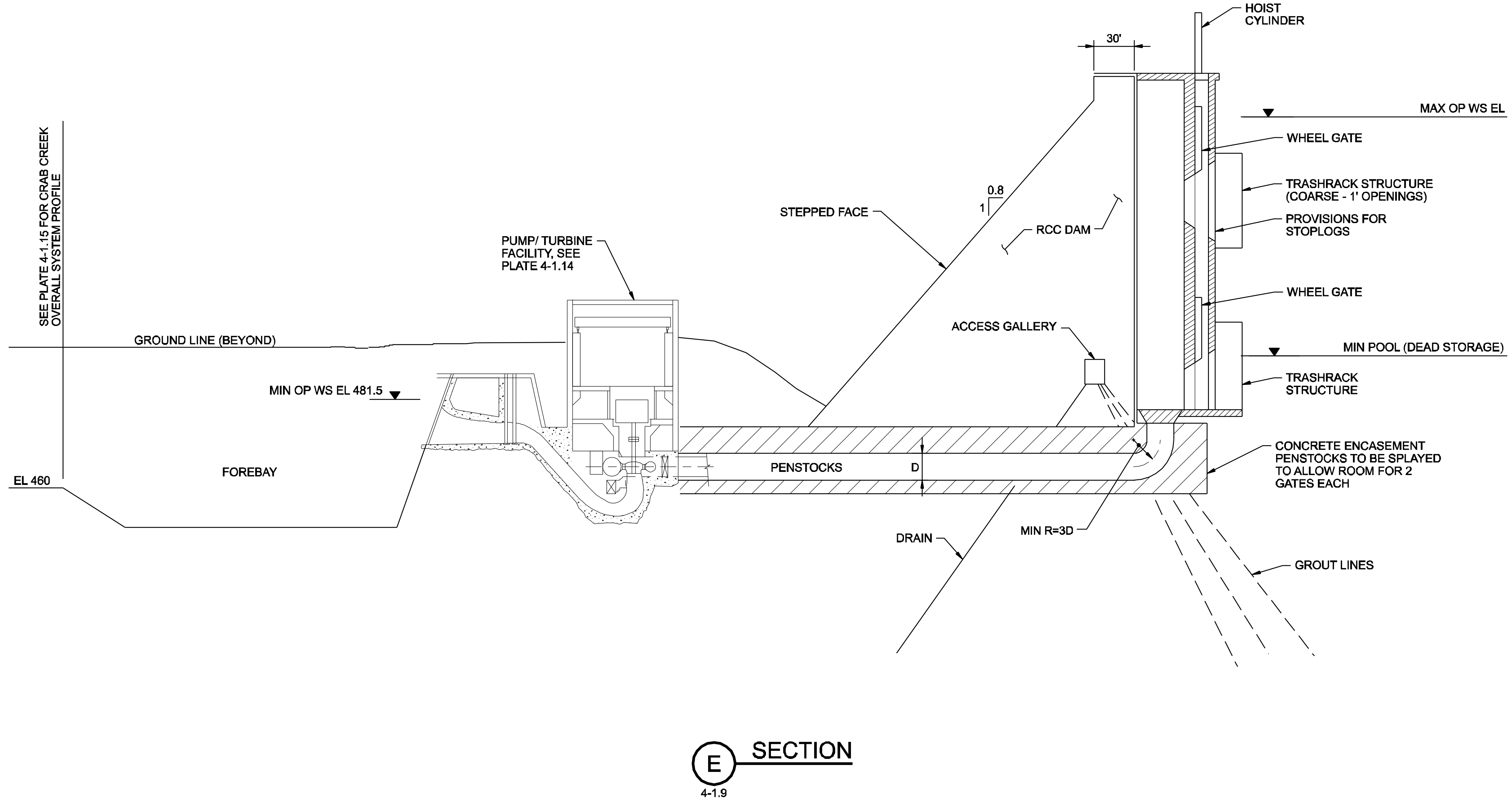
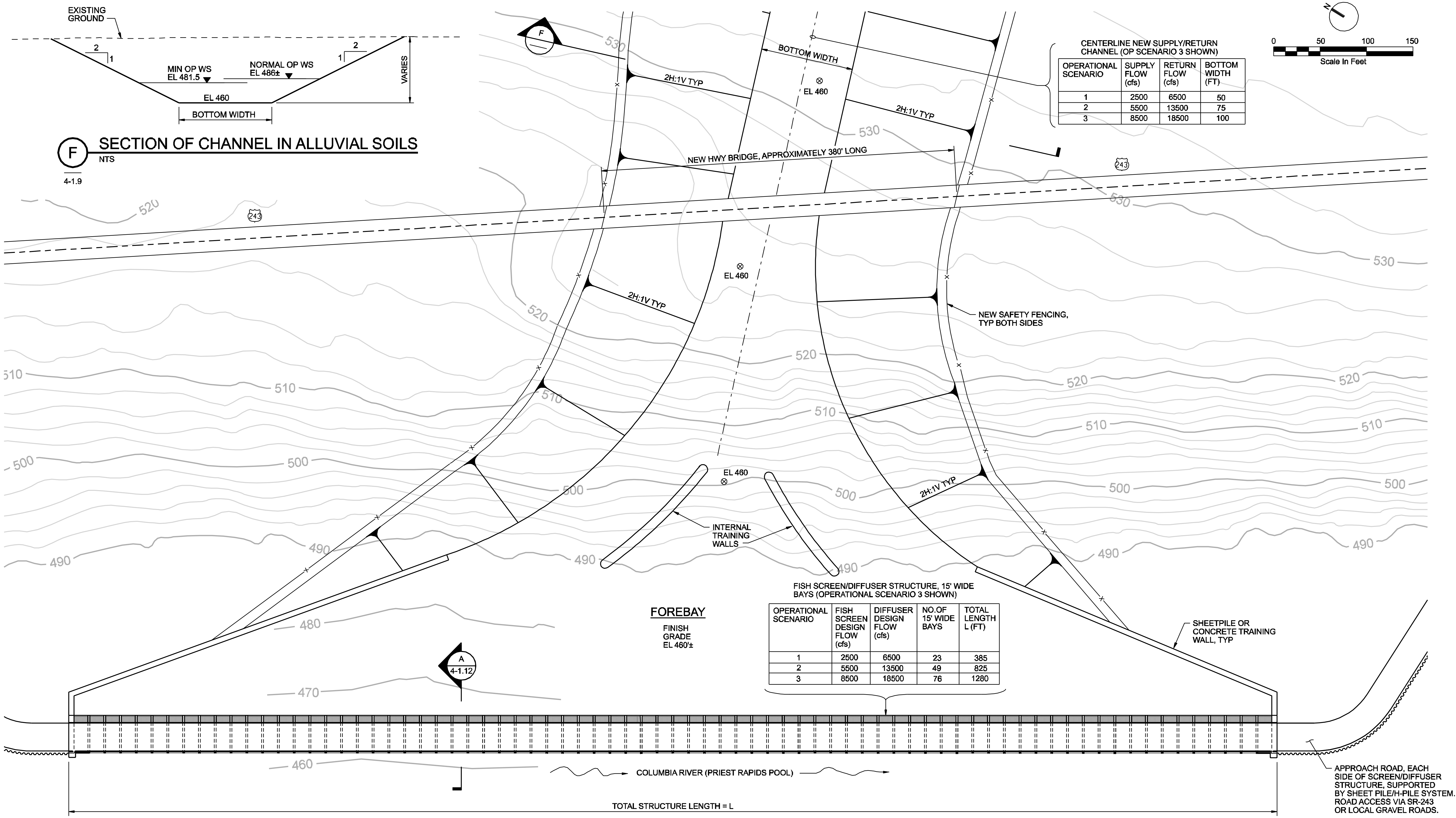


Plate 4-1.10
Crab Creek Inlet/Outlet Structure



CENTERLINE NEW SUPPLY/RETURN CHANNEL (OP SCENARIO 3 SHOWN)

OPERATIONAL SCENARIO	SUPPLY FLOW (cfs)	RETURN FLOW (cfs)	BOTTOM WIDTH (FT)
1	2500	6500	50
2	5500	13500	75
3	8500	18500	100

FISH SCREEN/DIFFUSER STRUCTURE, 15' WIDE BAYS (OPERATIONAL SCENARIO 3 SHOWN)

OPERATIONAL SCENARIO	FISH SCREEN DESIGN FLOW (cfs)	DIFFUSER DESIGN FLOW (cfs)	NO.OF 15' WIDE BAYS	TOTAL LENGTH L (FT)
1	2500	6500	23	385
2	5500	13500	49	825
3	8500	18500	76	1280

Plate 4-1.11

Crab Creek Fish Screen/Diffuser Structure and Supply/Return Channel Plan

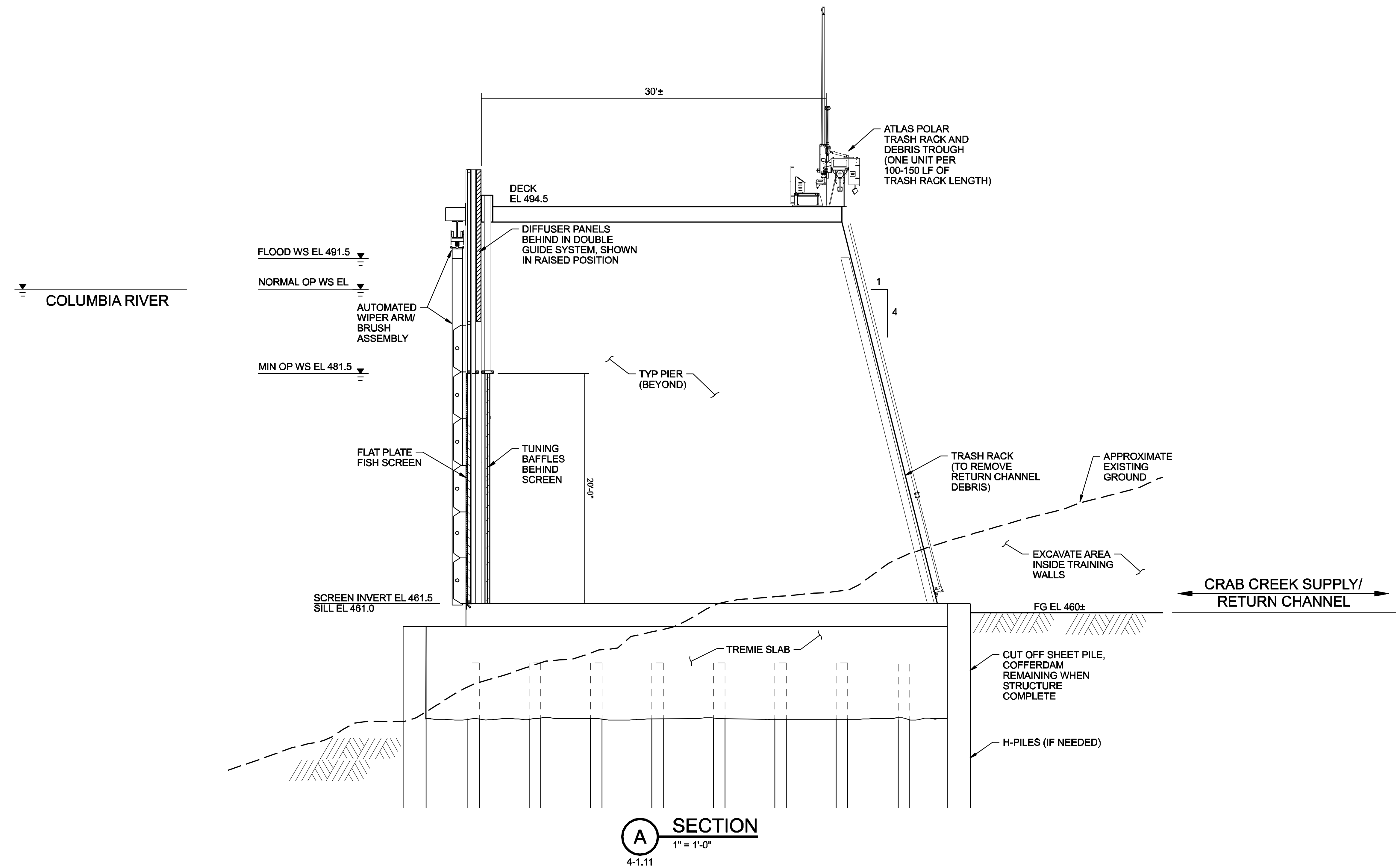
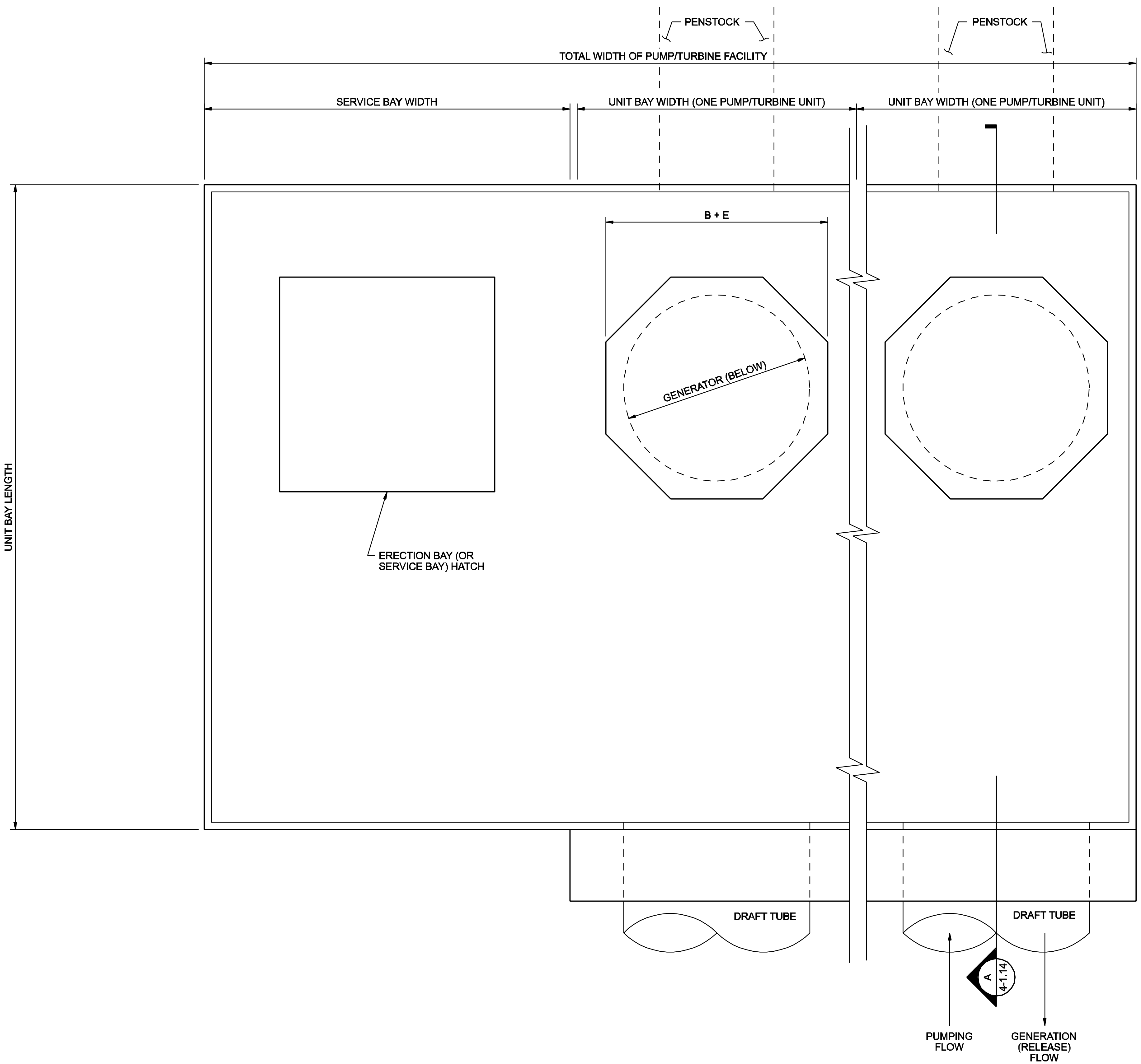
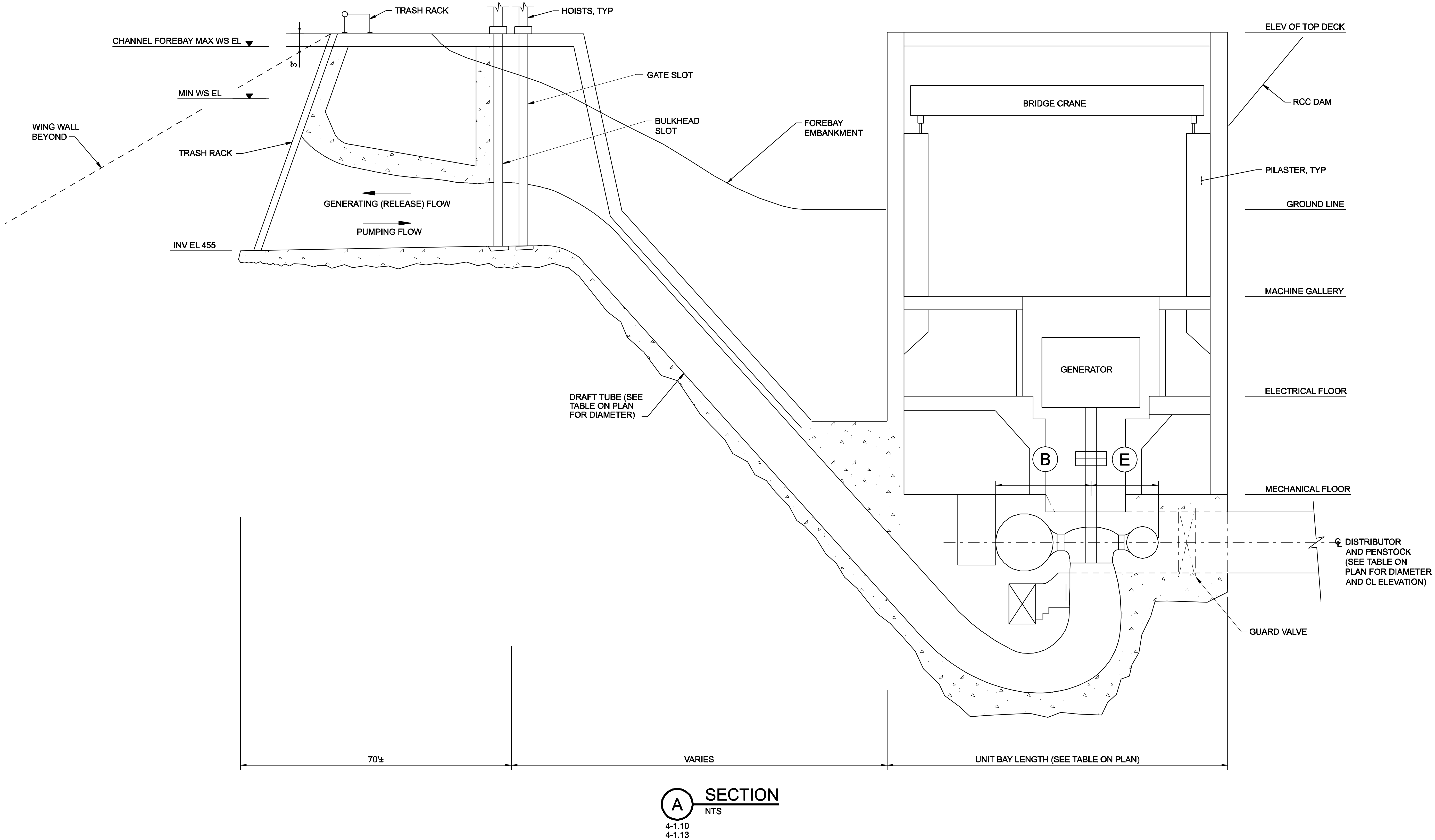


Plate 4-1.12
Crab Creek Fish Screen/Diffuser Structure Section



	OPERATIONAL SCENARIO 1	OPERATIONAL SCENARIO 2	OPERATIONAL SCENARIO 3
UNIT BAY WIDTH (ONE UNIT)	34	35	36
NUMBER OF UNITS	3	4	4
SERVICE BAY WIDTH	45	46	47
TOTAL WIDTH OF PUMP/TURBINE FACILITY	147	186	191
UNIT BAY LENGTH	71	76	79
B + E (SPIRAL CASE WIDTH PARALLEL TO FLOW)	26	27	28
DRAFT TUBE DIAMETER	25	26	24
NUMBER OF DRAFT TUBES	3	4	4
PENSTOCK DIAMETER	12	15	17
NUMBER OF PENSTOCKS	3	4	4
PEAK PUMPING FLOW (CFS)	2500	5500	8500
PEAK RELEASE FLOW (CFS)	6500	13,500	18,500
CENTERLINE ELEVATION OF PENSTOCKS/UNITS	450	443	437

Plate 4-1.13
Crab Creek Combined Pump/Turbine Facility - Plan


TRASH RACK
HOISTS, TYP
CHANNEL FOREBAY MAX WS EL
3'
MIN WS EL
GATE SLOT
BULKHEAD SLOT
FOREBAY EMBANKMENT
WING WALL BEYOND
TRASH RACK
GENERATING (RELEASE) FLOW
PUMPING FLOW
INV EL 455
DRAFT TUBE (SEE TABLE ON PLAN FOR DIAMETER)
ELEV OF TOP DECK
BRIDGE CRANE
RCC DAM
PILASTER, TYP
GROUND LINE
MACHINE GALLERY
GENERATOR
ELECTRICAL FLOOR
B
E
MECHANICAL FLOOR
℄ DISTRIBUTOR AND PENSTOCK (SEE TABLE ON PLAN FOR DIAMETER AND CL ELEVATION)
GUARD VALVE
70'±
VARIES
UNIT BAY LENGTH (SEE TABLE ON PLAN)
A
SECTION
NTS
4-1.10
4-1.13

