RECLAMATION
Managing Water in the West

Technical Memorandum
Alternative A—Crab Creek
(Note: This document supports Alternatives 2A and 2B in the Draft Environmental Assessment)

Potholes Reservoir Supplemental Feed Route Draft Environmental Assessment

Columbia Basin Project
Grant County, Washington

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

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Bureau of Reclamation—Supplemental Feed Route for Potholes Reservoir

Alternative A—Crab Creek

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Executive Summary

The Bureau of Reclamation (Reclamation) is evaluating three alternatives for supplementing water supply to the Potholes Reservoir in central Washington. This memorandum is focused on Alternative C, which provides supplemental flows (released from the outlet works of Pinto Dam) to the Potholes Reservoir through the existing channel of Crab Creek.

The Crab Creek work includes initial scoping and evaluation of alternatives, surveying, and conceptual design and development of estimated costs for each element of this alternative. The work includes an evaluation of feasibility of construction, impacts to property, capital costs, and operations and maintenance requirements to identify the most beneficial configuration of this alternative to design, fund, and construct.

The memorandum presents the Crab Creek findings in three primary sections:

- Sediment Transport Analysis
- Structural Modifications
- Dieringer Dairy Wastewater Improvements

Each of the three sections includes a description of the associated field work, data analysis/modeling, conceptual design, and cost estimates. To support this work, Reclamation performed a test release from the Pinto Dam outlet during summer and fall 2006, including a 1,000 cfs release for a short time (which is approximately the maximum possible release from the outlet). The test releases presented an opportunity to observe water flowing throughout the entire 23-mile reach as well as at specific locations of interest including the Pinto Dam outlet, Brook Lake and its outlet, Crab Creek between Brook Lake and the East Low Siphon, and around the Dieringer Dairy. The test releases also provide an opportunity to measure discharge and suspended sediment as well as providing calibration data for the hydraulic and sediment transport modeling.

The first section, Sediment Transport Analysis, examines how an increase to the flows in Crab Creek could potentially influence the way water and sediment are transported in Crab Creek. The first section specifically addresses the following potential issues:

- Immediate and long-term rates of sediment delivery to Moses Lake
- Extent of inundation relative to land ownership
- Bank erosion

Work on the Sediment Transport Analysis included meetings with Reclamation and Washington Department of Fish and Wildlife (WDFW) staff, field reconnaissance, sediment sampling, hydraulic and sediment transport modeling, evaluation of Reclamation-provided inundation maps, identification of erosion-prone reaches, and descriptions of potential bank stabilization treatments.

Two scenarios for the release of water from Pinto Dam are being considered by Reclamation and are expected to deliver the following amounts of sediment to Moses Lake:

- A continuous release of 150 cfs would contribute approximately 2,013 tons (895 cubic yards), and an additional release of 500 cfs (resulting in an estimated flow of 433 cfs at Road 7) for approximately 2 months would contribute approximately 2,157 tons (959 cubic yards). Under this scenario, an estimated annual total of 4,171 tons (1,854 cubic yards) would be delivered annually to Moses Lake.

- A second scenario that releases 650 cfs (resulting in an estimated flow of 580 cfs at Road 7) for approximately 3 months would contribute approximately 5,432 tons (2,414 cubic yards) annually to Moses Lake.

The extent of inundation, along Crab Creek when supplemental flows are being released, is dependent upon the discharge. At a release of 2,400 cfs, approximately 2,612 acres are inundated. Of this acreage, 54 percent (1,422 acres) occurs on federal, state, or county land. Private land ownership within the inundated area encompasses the remaining 1,190 acres.

Between Brook Lake and Road 7, data were collected at 27 locations along Crab Creek, including 3 structures and 7 road crossings. Based on field observations, 9 of the 27 sites are classified as moderate, high, or very high erodibility.

The second section, Structural Modifications, examines what modifications required to the channel and existing structures or facilities if flows were increased in Crab Creek. The second section specifically addresses the following potential issues:

- Channel modifications to Crab Creek between Brook Lake and the East Low Siphon to convey a maximum flow of 1,000 cfs

- Fish passage barrier to isolate Loan Springs at flows up to 850 cfs for the protection of a specific population of trout from other predatory species in Crab Creek

- Crossings at Road 10 NE, Walker Road, Lower Stratford, and Barren Road to convey 500 cfs

- Modifications to the Pinto Dam outlet spillway

- Modifications to the Brook Lake outlet

Work included meetings with Reclamation and Grant County staff, field reconnaissance and surveying assistance, hydraulic modeling, and development of conceptual-level drawings and associated cost estimates.

Results of the structural modifications assessment identified several key constraints including the following:

- To convey 1,000 cfs in Crab Creek from Brook Lake to the East Low Siphon, excavation of the channel alone could cost as much as $12,000,000. Additional modifications to ensure long-term stability of the newly excavated channel could push the costs significantly higher. Based on these costs, Reclamation terminated the effort to consider channel modifications in this section of Crab Creek.
- To reduce the potential for carp accessing Loan Springs, a fish passage barrier would be constructed at the south end of Willow Lake at an estimated cost of $75,000.
- A total of six crossings would need to be built or improved to convey the expected flows along Crab Creek at an estimated cost of $832,000.
- The 1,000 cfs test release from the Pinto Dam outlet eroded a large scour pool in the silty soils adjacent to the existing plunge pool. In addition, the Brook Lake elevation eventually rose above the invert of the Pinto Dam outlet pipe and inundated the Pinto Dam toe drain weirs.
- The erosion and significant impacts from backwater below Pinto Dam in Brook Lake observed during the test release must be addressed for Crab Creek to be a viable supplemental feed route option. Spillway improvements (including a concrete discharge structure and placement of additional riprap) to minimize erosion at the Pinto Dam outlet are estimated to cost approximately $651,000.
- A flow measurement structure at the outlet of Brook Lake is required to allow Reclamation to properly manage supplemental flows released from Pinto Dam into Crab Creek. The estimated cost for a flow measurement weir at the Brook Lake outlet is $248,000.

The third section, Dieringer Dairy Wastewater Improvements, examines the modifications required to allow dairy operations to continue at their present location when flows are increased in Crab Creek. The following improvements would be required if standing or flowing water were present in the Crab Creek channel south of the dairy barns (as occurred during the test releases):

- Construct two lined, 4,000,000-gallon lagoons to replace the existing lagoons.
- Construct a protective earth berm to isolate the dairy and irrigated land from the adjacent future water body.
- Construct two pump stations and a pipeline to convey wastewater from the dairy to and from the storage lagoons.
- Construct a stormwater collection and pumping system to convey water to the lagoons.

The estimated cost for these improvements is $2.6 million.

Sediment Transport Analysis

Introduction

This section examines how an increase to the flows in Crab Creek could potentially influence the way water and sediment is transported in Crab Creek. This section specifically addresses the following potential issues:

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- Extent of inundation relative to land ownership
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Work on the Sediment Transport Analysis included meetings with Reclamation and Washington Department of Fish and Wildlife (WDFW) staff, field reconnaissance, sediment sampling, hydraulic and sediment transport modeling, evaluation of Reclamation-provided inundation maps, identification of erosion-prone reaches, and descriptions of potential bank stabilization treatments.

Existing Resources Reviews

On July 18, 2006, CH2M HILL and Reclamation staff met to discuss the project goals and existing resources previously developed for the project area. Over the next several weeks, Reclamation provided aerial photography, topographic data, and land ownership mapping electronically. In addition, Reclamation provided access to past studies (see the following sections) that are relevant to the work.

Moses Lake Total Maximum Daily Load (TMDL) Groundwater Study (Washington State Department of Ecology, 2003)

This study attempts to characterize the concentration and potential sources of nutrients in groundwater directly discharging into Moses Lake. There is no discussion regarding tributary inputs of suspended sediment, however, there is useful information regarding the hydrogeology of the Crab Creek watershed. The report describes the dominant surface geologic features within the lower Crab Creek watershed and identifies soils with horizontal hydraulic conductivity ranging from 2,800 to 28,000 ft/day, with average seepage velocities of 1,100 ft/day. These high values reflect the coarse nature and open-framework texture of the deposits. The report also identifies sediments with much lower hydraulic conductivities that can often act as an aquitard, hydraulically separating groundwater in the flood deposits from groundwater in the uppermost basalt flows.

Moses Lake Inflow-Outflow Balance—A Component of the Moses Lake Total Phosphorous Total Maximum Daily Load (Washington State Department of Ecology, 2002)

This report documents the inflows and outflows to Moses Lake. The average daily inflow from the three major tributaries to Moses Lake (Rocky Ford Creek, Rocky Coulee Wasteway, and Crab Creek) was 452 cfs during the 2000 to 2001 water year. The outflow from Moses Lake by way of the North Culvert and the South Outlet averaged 536 cfs. This difference (that is, outflows exceeded the measured inflow by 84 cfs) is attributed to unmeasured inflow from minor streams, groundwater inflow, and errors in the calculations.

Field Data Collection

Field Reconnaissance

On July 19, 2006, CH2M HILL and WDFW staff met to discuss/observe site conditions, identify existing structures and potential erodible areas, and discuss site access. Reclamation provided a short tour of the reach between Pinto Dam and Road 20 on July 20.

Field work was conducted from July 19 through 21, along Crab Creek between Brook Lake and Road 7. Data were collected at 27 locations along the full project reach including 3 structures and 7 road crossings. Soil samples were collected at 18 of the sites (Figures 1A through 1C) for lab testing. Based on field observations described in Attachment A, 9 of the 27 sites were classified as moderate, high, or very high erodibility (Table 1).

TABLE 1
Erodibility of Soils at Specific Locations Along Crab Creek

Site	General Soil Type	Estimated Erosion Potential
ST1	Silt/Loam	Low
STR1	Silt/Loam	Low
ST3	*	Low
ST4	Sand/Silt	Medium
ST5	Sand/Silt	High
STR2	*	Low
ST6	Sand/Gravel	High
ST7	Bedrock	Very Low
ST8	Silt/Sand	High
ST9	*	*
ST10	Silt/Loam	High
ST11	Larger Boulder	Low
ST12	Mixed Sand to Large Boulder	Low
ST13	*	Low

TABLE 1
Erodibility of Soils at Specific Locations Along Crab Creek

Site	General Soil Type	Estimated Erosion Potential
ST14	Mixed Sand to Large Boulder	Very Low
ST15	Sand/Silt	Medium
ST16	Silt/Clay	Low
ST17	Silt/Organic	Low
ST18	Silt/Organic	Medium
ST19	Silt	Medium
STR3	Silt/Sand	Low
ST20	Silt/Sand	High
ST21	*	Low
ST22	Silt	Low
ST23	*	*
ST24	Silt/Sand	Low
ST25	*	*
ST26	*	Low
ST27	*	Low

Note: Determination of erodibility combines a number of factors based on field observations, including channel geometry, evidence of past erosion, vegetation, and soil types.

*No sediment data or no erodibility determination made.

Water and Sediment Discharge Sampling

On October 18, 2006, field work was conducted to collect suspended sediment and water discharge measurements at a number of locations along Crab Creek. Stream flow and suspended sediment samples were collected at 11 locations from the East Low crossing near the upstream end of Crab Creek to the Road 7 crossing near the U.S. Geological Survey (USGS) stream gage (Figures 1A, 1B, and 1C).

Stream flow varied between 90 cfs at the East Low crossing to 55 cfs between the Abandoned Structure and the Lower Stratford Road crossing. Stream flow increased to approximately 85 cfs at the Road 7 crossing because of the numerous irrigation return flows (Figure 1C). Based on observations at the time of the survey, it appeared that suspended sediment concentrations decreased in the downstream direction.

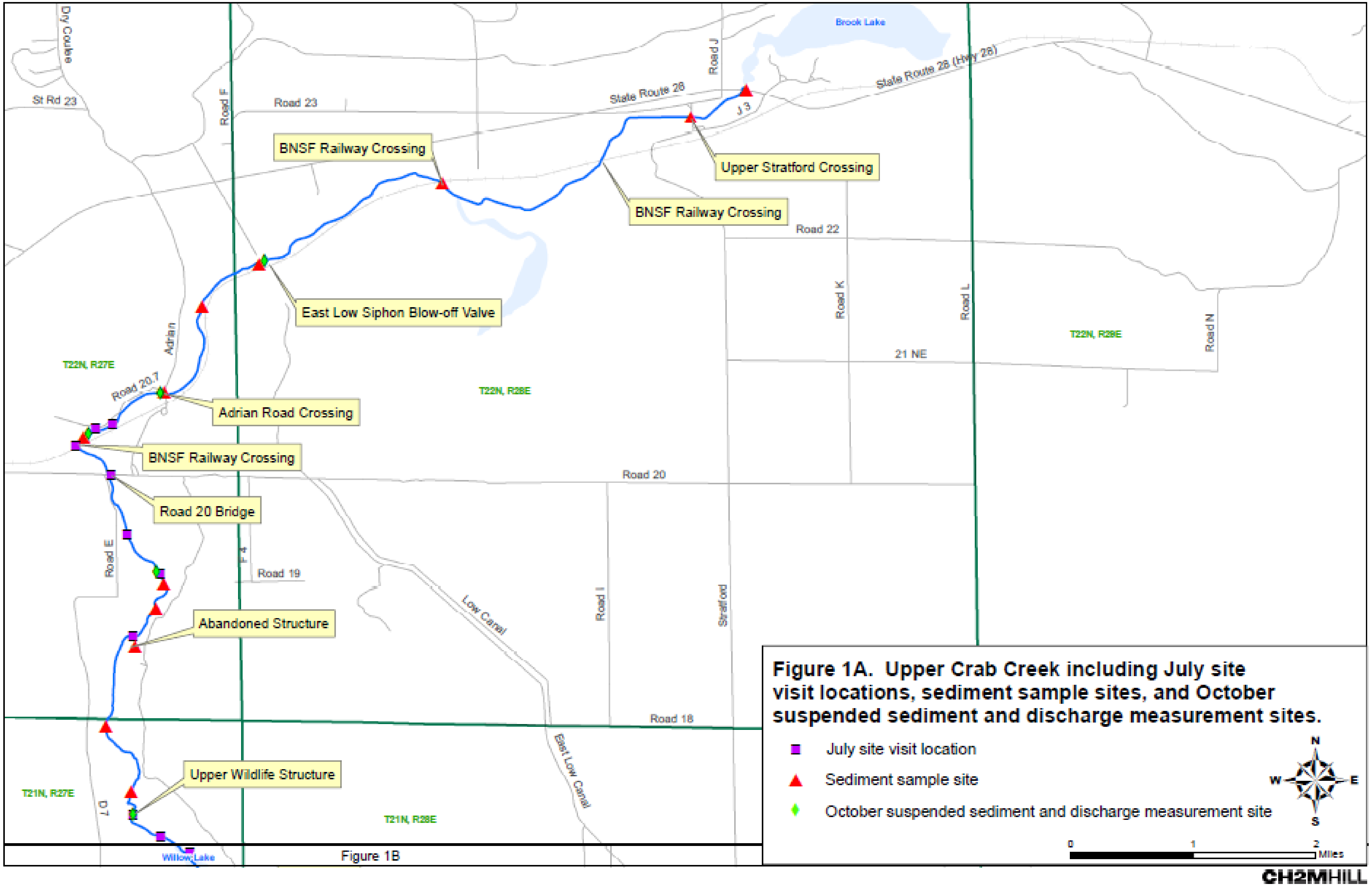


Figure 1A. Upper Crab Creek including July site visit locations, sediment sample sites, and October suspended sediment and discharge measurement sites.

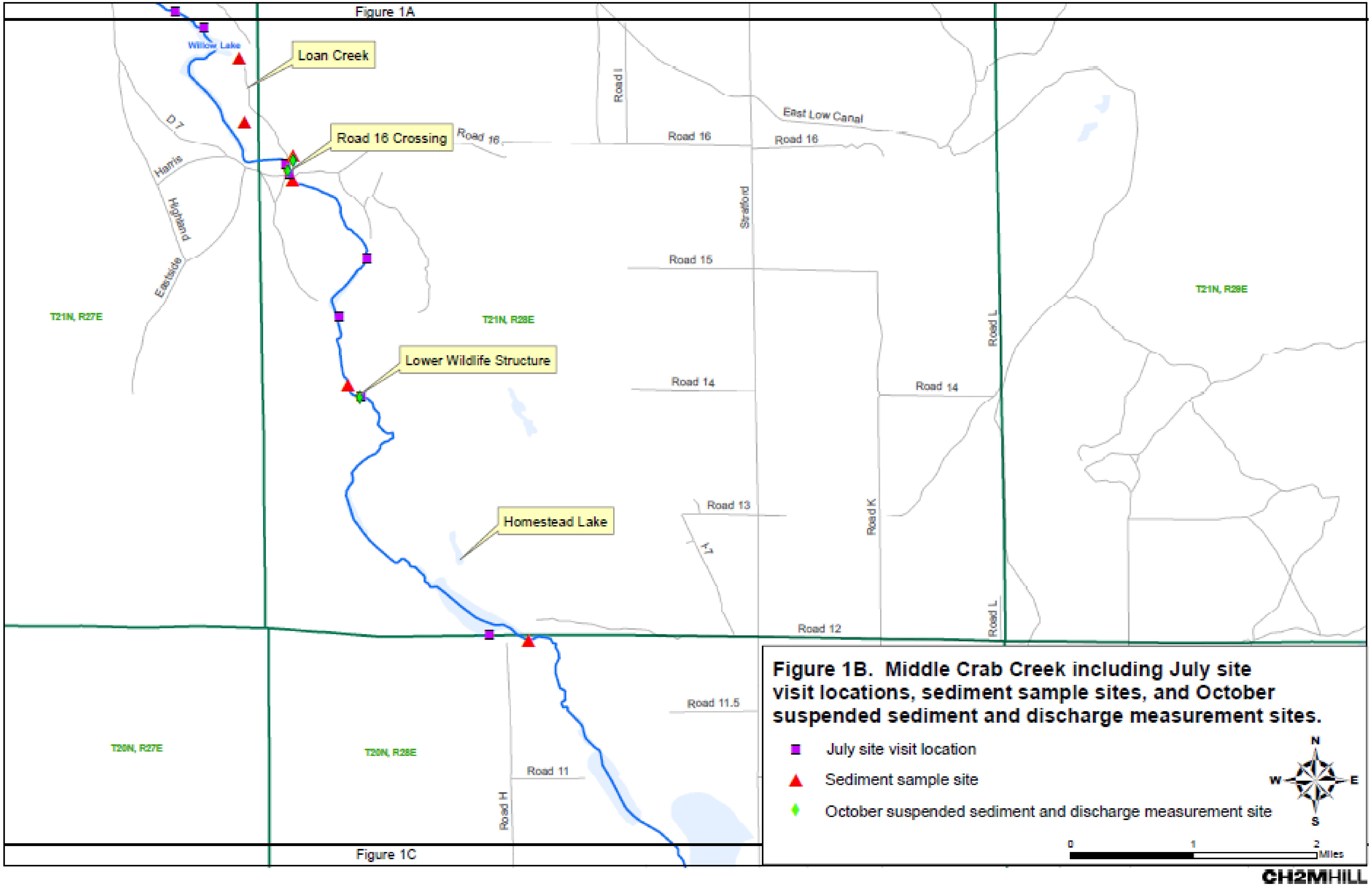


Figure 1B. Middle Crab Creek including July site visit locations, sediment sample sites, and October suspended sediment and discharge measurement sites.

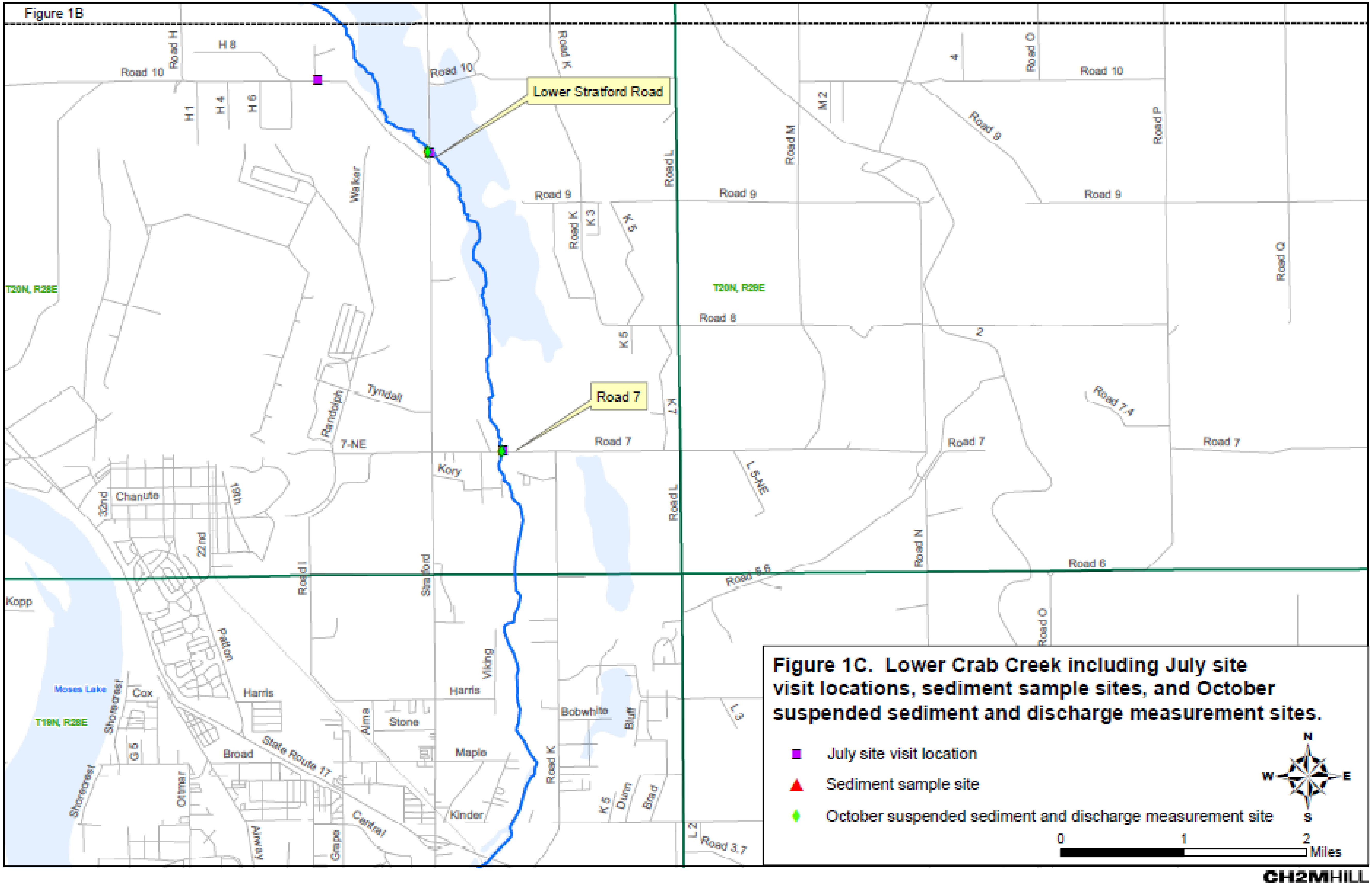


Figure 1C. Lower Crab Creek including July site visit locations, sediment sample sites, and October suspended sediment and discharge measurement sites.

At flows of 85 cfs, the downstream end of Crab Creek is near the top of the stream banks (Figure 2) and is often flowing across the wide floodplains (Figure 3).

FIGURE 2
Crab Creek, Looking Upstream from Road 7

FIGURE 3
Standing Water on Floodplain Near Upper Wildlife Structure

Data Analysis Methods

Topographic Surface Development

Reclamation provided CAD files covering approximately 23 miles of Crab Creek from Billy Clapp Reservoir to Moses Lake. Additional files included hydraulic model inundation images, scanned contour maps originating from the 1930s, and numerous Environmental Systems Research Institute (ESRI) shapefile coverages. Reclamation also provided two digital terrain models (DTM) covering the upper and lower portion of the 23-mile reach.

Public domain 10-meter digital elevation model (DEM) data were added to capture the full extent of the expected inundation area. The data sets were merged together, and a final DEM was created as the input file for surface generation in the hydraulic model. Figure 4 shows a portion of the final DEM surface in the vicinity of the East Low Canal at the siphon blow-off valve and the Town of Adrian, Washington (Reach 2, as described in the following section). Further details regarding the development of the hydraulic model are in the Hydraulic Modeling section.

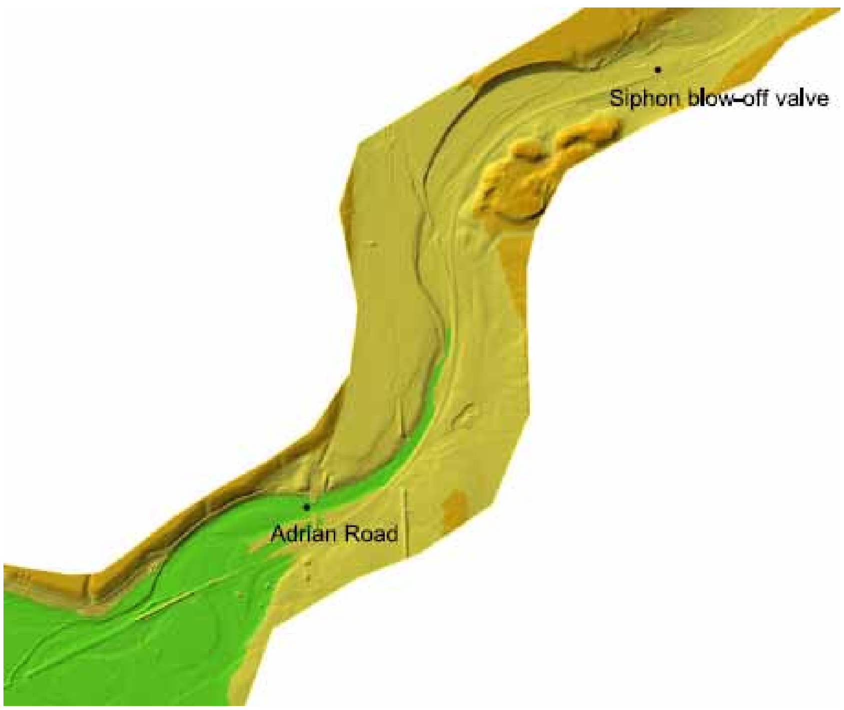


FIGURE 4
Portion of Crab Creek Generated Surface

Topographic photogrammetry mapping methods, used to describe the physical habitat in channels, remain problematic because channel bedforms and banks cannot be captured in areas inundated during the time of flight. It is common for surveyed cross sections to be incorporated into the model surface to capture topography under water; however, this method is costly, time consuming, and unwarranted for the level of detail required for this preliminary study. Assumptions, based on field site visit conditions and aerial photography and contour maps from the 1930s provided by Reclamation, were used in conjunction to modify portions of cross sections that were inundated during the time of photogrammetry data collection.