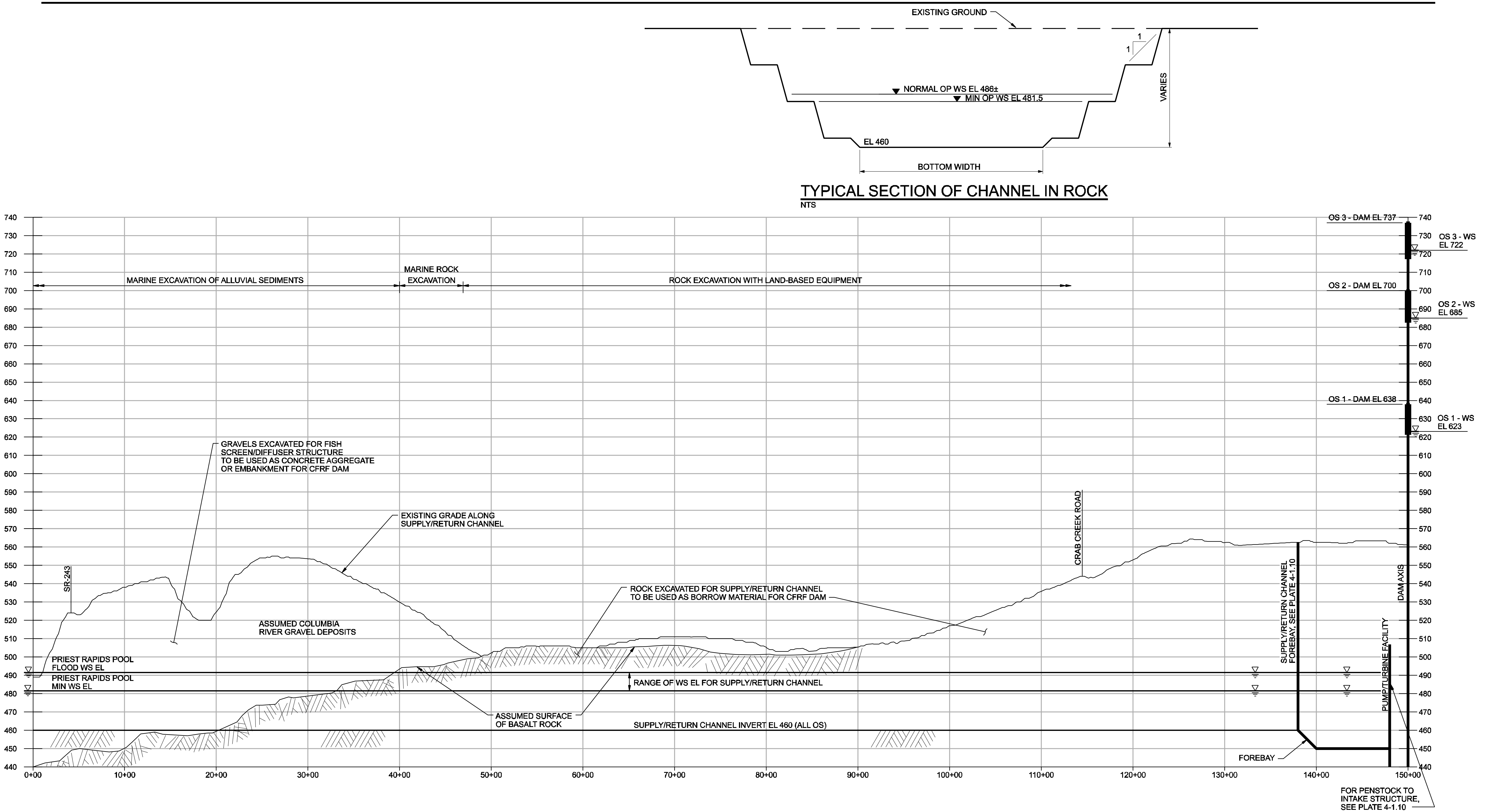


Plate 4-1.15
Crab Creek Overall System Profile

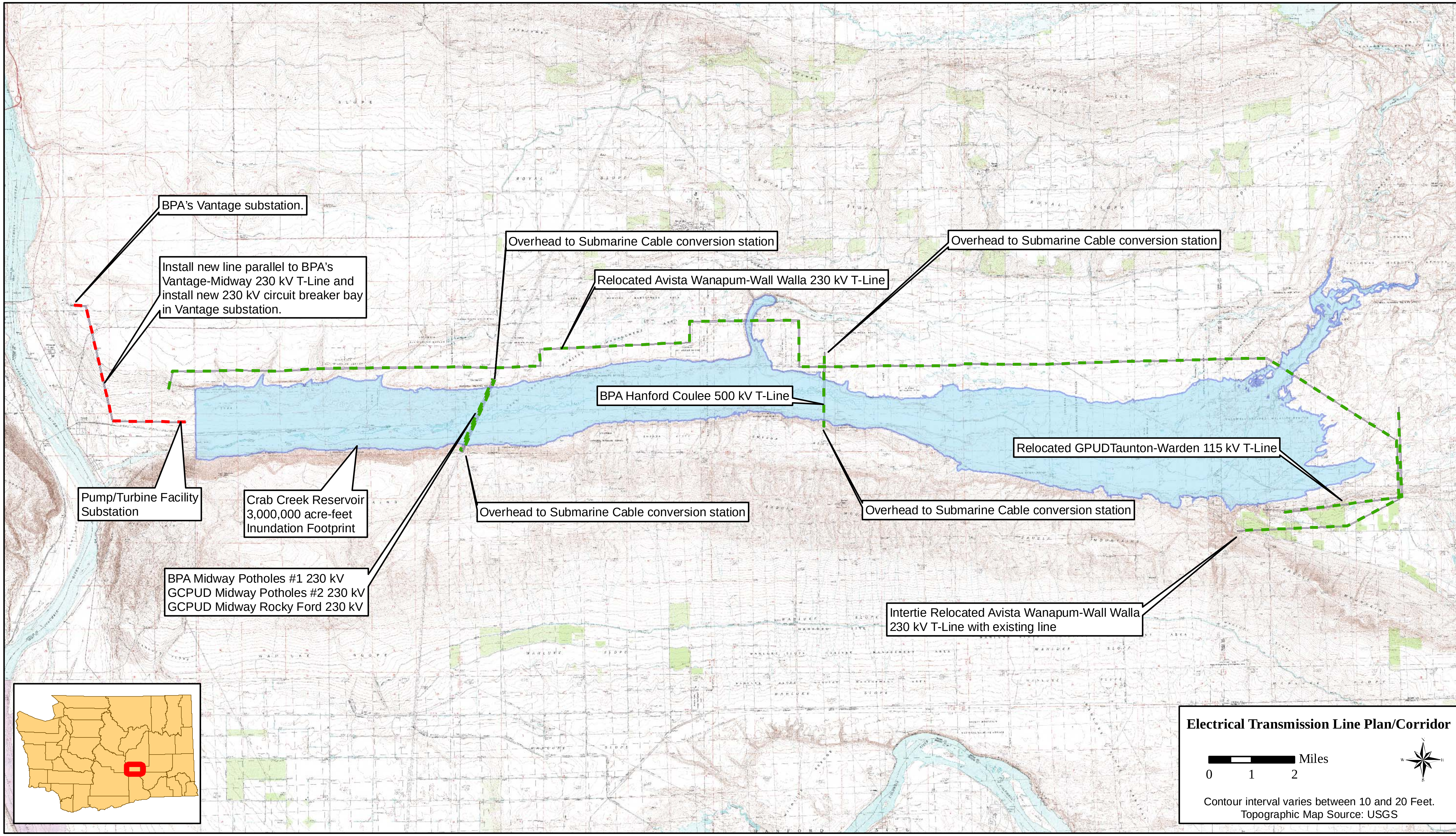
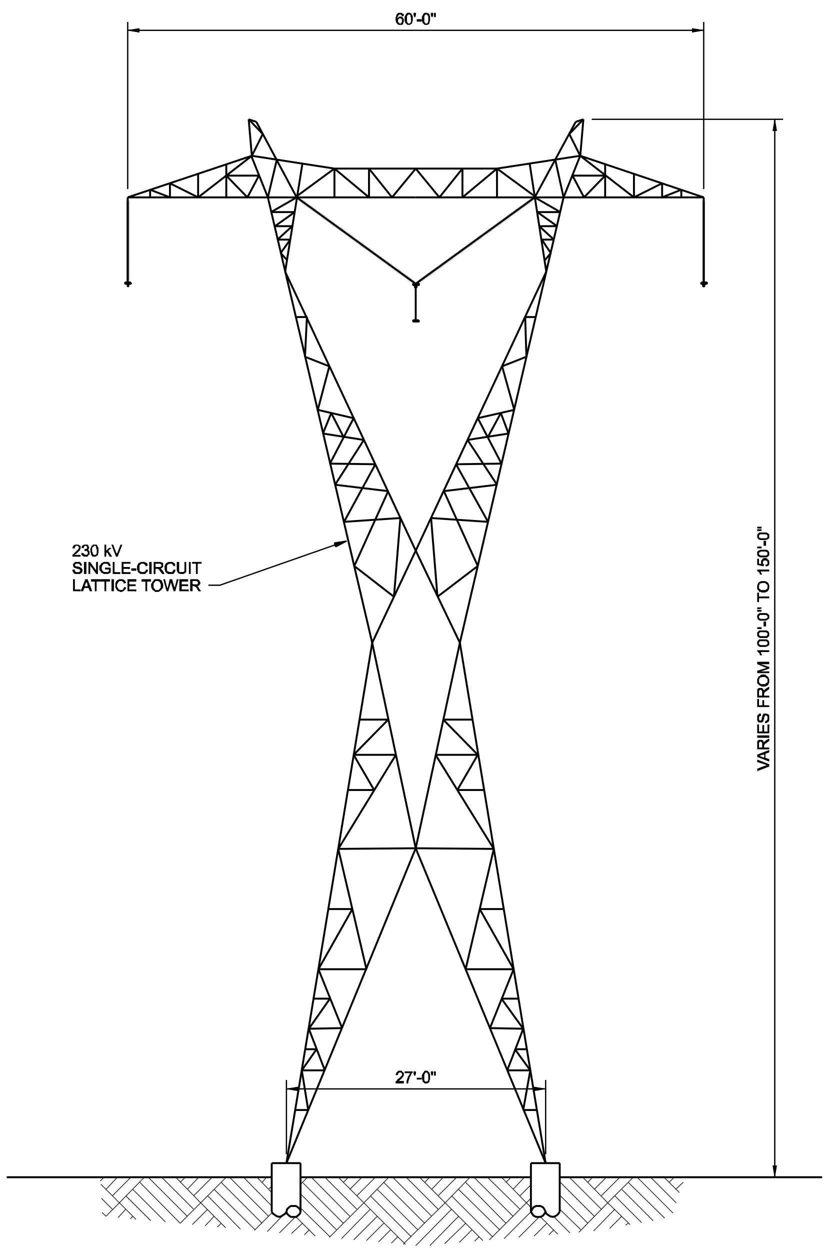


Plate 4-1.16
Crab Creek Electrical Transmission Line Plan/Corridor



NOTE:
TRANSMISSION LINE DETAIL APPLIES TO CRAB CREEK, SAND HOLLOW, AND HAWK CREEK.

Plate 4-1.17
Transmission Line Detail
Crab Creek and Other Sites

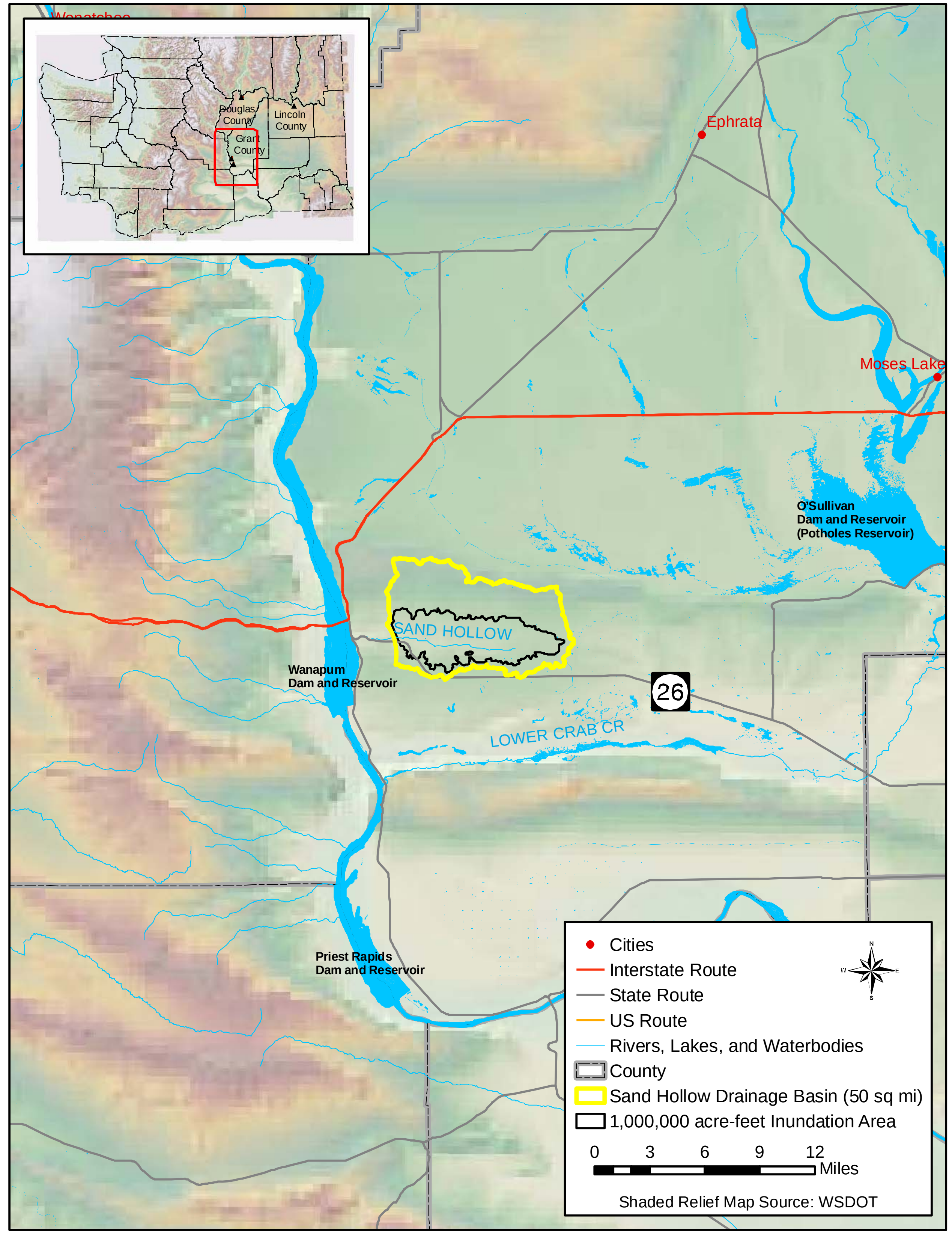


Plate 4-2.1
Sand Hollow Drainage Basin

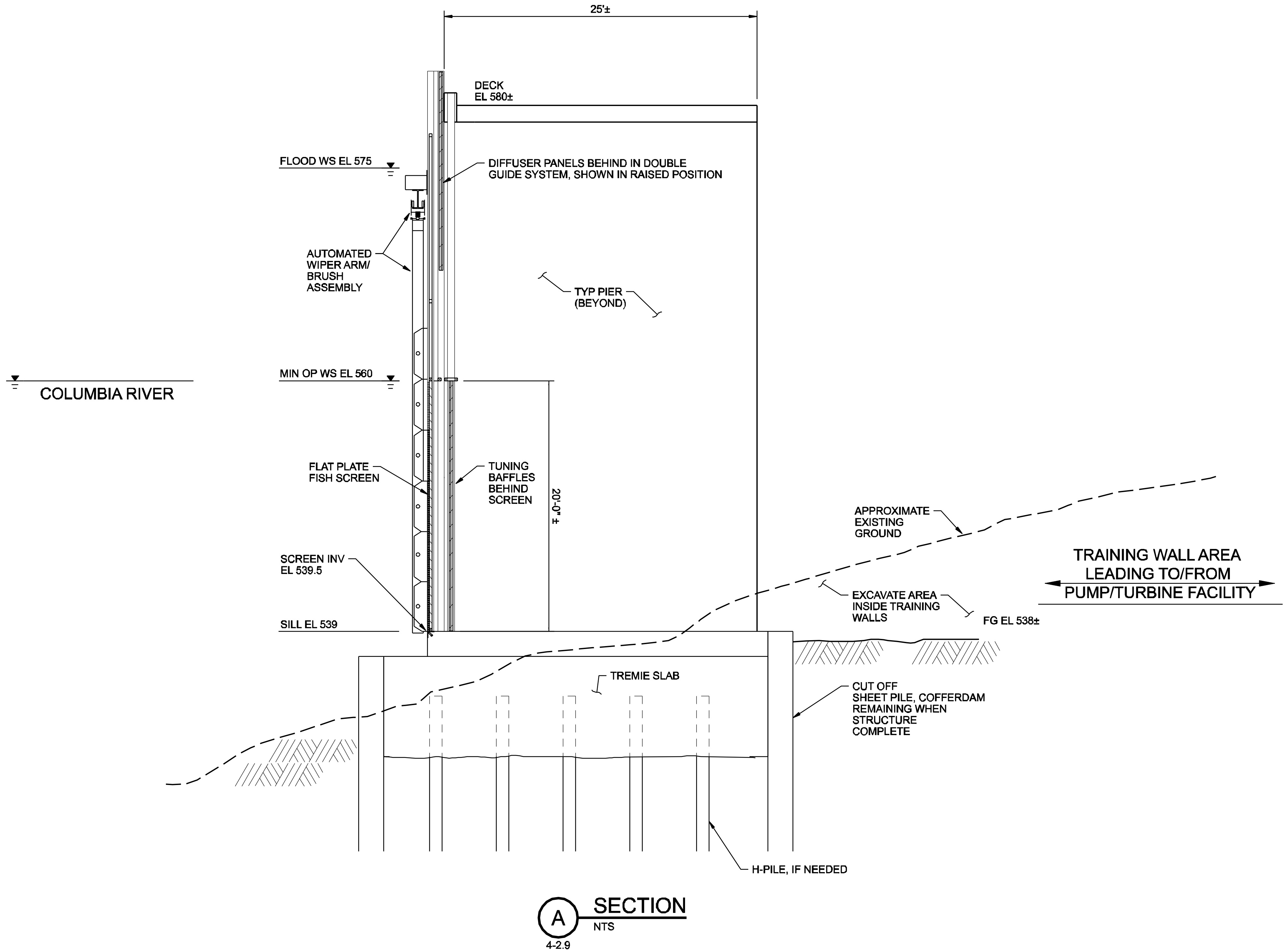
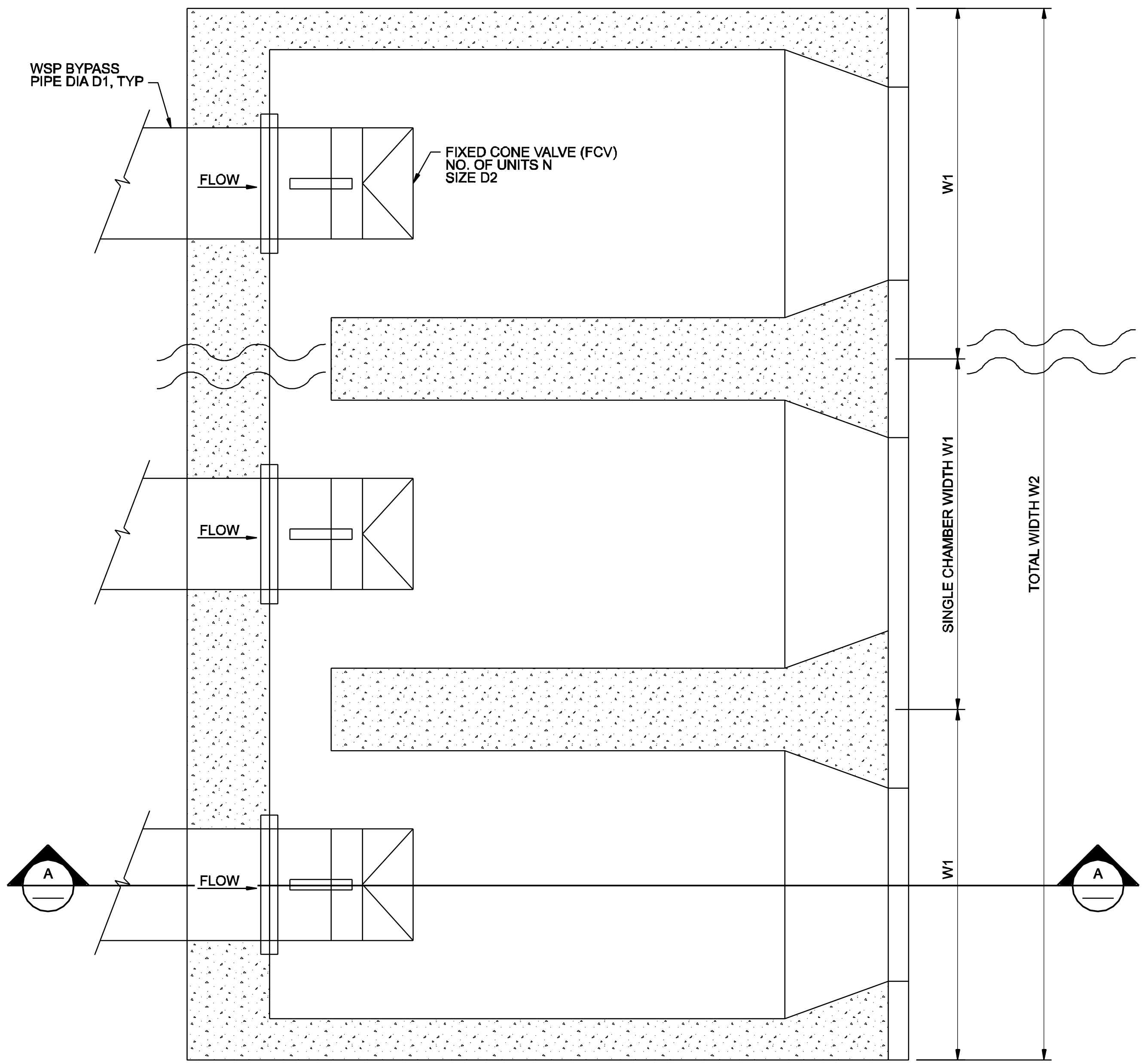
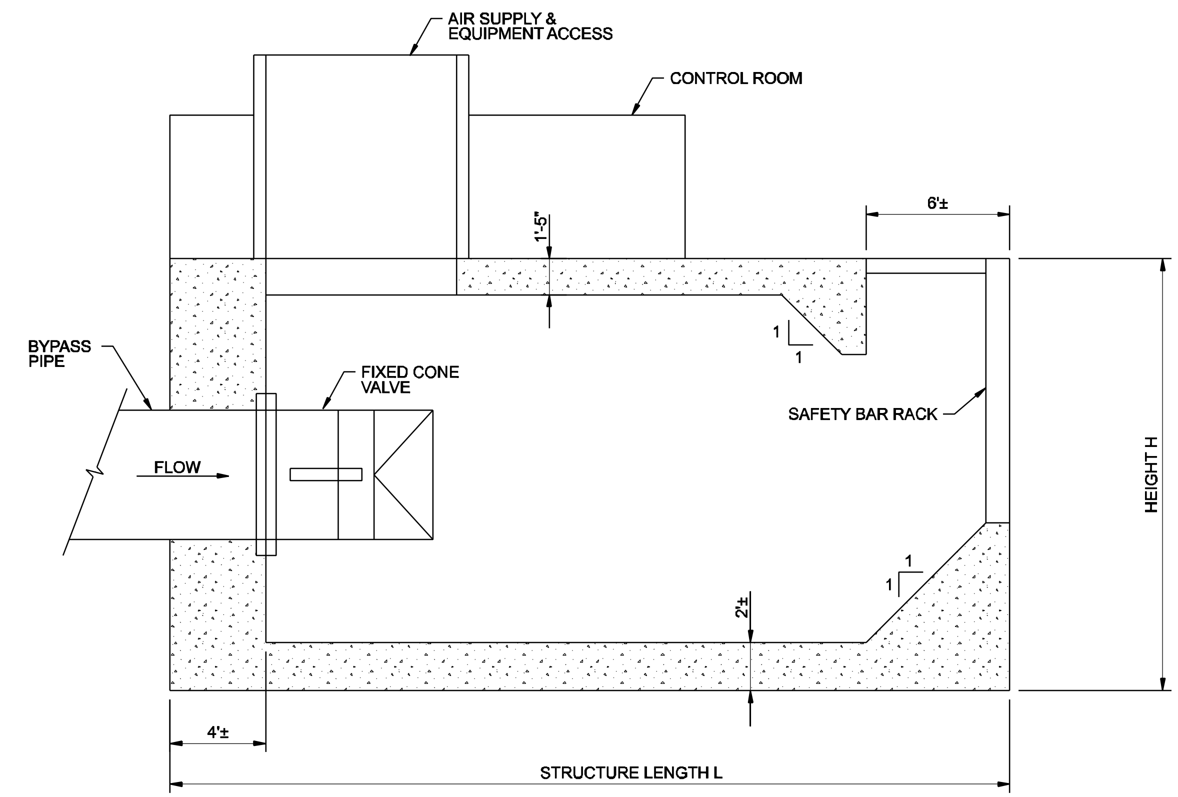


Plate 4-2.10
Sand Hollow Fish Screen/Diffuser Structure Section



PLAN
1/8"=1'-0"

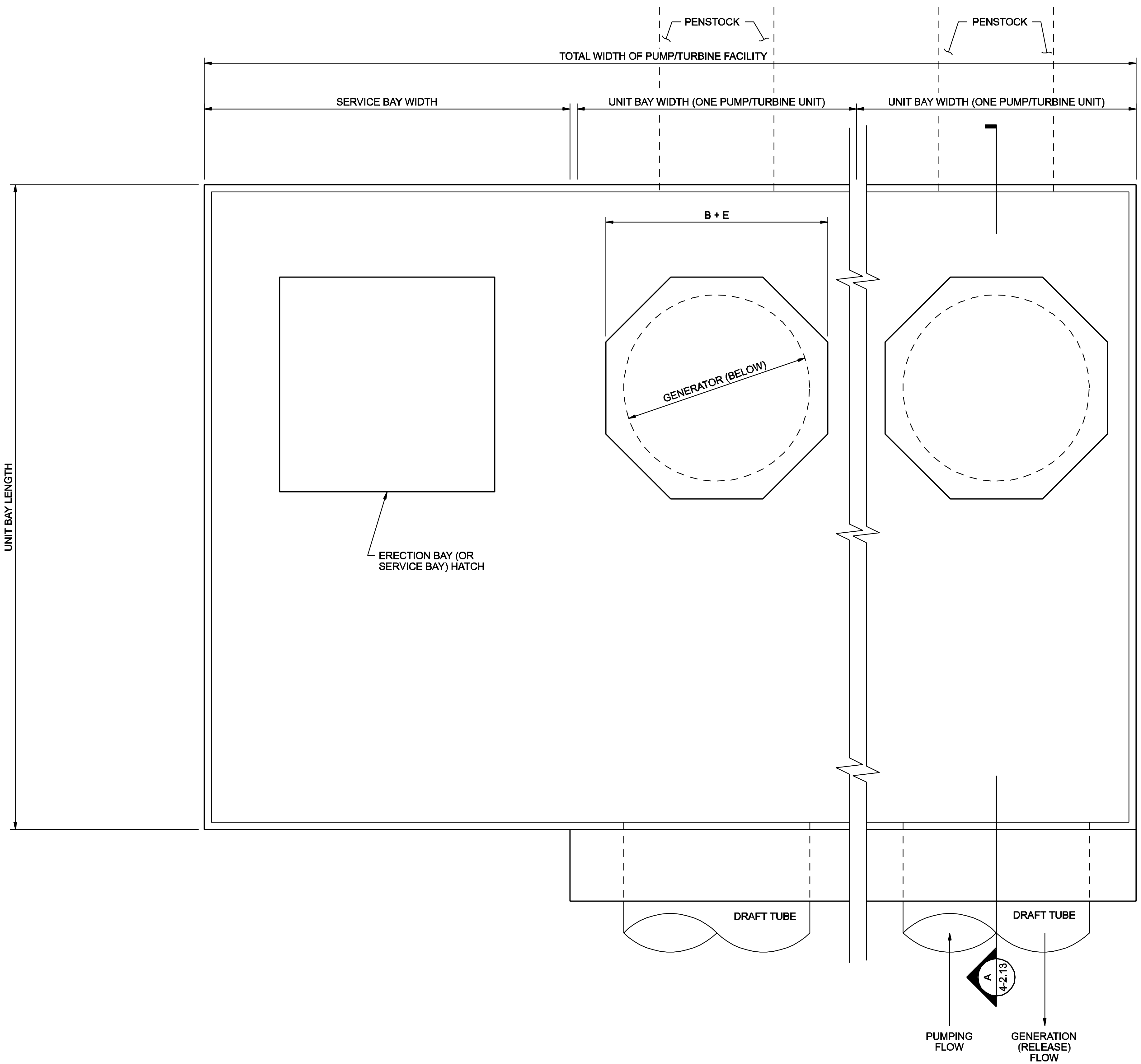
0 4 8 12
1/8"=1'-0"



A SECTION
1/8"=1'-0"

SIZE	OPERATIONAL SCENARIO	NO. OF UNITS N	BYPASS PIPE DIA D1 (FT)	FCV SIZE SIZE D2 (IN)	STRUCTURE LENGTH L (FT)	SINGLE CHAMBER WIDTH W1 (FT)	TOTAL WIDTH W2 (FT)	HEIGHT H (FT)
CRAB CREEK SEE PLATE 4-1.9	OS1	3	11	72	37	19	57	21
	OS2	4	12	84	40	20	80	23
	OS3	4	13	90	40	20	80	23
SAND HOLLOW	OS1	3	8	54	33	17	51	19
HAWK CREEK SEE PLATE 4-4.13	OS1	3	8	54	33	17	51	19
	OS2	4	9	60	40	20	80	23
	OS3	4	10	66	38	19	76	22

Plate 4-2.11
Fixed Cone Valve Structure
Sand Hollow and Other Sites - Plan and Section



	OPERATIONAL SCENARIO 1
UNIT BAY WIDTH (ONE UNIT)	34
NUMBER OF UNITS	3
SERVICE BAY WIDTH	45
TOTAL WIDTH OF PUMP/TURBINE FACILITY	147
UNIT BAY LENGTH	71
B + E (SPIRAL CASE WIDTH PARALLEL TO FLOW)	26
DRAFT TUBE DIAMETER	25
NUMBER OF DRAFT TUBES	3
PENSTOCK DIAMETER	12
NUMBER OF PENSTOCKS	3
PEAK PUMPING FLOW (CFS)	2500
PEAK RELEASE FLOW (CFS)	6500
CENTERLINE ELEVATION OF PENSTOCKS/UNITS	446