Geomorphic Reach Descriptions

Based on field observations related to channel shape, substrate, and flow conditions and a thalweg profile generated from the DEM, 8 geomorphically distinct reaches within the approximately 23-mile project reach from the Brook Lake outlet at Highway 28 to Highway 17 near Moses Lake (Figures 5 and 6) were identified. Each of those reaches is described individually in the following text.

Reach 1 begins at the Highway 28 Bridge and ends at the East Low Canal siphon blow-off valve. Reach 1 is low gradient (slope 0.0005) with a length of 24,821 feet and can be characterized as having a dry channel most of the year. Crab Creek meanders through agricultural tilled fields, and the channel is sometimes undefined in such locations. The channel becomes defined near the uppermost Burlington Northern Santa Fe (BNSF) Railway crossing. Channel substrate is dominated by sand and small gravel with little or no presence of bedrock outcrops. While access is limited by private property ownership, much of this reach is visible from the roads, especially the portions in agricultural use, which appeared to have high erosion potential (caused by the fine substrate).

Reach 2 has a length of 14,923 feet and extends from the East Low Canal siphon blow-off valve to County Road 20. Reach 2 exhibits a steeper gradient of 0.0027 within which lie several notable features. The "Adrian Sink" commonly refers to an area near the Town of Adrian near the downstream end of this reach where subsurface materials with high groundwater flow rates result in significant Crab Creek infiltration losses. These higher infiltration losses likely occur throughout much of Reaches 1 and 2 and then culminate in groundwater flows through the Adrian area. The majority of this reach lies within a canyon and is confined by the BNSF Railway. Gravel fill deposits were found scattered within the streambed, in addition to large cobble and widely dispersed large boulders. Sand dominates the channel directly upstream of the Adrian Road crossing, but coarser substrate exists immediately downstream. It appears that backwater conditions exist at higher flows and result in sediment deposition. Water overtops the Adrian Road crossing at approximately 2,000 cfs, as seen in the oblique aerial photography provided by Reclamation. A source of sediment, caused by erosion of the man-made berm along the right bank, was noted downstream of the Adrian Road crossing and upstream of the BNSF Railway bridge. Crab Creek makes a 90-degree bend at this location. Overall, this reach is characterized as exhibiting high-erosion potential.

Reach 3 has a length of 17,910 feet, an average gradient of 0.0008, and extends from County Road 20 to the Upper Wildlife Structure. Crab Creek winds through agricultural fields, and irrigation return flow enters Crab Creek at Road 20. Bedrock outcrops were observed at an Abandoned Structure and an old berm. Fine substrate material was observed just upstream of the Abandoned Structure, possibly caused by backwater conditions. At the downstream end of this reach is a second control structure, the Upper Wildlife Structure. Immediately upstream of this structure is an area commonly referred to as "Flood Flats." The Upper

Wildlife Structure was blasted through bedrock, and it is apparent in the substrate as well as topography that lake-like conditions existed historically upstream of this structure. Overall, this reach is characterized as exhibiting low-erosion potential.

Reach 4 has a length of 13,051 feet and an average gradient of 0.0012. It is bounded by the Upper Wildlife Structure and County Road 16. Numerous bedrock outcrops were observed between the Upper Wildlife Structure and Willow Lake. Willow Lake is found within Reach 4 and has two outlets referred to as the East and West Channels. Loan Spring feeds the East Channel year-round, while the main channel (West) is often dry and undefined. Only at high flows does water leave Willow Lake by way of the East Channel. Road 16, the downstream end of this reach, marks the beginning of perennial flow within Crab Creek. This reach is characterized as being very low in erodibility.

Reach 5 has a length of 12,717 feet and an average slope of 0.0006. Reach 5 ends at a control structure referred to as the Lower Wildlife Structure. Crab Creek appears to be perennial, low-gradient, and slow-flowing with strings of ponds. A wide and deep channel exists north of an area known as the “Spud Field.” Crab Creek then flows along the west edge of the tilled field (and through it at higher flows). Like the Upper Wildlife Structure, the Lower Wildlife Structure is blasted through bedrock, which historically acted as a geologic control for flow. This reach is characterized as low in erodibility despite the presence of very highly erodible conditions in the Spud Field.

Reach 6 has a length of 16,836 feet and average slope of 0.0018. This reach ends near the outlet of Homestead Lake. Reach 6 is relatively steep; however, it was considered low in erodibility because of the presence of perennial water and the lack of fine substrate encountered while walking the outlet channel of Homestead Lake. Crab Creek looks similar to a reservoir at the junction of Homestead Creek. It is expected that sediment loads would decrease considerably at this confluence.

Reach 7 has a length of 42,902 feet, an average slope of 0.0012, and ends at the midpoint between County Road 7 and State Route 17 at a marked transition in slope (Figure 5). This reach is predominantly private land, and field observations were limited to points observable from the public roads. Fine sediment was observed at both Lower Stratford and County Road 7 Bridges in excess of 1-foot deep. During the July field visit, backwater-like conditions were observed at the USGS gage located at the Road 7 Bridge.

Reach 8 has a length of 13,163 feet, an average slope of 0.0028, and is predominantly private land. An eroded stream bank identified by Reclamation and WDFW south of Road 7 could not be located within 50 meters of the provided coordinates, despite discussions with two landowners. This reach is considered low in erodibility potential, however, sediment sources may be present along the private reaches of Crab Creek.

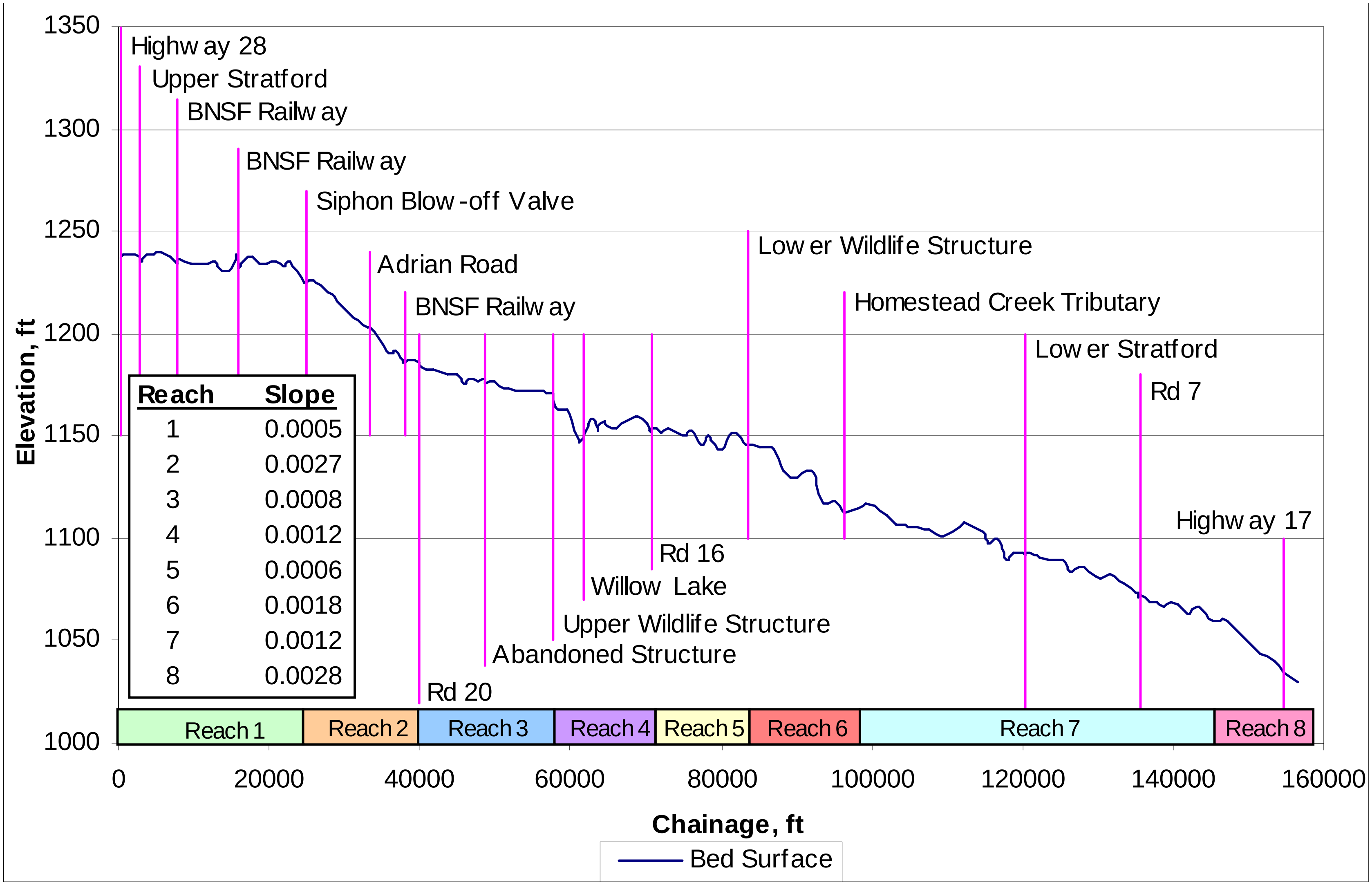


FIGURE 5
Longitudinal Profile of Channel Bed Elevation

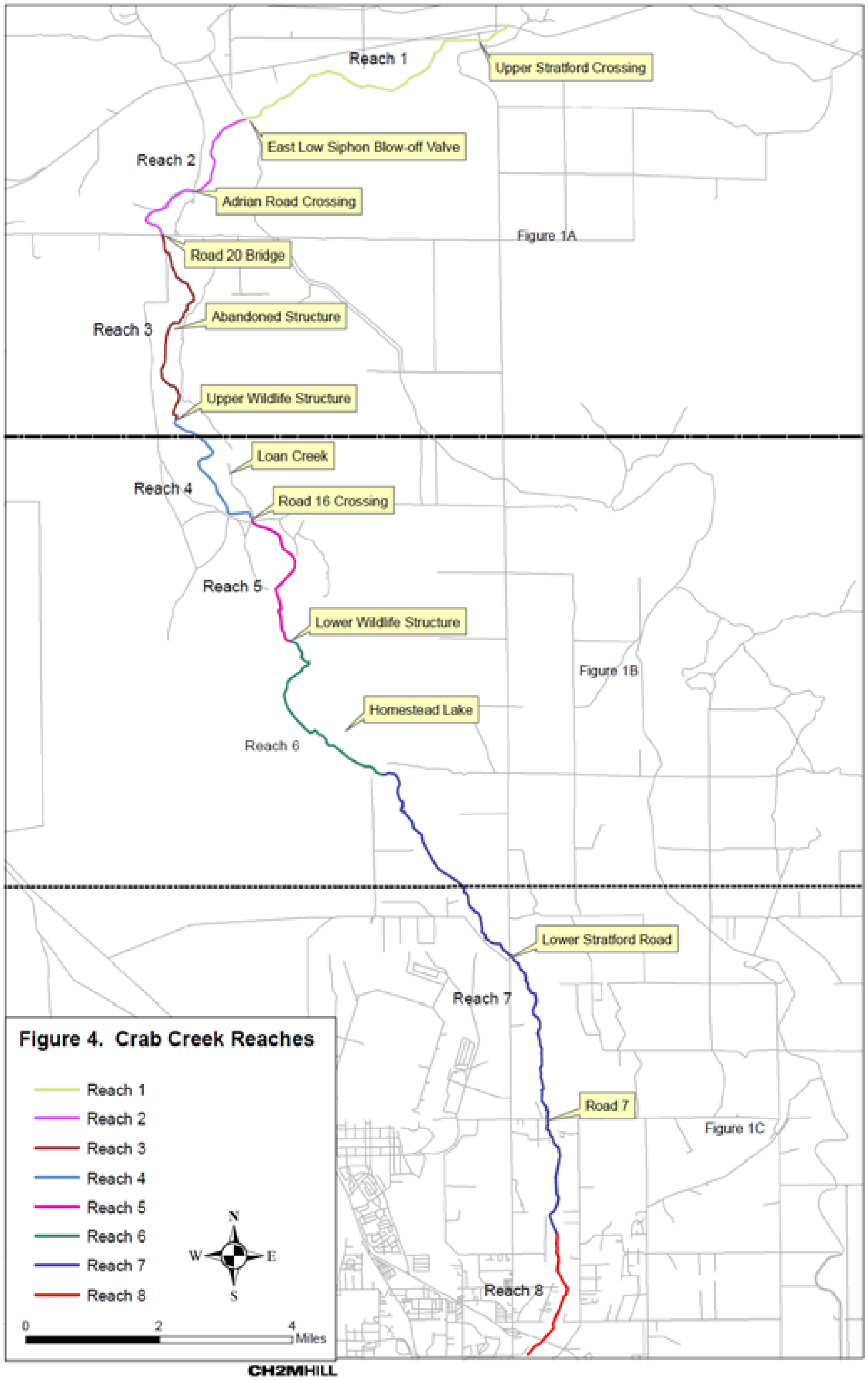


FIGURE 6
Crab Creek Reaches

Results

This section summarizes the primary findings related to the sediment discharge sampling, seepage, hydraulic modeling, sediment transport modeling, and inundation. Additional detail and maps are included as Attachments B, C, and D.

Sediment Discharge

Suspended sediment samples were collected at 11 locations (Figures 1A, 1B, and 1C) to document the trends in suspended sediment concentration measurements along Crab Creek. (An additional sample was collected at Sites 9 and 10 to document variability at the measurement location.) Sediment samples were analyzed for total suspended solids (TSS). A known volume of water from each suspended sediment sample was passed through a 0.00045-mm screen and the sediment that remained on the screen was dried and weighed. Sediments smaller than 0.00045 mm are transported as part of the dissolved load rather than in the suspended or bed load. Lab results for each sample are presented in Table 2.

TABLE 2
Lab Results for Total Suspended Solids

Site/Location	Measured Stream Flow (cfs)	Total Suspended Solids (mg/L)	Total Suspended Solids (tons/day)
East Low Siphon Blow-off Valve	90.5	43	10.49
Downstream of Adrian Road Crossing	68.7	27	5.00
Upstream of Road 20 Bridge-Site 7.1 [a] Upstream of Road 20 Bridge-Site 7.2 [a]	69.6	82	15.39
Abandoned Structure [b] Abandoned Structure-Duplicate [b]	55.2	22	3.27
Upper Wildlife Structure [c] Upper Wildlife Structure-Duplicate [c]	55.2	12	1.79
Road 16 Crossing [d]	38	12	1.23
Road 16 Crossing [d]	27.6	2	0.15
Lower Wildlife Structure	57.6	24	3.73
Lower Stratford Road	55.5	2	0.30
Road 7	86.3	7	1.63

[a] At site 7, the main channel is sample 7.2, and the side channel is sample 7.1. The combination of samples 7.1 and 7.2 is equal to the total TSS at Site 7.

[b] Site 9 TSS is taken as the average of the two samples.

[c] Site 10 TSS is taken as the average of the two samples.

[d] Crab Creek splits at this location. Total Crab Creek TSS at this location is taken as the summation of the Site 12 and Site 13 samples.

Seepage

Understanding the connections between surface water and groundwater within the project study area is difficult, given the number of variables that must be considered. Quantifying the hydraulic properties of the streambed and the magnitude of seepage between the stream and groundwater system is critical to understanding what losses may occur at different flows in Crab Creek.

A common approach to investigating seepage flux between a stream and an underlying aquifer is to measure stream flow at specific locations. This approach, called a seepage run, uses the measurement sites to subdivide the stream into reaches. The results allow a water budget to be estimated for each reach, accounting for inputs (such as tributary flows) and outputs (such as evaporative losses and diversions). The difference between inflows and outflows is then attributed to the interaction between the stream and the underlying aquifer. When applied to a defined reach, the groundwater flux (Qgw) can be estimated from the following equation:

$$Qgw = Qdn - Qup + \sum Qout - \sum Qin$$

In this equation, Qdn is the flow at the downstream end of the reach, Qup is the flow at the upstream end, Qout represents outputs from the reach (such as distributaries, evaporation, and extraction), and Qin represents inputs to the reach (such as direct rainfall, runoff, tributaries, irrigation drainage, and sewage outfall). A positive Qgw indicates a net input of groundwater to the reach. A negative Qgw indicates a net loss of surface water to the groundwater system and is commonly termed a transmission loss.

Although the calculation is straightforward, the approach is difficult to apply in many cases because of the challenge of identifying and quantifying each variable. The method relies on an accurate measurement of surface water flow as well as appropriately accounting for all gains and losses evident for a reach. The uncertainties associated with flow measurements and estimates for water balance components can often exceed the magnitude of the seepage flux being estimated.

Alternatives to calculations based on seepage runs include baseflow separation, seepage meters, groundwater assessment, and temperature gradient methods. Each of these methods has both advantages and limitations tied to the availability of data and/or the ability to collect the data required by a specific methodology.

The best available information for supporting an analysis of seepage rates along Crab Creek comes from flow measurements made by Reclamation. In addition, Reclamation has invested considerable effort into understanding the relationship between flows in Crab Creek and groundwater flows in the area around Crab Creek. These efforts resulted in the development of a model of the Crab Creek drainage that estimates the probable losses and gains along Crab Creek based on surface flow measurements and a mass balance within the water system. The summer and fall 2006 test flows provided Reclamation an opportunity to supplement its existing model. During a test flow release of approximately 145 cfs from Pinto Dam, flow measurements were made at selected locations along Crab Creek. These measurements correlated reasonably well with the model. Based on this available information, Figure 7, developed using the model, represents a reasonable estimate of probable losses along Crab Creek.

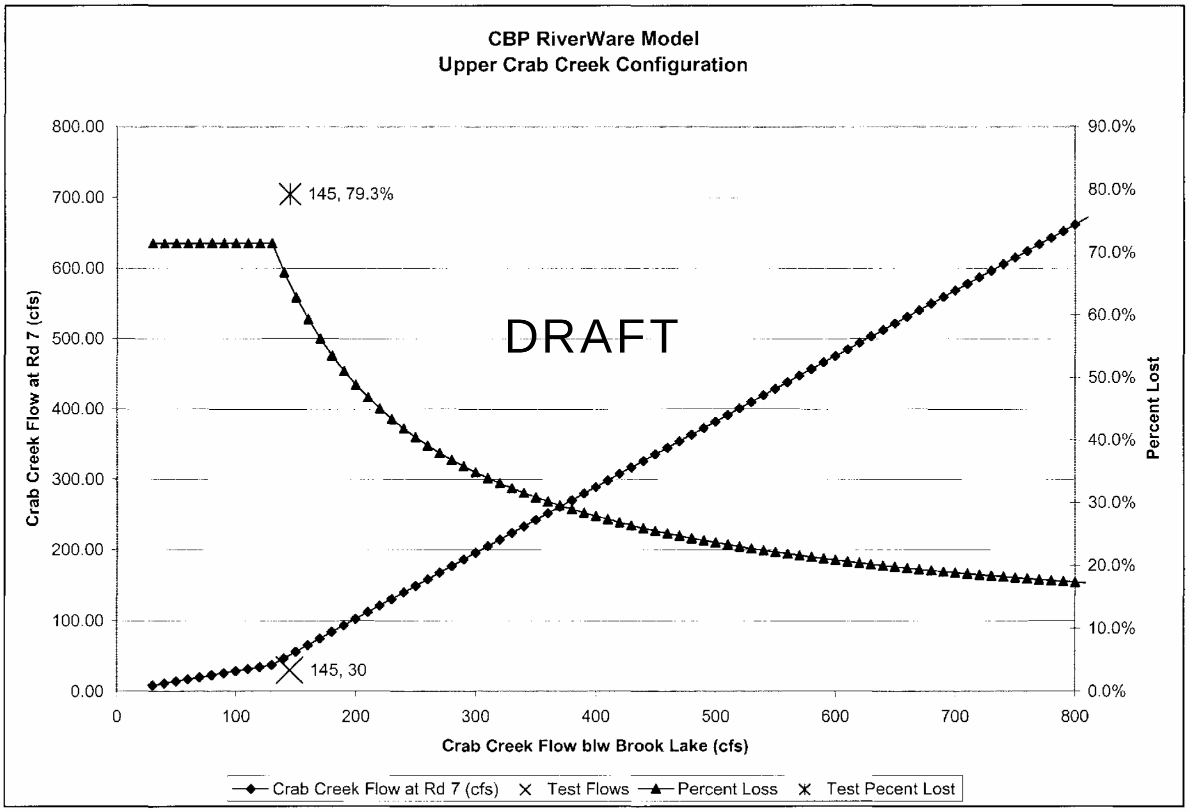


FIGURE 7
Estimated Crab Creek Flow Losses

Based on results from the model and measured flows during the test releases, Table 3 summarizes the estimated flows at various locations along Crab Creek.

TABLE 3
Crab Creek Flow Estimates

Measurement Point	Measured Flow during Test Release (approximate cfs)	Estimated Flows (cfs)			
Pinto Dam Outlet	150	400	650	1,000	2,400*
East Low Siphon	90	320	590	900	2,160
Flood Field Check Structure	55	260	530	810	1,950
Spud Field Check Structure	58	270	550	850	2,000
Stratford Road	56	260	530	800	2,050
Road 7	86	335	580	875	2,100

Note: The maximum discharge capacity of the Pinto Dam Outlet is approximately 1,000 cfs. Flows greater than 1,000 cfs typically indicate storm runoff flows in Crab Creek above Brook Lake.

Flows change throughout the year as variables affecting the system change. For example, during the period when the test flow measurements were collected, return flows from irrigation flowed back into Crab Creek above Road 7 (accounting for at least some of the increase in flow between Stratford Road and Road 7). When less flow is being released from Pinto Dam, irrigation return flows could substantially affect the amount of water flowing past Road 7.

Evaporation losses are inherently accounted for through direct measurement of flow in the stream, but these losses vary from season to season. Typical evaporation losses range from 34 to 42 inches annually for the project area according to the Western Regional Climate Center. Releases of 1,000 cfs from Pinto Dam will inundate approximately 1,000 to 1,300 acres, which would create approximately 2,800 to 4,500 ac-ft of evaporation loss annually or approximately 4 to 6 cfs in flow. Although evaporation losses are relatively insignificant (and probably less than the error in field measurements), an accumulation of smaller losses could contribute to a more substantial change in flows.

Accurate flow records describing future releases from Pinto Dam provide opportunities to continue adjusting and refining the existing model.

Hydraulic Modeling

A one-dimensional (1-D), numerical hydraulic model of the study reach was created using the MIKE11 software package. The model provides a means for quantifying the general hydraulic characteristics throughout the study reach. In addition, the hydraulic model is required to conduct a detailed suspended transport analysis, which addresses the primary question of how much sediment would ultimately be deposited in Moses Lake.

This section describes only the results and assumptions of the hydraulic modeling process. Additional elements of the hydraulic modeling process, beginning with model development and concluding with a general discussion of the appropriate use of the model and its limitations, are described in more detail in Attachment B.

Model Results

The model produces stable and reasonable results for the calibration flow rate of 1,860 cfs. (Additional detail on the calibration process is provided in Attachment B.) Figure 8 depicts water surface elevation, left and right bank (dashed and solid lines), and channel bed elevation from the Brook Lake Outlet (chainage = 0 ft) to just below Highway 17 at Moses Lake (chainage = 156,501 feet). Table 4 summarizes average depth and velocity at specific discharge measurement site locations.

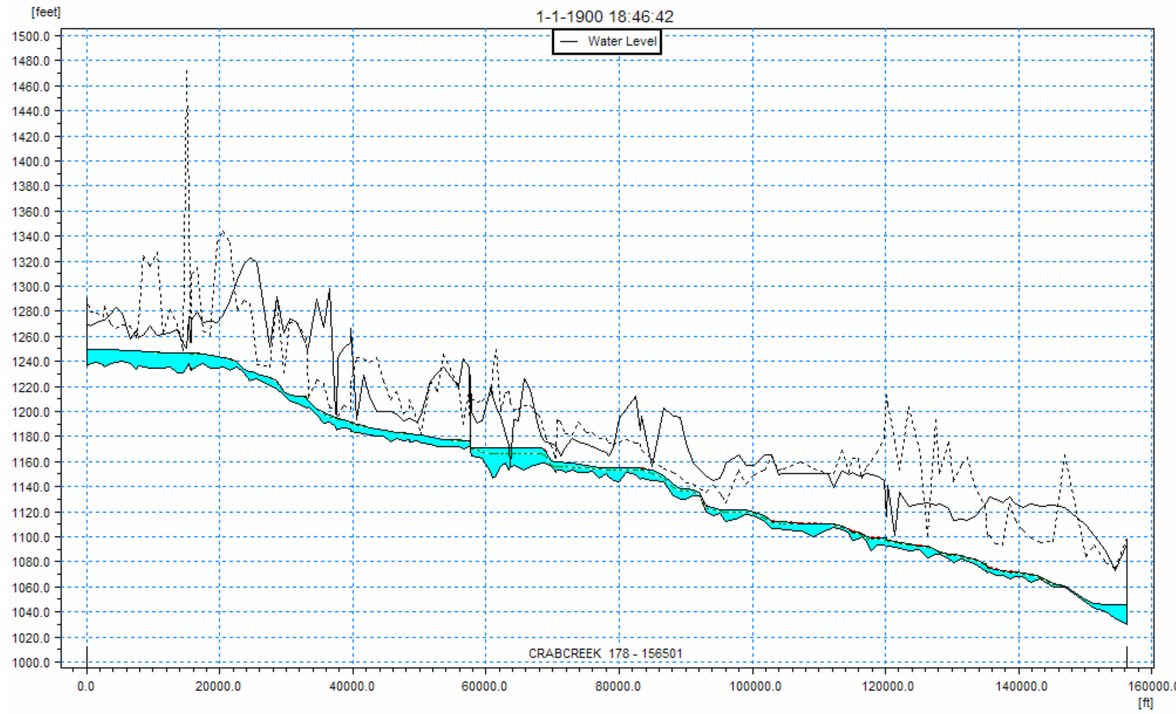


FIGURE 8
Profiles of Water Surface at 2,400 cfs, Left and Right Banks, and Channel Bed Elevation Over Modeled Reach

TABLE 4
Average Depth and Velocity Identified by Flow Measurement Site

Flow Measurement Site*	Avg. Velocity (ft/s)	Avg. Depth (ft)	Distance Downstream from Brook Lake Outlet (ft)
1 Siphon Blow-off Valve	2.6	5.9	24999.0
2 Adrian Road Crossing	3.1	4.4	33444.0
3 BNSF Railway above Road 20	0.7	5.5	37481.6
4 Abandoned Structure	1.8	4.4	44788.4
5 Upper Wildlife Structure	14.9	4.3	57768.7
6 Willow Lake Main Outlet (West Channel)	0.1	4.5	70542.6
7 Lower Wildlife Structure	1.4	7.5	83401.0
8 Lower Stratford Crossing	1.2	4.3	119987.0
9 Road 7 Crossing	0.7	3.6	135440.0

Note: Discharge was measured in October 2006.

Model Assumptions and Limitations

The model produces results that are suitable for general interpretation of the hydraulic conditions in Crab Creek and input for a general sediment transport model. The results could also be used to evaluate inundation widths and design bank protection measures.