Plate 4-2.12
Sand Hollow Pump/Turbine Facility - Plan

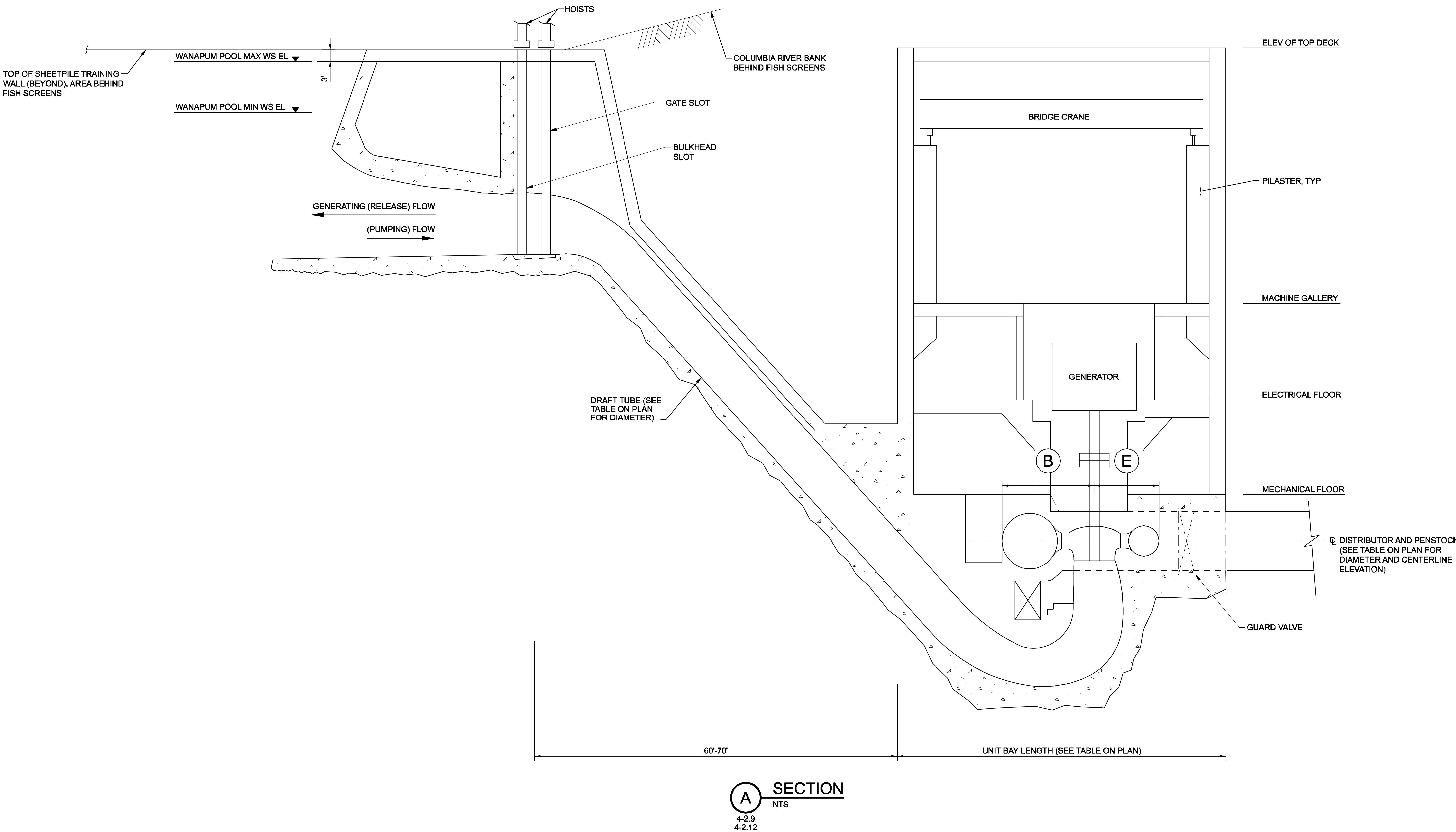


Plate 4-2.13
Sand Hollow Combined Pump/Turbine Facility Section

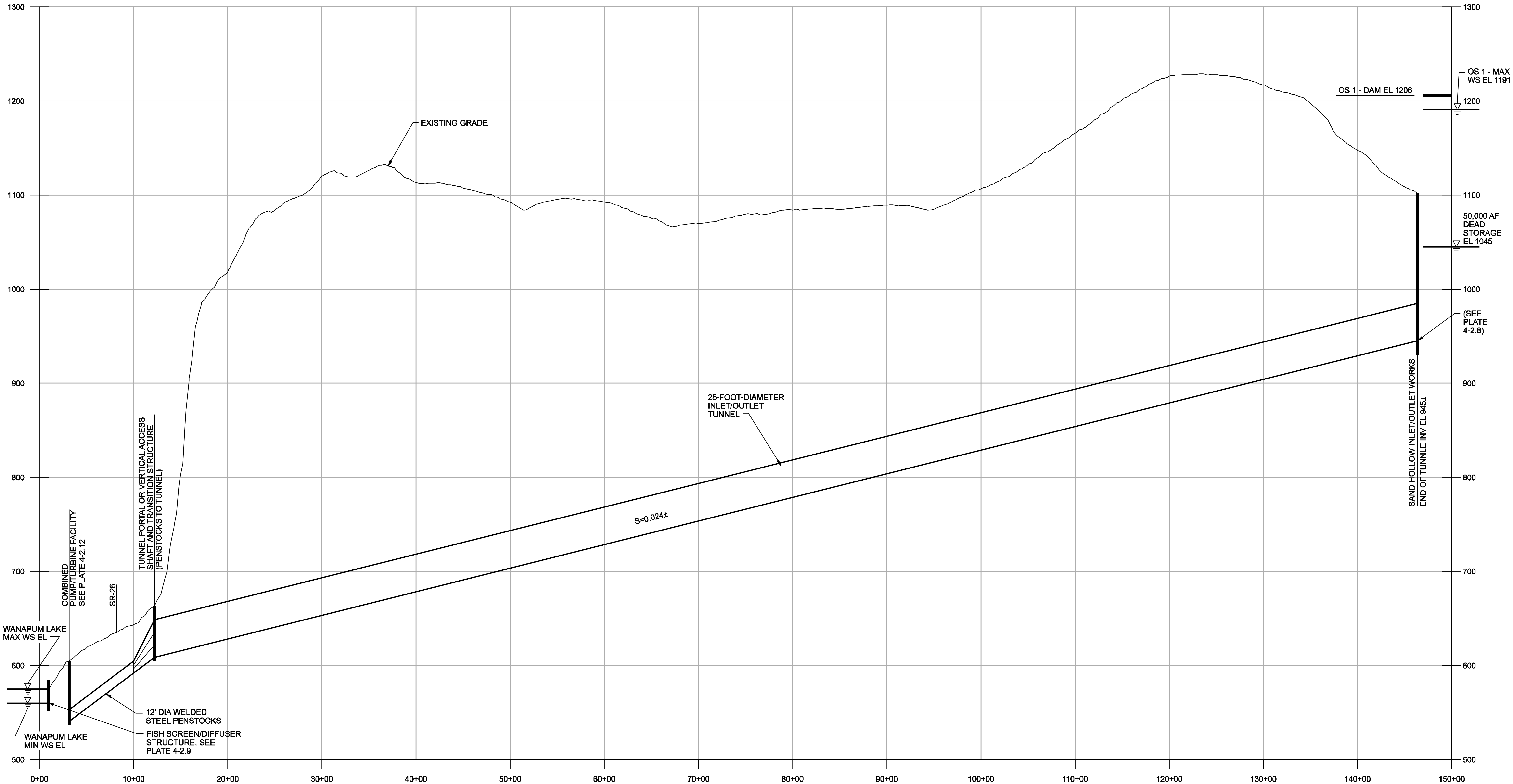


Plate 4-2.14
Sand Hollow Overall System Profile

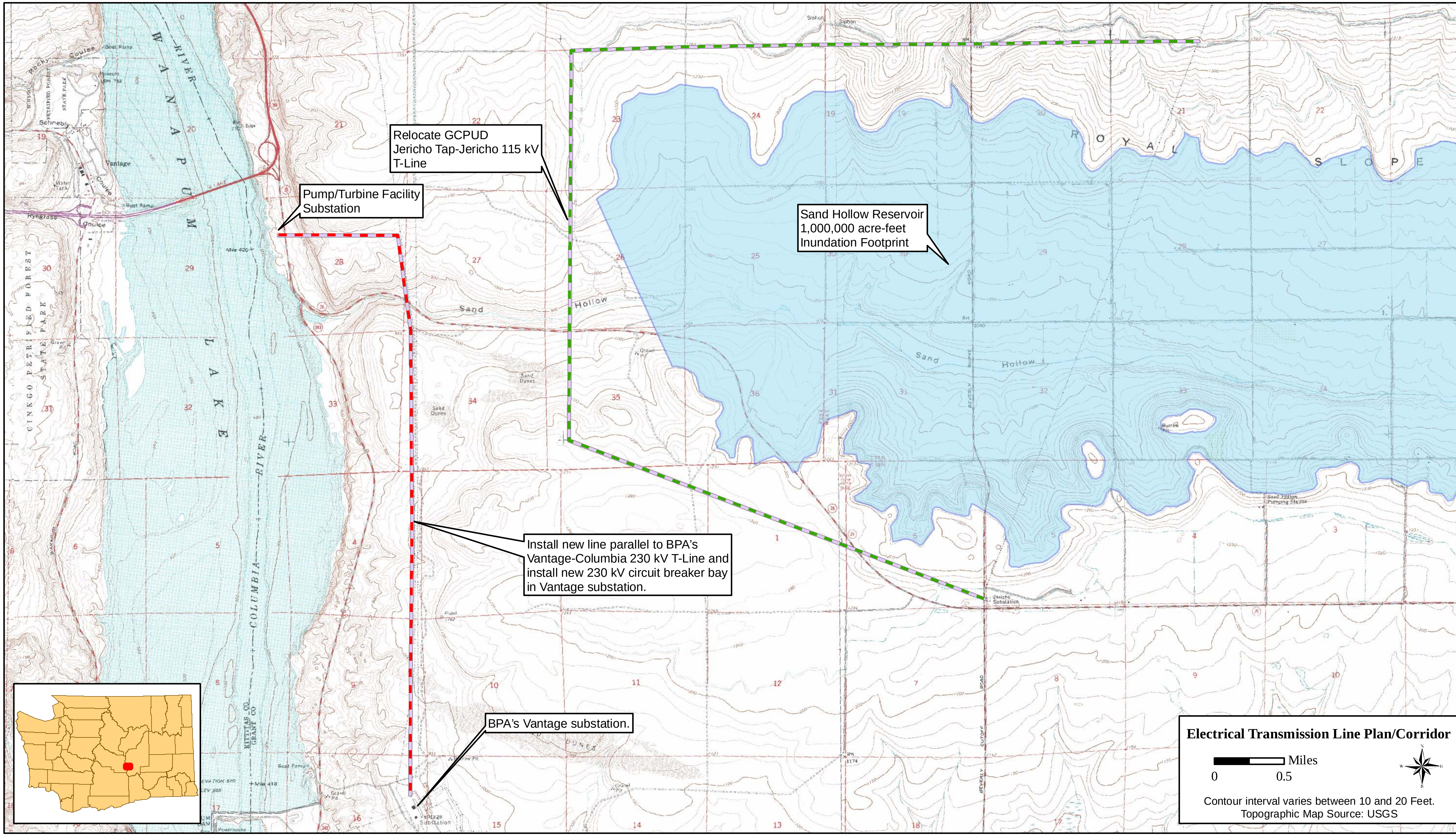


Plate 4-2.15
Sand Hollow Electrical Transmission Line Plan/Corridor

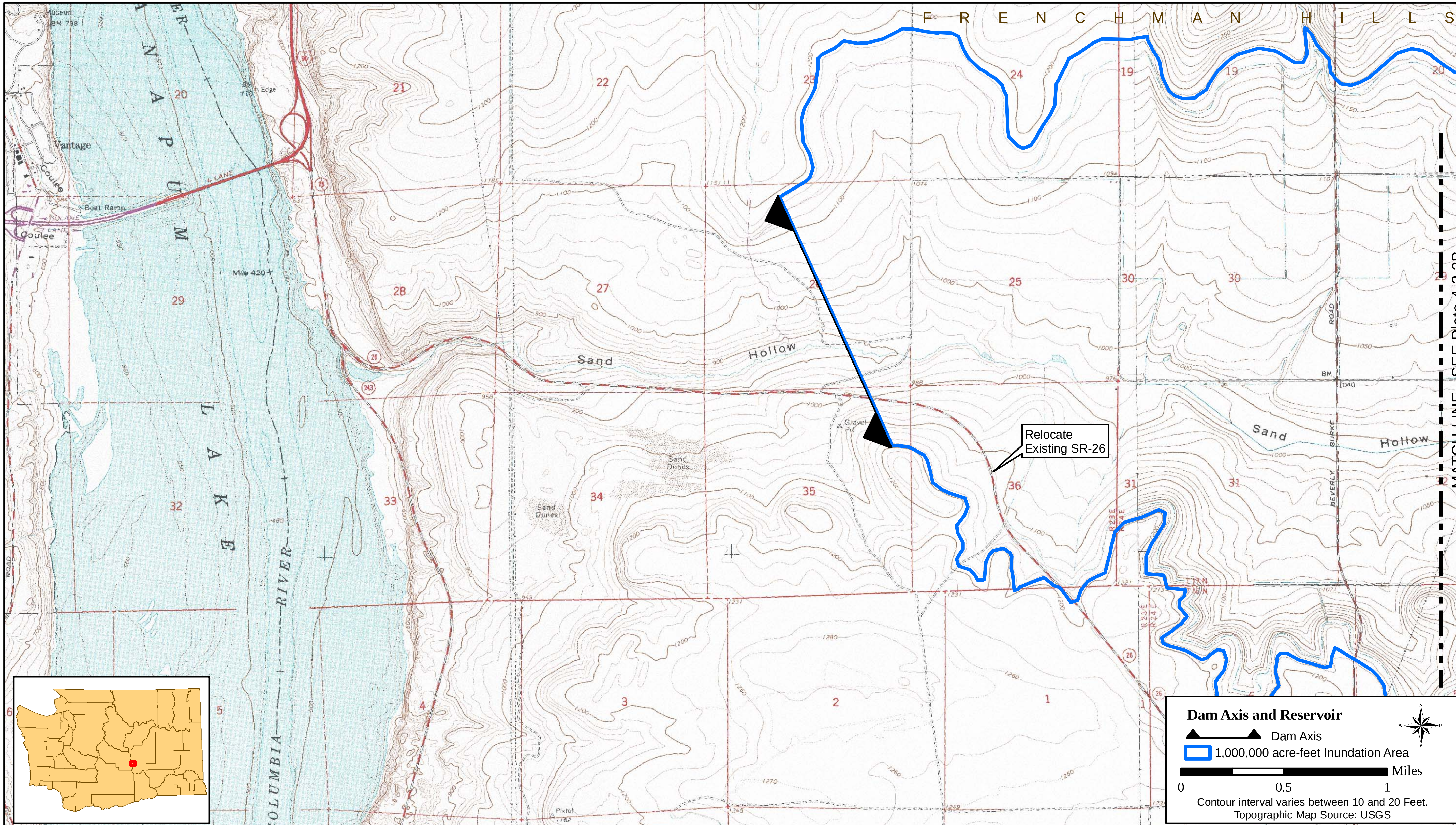


Plate 4-2.2A
Sand Hollow Dam Axis and Reservoir

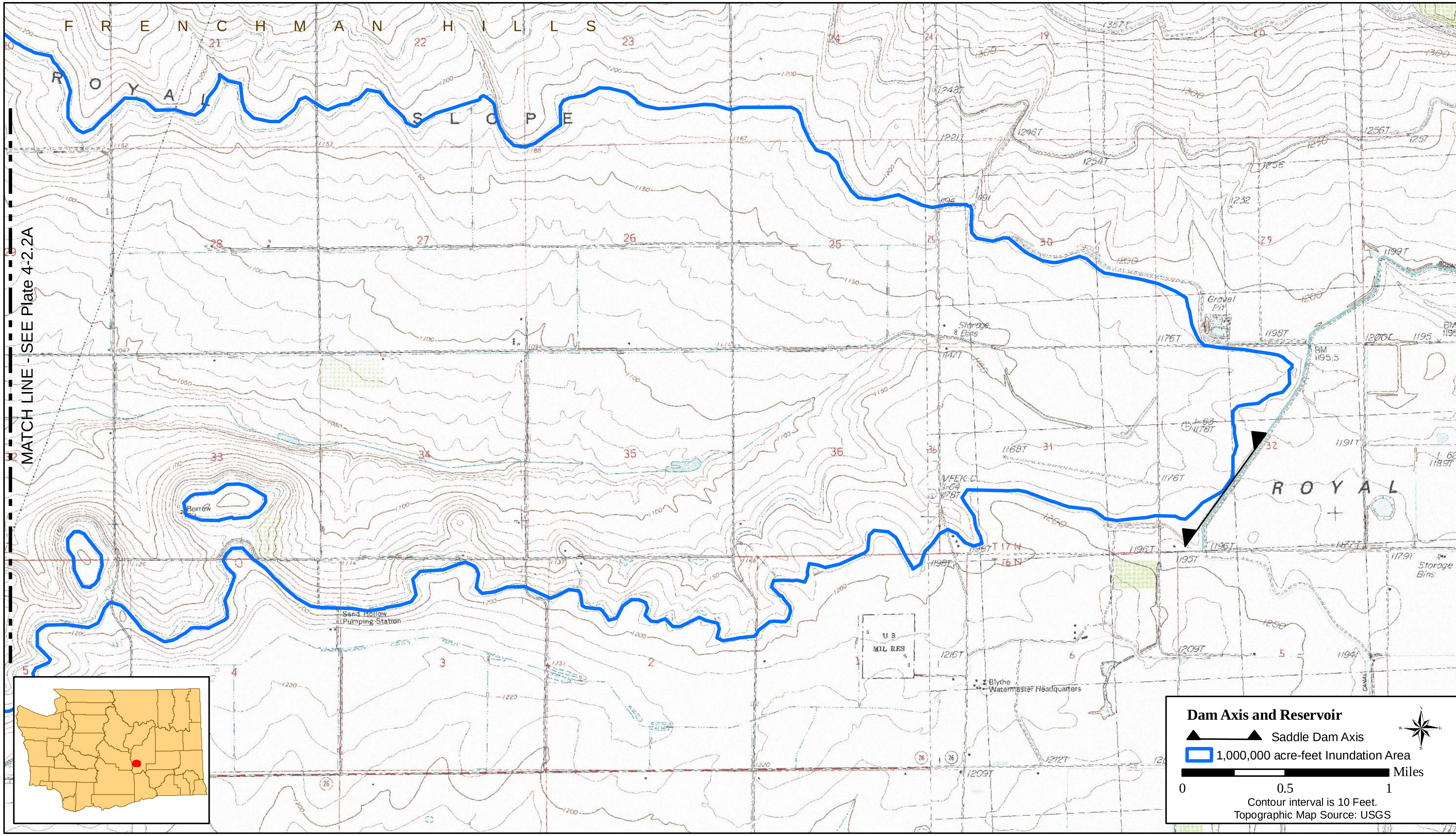


Plate 4-2.2B
Sand Hollow Dam Axis and Reservoir, Cont.

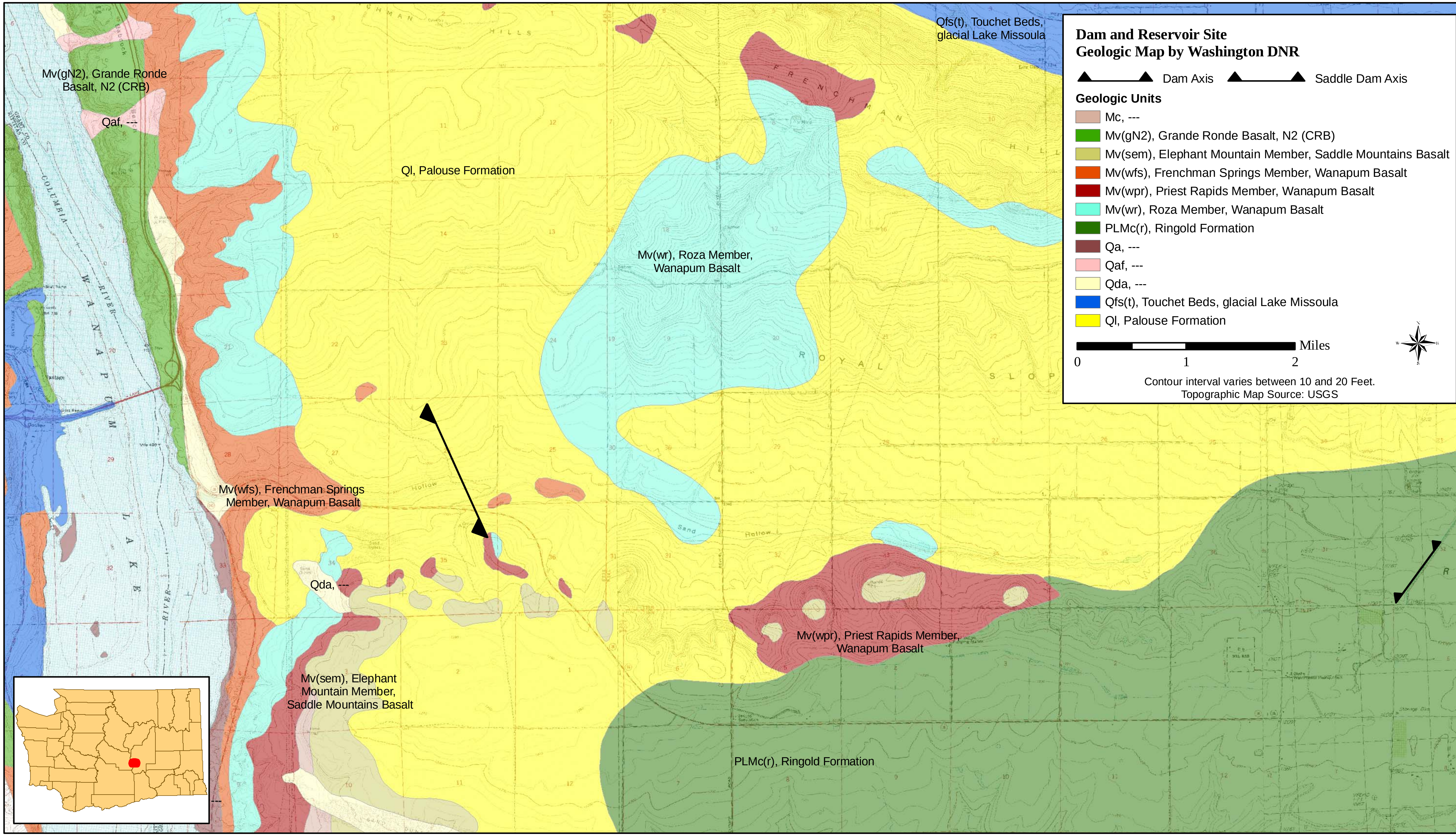


Plate 4-2.3
Sand Hollow Dam and Reservoir Site Map

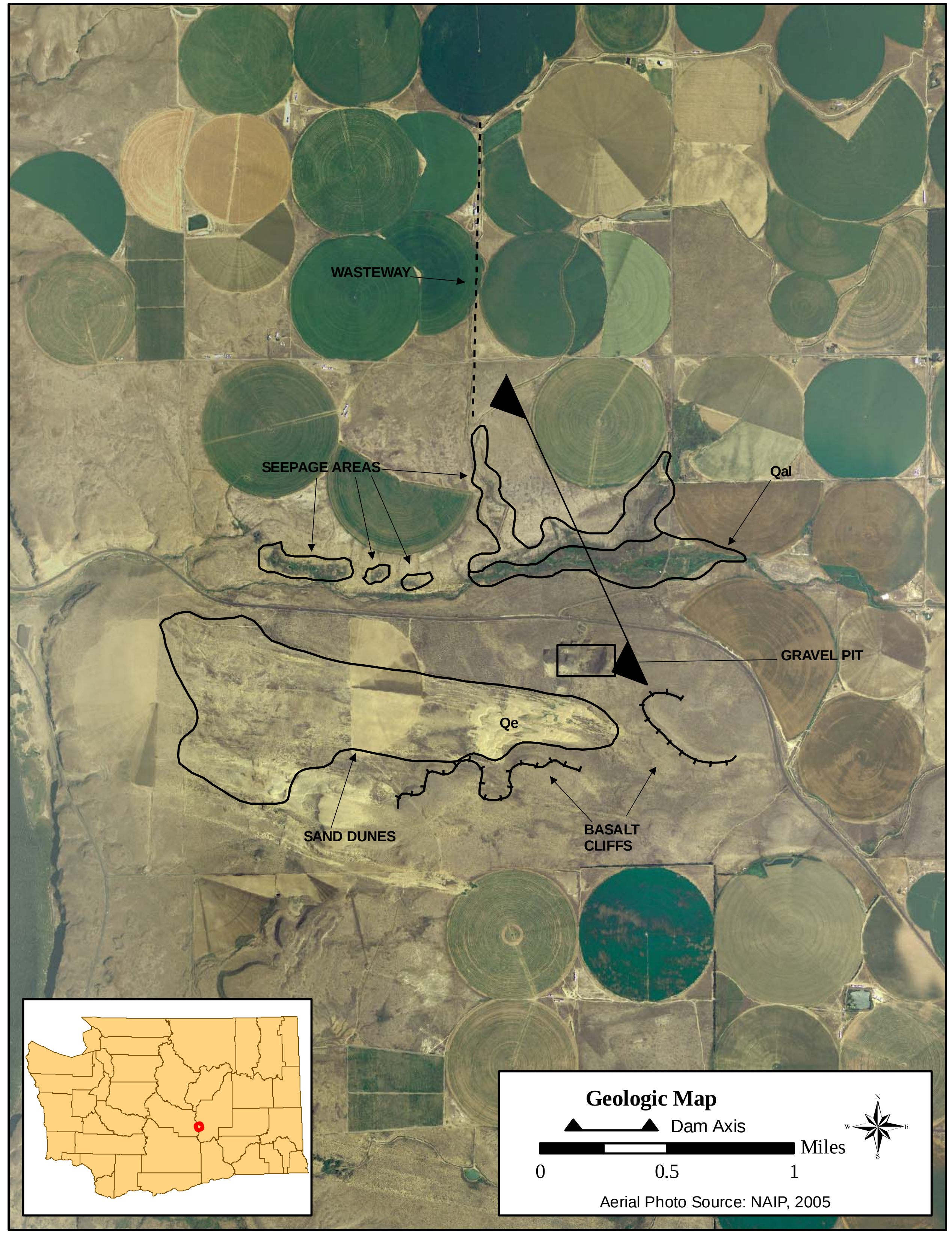


Plate 4-2.4
Sand Hollow Geologic Map

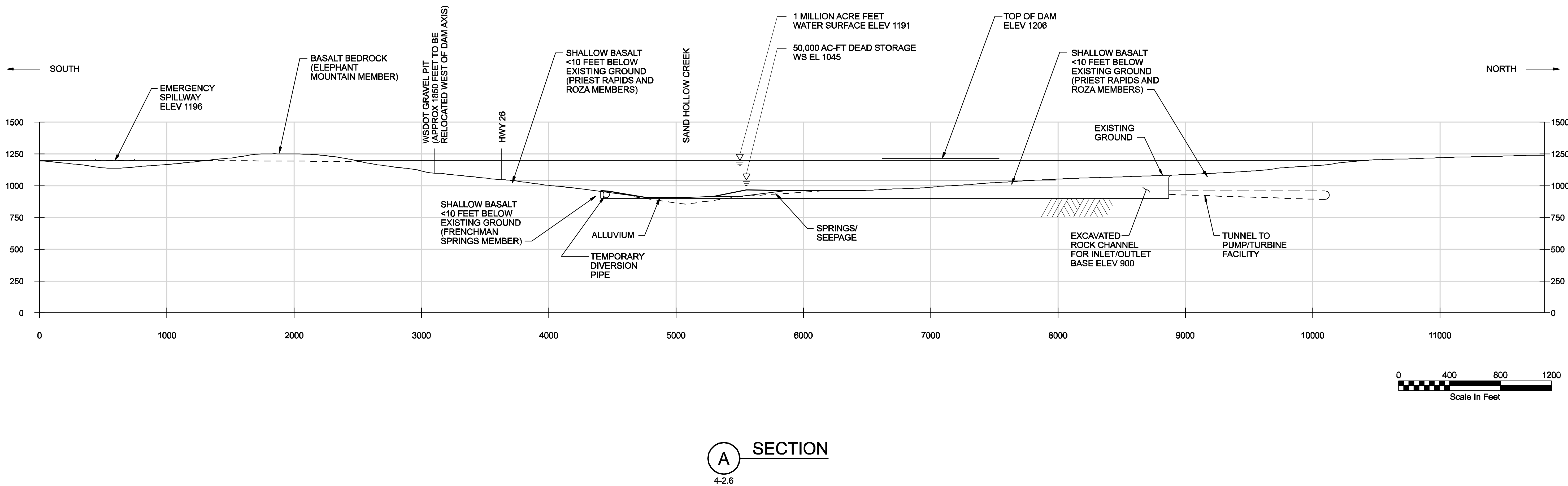


Plate 4-2.5
Sand Hollow Dam Axis Cross Section

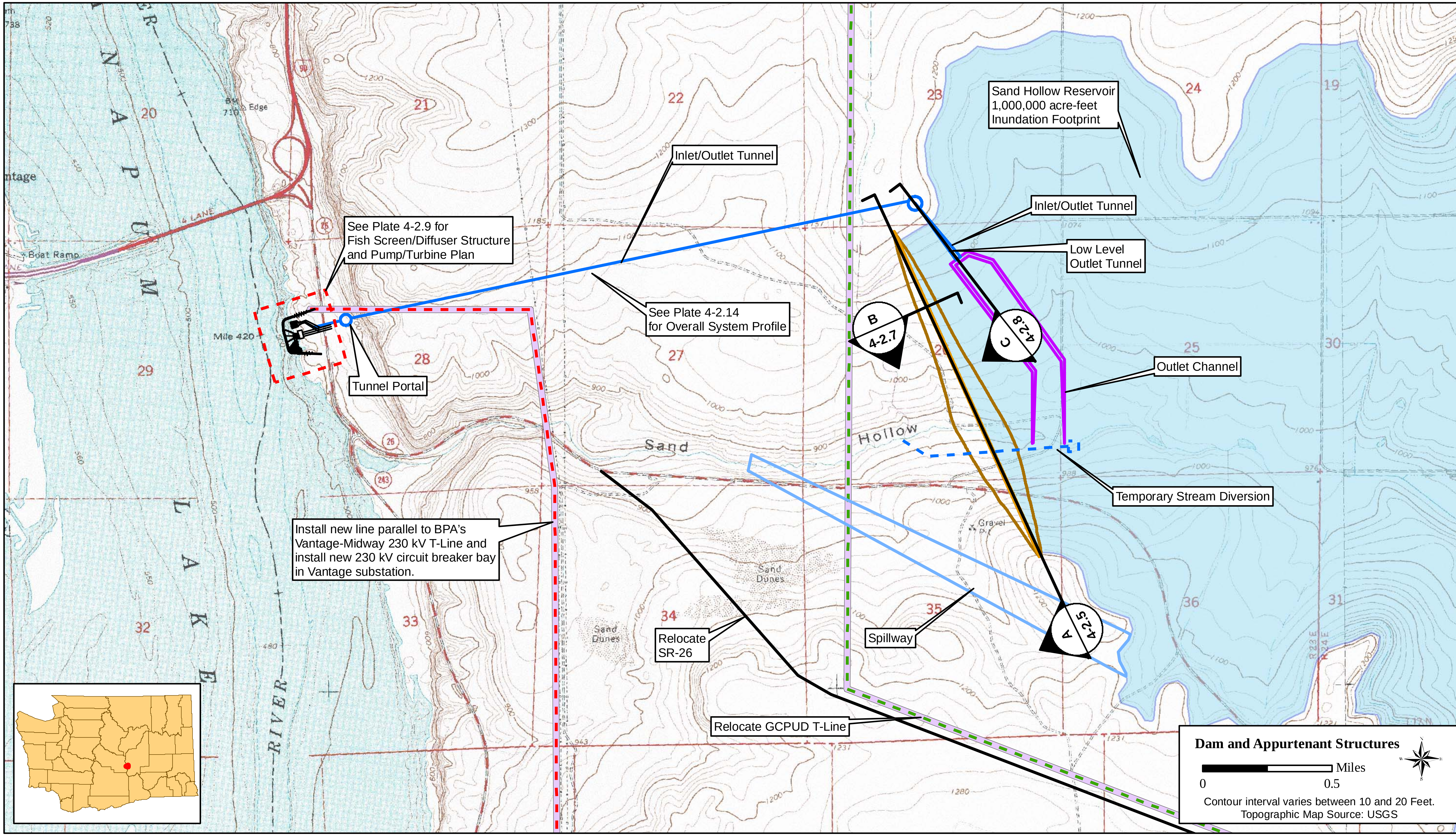
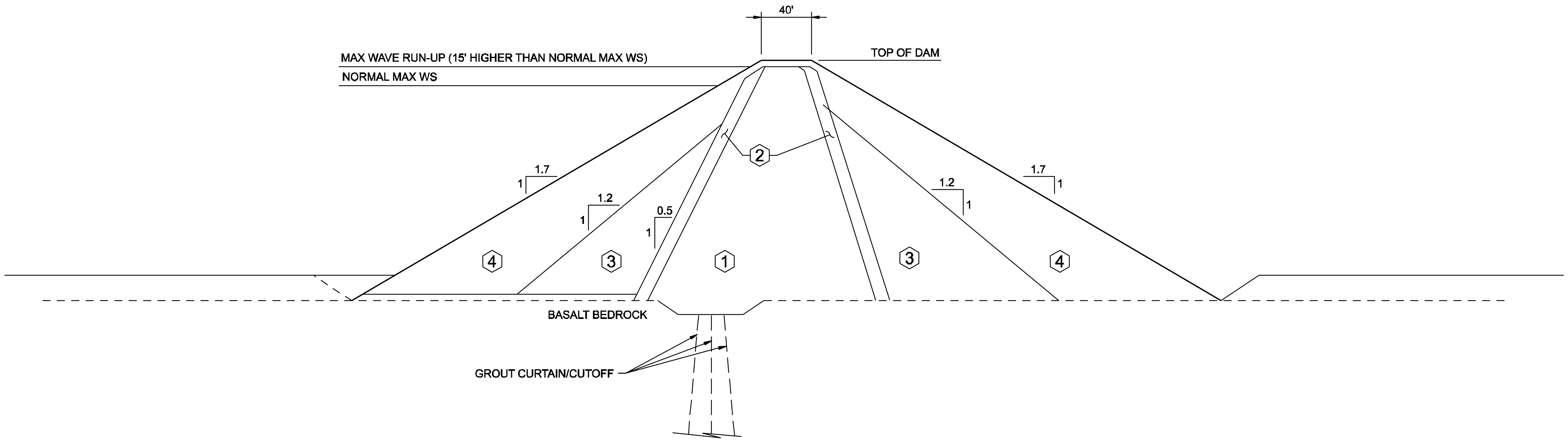


Plate 4-2.6
Sand Hollow Dam and Appurtenant Structures

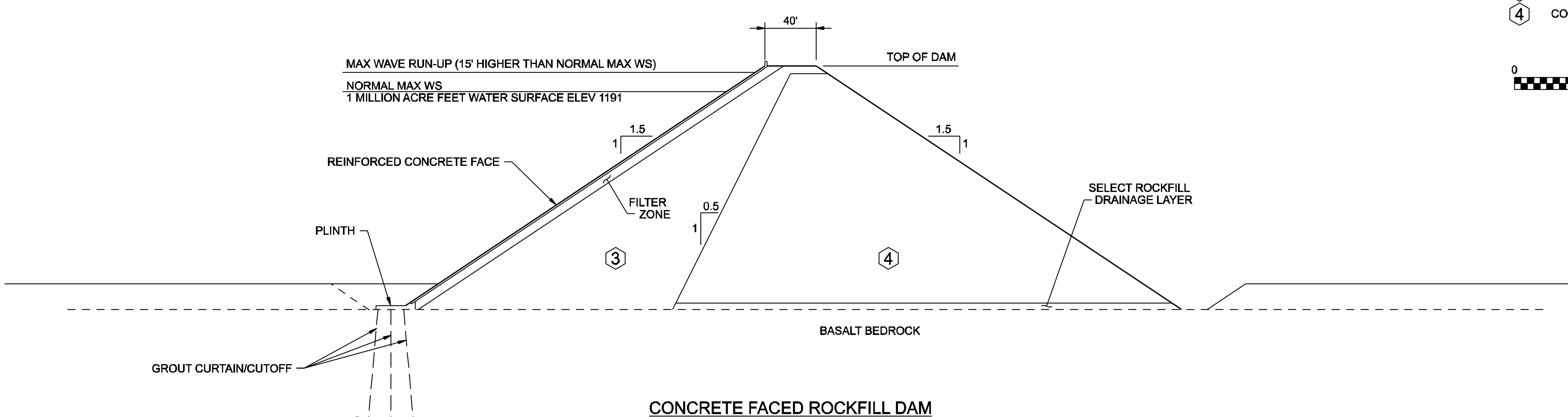


ROCKFILL DAM WITH EARTH CORE

B SECTION
4-2.6

ZONE	DESCRIPTION
1	WELL GRADED SILTY SAND AND GRAVEL
2	SAND/GRAVEL FILTER, LESS THAN 3"
3	CRUSHED ROCK, LESS THAN 6" DIA
4	COMPACTED ROCK FILL, 6" TO 24"

0 50 100 150
Scale In Feet



CONCRETE FACED ROCKFILL DAM

B SECTION
4-2.6

Plate 4-2.7
Sand Hollow Typical Dam Section

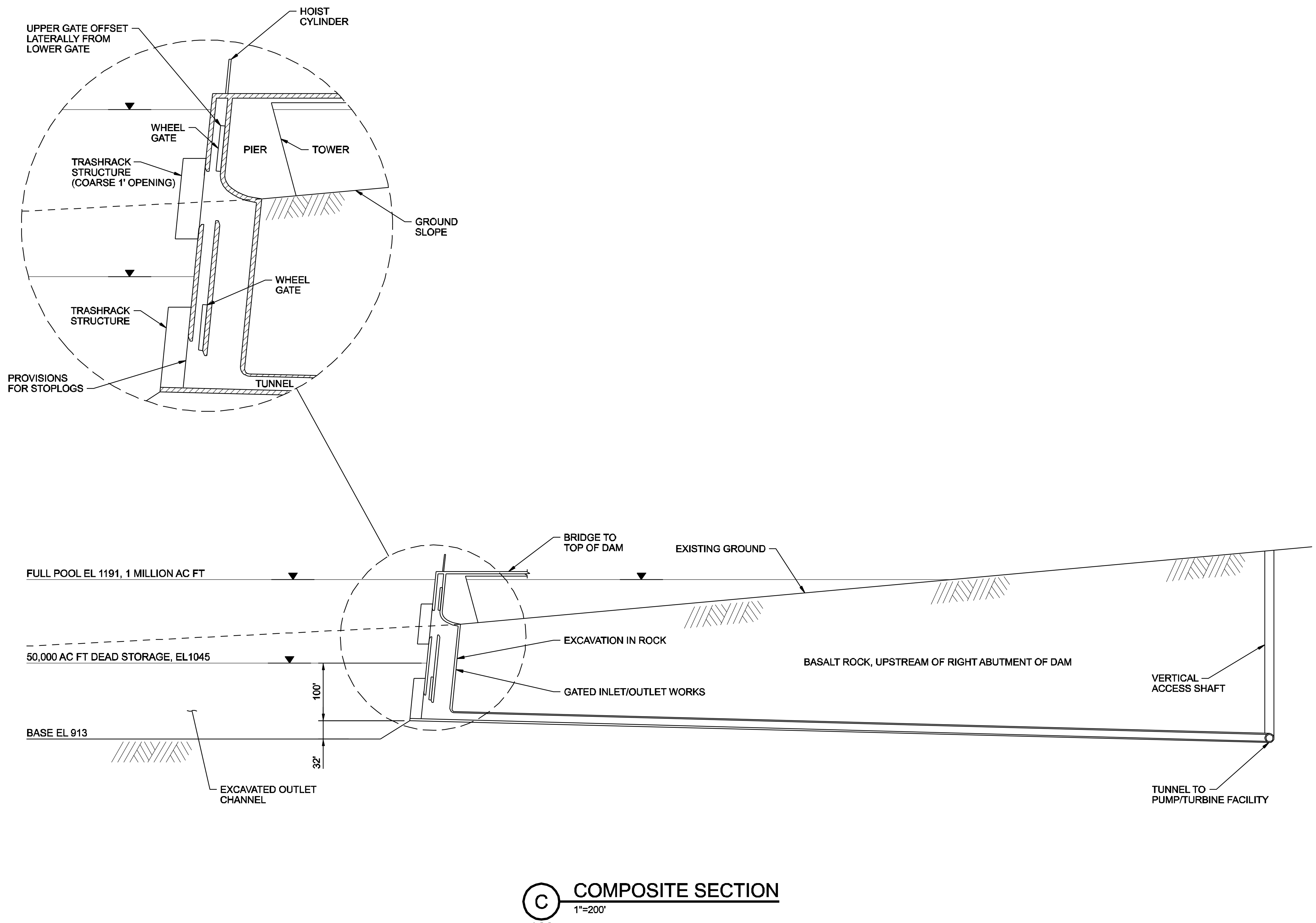
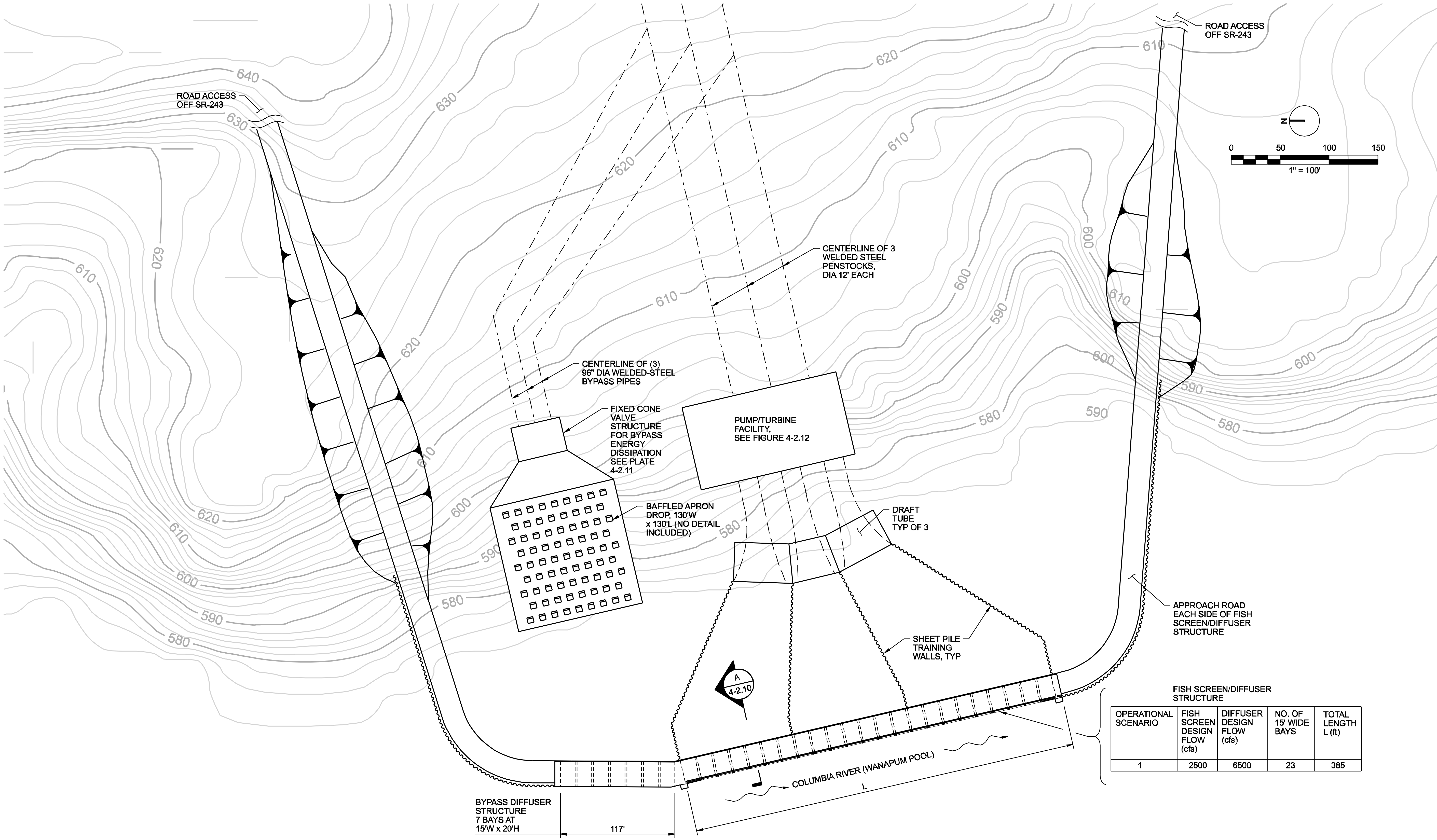


Plate 4-2.8
Sand Hollow Inlet/Outlet Works



FISH SCREEN/DIFFUSER STRUCTURE

OPERATIONAL SCENARIO	FISH SCREEN DESIGN FLOW (cfs)	DIFFUSER DESIGN FLOW (cfs)	NO. OF 15' WIDE BAYS	TOTAL LENGTH L (ft)
1	2500	6500	23	385

Plate 4-2.9
Sand Hollow Fish Screen/Diffuser Structure Plan

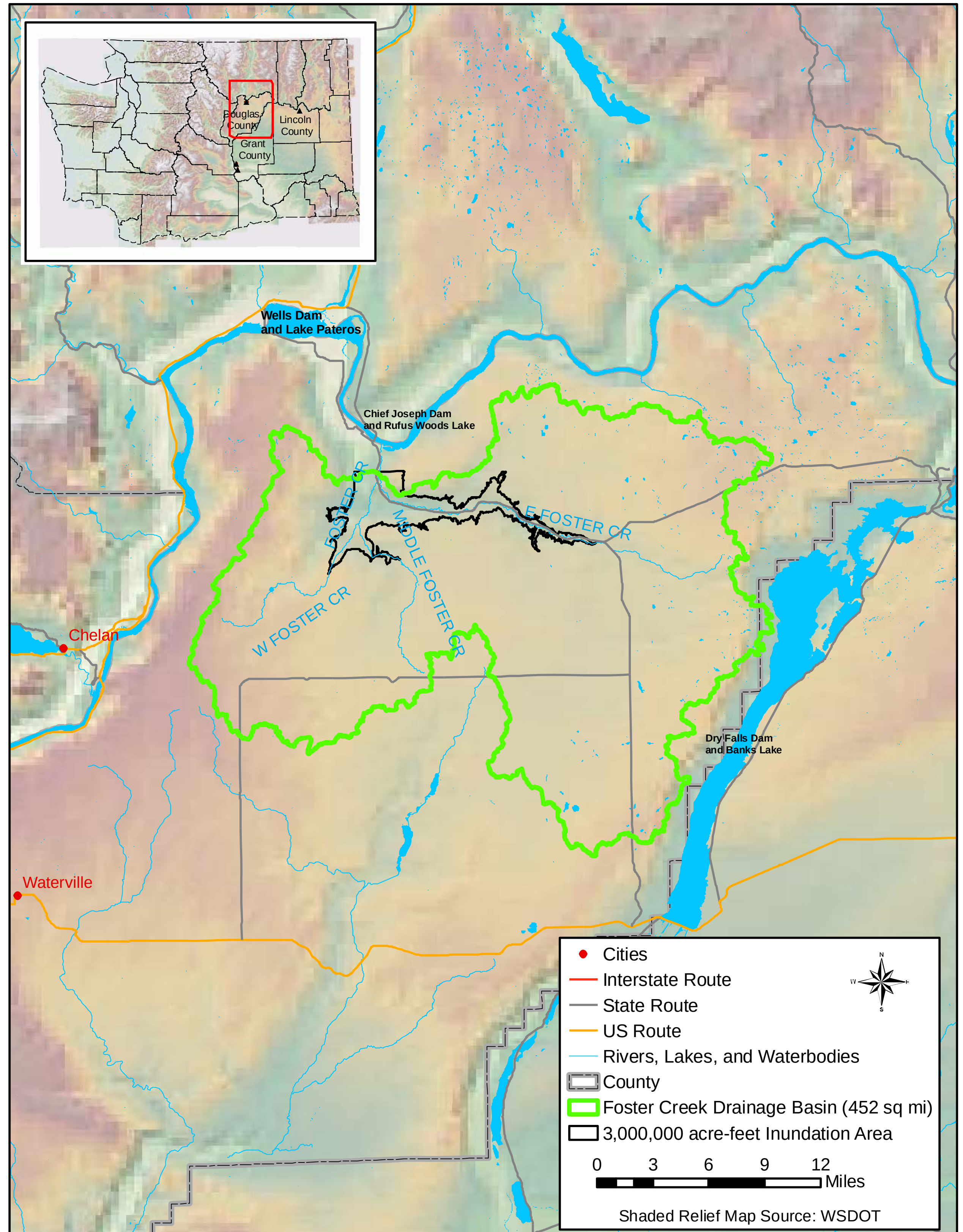


Plate 4-3.1
Foster Creek Drainage Basin

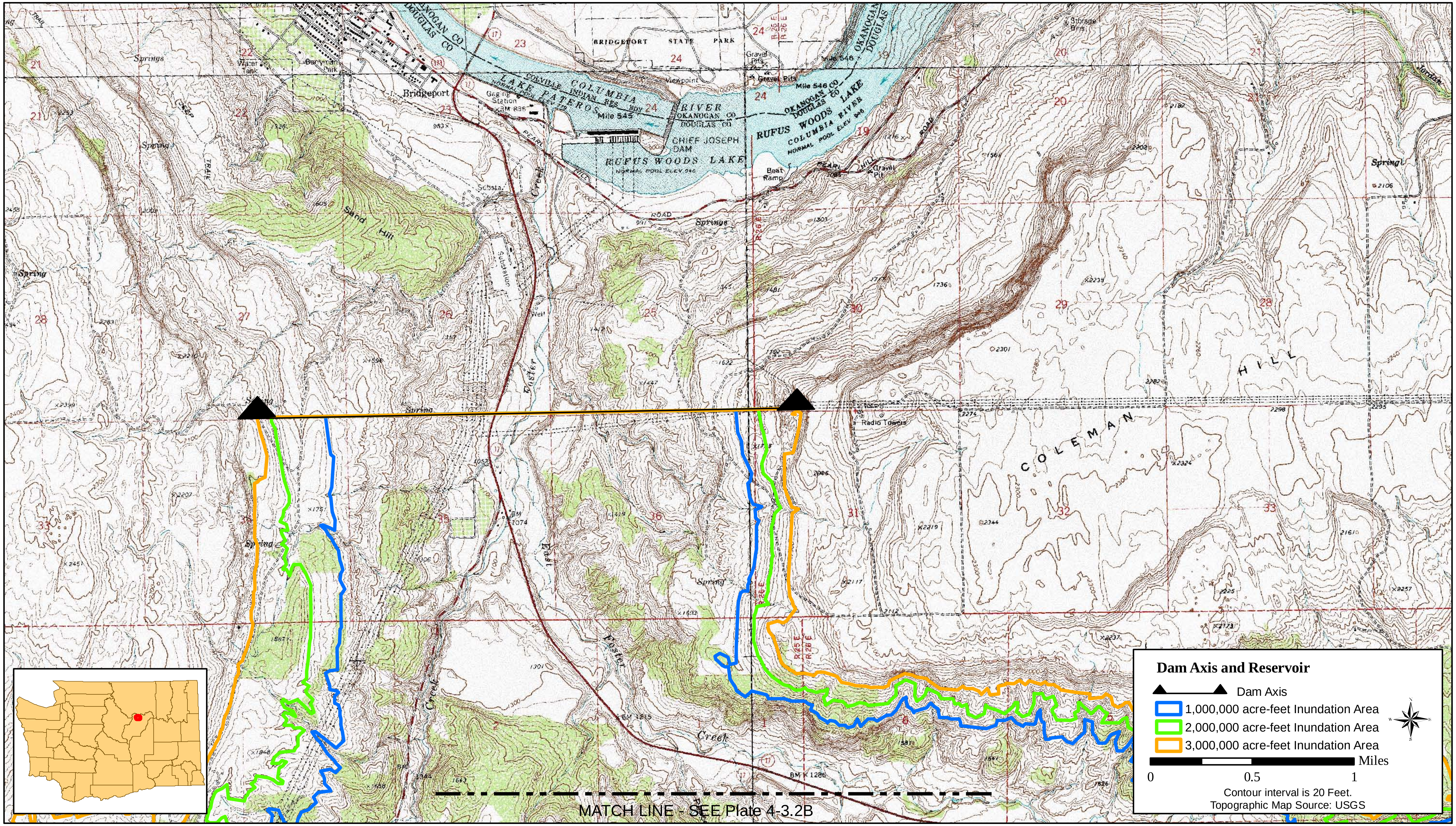


Plate 4-3.2A
Foster Creek Dam Axis and Reservoir

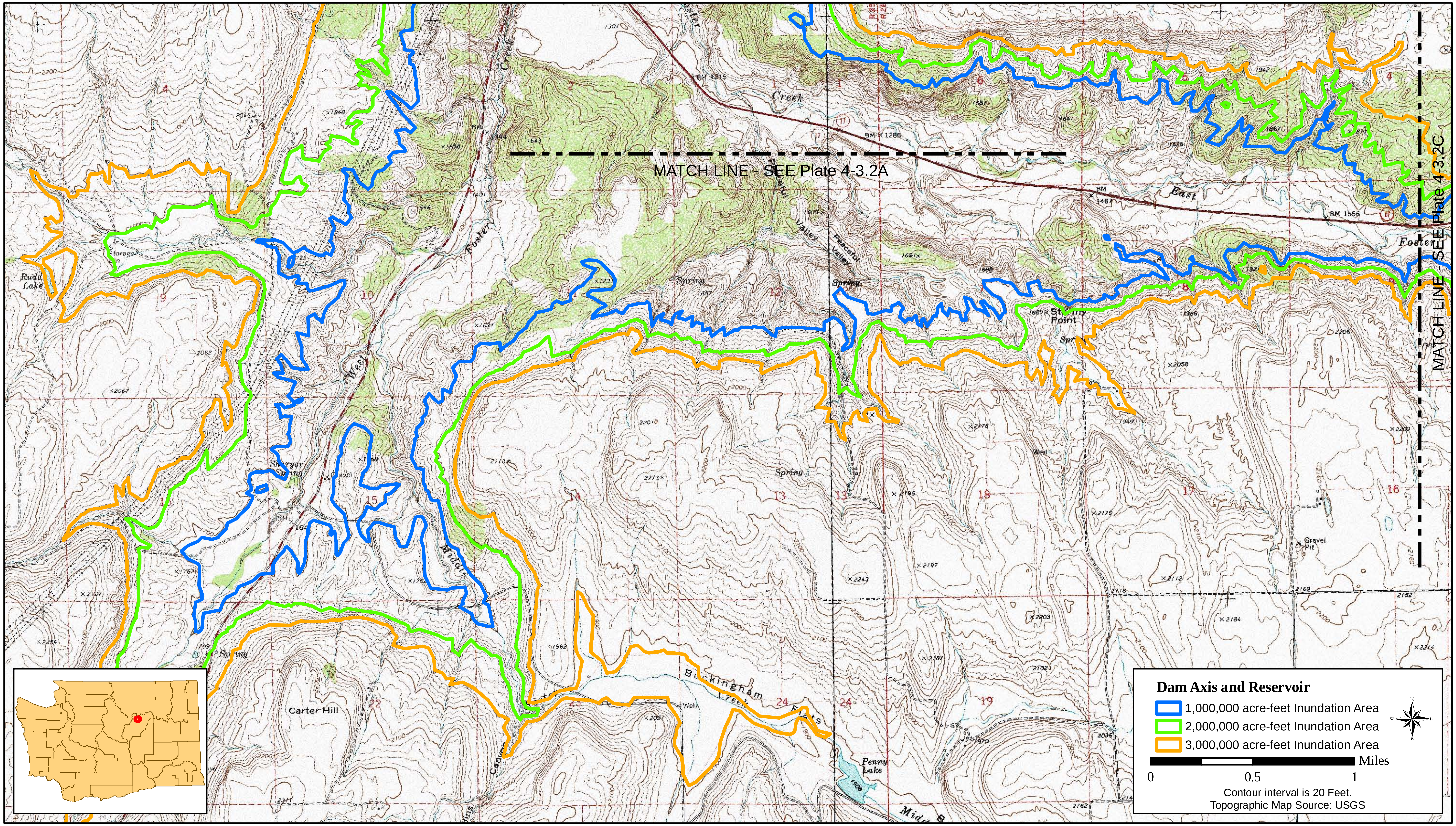


Plate 4-3.2B
Foster Creek Dam Axis and Reservoir, Cont.