The model is a 1-D flow analysis and assumes that hydraulic parameters are uniform throughout the entire wetted channel area. The model is only accurate as an average for a specific cross section location on the stream. For instance, peak flow velocity along the outside of a bend may be 1.5 times greater than the listed average velocity for that cross section.

Sediment Transport Modeling

Estimates of suspended sediment delivery into Moses Lake were made for a range of flows (86 to 875 cfs) to quantify short- and long-term rates of sediment delivery to Moses Lake. The results are based on existing conditions. If future channel modifications are made to Crab Creek, such as increasing conveyance through Reach 1, bank stabilization treatments would likely be required to prevent additional sediment transport. The flows selected are correlated to a range of releases from Pinto Dam that account for the anticipated losses in Crab Creek (Table 3). This section describes only the results and assumptions of the sediment transport modeling process. Additional elements of the sediment transport modeling process, beginning with model development and concluding with a general discussion of the appropriate use of the model and its limitations, are described in more detail in Attachment C.

Model Results

Observed suspended sediment transport measurements illustrate a generally decreasing trend in the downstream direction (Table 2), except at the Lower Wildlife Structure and the Road 7 crossing where the suspended sediment concentrations increase as a result of agricultural uses. Despite these local increases in suspended sediment concentrations, the observed rates are quite small (0.1 to 3 tons per day downstream of the Road 20 Bridge [Figures 1A, 1B, 1C]). The farthest downstream measurement location was at the USGS gage on Crab Creek at Road 7 (#12467000). Approximately 1.6 tons per day of suspended sediment transport was measured at the Road 7 Bridge at 86 cfs.

Four methods were used to estimate suspended sediment transport rates at the Road 7 Bridge (used as a surrogate for estimating possible impacts to Moses Lake) under a range of flow conditions (86, 335, 580, and 875 cfs) including the following:

1. Lane and Kalinske (1941) and van Rijn (1984) suspended sediment transport equations.
2. Observed suspended sediment rating curves for Crab Creek at Rocky Ford Road (USGS Gage #12464770) and Frenchman Hills Wasteway (USGS Gage #12471090).
3. Extrapolation of the relationship between unit-suspended sediment transport rate and drainage area across 33 sites in Idaho to the drainage area of Crab Creek at the Road 7 Bridge.

4. Extrapolation of the low-flow relationship between unit-suspended sediment transport rate and drainage area at the three local USGS gages previously described.

These methods are discussed in greater detail in Attachment C.

The results of applying these four methods at the Road 7 Bridge are summarized in Figure 9 for the four flows: 86, 335, 580, and 875 cfs. At the lowest flow, only three data points are shown, one of which is the measured suspended sediment transport rate, because this is the flow that was used to calibrate the two equations. At 335 cfs, the suspended sediment transport rate ranges from less than 10 to more than 100 tons per day. At the two higher flows, the transport rate ranges from 10 to 1,000 tons per day.

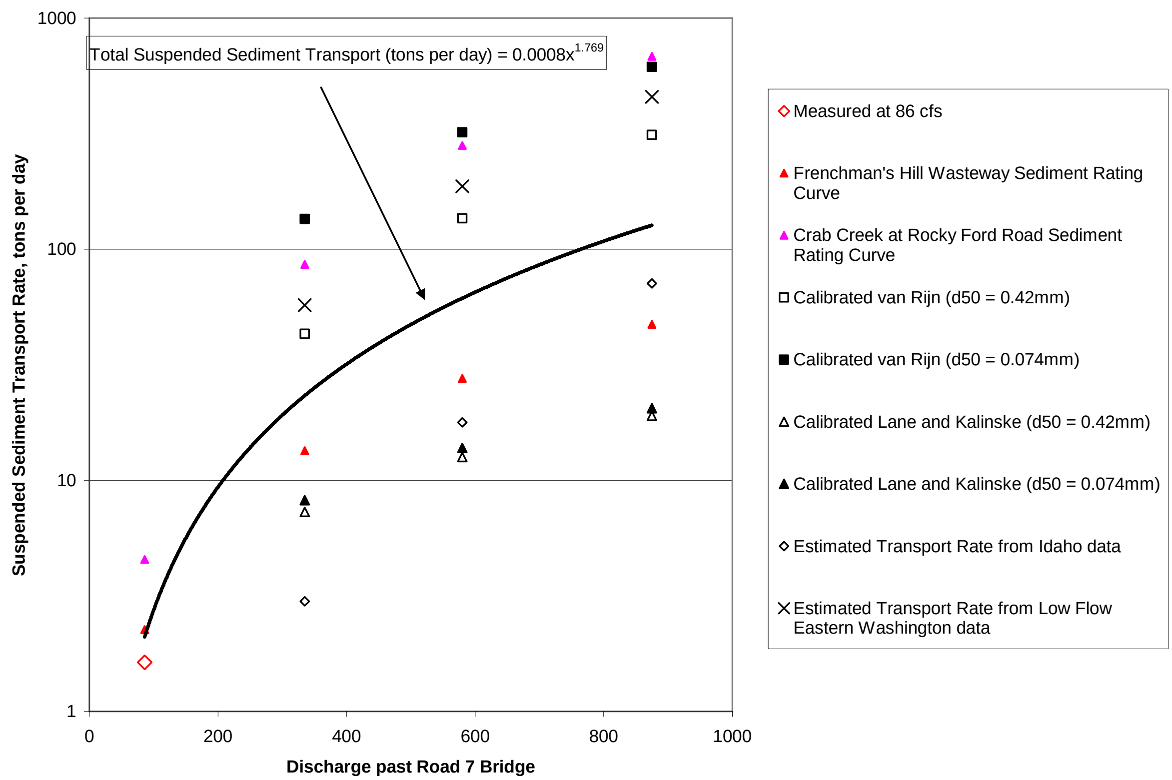


FIGURE 9
Predicted Suspended Sediment Transport Rate at Crab Creek and at the Road 7 Bridge Using a Variety of Prediction Methods

Table 5 shows a wide range in the estimated values from the four methods. The trendline in Figure 9 (middle column of Table 5) represents an estimate of suspended sediment transport rates past the Road 7 Bridge for a given flow.

Assuming a sediment density of 165.4 lbs/ft^3, the estimated volume of suspended sediment transported into Moses Lake under the various flow conditions is shown in Table 6. That is, assuming a flow of 875 cfs past the Road 7 Bridge, the estimated range of suspended sediment transport rates falls between 20 and 680 tons per day (Table 5) or 8 to 300 cubic yards per day (Table 6). However, the best-fit trendline would predict either 128 tons per day or 57 cubic yards per day (Table 6).

If these flows were continued for 14 days, approximately 1,800 tons may be transported past the Road 7 Bridge, and potentially enter Moses Lake (800 cubic yards). On the other hand, if the flow was 580 cfs for 14 days, approximately 870 tons of suspended sediment could potentially enter Moses Lake (386 cubic yards).

Depending on the range of flows selected for a proposed operational scheme, the data in Tables 5 and 6 can be used to estimate the amount of sediment that could enter Moses Lake. Reclamation has initially proposed two flow scenarios as follows:

1. Release 150 cfs from Pinto Dam year round and increase the releases to 500 cfs for approximately 2 months in the spring.
2. Release 650 cfs from Pinto Dam for approximately 3 months in the spring and early summer.

Using the trendline estimate of sediment transport, the amounts entering Moses Lake can be estimated as follows:

Under the first scenario, the model suggests that the continuous 150-cfs release from Pinto Dam would contribute approximately 2,013 tons (895 cubic yards) and the release of 500 cfs from Pinto Dam (resulting in an estimated flow of 433 cfs at Road 7) for approximately 2 months would contribute approximately 2,157 tons (959 cubic yards) for an estimated annual total of 4,171 tons (1,854 cubic yards) to Moses Lake.

The second scenario involves a 650-cfs release from Pinto Dam (resulting in an estimated flow of 580 cfs at Road 7) for approximately 3 months that would annually contribute approximately 5,432 tons (2,414 cubic yards) to Moses Lake.

TABLE 5
Range in Estimated Suspended Sediment Transport Rates Under Three Flow Conditions

Flow at Road 7 (cfs)	Approximate Release from Pinto Dam (cfs)	Low Estimate of Suspended Sediment Transport (tons per day)	Trendline Estimate of Suspended Sediment Transport (tons per day)	High Estimate of Suspended Sediment Transport (tons per day)
86	150	1.6	2.1	5
335	400	3.0	23.4	135
580	650	12.6	61.9	320
875	1000	19.0	128	684

TABLE 6
Range in Estimated Suspended Sediment Transport Volumes Under Three Flow Conditions

Flow at Road 7 (cfs)	Approximate Release from Pinto Dam (cfs)	Low Estimate of Suspended Sediment Transport (cubic yards per day)	Trendline Estimate of Suspended Sediment Transport (cubic yards per day)	High Estimate of Suspended Sediment Transport (cubic yards per day)
86	150	0.7	0.9	2.0
335	400	1.3	10.4	60.3
580	650	5.6	27.6	142.9
875	1000	8.5	57.1	305.4

Model Assumptions and Limitations

Limited data were available for describing the surface sediment sizes. Consequently, the accuracy of the suspended sediment estimates is limited by the accuracy and representativeness of the Grant County Soil Survey (SCS, 1984).

In addition, no transport observations were included in the data sets used to determine the parameters and coefficients embedded within the Lane and Kalinske (1941) and van Rijn (1984) equations. Consequently, the applicability of these equations to Crab Creek is unknown.

In addition, only a single suspended sediment transport observation at a low flow (86.3 cfs) was available for calibrating the equations. No information is available on how transport rates change at a constant discharge through time or how increasing or decreasing discharge changes the suspended sediment concentration. That is, the Lane and Kalinske (1941) and van Rijn (1984) equations were calibrated to reproduce the low flow transport observation, and that same calibration was applied to suspended sediment estimates at 335, 580, and 875 cfs.

If possible, we suggest additional suspended sediment transport measurements over a range of flows to calibrate the applicable equations to higher flow events.

Inundation Maps/Land Ownership Comparison

Reclamation supplied a parcel map identifying land ownership in the Crab Creek corridor from Billy Clapp Reservoir to State Route 17 at Moses Lake, Washington. The parcel map identifies the parcel ownership by indicating if the parcel is federal, state, county, public utility, or privately owned. Reclamation also supplied inundation images at 100, 400, 650, and 2,400 cfs flow events produced by Matt Jones and Dan Calahan with Reclamation's Technical Service Center (TSC). It is CH2M HILL's understanding that the two DTMs provided by Reclamation were used as the model surface for generation of inundation maps (using the model Trimmer-2D) also provided by Reclamation. The 2,400-cfs inundation images were converted to inundation polygons, and the inundation polygons were then dissolved and spatially intersected with the ownership polygons.

Land within the inundation area was summed into public or private ownership. Based on the spatial analysis, approximately 2,612 acres are inundated at the 2,400-cfs flow event. Of this, 54 percent (1,422 acres) occurs on federal, state, or county land. Private land ownership within the inundated area totals 1,190 acres. Inundation maps from this analysis are included in Attachment D.

Structural Modifications

Introduction

This second section examines what modifications are required to the channel and existing structures if flows were to be increased in Crab Creek. This section specifically addresses the following potential issues:

- Channel modifications to Crab Creek between Brook Lake and the East Low Siphon to convey 1,000 cubic feet per second (cfs)
- Fish passage barrier to isolate Loan Springs at flows up to 850 cfs
- Crossings at Road 10 NE, Walker Road, Lower Stratford, and Barren Road to convey 500 cfs
- Modifications to Pinto Dam outlet spillway
- Modifications to Brook Lake outlet

Work on the structural modifications included meetings with Reclamation and Grant County staff, field reconnaissance and surveying assistance, hydraulic modeling, and development of conceptual-level drawings and associated cost estimates.

Data Collection

On January 30, 2007, CH2M HILL met with Reclamation at Reclamation's office in Ephrata, Washington, to gather existing information and complete additional field work during the next few days. Reclamation provided construction drawings for the East Low Siphon and the irrigation system near Road 10, photos taken during the test flow, and well log reports for wells located near Crab Creek. Field work included identification of potential project constraints, critical features to be included in the field survey, and documentation of features that affect the hydraulics and stability of the system. The location of these features is shown in Figure 10. The survey work included collection of additional topographic mapping to support hydraulic modeling and water surface elevations from the recent test flow based on high water marks as well as identification of existing features such as culverts and roadway geometry.

The following key observations were noted:

- High water marks from the test flow are readily visible and will ensure a higher quality of calibration for the hydraulic model.
- Several inline features significantly obstruct flows in Upper Crab Creek: 1) the Brook Lake outlet, 2) a rock weir located several hundred feet upstream of the middle Burlington Northern Santa Fe (BNSF) Railway trestle, and 3) three beaver dams located downstream of the middle BNSF Railway trestle.
- Bedrock is encountered on the surface in the channel from the East Low Siphon to approximately 2,000-ft upstream from the siphon.

Example photographs are included in Attachment E. Attachment F contains a complete list of the survey data collected.