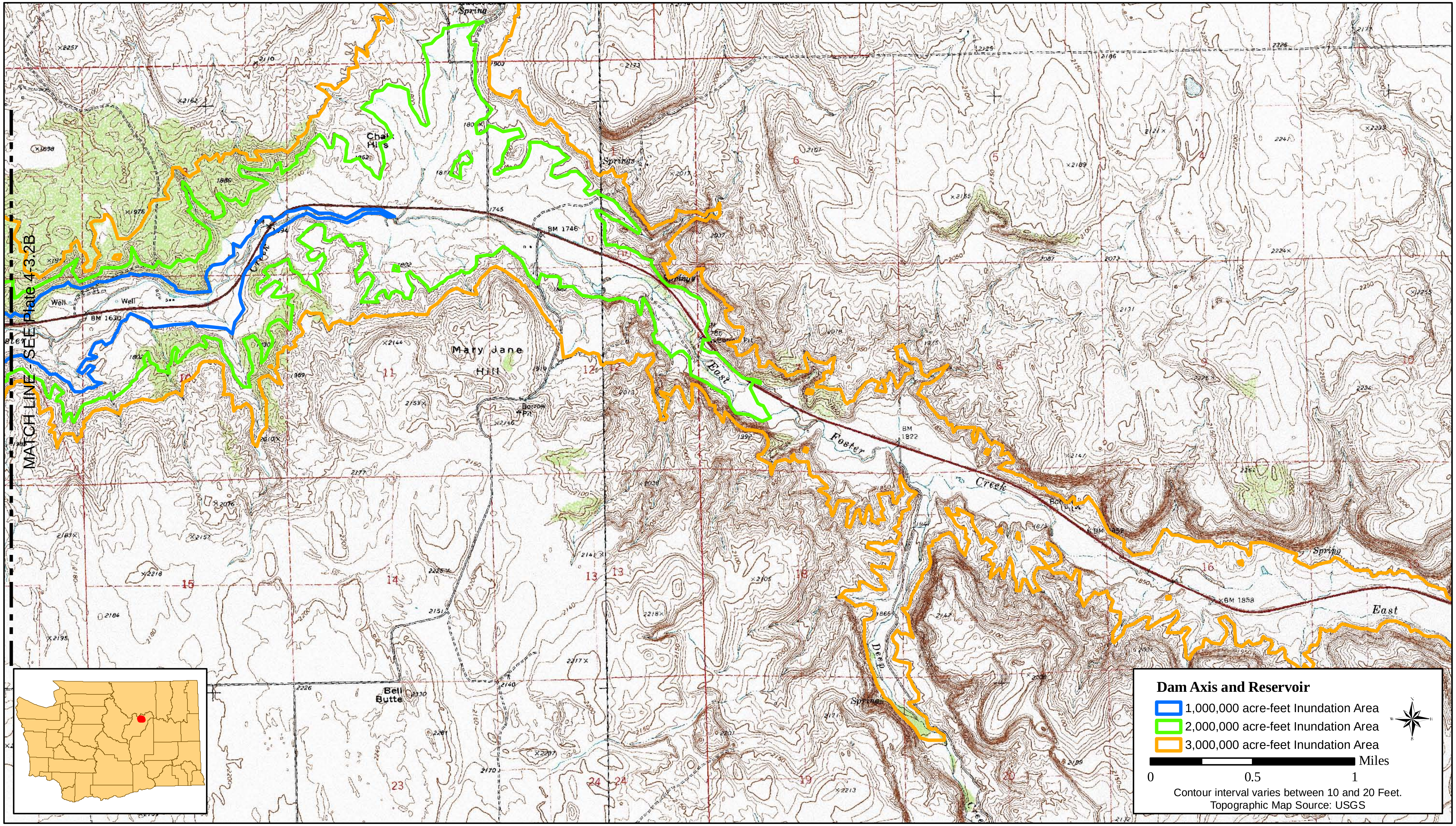
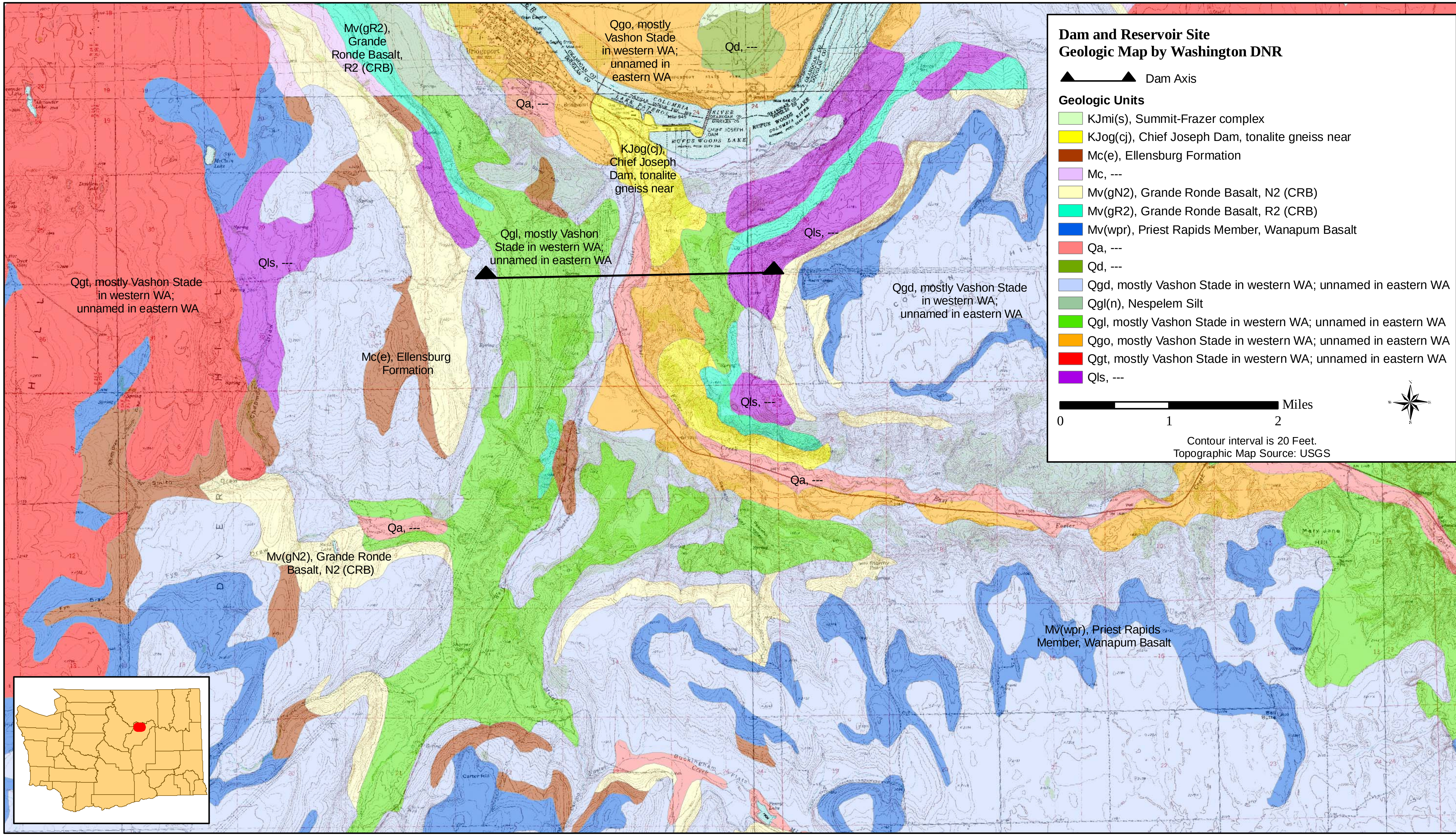


Plate 4-3.2C
Foster Creek Dam Axis and Reservoir, Cont.


Dam and Reservoir Site
Geologic Map by Washington DNR
Dam Axis
Geologic Units
KJmi(s), Summit-Frazer complex
KJog(cj), Chief Joseph Dam, tonalite gneiss near
Mc(e), Ellensburg Formation
Mc, ---
Mv(gN2), Grande Ronde Basalt, N2 (CRB)
Mv(gR2), Grande Ronde Basalt, R2 (CRB)
Mv(wpr), Priest Rapids Member, Wanapum Basalt
Qa, ---
Qd, ---
Qgd, mostly Vashon Stade in western WA; unnamed in eastern WA
Qgl(n), Nespelem Silt
Qgl, mostly Vashon Stade in western WA; unnamed in eastern WA
Qgo, mostly Vashon Stade in western WA; unnamed in eastern WA
Qgt, mostly Vashon Stade in western WA; unnamed in eastern WA
Qls, ---
Miles
0
1
2
Contour interval is 20 Feet.
Topographic Map Source: USGS
Mv(gR2), Grande Ronde Basalt, R2 (CRB)
Qgo, mostly Vashon Stade in western WA; unnamed in eastern WA
Qd, ---
Qa, ---
KJog(cj), Chief Joseph Dam, tonalite gneiss near
Qgl, mostly Vashon Stade in western WA; unnamed in eastern WA
Qls, ---
Qgt, mostly Vashon Stade in western WA; unnamed in eastern WA
Qgd, mostly Vashon Stade in western WA; unnamed in eastern WA
Mc(e), Ellensburg Formation
Mv(gN2), Grande Ronde Basalt, N2 (CRB)
Mv(wpr), Priest Rapids Member, Wanapum Basalt

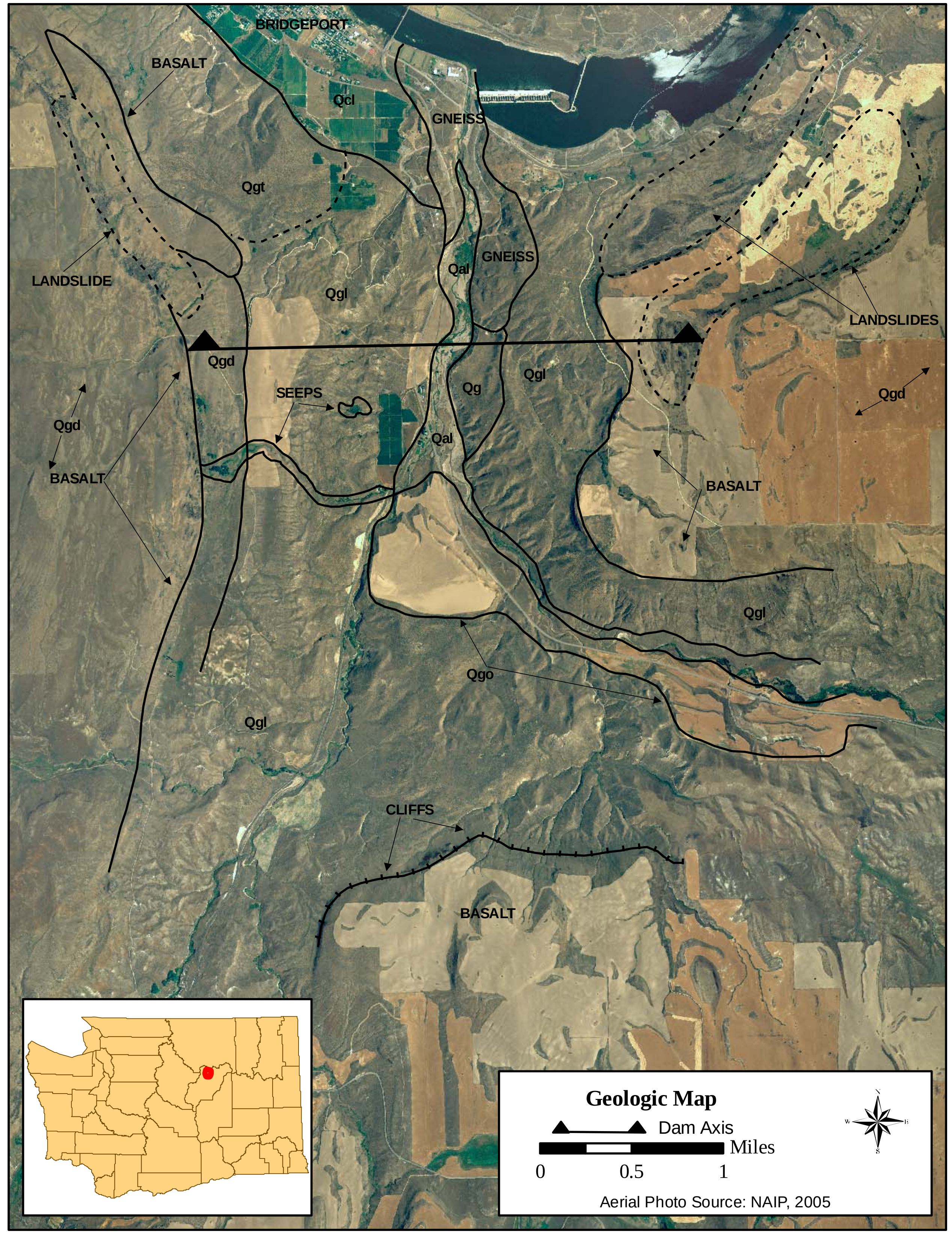


Plate 4-3.4
Foster Creek Geologic Map

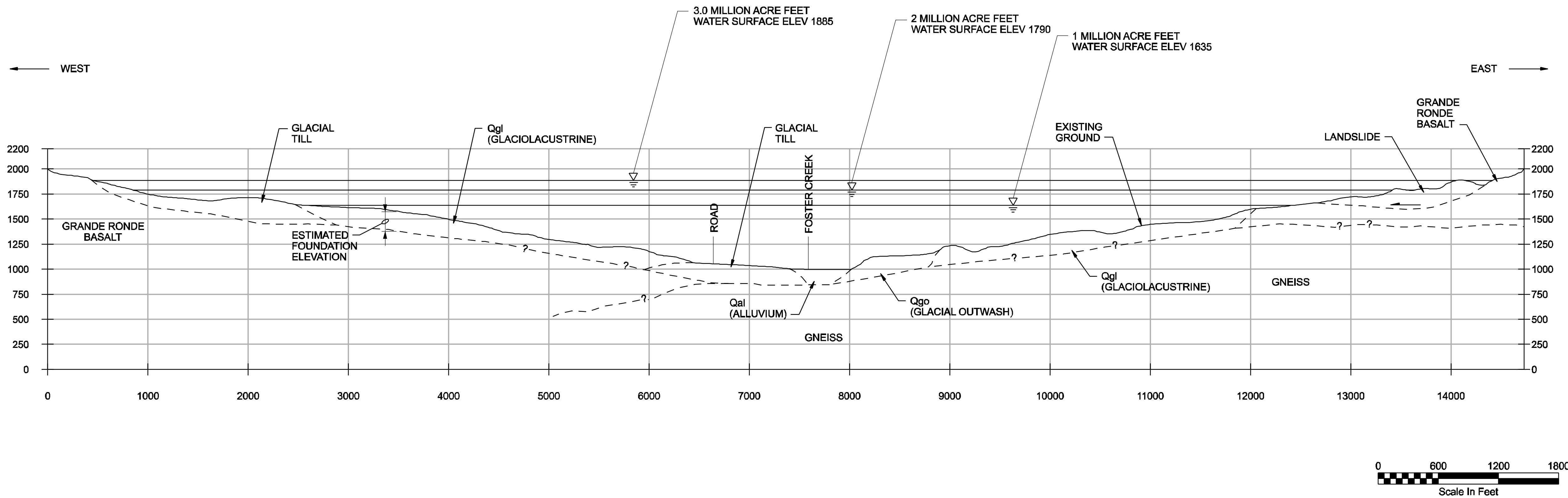


Plate 4-3.5
Foster Creek Dam Axis Cross Section

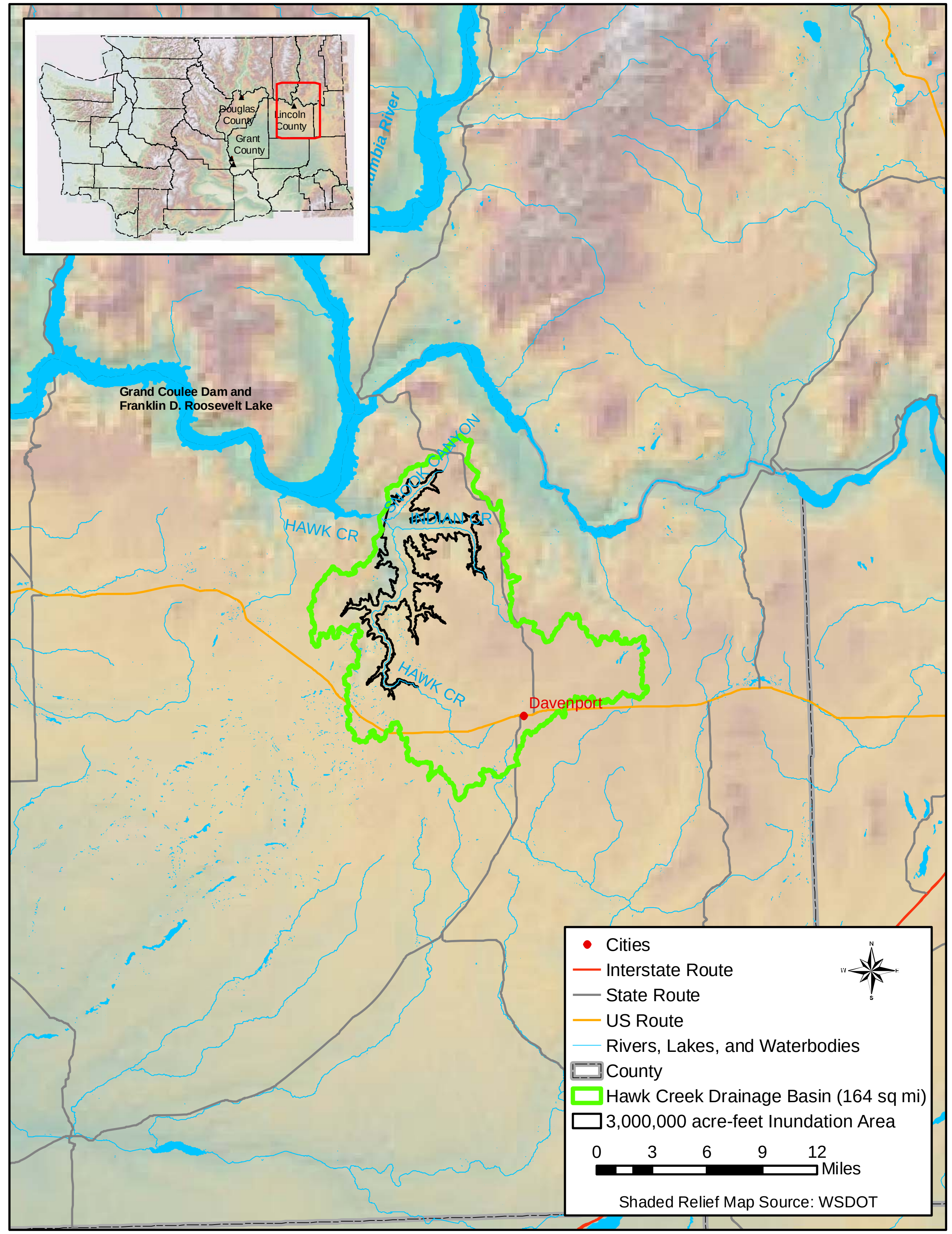


Plate 4-4.1
Hawk Creek Drainage Basin

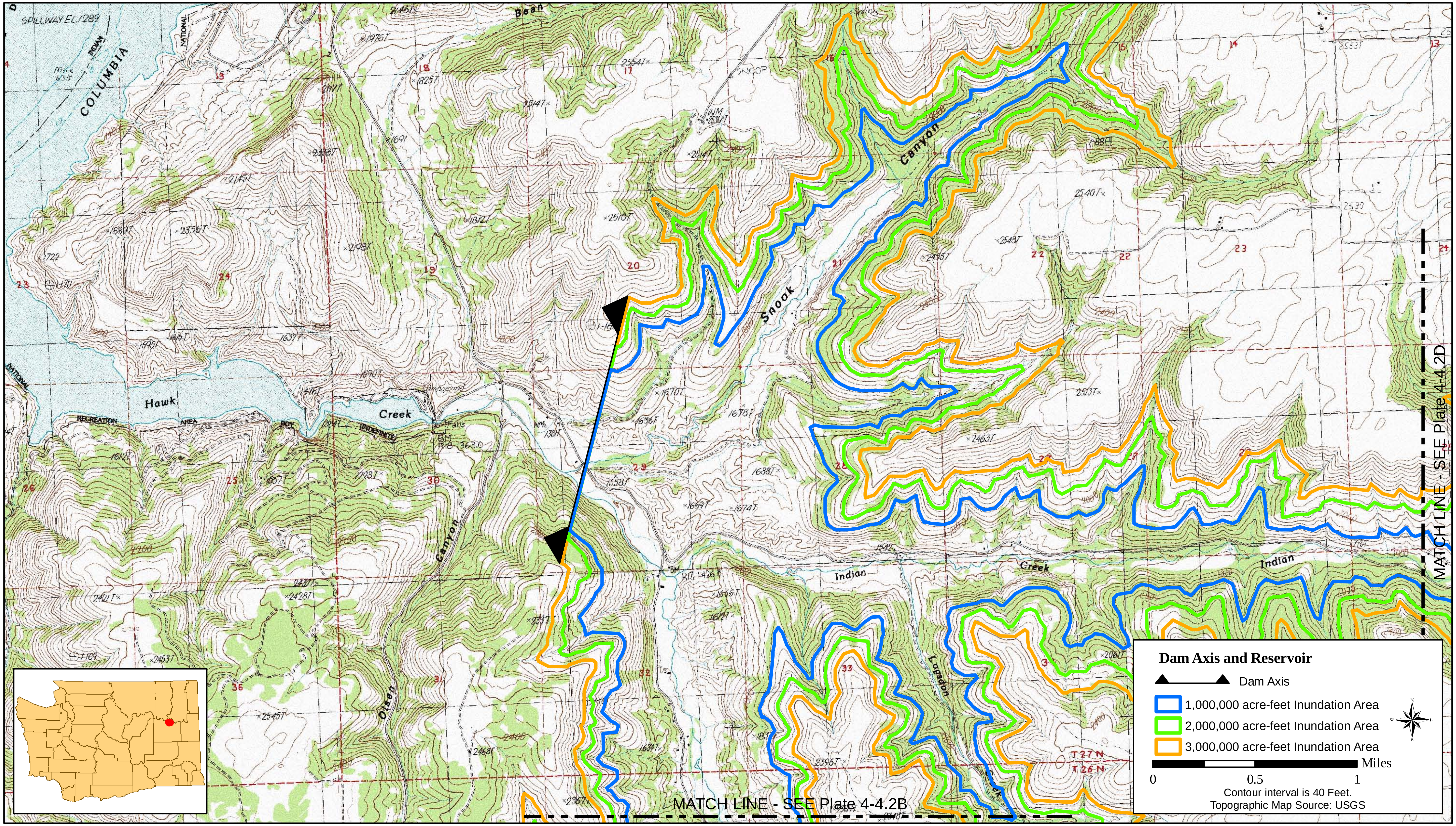


Plate 4-4.2A

Hawk Creek Dam Axis and Reservoir

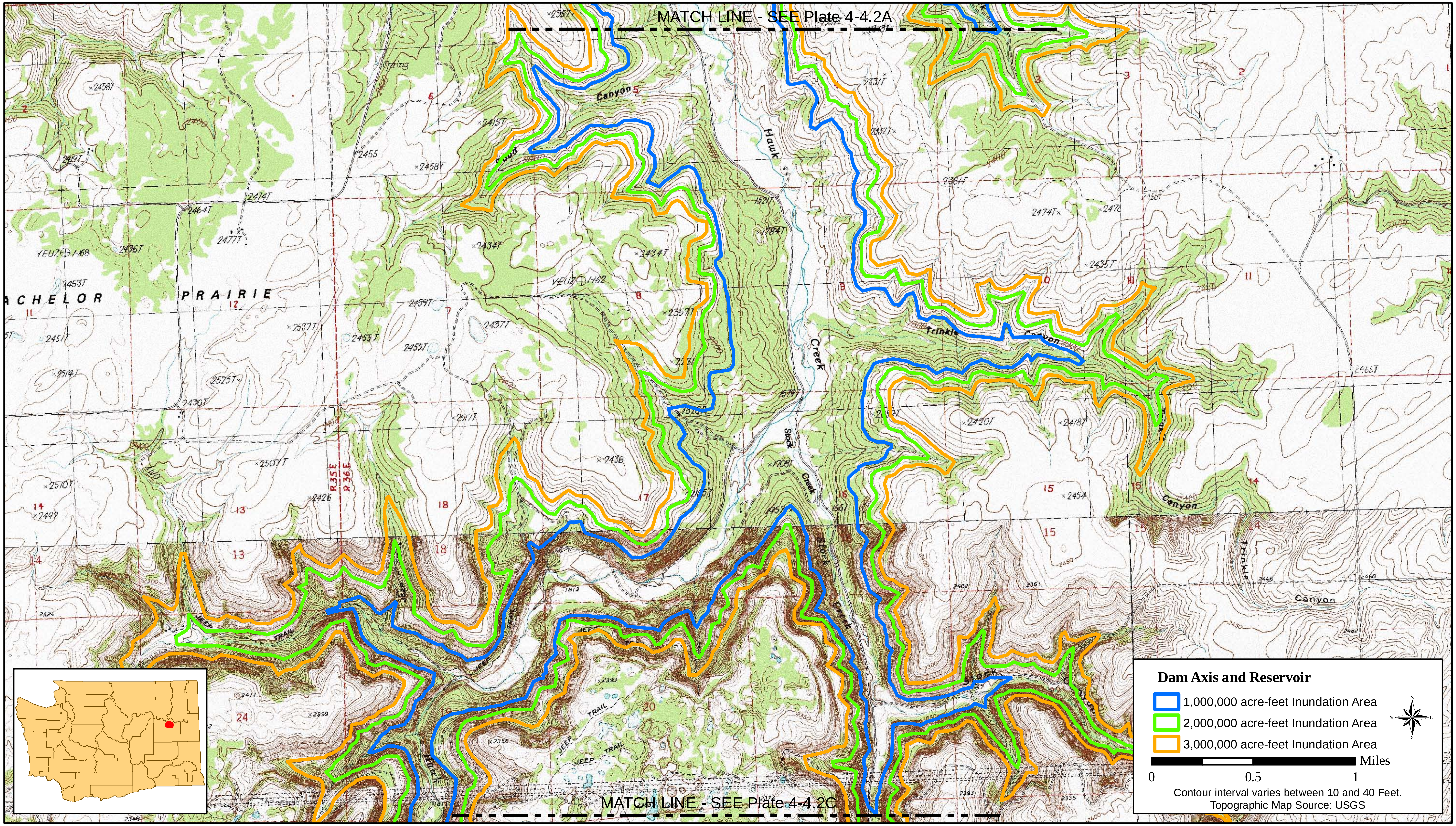


Plate 4-4.2B
Hawk Creek Dam Axis and Reservoir, Cont.