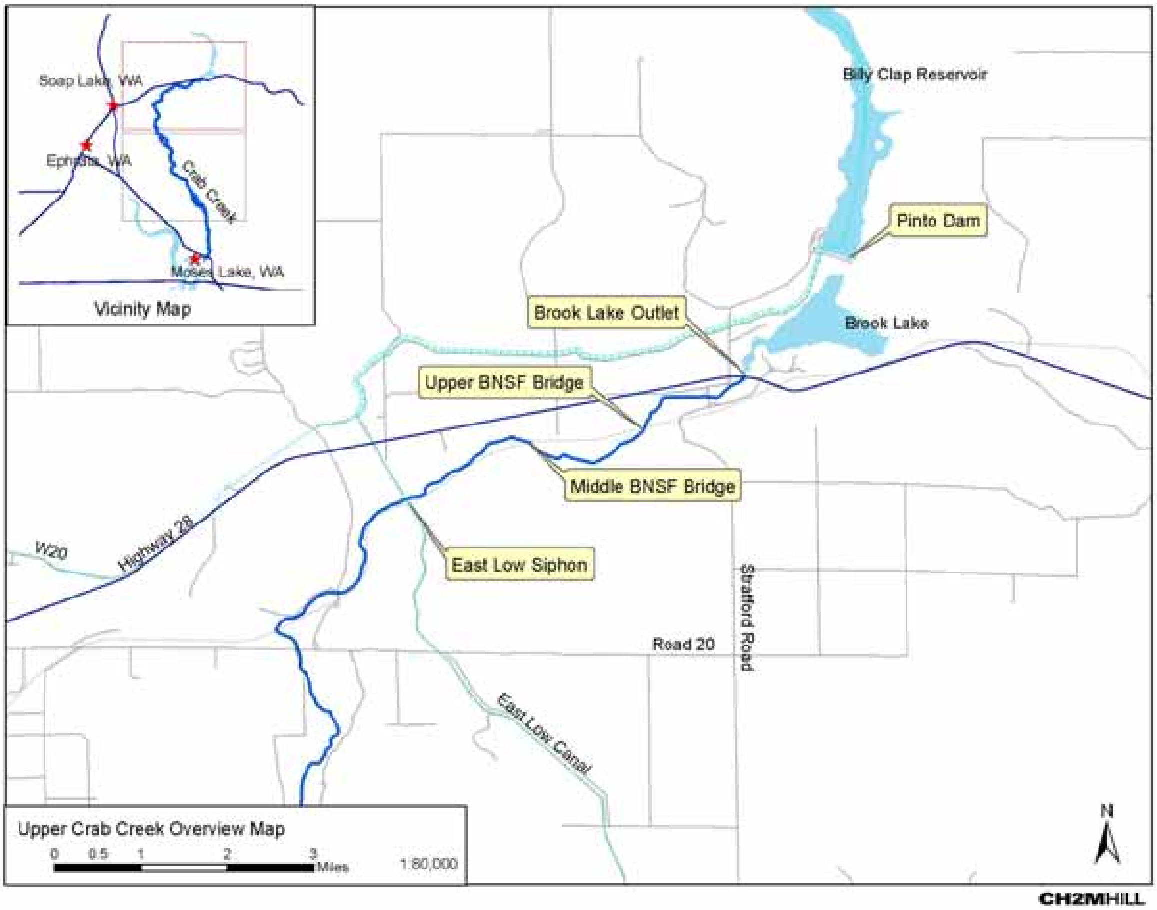


FIGURE 10
Plan View of Reach 1 Channel

Crab Creek Modifications

The capacity of the 4x4 outlet gate at Pinto Dam is estimated to be 1,000 cfs, and Reclamation expressed a desire to allow flows up to 1,000 cfs. Reclamation released flows of approximately 145 cfs from the 4x4 outlet gate at Pinto Dam into Crab Creek during fall 2006, and Reclamation staff observed backwater conditions in the approximately 5-mile long reach of Crab Creek between Brook Lake and the East Low Siphon as well as partial inundation of the toe drains at Pinto Dam.

Reclamation requested development of a more detailed hydraulic model for this reach to better evaluate potential backwater conditions and propose modifications that would decrease the water surface elevation in Brook Lake by increasing the conveyance of Crab Creek. The analysis focused on the following three objectives for flows up to 1,000 cfs:

1. Determine if the water surface elevation of Brook Lake can be lowered below the Pinto Dam toe drain invert elevation by modifying the Crab Creek channel.

2. Recommend a channel profile and dimensions, within the existing channel alignment, to meet the first objective. Develop a conceptual-level construction cost estimate to make the necessary improvements.
3. Identify an appropriate location and method to measure discharge in Crab Creek as close as possible to the outlet of Brook Lake without creating a condition that compromises the first objective.

As will be explained in following sections, after completing Objective 1 and part of Objective 2, CH2M HILL shared its preliminary findings with Reclamation. After reviewing the preliminary findings, Reclamation agreed that the estimated construction cost for only the excavation was too high and directed that the remaining work associated with Task 1B in the Modification 4 Scope of Work be suspended. Work completed before receiving the direction to suspend work is summarized in the following section.

Geomorphic Reach Descriptions

The approximately 4.8-mile Crab Creek reach from the Brook Lake outlet at Highway 28 to the East Low Canal siphon has a very flat slope of 0.0005. The channel is dry much of the year and meanders through agricultural tilled fields, gradually becoming more defined near the upper BNSF Railway crossing (Figure 10). Soils in the channel are mostly sand and small gravel with little or no presence of bedrock outcrops and appear to have a high potential for erosion.

The entire length of the Crab Creek channel from Brook Lake to the East Low Siphon was walked, and observations were documented using a geographic positioning system (GPS) unit and color photos. Based on field observations related to channel shape, substrate, and recent flow conditions, this reach of Crab Creek is subdivided into five subreaches (Figure 11). The characteristics of each subreach are summarized in Table 7. In addition to using the field observations to help calibrate the hydraulic model, the characteristics were also incorporated into the proposed channel design and were to have been used in the selection of bank stabilization treatments and associated costs. (These last two steps were not completed following Reclamation's request to suspend work, but the preliminary bank stabilization analysis is summarized in Attachment G.)

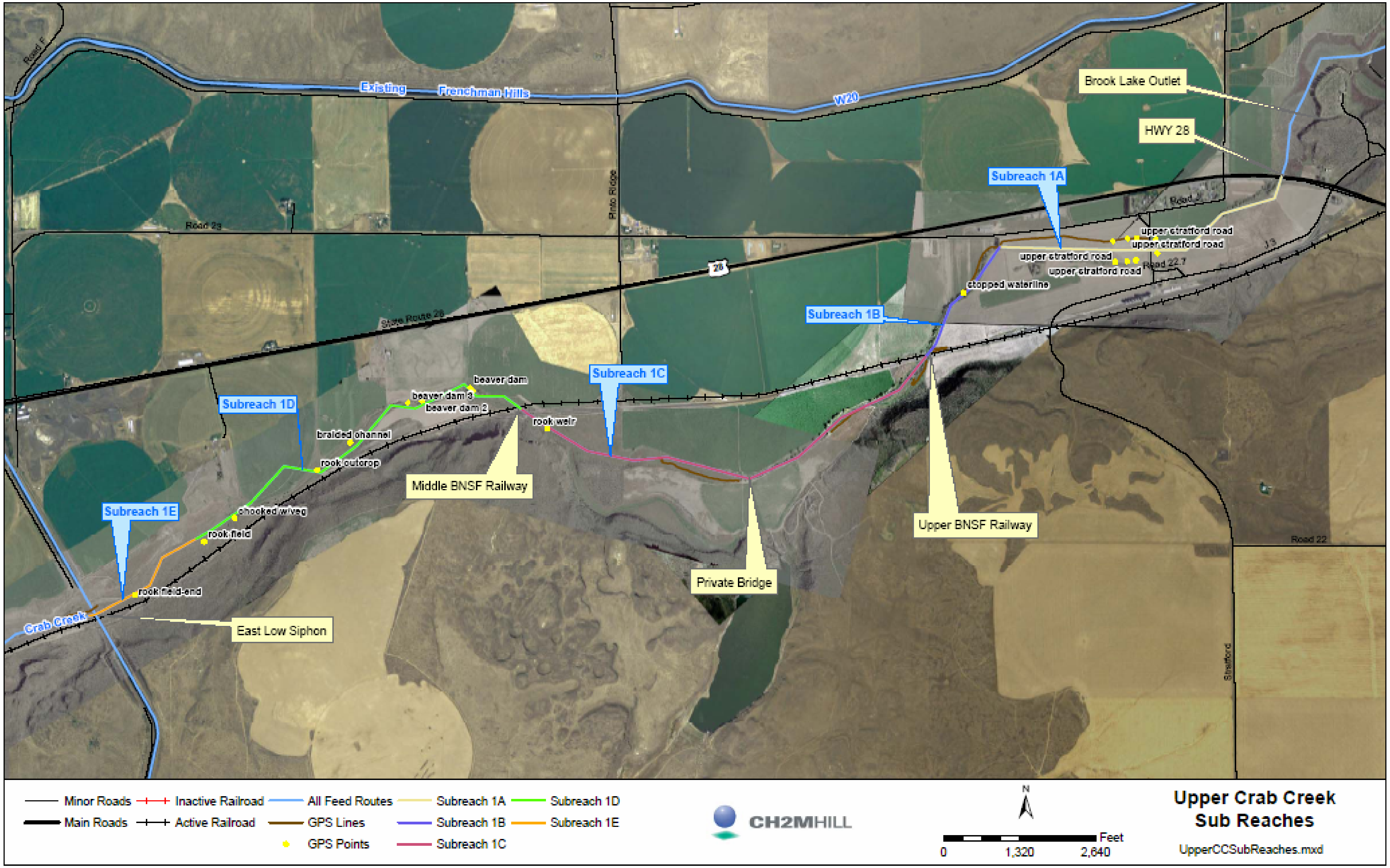


FIGURE 11
Five Subreaches of Reach 1

TABLE 7
Summary of Subreach Characteristics Within Reach 1 of Crab Creek

Subreach	Location	Geomorphic Characteristics	Erosion Potential
1A	From: Highway 28 To: 5,400-feet downstream of HWY 28 Length: 5,500 feet	This reach flows through agricultural fields. The channel is poorly defined with a silty/sand substrate and no riparian vegetation other than planted crops, with the exception of several hundred feet downstream of Highway 28 where the banks are lined with heavy brush and small trees. The potential for erosion is high because of loosely compacted tilled soils.	High
1B	From: Subreach 1A To: Upper BNSF Railway Length: 2,330 feet	The channel distinctly becomes more defined, composed of a slightly entrenched trapezoidal channel with an average top width of 20 feet, a fine alluvial substrate, and medium to heavy vegetation along the banks. The floodplain is composed of agricultural fields. This reach appears quite stable, however, if the existing vegetation is disturbed, the banks would become unstable and subject to erosion.	Medium
1C	From: Subreach 1B To: Lower BNSF Railway Length: 8,060 feet	Below the upper BNSF Railway crossing, the channel becomes broad with top widths ranging from 50 feet to 200 feet. The bank vegetation is light brush and grass. The floodplain is elevated and composed of planted agricultural crops. Similar to Subreach 1B, the reach is currently stable but disturbance would likely lead to instability.	Medium
1D	From: Subreach 1C To: 2,350-feet upstream of the East Low Siphon Length: 6,860 feet	The channel is moderately entrenched, trapezoidal in shape, medium to heavy vegetation along the banks. There are short sections characterized by a braided channel with unstable vertical banks. The substrate is composed of coarse alluvium and highly erosive. Located three beaver dams, 3-6 feet in height.	High
1E	From: Subreach 1D To: East Low Siphon Length: 2,380 feet	The substrate becomes fractured basalt bedrock. The channel is very wide (~ 100 feet) with no distinct shape. The banks are lightly vegetated. This reach is highly stable with no potential for erosion.	Low

Hydraulic Modeling

As part of the initial analysis, a one-dimensional (1-D), numerical hydraulic model of the study reach was set up using the HEC-RAS software package. The hydraulic model was to be used to evaluate the effectiveness of alternative channel modifications with respect to lowering the water surface in Brook Lake at the design flow of 1,000 cfs. Details on the initial steps of the model development, approach, and limitations are described in Attachment H.

Preliminary Analysis and Findings

As soon as possible, a straightforward uniform flow analysis was performed to determine alternative channel configurations that have potential to meet the design criteria.

The following design criteria were used as the basis for the preliminary analysis:

- Maximum water surface elevation at Brook Lake = 1,241.0 feet at Q = 1,000 cfs, maximum possible release from the 4x4 gates at Pinto Dam.
- A year-round flow of 100 cfs will be contained in a low-flow channel.
- Spring flows of 650 cfs will be contained within a middle terrace.
- The maximum release from Pinto Dam of 1,000 cfs will be contained within the banks of the modified channel.
- The 10-year storm of 2,400 cfs will not adversely affect the integrity of impacted structures.

The uniform flow analysis indicates substantial channel modifications are needed to meet the preliminary design criteria previously listed. Excavation would start at Brook Lake (bottom of lake elevation) and extend to the East Low Siphon (Figure 12) to excavate the steepest possible slope that could be created given the topographic constraints (that is, fixed endpoints—the lake bottom and the existing protective armor layer over the siphon). In addition, the area of the required channel cross section needs to be very large, thus requiring a large volume of excavation that includes reaches of bedrock. (Figure 13) Table 8 summarizes the estimated soil and rock excavation volumes for the entire reach required to meet the design criteria.

TABLE 8
Estimated Excavation Volumes

Material	Excavation volumes (CY)
Bedrock	120,000
Soil	1,380,000

The total estimated excavation cost for this volume is between $8 million and $12 million, assuming typical unit costs. Additional costs are required to construct structures within the modified channel to provide long-term stability.