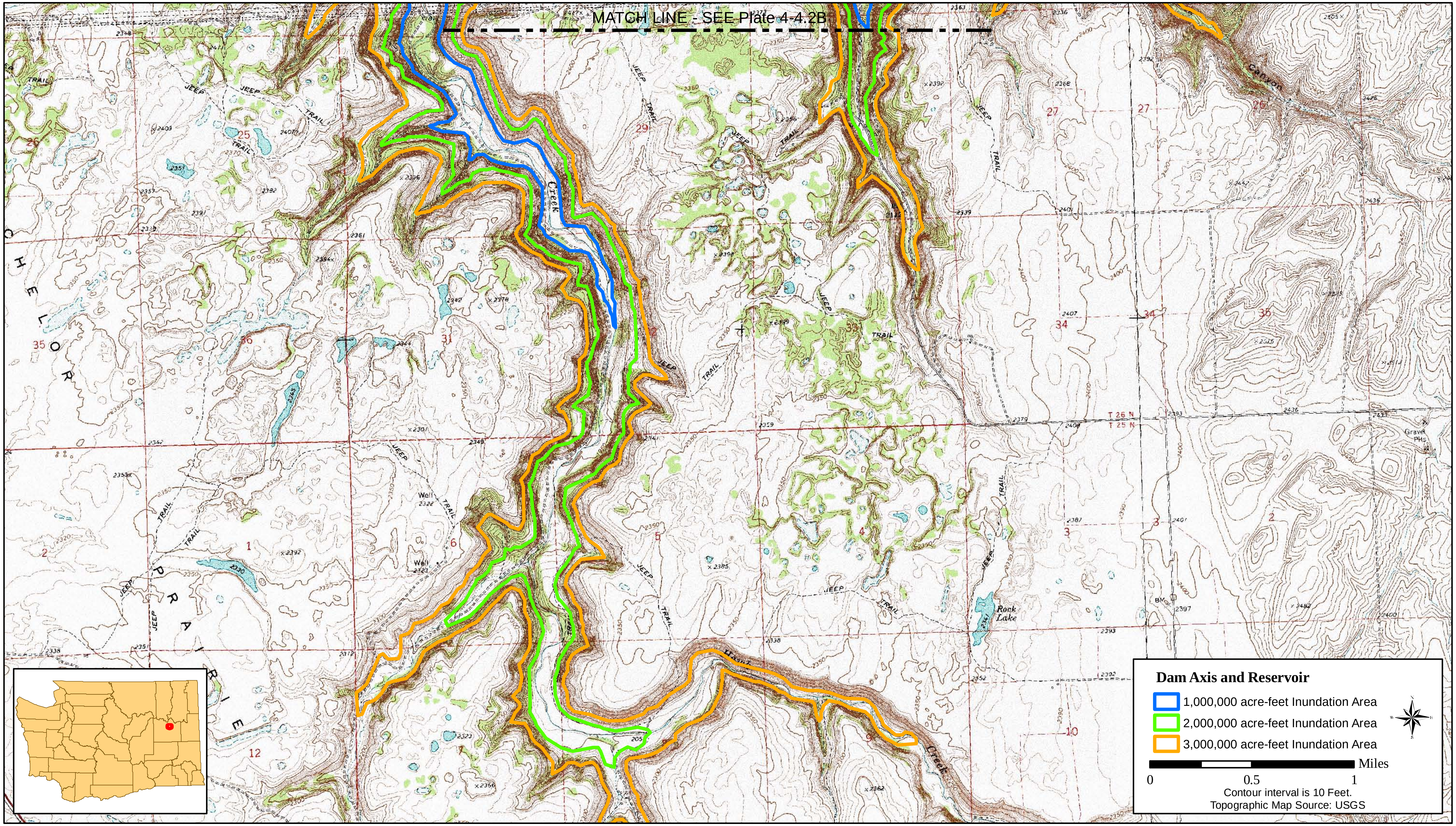


Plate 4-4.2C
Hawk Creek Dam Axis and Reservoir, Cont.

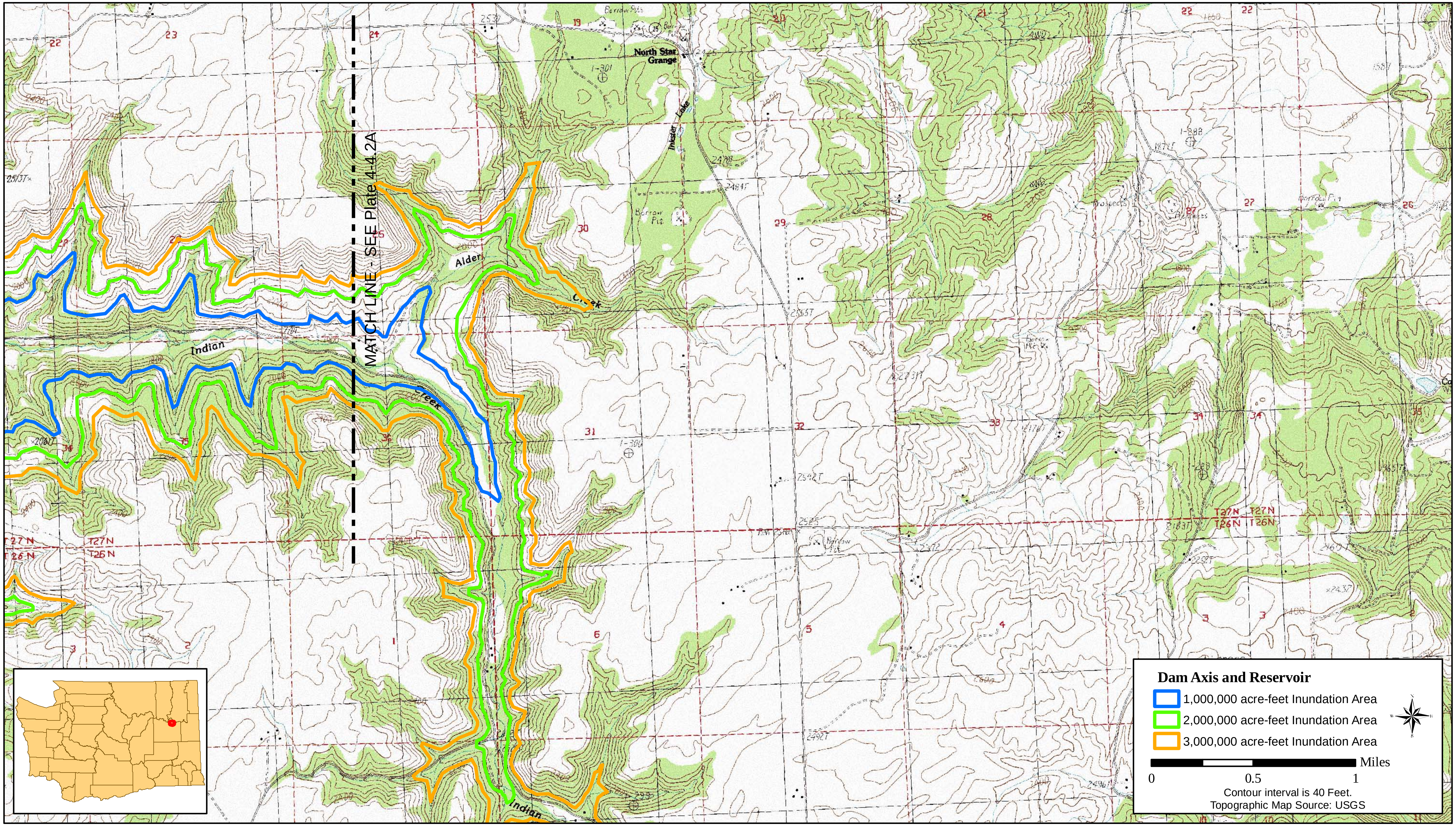


Plate 4-4.2D
Hawk Creek Dam Axis and Reservoir, Cont.

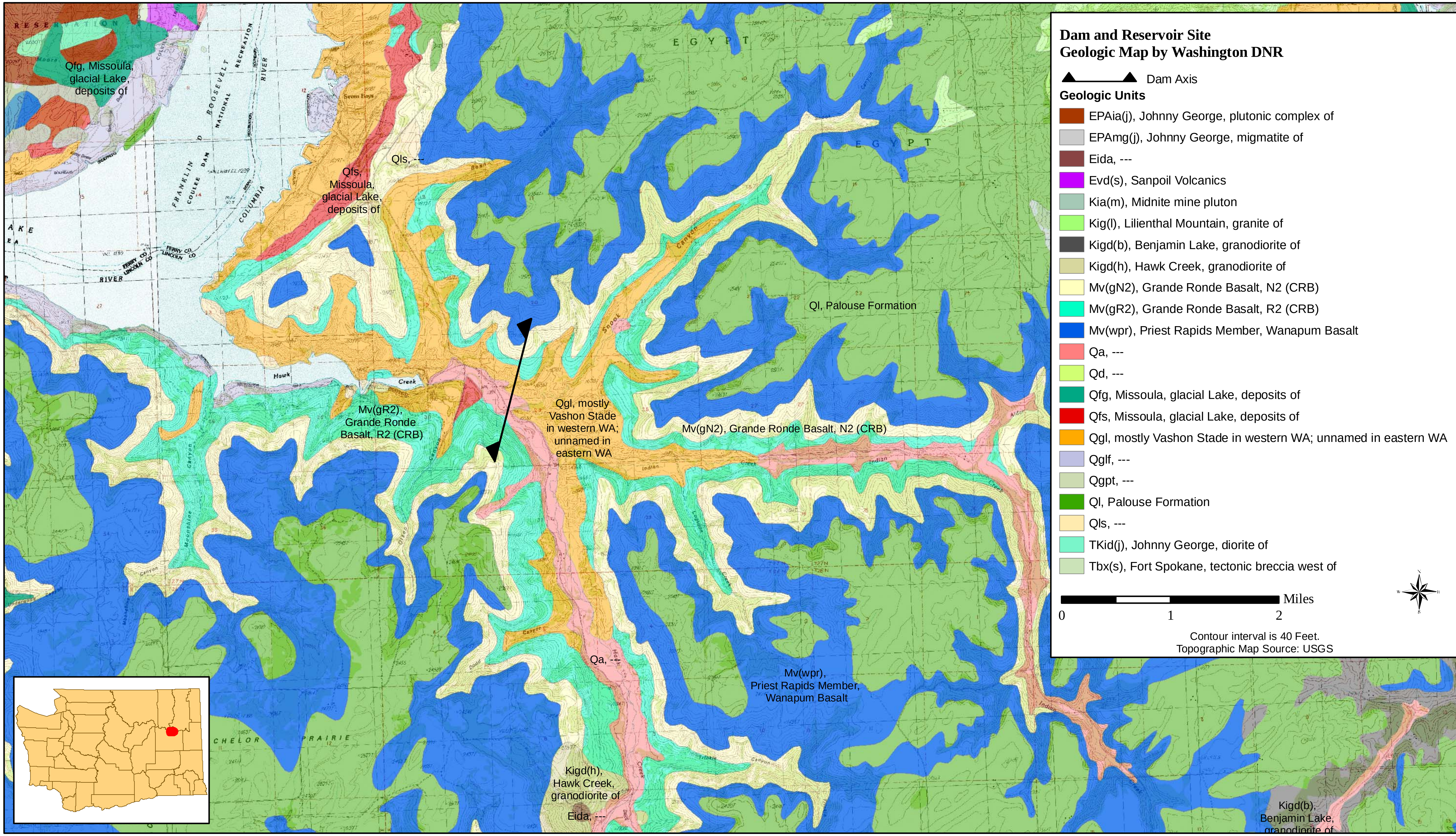


Plate 4-4.3
Hawk Creek Dam and Reservoir Site Map

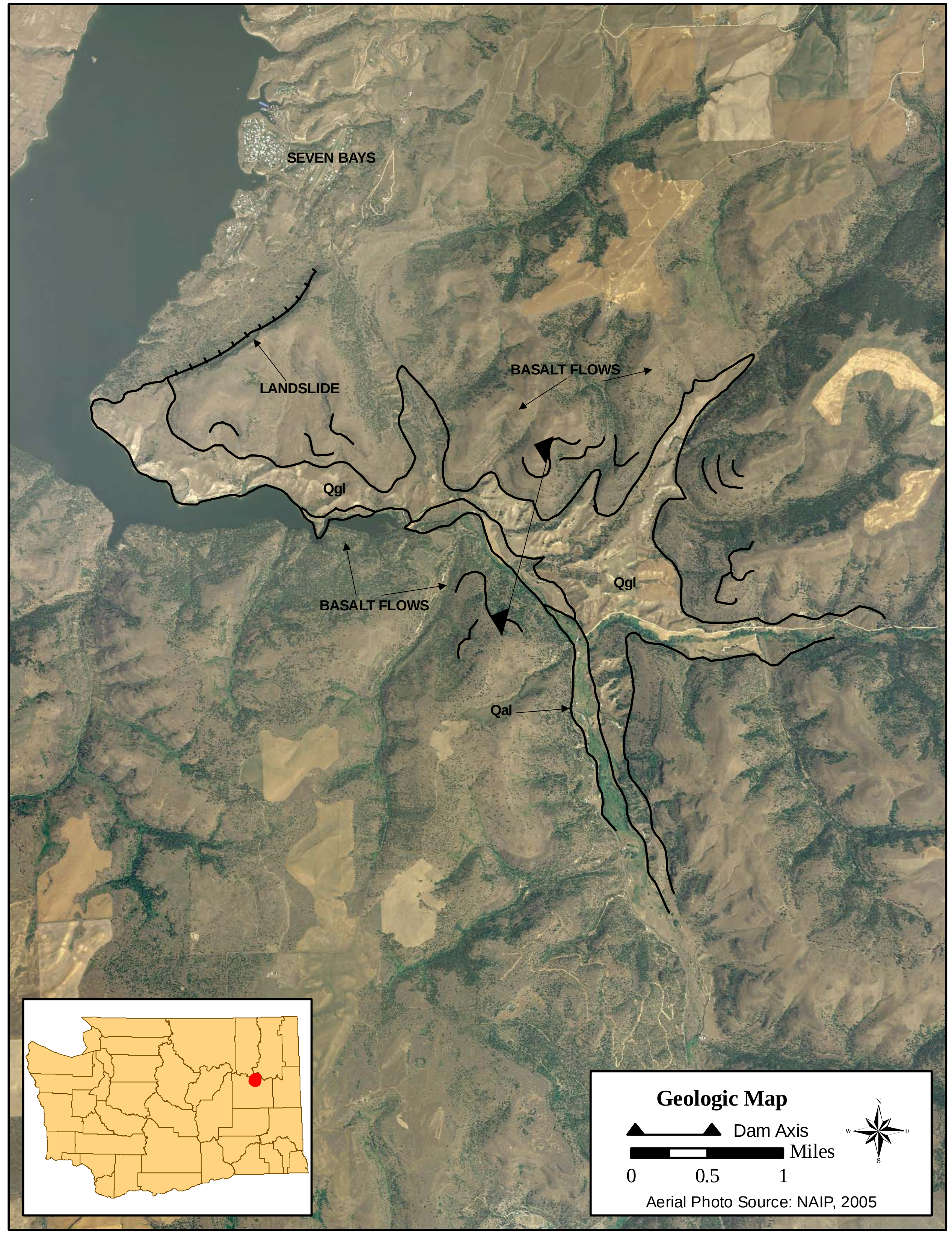


Plate 4-4.4
Hawk Creek Geologic Map

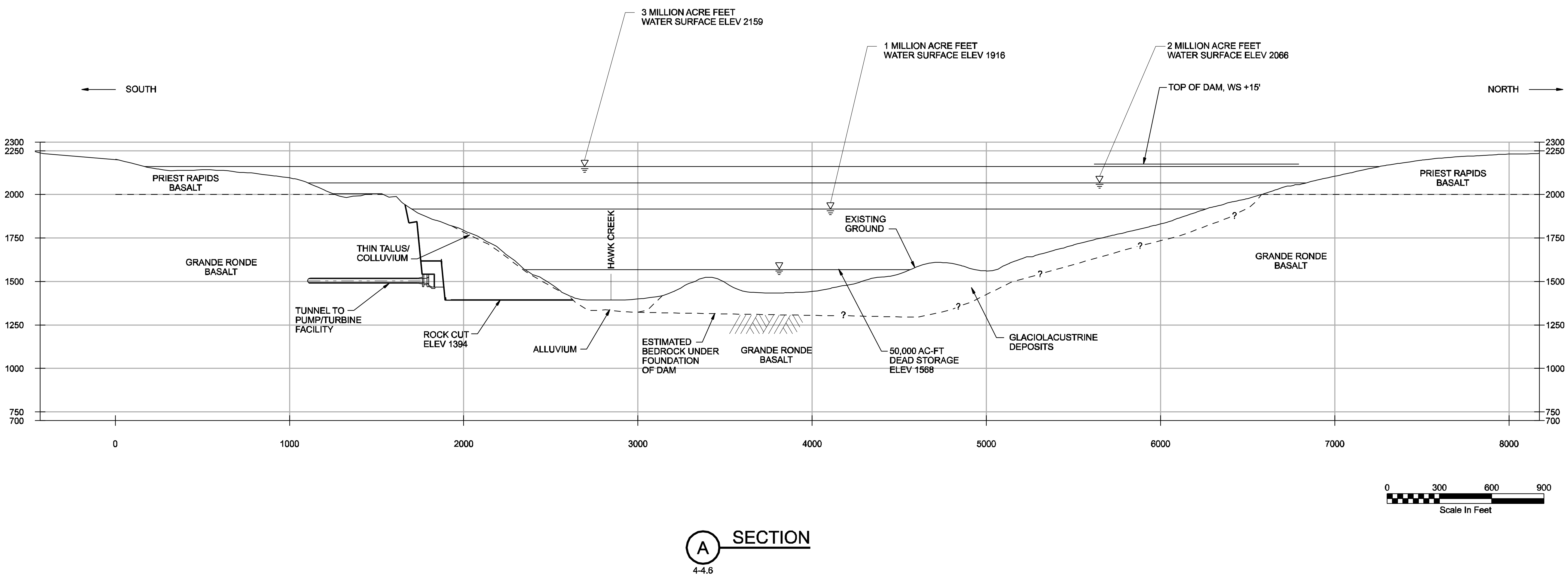
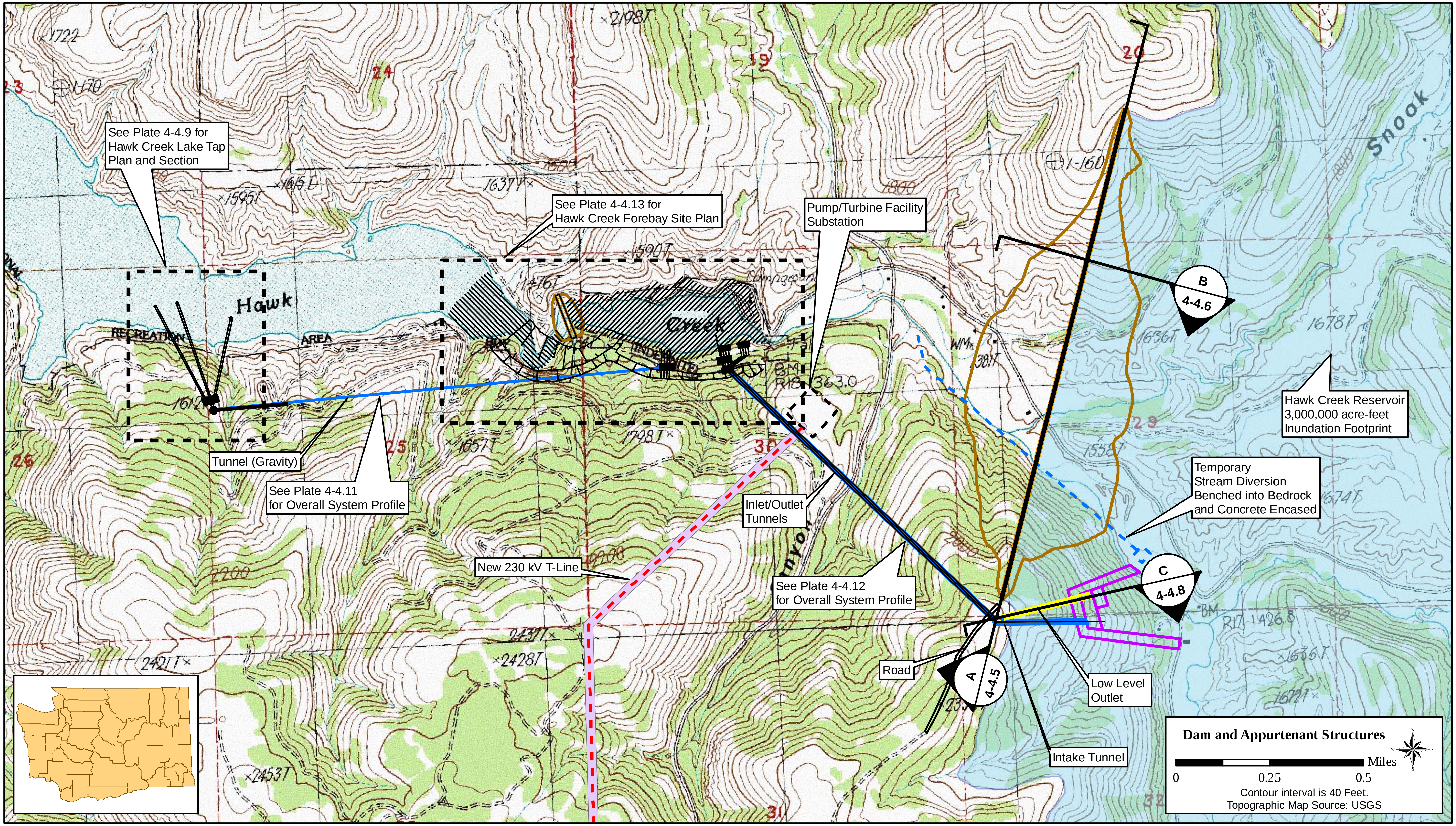
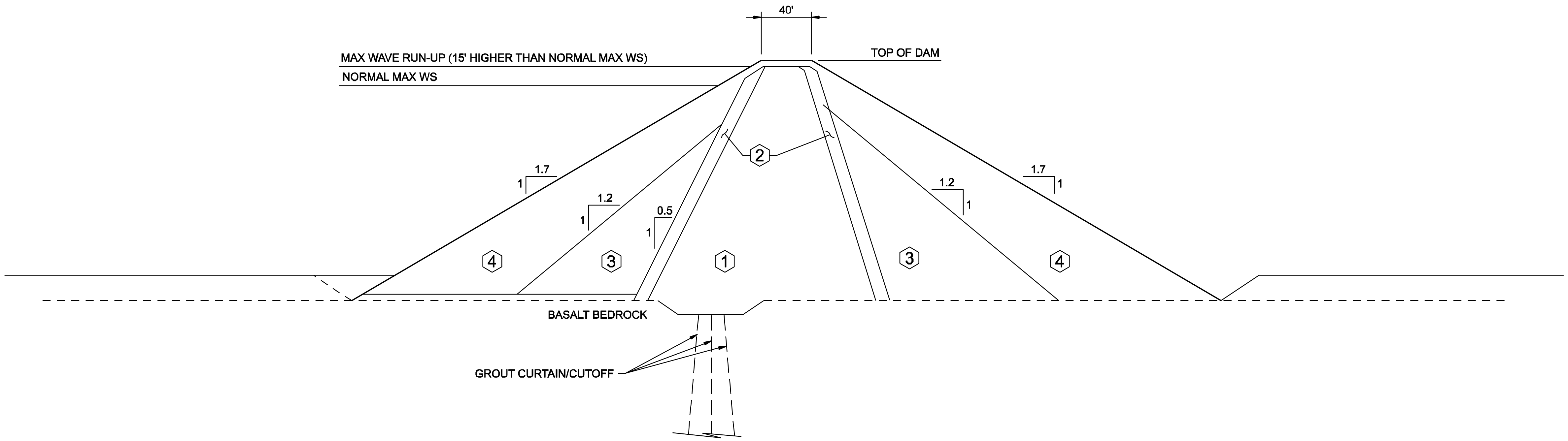


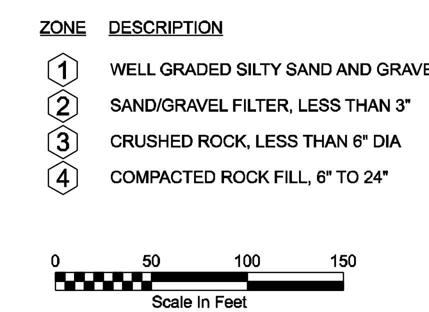
Plate 4-4.5
Hawk Creek Dam Axis Cross Section