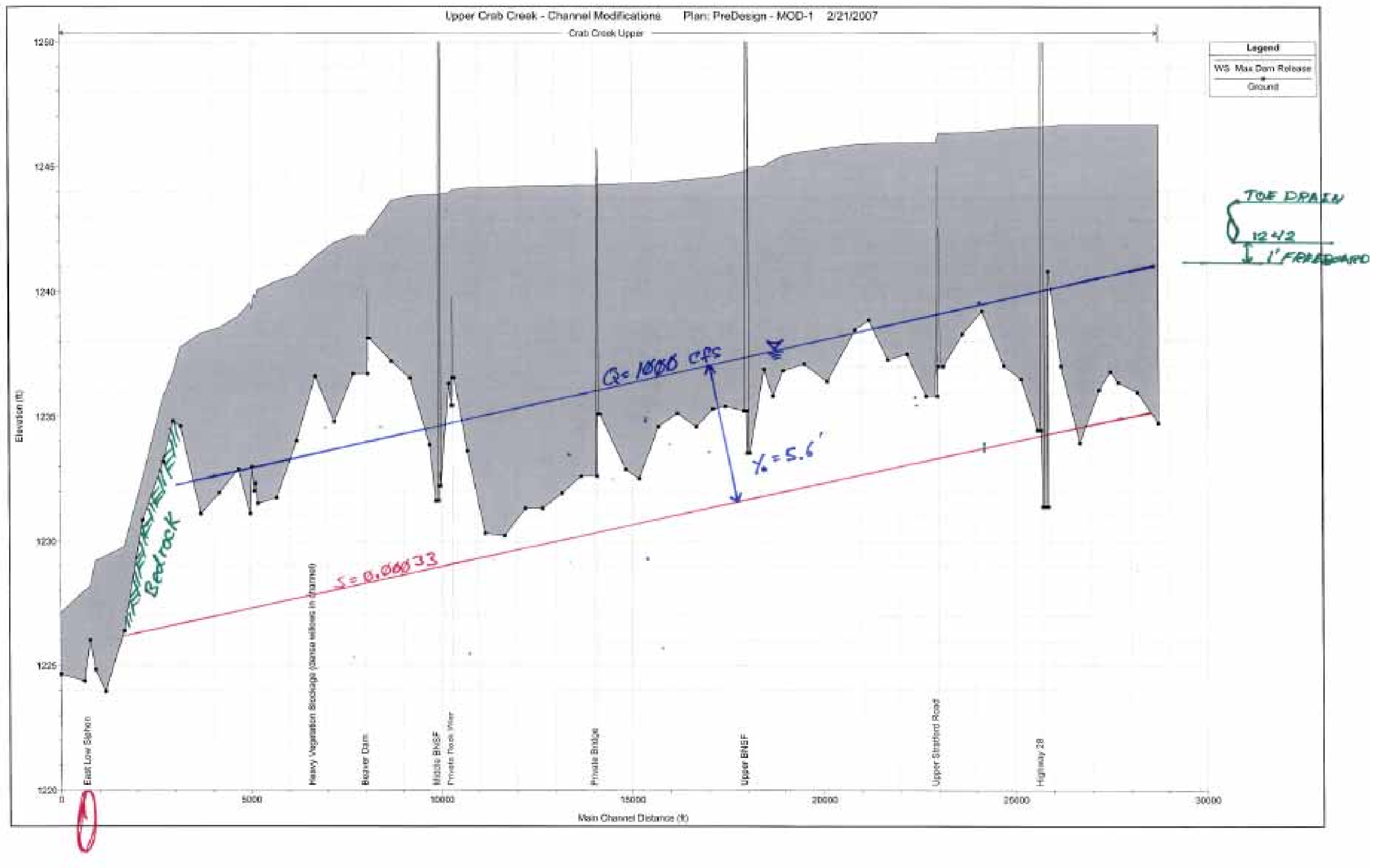


FIGURE 12
Preliminary Vertical Alignment Representing the Maximum Possible Slope (and thus, the smallest possible channel section) Required to Meet the Design Criteria
Upstream point corresponds to bed elevation of Brook Lake, and downstream boundary corresponds to bed elevation of cover over East Low Siphon.

Figure 13 depicts a typical terraced cross section cut over the existing channel several hundred feet downstream of Highway 28. This typical channel section meets the design criteria and shows the magnitude of excavation required to meet the current design criteria. The bottom width is 60 feet, the width of the middle terrace is 90 feet, the width of the upper terrace is 120 feet, and the top width is 200 feet. Bank slopes are 2H:1V. Depths are based on normal depth calculations associated with each of the three design discharges (Results from a true backwater rating curve result in higher elevations for the same discharges.)

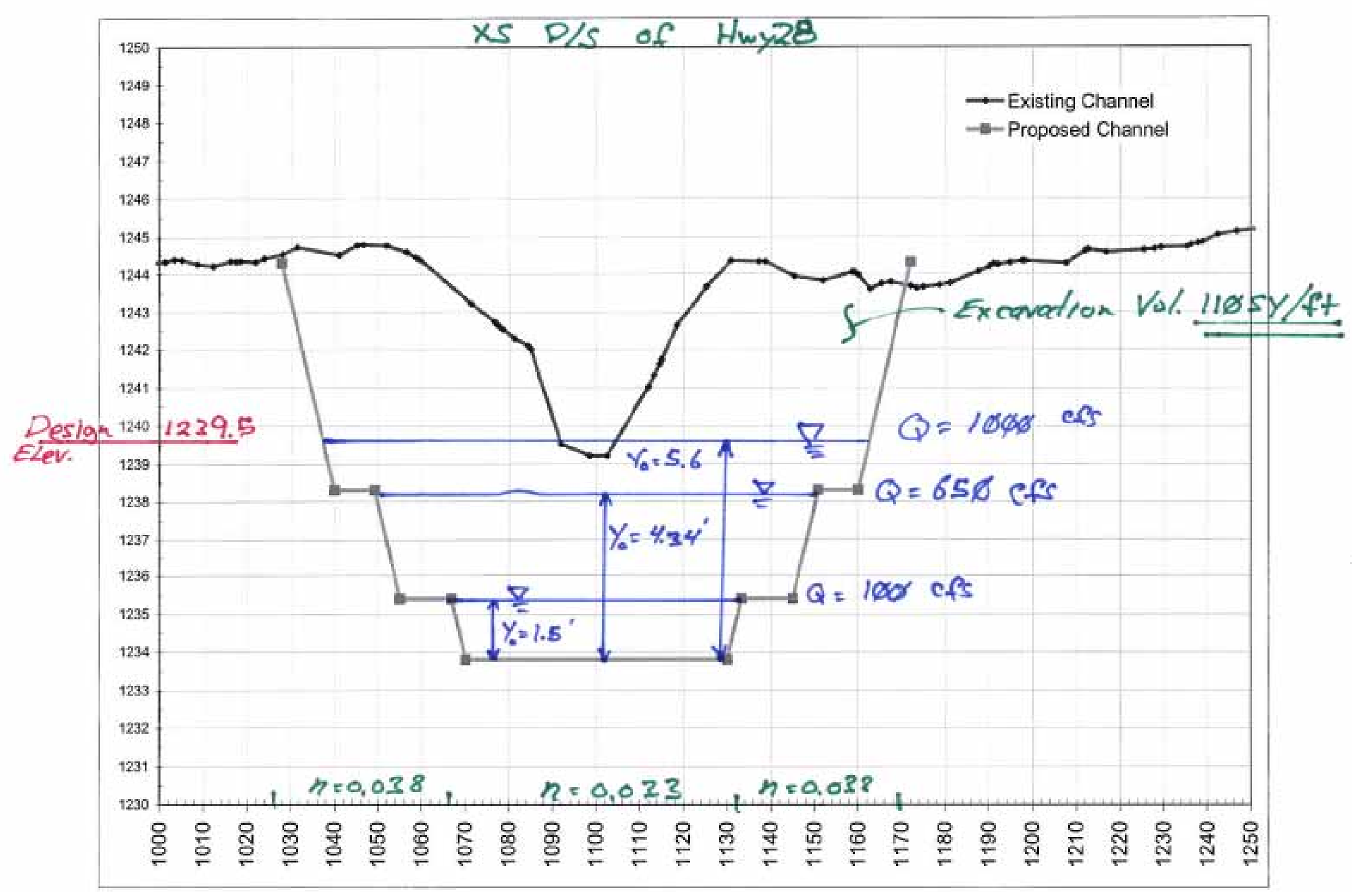


FIGURE 13
Typical Cross Section Template

Rating curves for the Brook Lake outlet, computed using a calibrated 1-D stepped backwater hydraulic model (HEC-RAS), as compared to the design criteria at the toe drain and the Brook Lake outlet, are shown in Figure 14. The black (dash-dot) line shows the calibrated existing condition, and the blue (solid) line shows the existing channel with three obstructions removed (Upper Stratford culvert, rock weir, and beaver dams) and a 3.8-foot lowering of the Brook Lake outlet. The lack of a marked decrease following removal of obstructions emphasizes how much the system is controlled by the gradient of the surface topography rather than backwater created by obstructions.

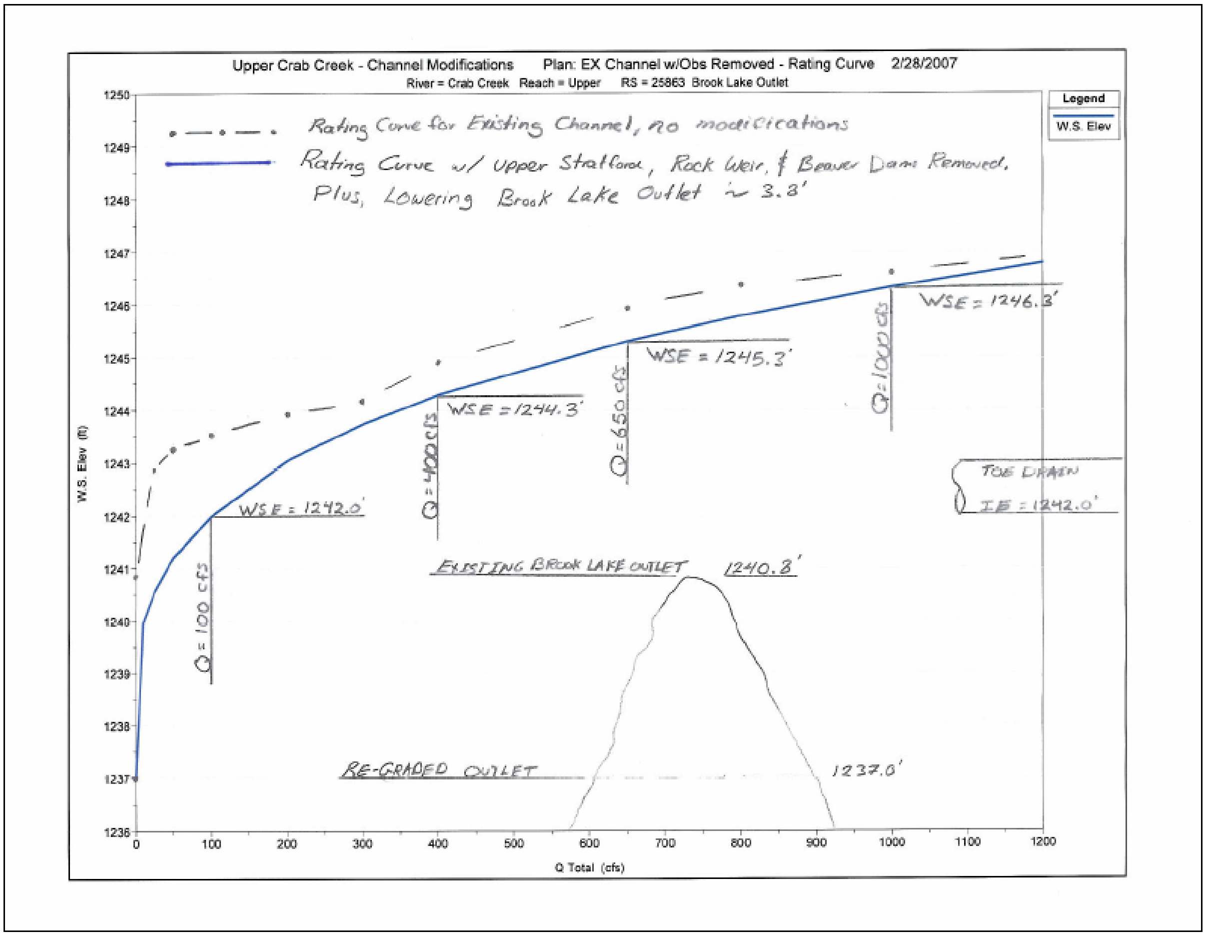


FIGURE 14
Rating Curves for the Brook Lake Outlet

Discussion

Based on these preliminary findings, Reclamation directed that CH2M HILL suspend further analysis on modifications to this reach of Crab Creek. While completing the preliminary analysis, several alternative design criteria and approaches were identified as follows:

- Other alternatives that allow raising the design water surface elevation should be considered.
- Reduced releases from the Pinto Dam outlet, combined with releases of supplemental flows at other locations, may provide an adequate solution.
- Reduction of the design flow, if possible, may provide a more realistic solution.

Fish Passage Barrier to Isolate Loan Springs

Crab Creek flows through lands owned by federal agencies as well as the State of Washington Department of Fish and Wildlife (WDFW). WDFW has expressed concerns that perennial flow in Crab Creek may allow carp, currently living in the perennial pond system to the south and in Brook Lake to the north, to move into the Loan Springs drainage where an existing population of trout exist.

The existing hydraulic model developed for this reach was used to evaluate flow paths and depths and to prepare a preliminary design and cost estimate for construction of a fish passage barrier to prevent Crab Creek flows from entering the Loan Springs drainage from the north. It was noted that 1000 cfs released from Pinto Dam would experience channel losses sufficient to reduce the flow in Crab Creek to approximately 850 cfs at the north end of the Loan Springs drainage. The depth of flow in the Loan Springs channel is shallow enough across Road 16 that carp are not expected to swim upstream from the perennial ponds into the Loan Springs drainage from the south. Based on these assumptions, the work was focused on development of a fish passage barrier to divert fish and flows less than 850 cfs down the west channel of Crab Creek.