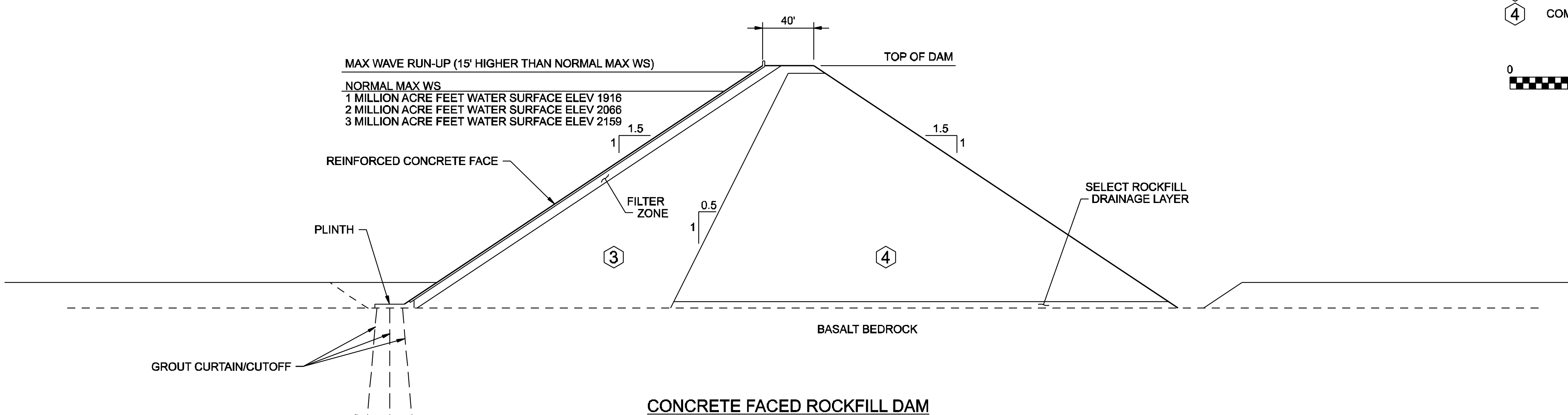

See Plate 4-4.9 for
Hawk Creek Lake Tap
Plan and Section
See Plate 4-4.13 for
Hawk Creek Forebay Site Plan
Pump/Turbine Facility
Substation
Hawk Creek Reservoir
3,000,000 acre-feet
Inundation Footprint
Temporary
Stream Diversion
Benched into Bedrock
and Concrete Encased
Tunnel (Gravity)
See Plate 4-4.11
for Overall System Profile
Inlet/Outlet
Tunnels
New 230 kV T-Line
See Plate 4-4.12
for Overall System Profile
Road
Low Level
Outlet
Intake Tunnel
B
4-4.6
C
4-4.8
A
4-4.5
Hawk
Creek
RECREATION
AREA
Snoak
Dam and Appurtenant Structures
Miles
0
0.25
0.5
Contour interval is 40 Feet.
Topographic Map Source: USGS



ROCKFILL DAM WITH EARTH CORE

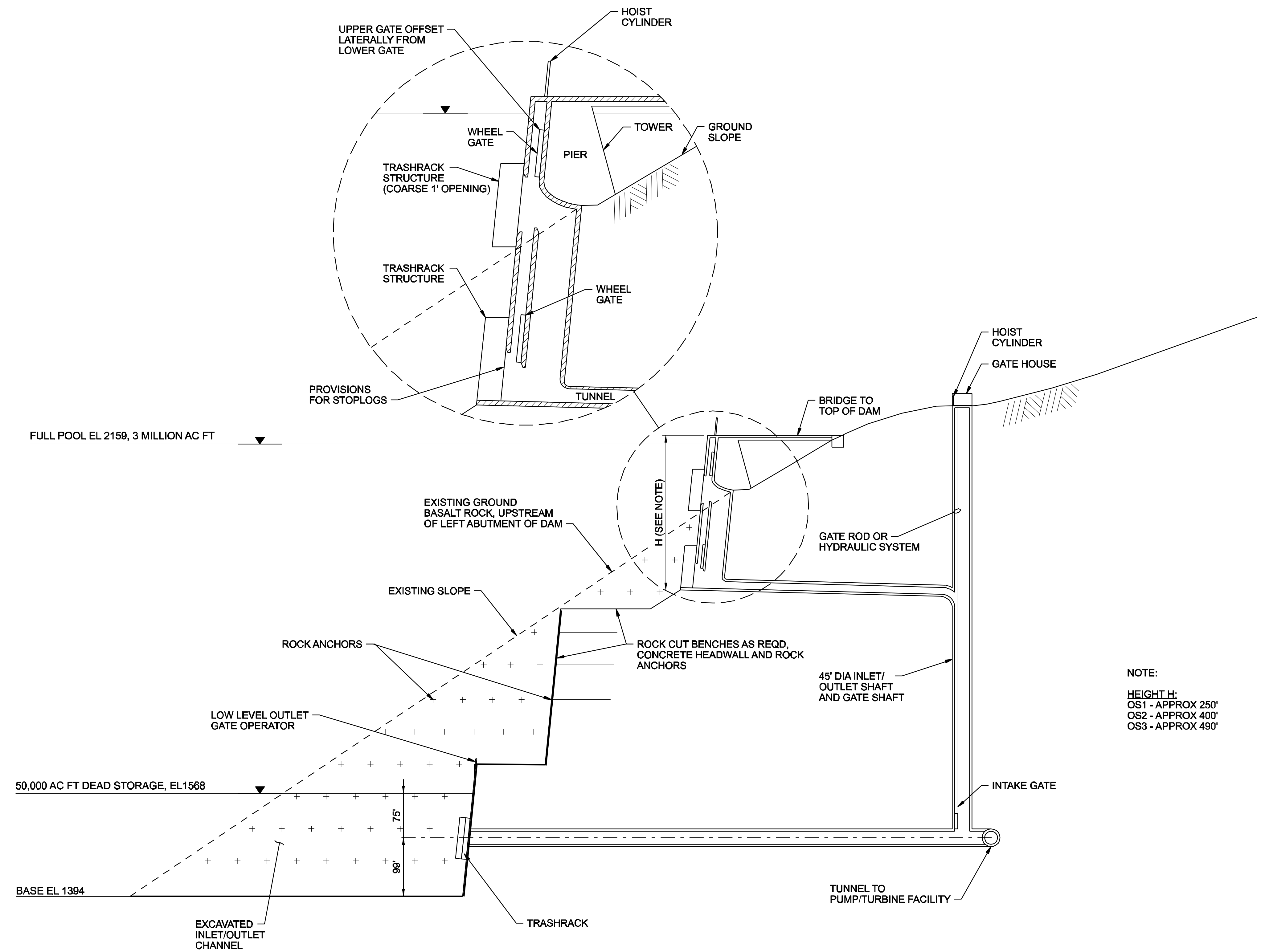
B SECTION
4-4.6





CONCRETE FACED ROCKFILL DAM

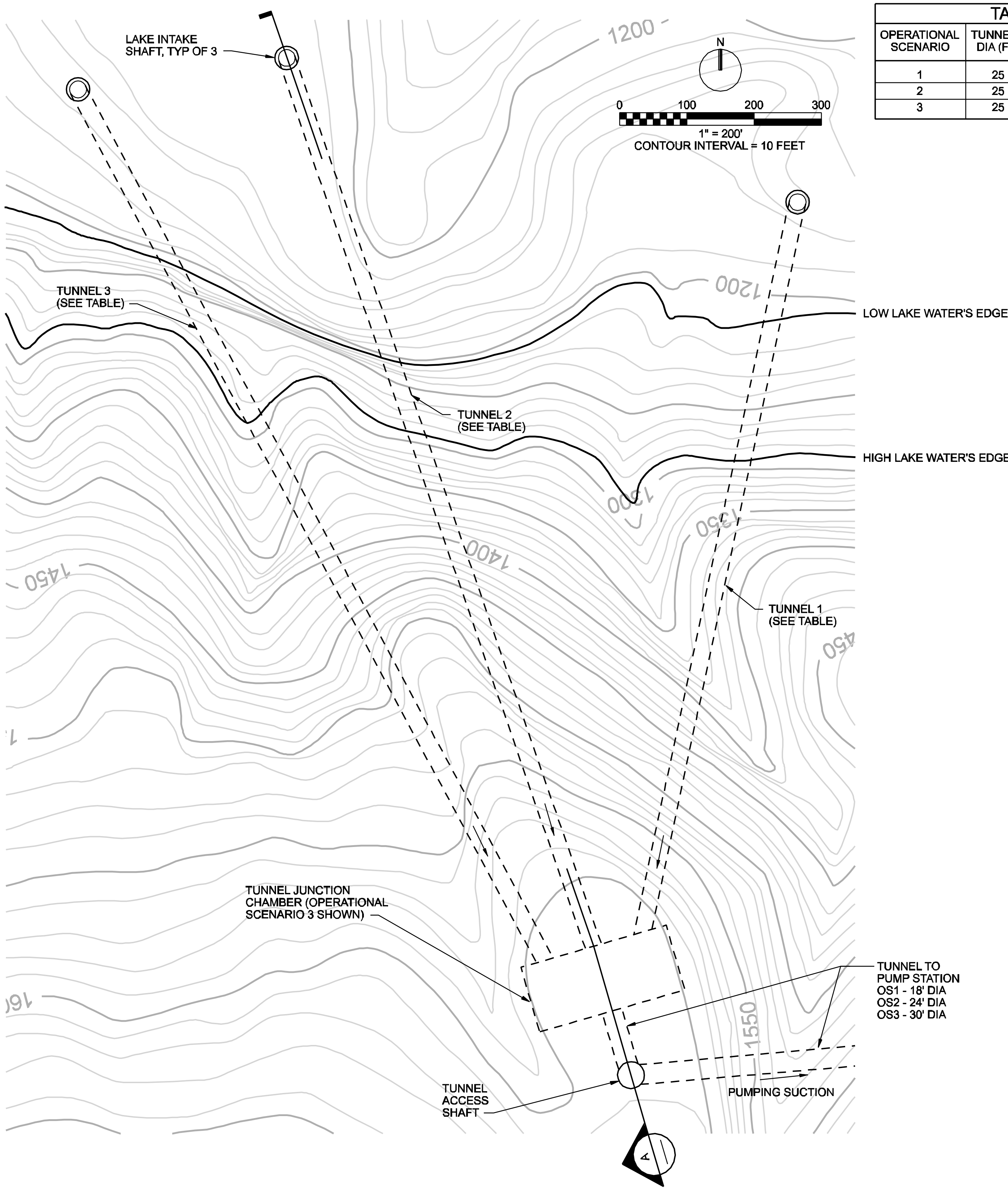
B SECTION
4-4.6



C
4-4.6
COMPOSITE SECTION
NTS

Plate 4-4.8
Hawk Creek Inlet/Outlet Works - Section

TABLE			
OPERATIONAL SCENARIO	TUNNEL 1 DIA (FT)	TUNNEL 2 DIA (FT)	TUNNEL 3 DIA (FT)
1	25	--	--
2	25	25	--
3	25	25	25



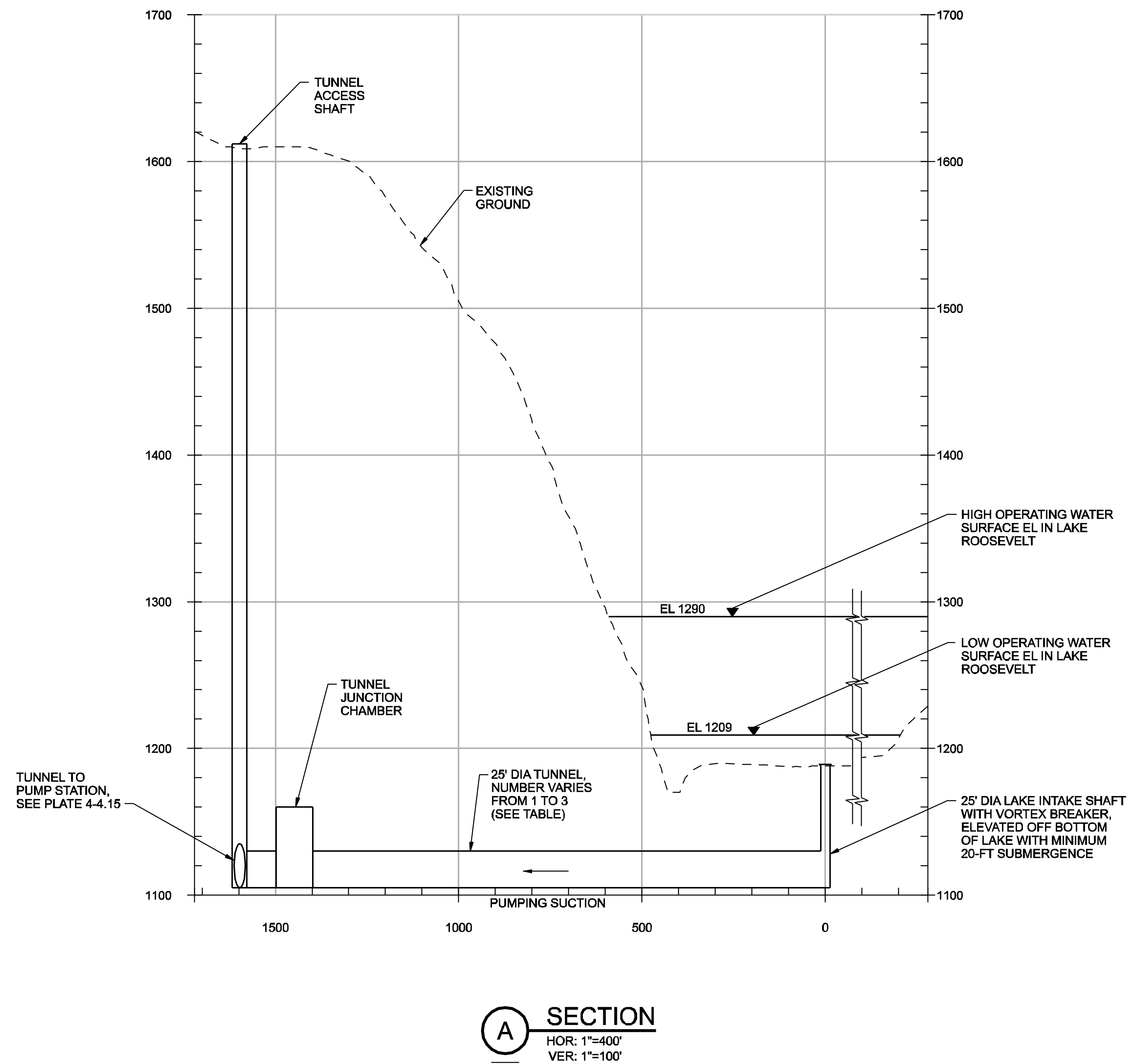
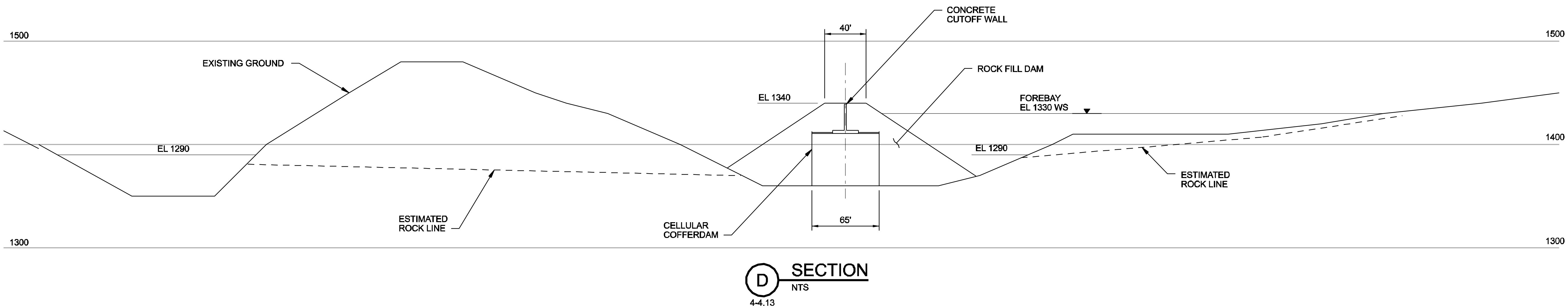


Plate 4-4.9
Hawk Creek Lake Tap Plan and Section



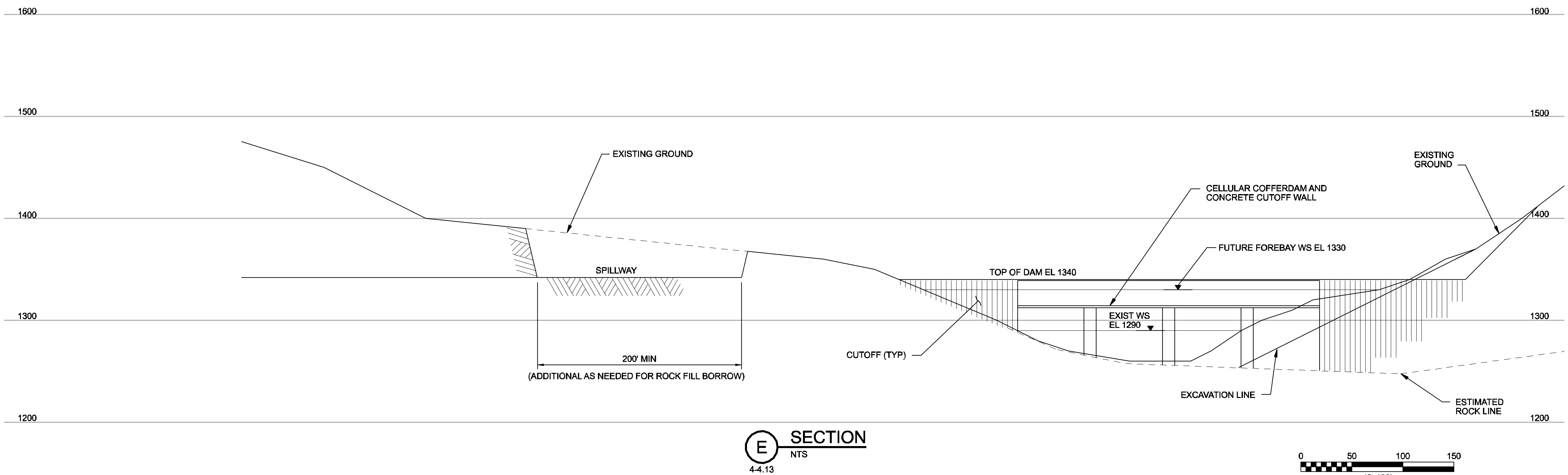


Plate 4-4.10
Hawk Creek Forebay Dam

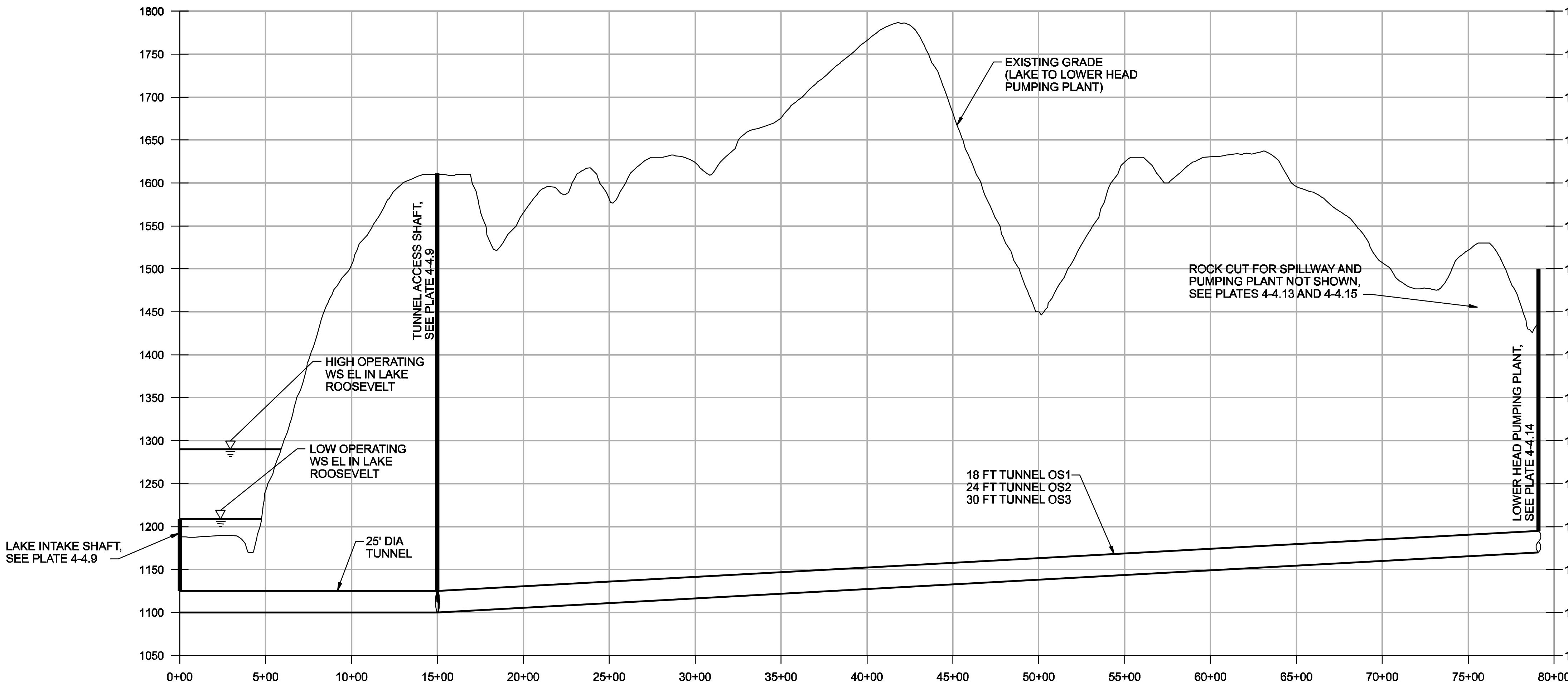


Plate 4-4.11
Hawk Creek Overall System Profile

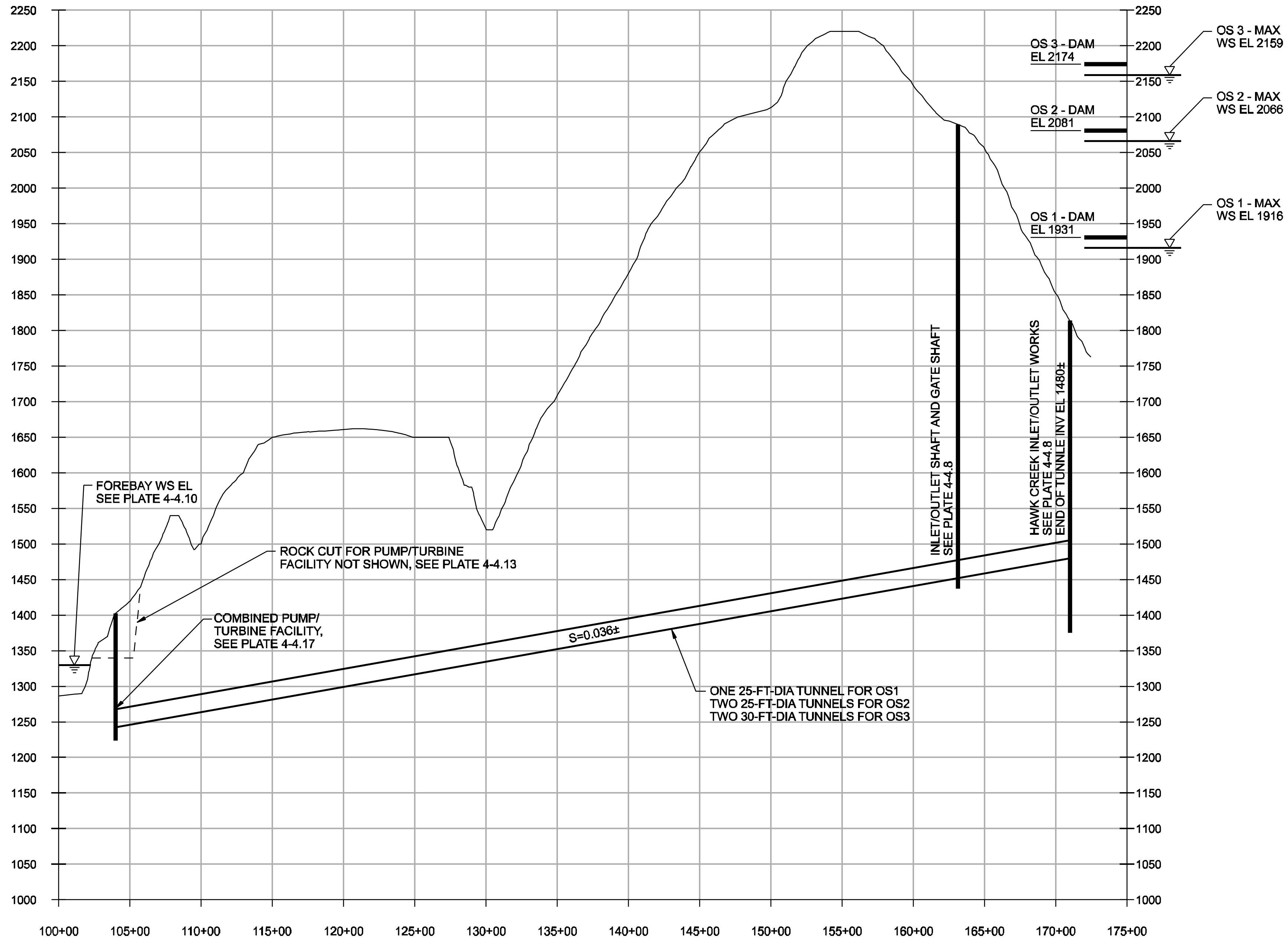


Plate 4-4.12
Hawk Creek Overall System Profile

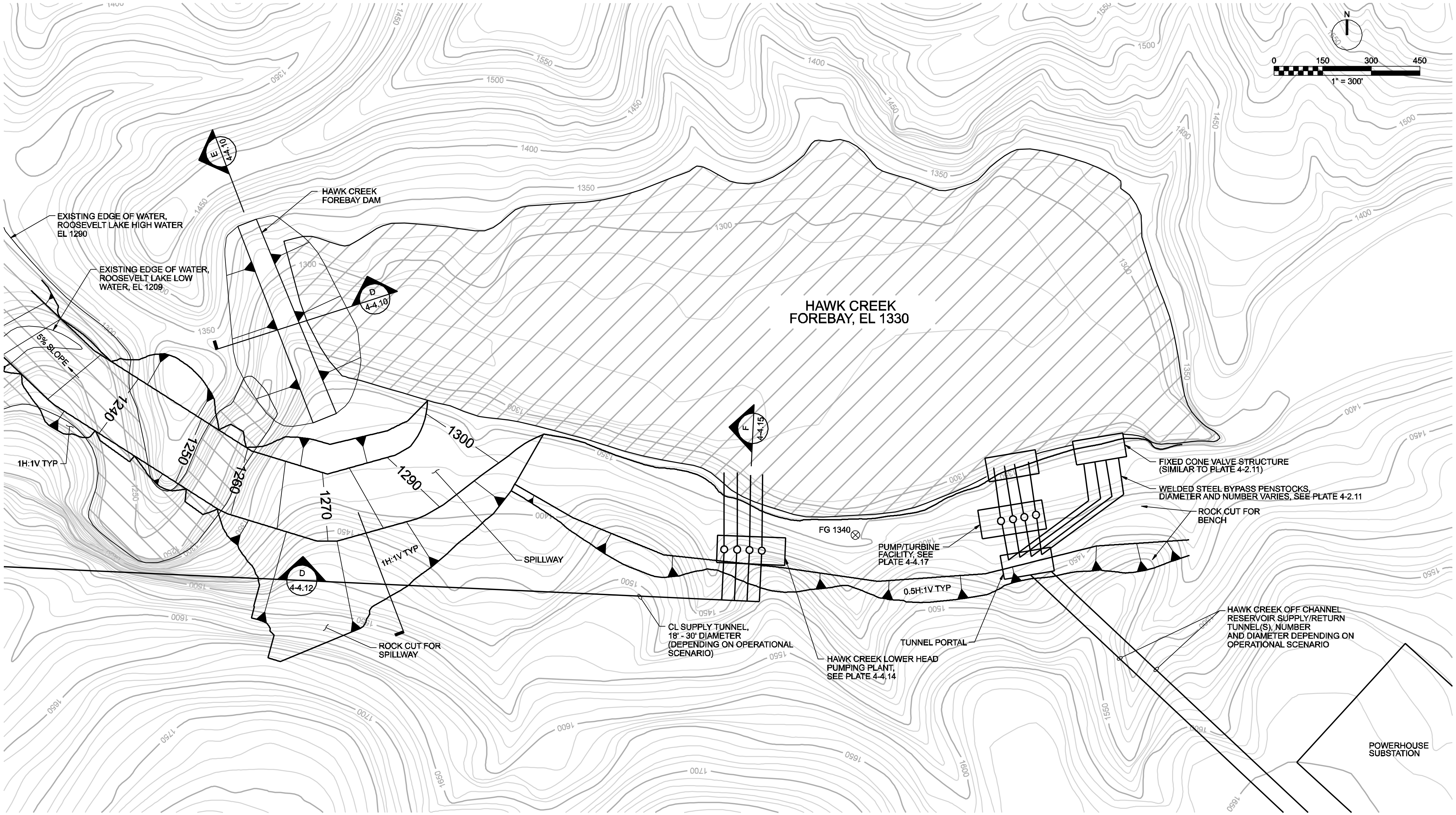
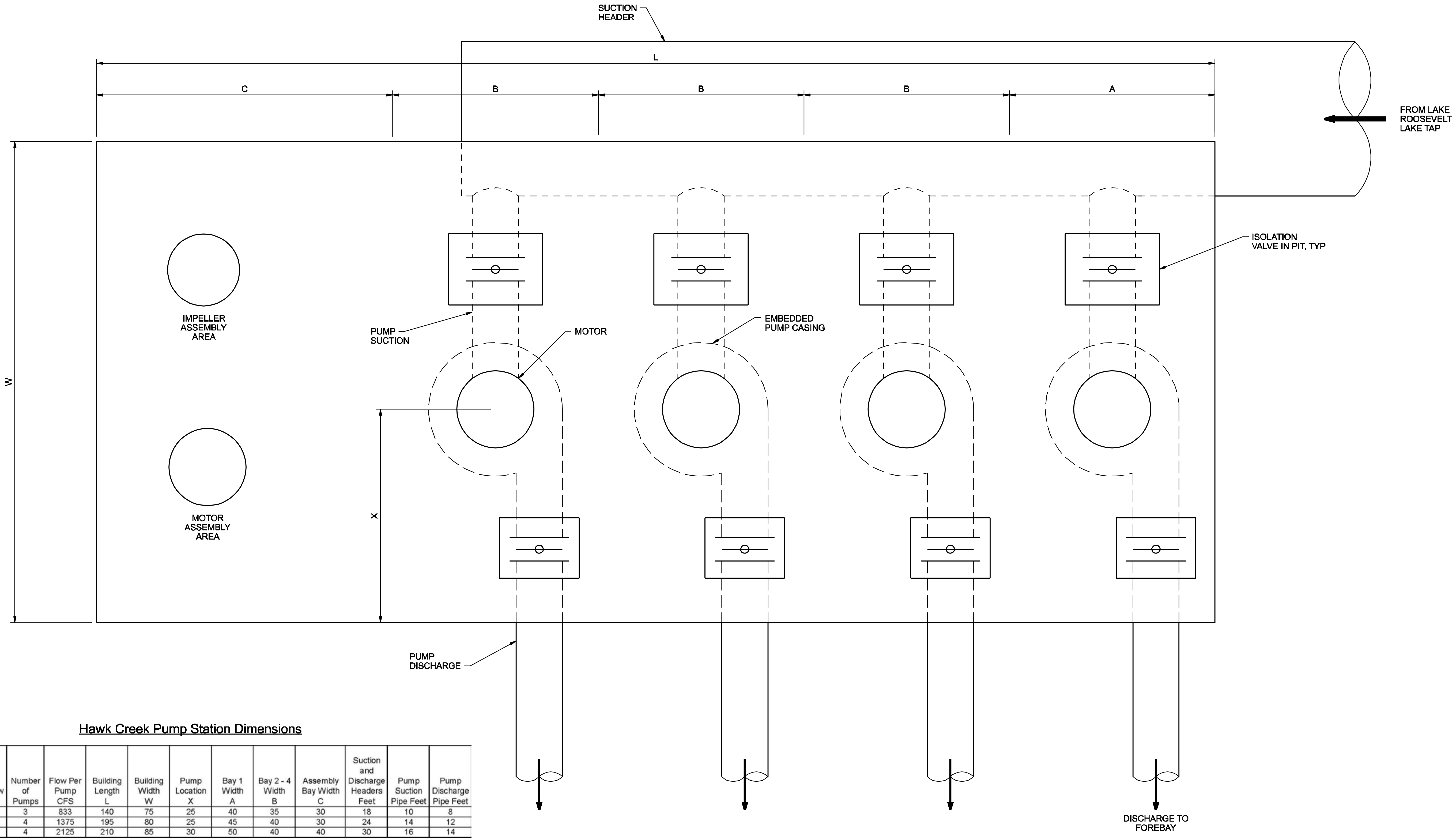


Plate 4-4.13
Hawk Creek Forebay Site Plan



Hawk Creek Pump Station Dimensions

Operational Scenario	Pump Plant Flow CFS	Number of Pumps	Flow Per Pump CFS	Building Length L	Building Width W	Pump Location X	Bay 1 Width A	Bay 2 - 4 Width B	Assembly Bay Width C	Suction and Discharge Headers Feet	Pump Suction Pipe Feet	Pump Discharge Pipe Feet
1	2500	3	833	140	75	25	40	35	30	18	10	8
2	5500	4	1375	195	80	25	45	40	30	24	14	12
3	8500	4	2125	210	85	30	50	40	40	30	16	14

PLAN
NTS

Plate 4-4.14
Hawk Creek Lower Head Pumping Plan - Plan

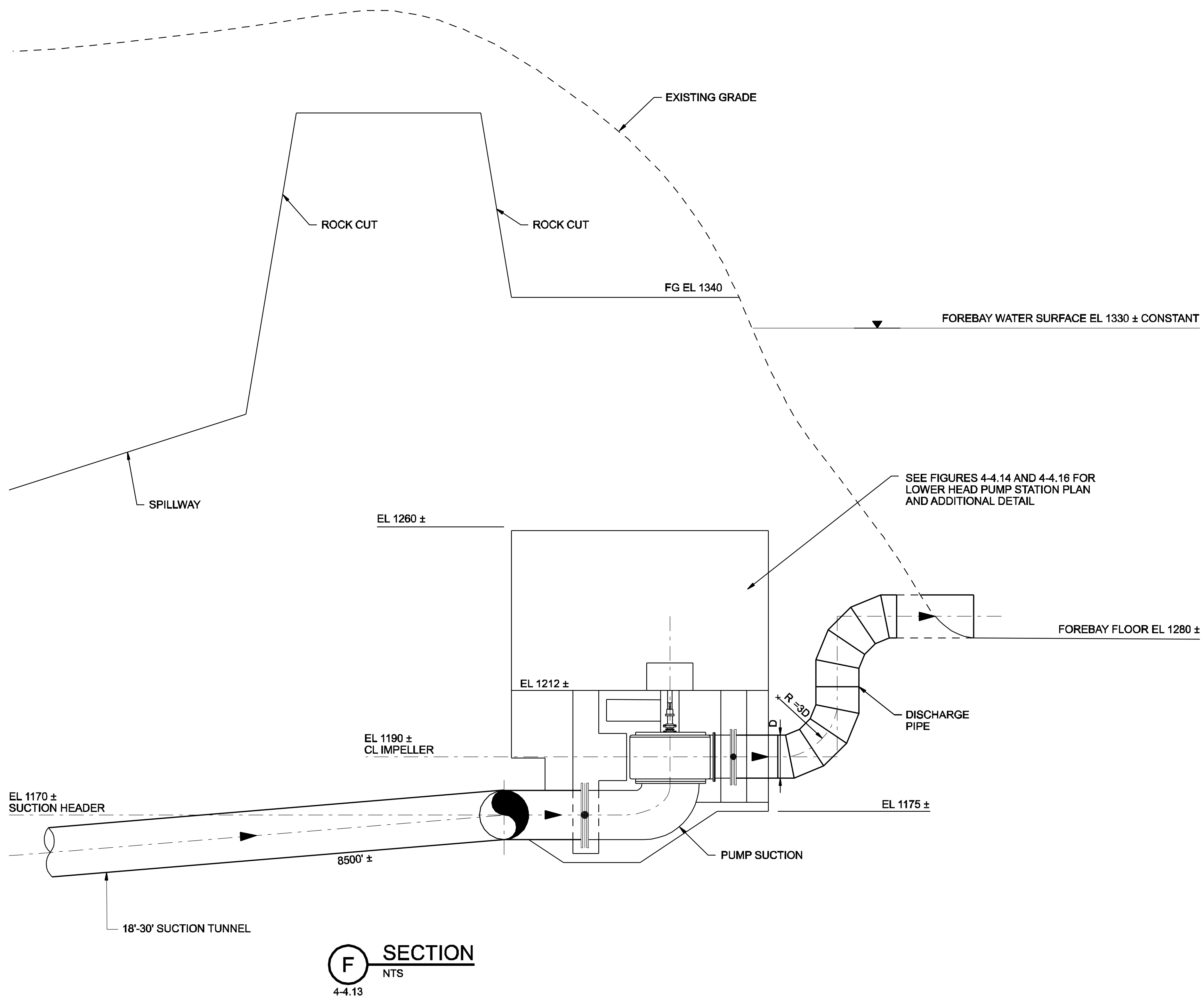
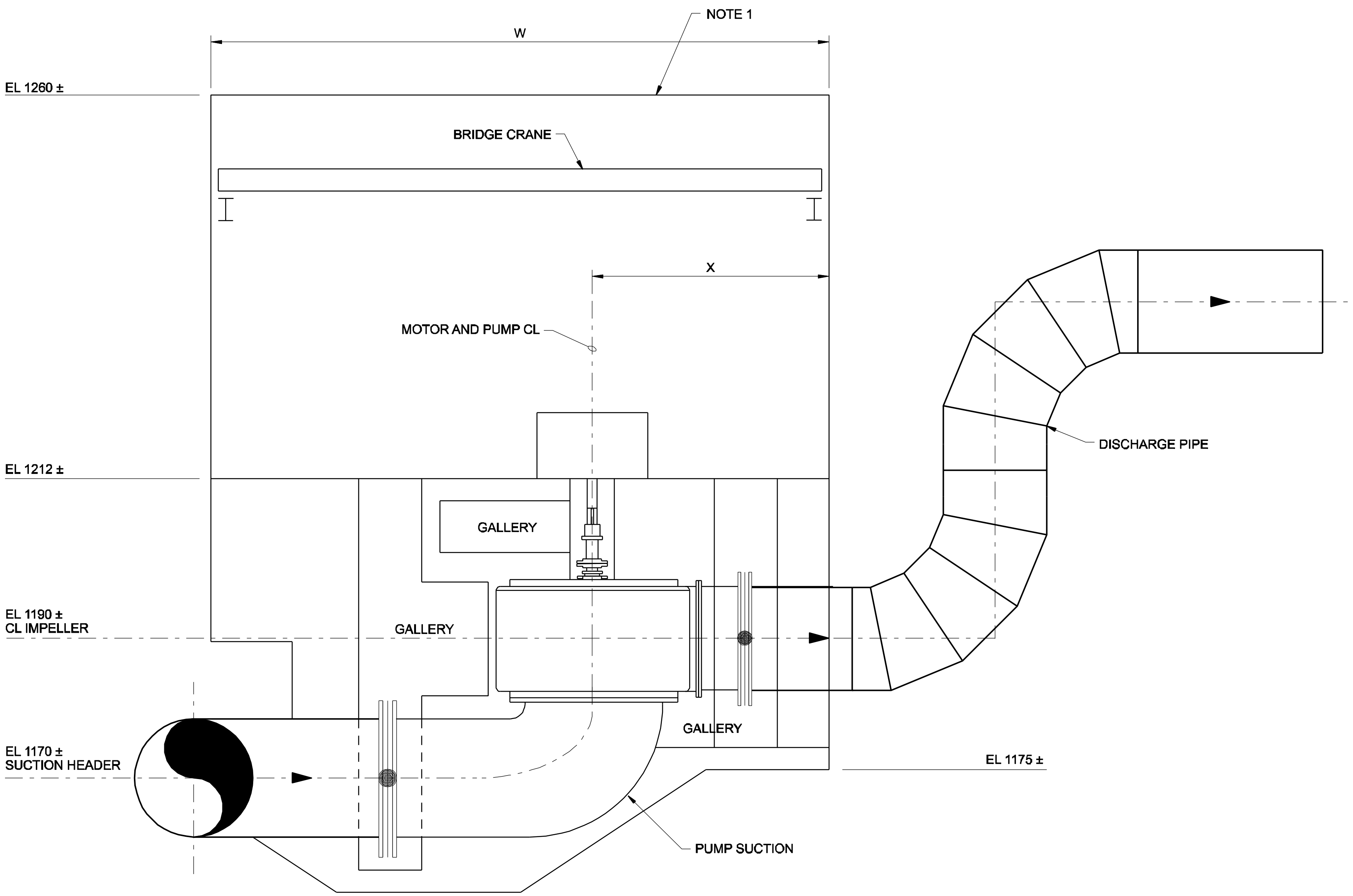


Plate 4-4.15
Hawk Creek Lower Head Pumping Plan - Section/Profile

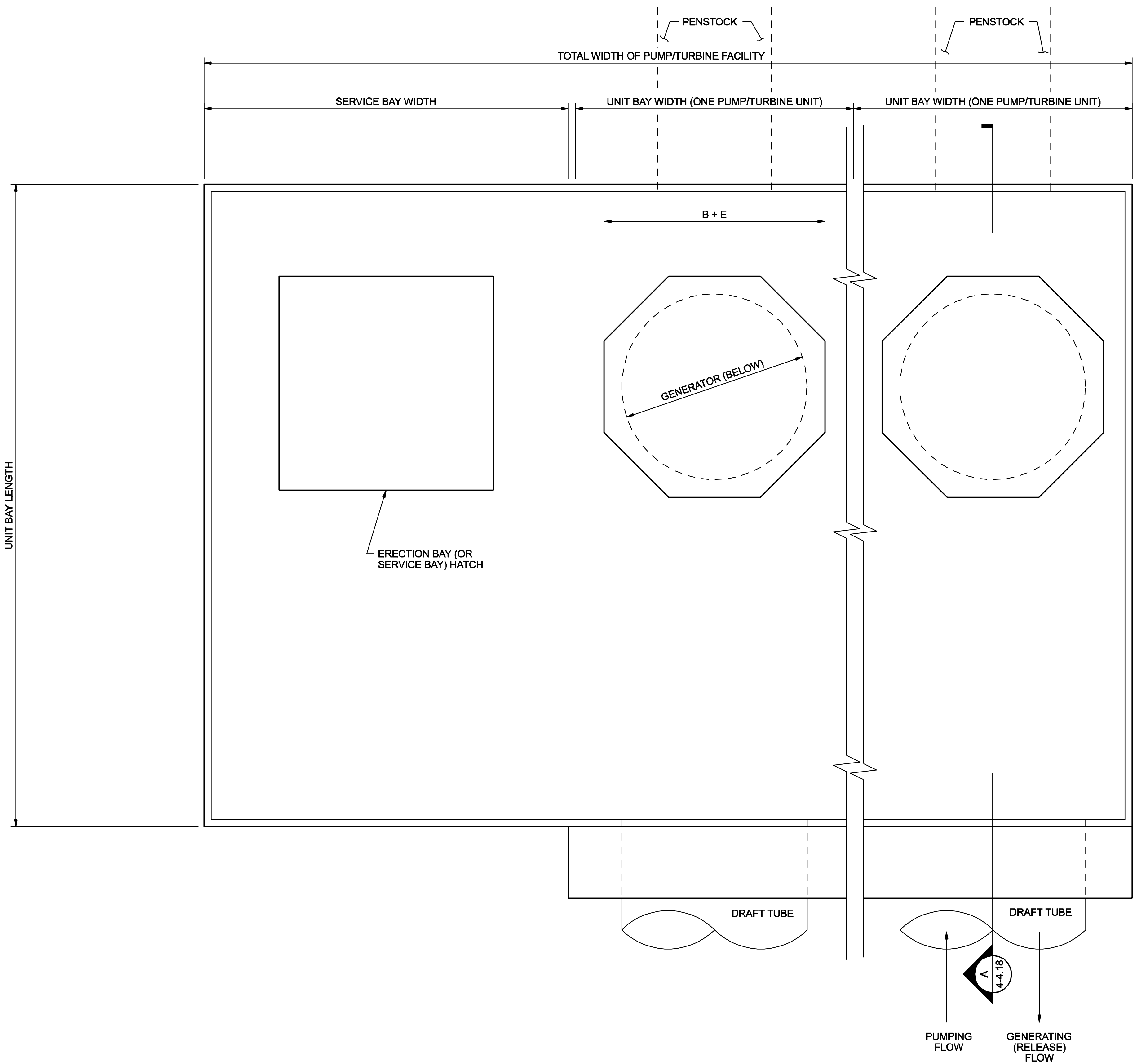


NOTE:
ROOF STRUCTURE MAY NEED TO BE ARCHED FOR THIS UNDERGROUND INSTALLATION.

Hawk Creek Pump Station Dimensions

Operational Scenario	Pump Plant Flow CFS	Number of Pumps	Flow Per Pump CFS	Building Length L	Building Width W	Pump Location X	Bay 1 Width A	Bay 2 - 4 Width B	Assembly Bay Width C	Suction and Discharge Headers Feet	Pump Suction Pipe Feet	Pump Discharge Pipe Feet
1	2500	3	833	140	75	25	40	35	30	18	10	8
2	5500	4	1375	195	80	25	45	40	30	24	14	12
3	8500	4	2125	210	85	30	50	40	40	30	16	14

Plate 4-4.16
Hawk Creek Lower Head Pumping Plan - Detail



	OPERATIONAL SCENARIO 1	OPERATIONAL SCENARIO 2	OPERATIONAL SCENARIO 3
UNIT BAY WIDTH (ONE UNIT)	36	37	37
NUMBER OF UNITS	3	4	4
SERVICE BAY WIDTH	47	48	48
TOTAL WIDTH OF PUMP/TURBINE FACILITY	156	195	194
UNIT BAY LENGTH	84	86	86
B + E (SPIRAL CASE WIDTH PARALLEL TO FLOW)	28	28	28
DRAFT TUBE DIAMETER	25	26	24
NUMBER OF DRAFT TUBES	3	4	4
PENSTOCK DIAMETER	12	15	17
NUMBER OF PENSTOCKS	3	4	4
PEAK PUMPING FLOW (CFS)	2500	5500	8500
PEAK RELEASE FLOW (CFS)	6500	13500	18500
CENTERLINE ELEVATION OF PENSTOCKS/UNITS	1198	1182	1198

Plate 4-4.17
Hawk Creek Pump/Turbine Facility - Plan

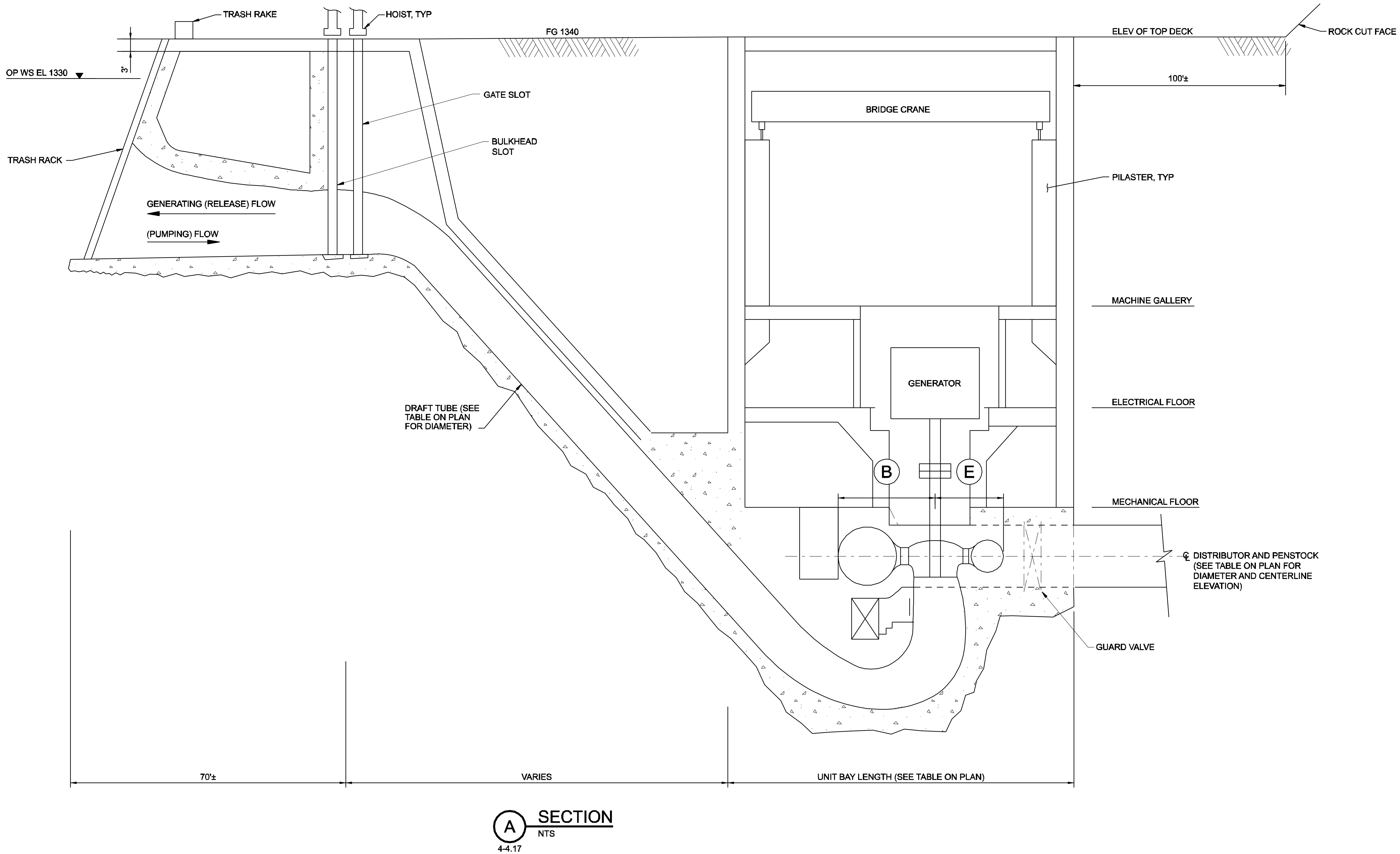


Plate 4-4.18
Hawk Creek Combined Pump/Turbine Facility Section

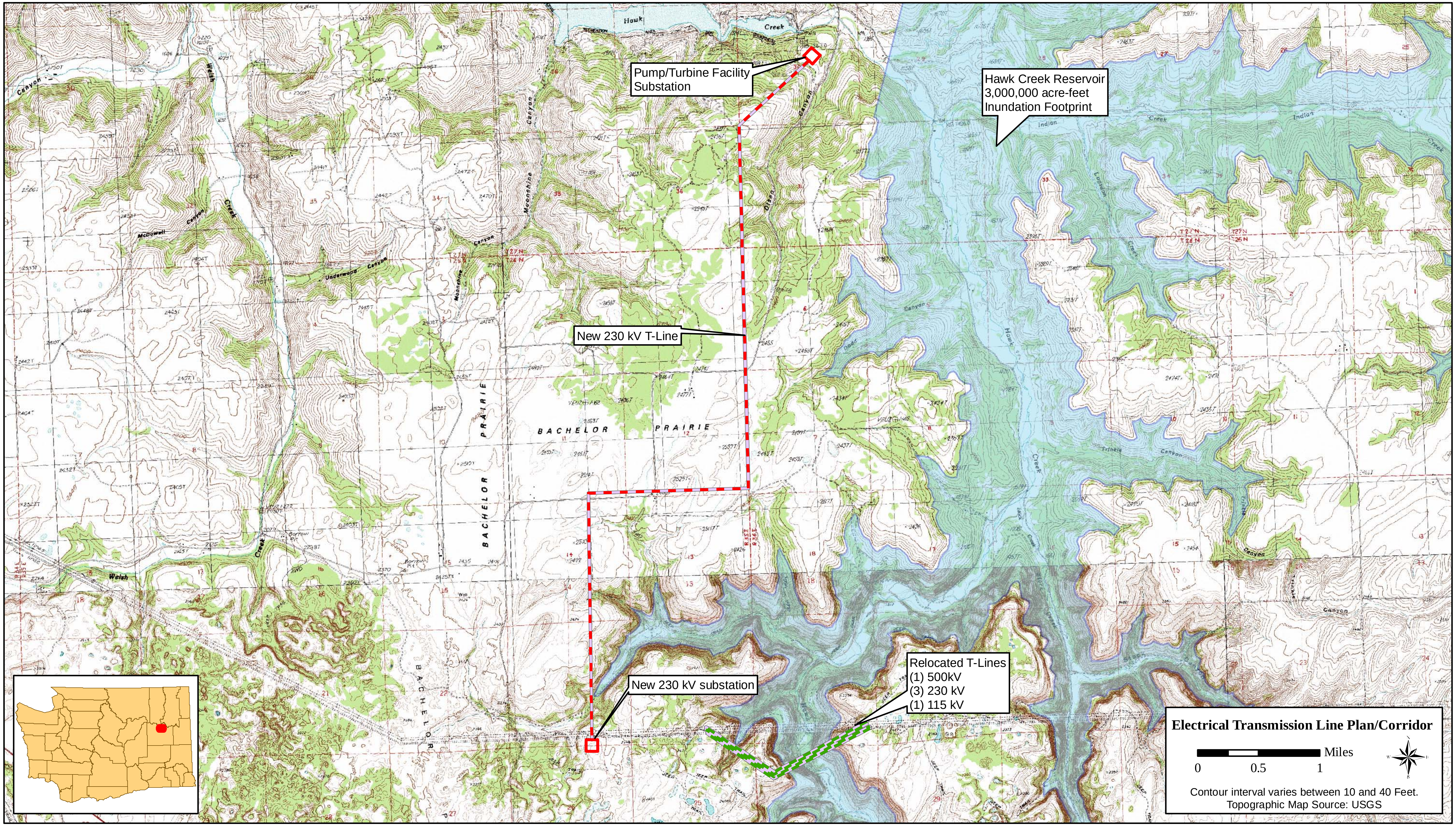


Plate 4-4.19
Hawk Creek Electrical Transmission Line Plan/Corridor