Hydraulic Modeling

The MIKE 11 hydraulic model developed to model flows throughout Crab Creek within the project area was used to estimate a water surface profile at 850 cfs near the outlet of Willow Lake, in the vicinity of Loan Springs. The barrier that would prevent Crab Creek flows from entering the Loan Springs drainage from the north was designed based on the following criteria provided by Reclamation:

- Maintain 1 foot of freeboard above the estimated water surface at 850 cfs.
- Flows greater than 850 cfs may overtop the barrier.
- Barrier is not intended to contain flood flows above 850 cfs, and may suffer some damage above this flow.

At 850 cfs, the water surface elevation within the vicinity of the proposed berm is 1,168.4 feet. The average flow velocity is about 1 foot per second within Willow Lake.

Conceptual Design

In developing the conceptual design of the barrier, embankment slopes that are generally stable in granular material were assumed for the upstream and downstream faces of the barrier. The final slopes will have to be evaluated once the concept is accepted, by conducting a geotechnical stability analysis of the barrier, under the range of potential hydraulic conditions.

The barrier was not designed as an impermeable barrier. It is assumed that seepage through the barrier will be allowed, and the actual flow passing through the barrier depends on the gradation of the borrow material. To minimize the potential for damage to the barrier at flows above 850 cfs, a rock spillway was incorporated into the design. The details of this spillway and the barrier are shown in Attachment I. The drawings in Attachment I show an overall plan view of the barrier, overlaid on the aerial photo for the selected location near the Willow Lake outlet.

The barrier was located approximately at the narrowest section of the East Crab Creek channel, based on available aerial mapping. The average length of the barrier at this location is approximately 400 feet, measured along its axis. The barrier has a top width of 10 feet, and side slopes of 2 horizontal: 1 vertical. Additional detail is shown on the drawings (Attachment I).

For material to construct the barrier, a reasonably short haul distance (less than 1 mile from the site) was assumed. From limited field visits, it has been observed that there are acceptable borrow sites within this distance from the site, that appear to be comprised of sufficient material to construct the barrier. However, a thorough borrow source exploration has not been completed under the current phase of work.

For the rock apron, it is assumed that a rock source can be developed locally. There is a significant amount of bedrock that outcrops in the area. Although a contractor may likely develop a rock source nearby, for the small volume needed for the rock apron, imported riprap may be a more attractive option. For the basis of the cost estimate, this latter option was assumed.

Because of the significant amount of bedrock in the area observed at the surface, it was assumed that the location selected for the barrier will provide a reasonable foundation. There is also the chance that some rock excavation may be necessary, if it is encountered at shallow depths during construction, and would impact the design function.

For long-term erosion control, seeding is proposed for the completed barrier. This mix will only be temporary to hold soils in place and limit invasive weeds, until native seed can take over. Over the long term, and depending on the hydraulic cycles experienced by the barrier, occasional maintenance may be required to clean up or regrade the slopes, or potentially build up areas with embankment material or rock that are adversely affected by overtopping flows.

Cost Estimate

A conceptual-level cost estimate was prepared for the construction of the barrier. Current unit cost information was collected for the materials, as opposed to relying strictly on historical information. The cost estimate excludes impacts from tasks that have not been performed such as soils investigations.

The estimate was prepared in accordance with the guidelines of the Association for the Advancement of Cost Engineering (AACE) International. According to the definitions of AACE International, the Class 5 Estimate is defined as the following:

> *Class 5 Estimate*: This estimate is prepared based on limited information, where little more than proposed plant type, its location, and the capacity are known. Strategic planning purposes include but are not limited to, market studies, assessment of viability, evaluation of alternate schemes, project screening, location and evaluation of resource needs and budgeting, and long-range capital planning. Examples of estimating methods used include cost/capacity curves and factors, scale-up factors, and parametric and modeling techniques. Typically, little time is expended in the development of this estimate. The expected accuracy ranges for this class estimate are –20 to –50 percent on the low side and +30 to +100 percent on the high side.

The cost estimates shown, which include 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 will 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. Therefore, the final project costs will vary from the estimate presented here. Because of these factors, project feasibility, benefit/cost ratios, risks, and funding needs must be carefully reviewed before making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

Individual line item components and the total amount are summarized in Table 9.

TABLE 9
Loan Springs Isolation Barrier Conceptual Level Cost Estimate

Item Description	Item Quantity	Unit	Unit Cost	Cost
Excavate and Load Borrow	2,500	CY	$1.63	$4,075
Haul, Spread, Compact Fill	3,000	CY	$6.73	$20,184
Final Grade Embankment	1,333	SY	$1.76	$2,347
Import and Place Riprap for Rock Apron	300	CY	$45.92	$13,776
Erosion Control and Seeding	—	LS	—	$1,000
Tax and Contractor General Conditions	—	—	—	$4,773
Subtotal	—	—	—	**$46,155**
Division 01 Job Site Costs	0%	—	—	$0
Contractor Markups (Overhead, Profit, Insurance)	17.5%	—	—	$8,503
Estimating Contingency	25%	—	—	$13,664
Escalation (6 Months)	4%	—	—	$2,733
Market Adjustment Factor	5%	—	—	$3,565
Total Estimated Project Cost	—	—	—	**$74,620**

Road Crossings

If the flows are increased in Crab Creek without changes to the existing infrastructure, several currently used roadway crossings could become impassible. In total, there are six roadway crossings in the project reach: two located south of Willow Lake and four located along West Crab Creek near Road 10 and Stratford Road (Figure 15).

South of Willow Lake, Road 16 crosses two waterways: Crab Creek and Loan Springs. Road 16 is a gravel road that serves as the primary access to private properties located west of Crab Creek along Road 16. Currently, Road 16 fords both Crab Creek and Loan Springs and is impassable during high flows.

At the south end of Farm Unit Lake, Crab Creek branches into two systems that are herein referred to as West Branch and Crab Creek. As the West Branch flows parallel, and to the west of Crab Creek, it crosses four roadways, listed from north to south: 1) Road 10 NE, 2) Walker Road, 3) Barren Road, and 4) Lower Stratford Road.

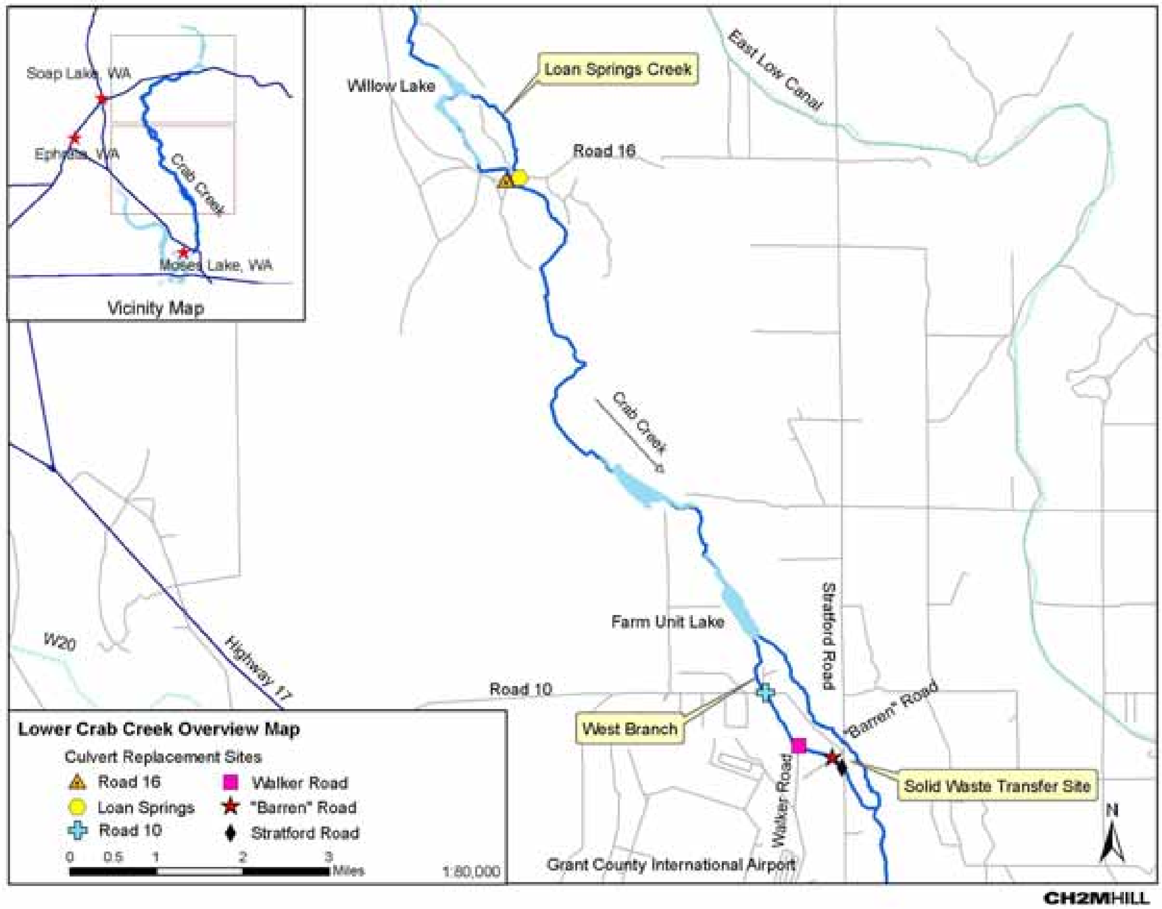


FIGURE 15
Lower Crab Creek Overview Map

Reclamation requested that CH2M HILL develop preliminary designs and cost estimates for the six crossings using the design criteria described here and summarized in Table 10 along with the existing culverts at each crossing.

1. At the Road 16 crossing of Crab Creek, develop two separate designs: one to convey flows up to 850 cfs and one to convey flows up to 240 cfs. For this crossing only, the structure shall also be designed to keep the structure intact at flows up to 2,400 cfs (10-year recurrence interval flood flow), even though vehicle access will be limited to the lower design flow.
2. At the Road 16 crossing of Loan Springs, convey flows up to 10 cfs.
3. At the Road 10 NE, Walker Road, Stratford Road, and Barren Road crossings over West Crab Creek, convey flows up to 500 cfs.

TABLE 10
Crab Creek Culverts

Road/Waterway	Design Flow (cfs)	Existing Infrastructure
Road 16 / Crab Creek	840/240[a]	None, the road fords the creek.
Road 16 / Loan Springs	10	None, the road fords the creek.
Road 10 / West Crab Creek	500	6 – 48” Circular CMP
Walker Road / West Crab Creek	500	1 – 18” Circular CMP
Barren Road / West Crab Creek	500	None, the road fords the creek.
Lower Stratford Road / West Crab Creek[b]	500	1 – 18” Circular CMP & 2 – 24” Circular CMP

[a]There are two alternative designs at this site.
[b]Reclamation requested that the proposed Lower Stratford Road crossing be relocated south of the solid waste transfer station.

Hydraulic Analysis

Two hydraulic models were created, one for Crab Creek south of Willow Lake (Road 16 area) and one for West Branch. The hydraulic model provides a means for evaluating alternative culvert configurations at each of the six road crossings. Modeling was performed using the U.S. Army Corps of Engineers HEC-RAS Hydraulic Modeling Software (v3.1.3).

The models were constructed using a combination of topographic data collected during the January 2007 field survey and available topographic data.

The Crab Creek model of the Road 16 crossing begins (upstream) on the main stem of Crab Creek, above the inlet to Willow Lake, an area commonly referred to as Flood Flats, and continues downstream 34,415 feet to its downstream boundary west of Homestead Creek. In total, there are 49 cross sections and a single road crossing at Road 16. These hydraulic structures were defined using field survey data. The downstream boundary condition was defined as normal depth, using a friction slope of 0.008 feet/feet.

The West Branch model begins (upstream boundary) on the main stem of Crab Creek, at Farm Unit Lake, approximately 3,700-ft north of Road 10 where it branches off from the main stem and continues downstream 14,450 feet to its downstream boundary where it rejoins with the main stem of Crab Creek. In total, there are 39 cross sections, 4 roadway crossings, and 2 in-line berms. These hydraulic structures were defined using field survey data. The downstream boundary condition was defined as normal depth, using a friction slope of 0.0016 feet/feet.

Friction losses were modeled using the Manning’s equation. Roughness coefficients were determined using typical values and engineering judgment. Ineffective flow areas were used at each crossing to simulate the contraction and expansion of flow through each crossing.

The following criteria were used in designing each culvert crossing:

- Circular corrugated metal pipe (CMP).
- A 2-ft minimum pipe cover, which corresponds to about 50,000 lbs maximum axle load.

- A minimum separation between pipes of 1/2 the diameter of the culvert.
- One foot of freeboard below the top of the road is preferred.
- Culvert ends projected from fill slope with no additional end treatment.
- Avoid raising the roadway grade when practical

The flowing design flow rates were used as follows:

- West Crab Creek, Q = 500 cfs
- Crab Creek south of Willow Lake, Q1 = 850 cfs, Q2 = 240 cfs (*There are two alternative designs for this crossing, one for each flow rate.*)
- Loan Springs, Q = 10 cfs

Attachment J contains print outs from the hydraulic models including plan view schematics, cross sections, and hydraulic profiles.

Results and Recommendations

The existing capacity and proposed improvements for each crossing are summarized below by location. Figure 16 shows a general culvert profile containing all the design information for each of the six crossings. Figures 17 through 20 show the general plan layout. Hydraulic model results are contained in Attachment J.

Crab Creek Road 16 Crossings

The Road 16 crossing of Crab Creek is currently a ford. Two different design flows were considered. At 850 cfs, six (6) 72-inch CMPs, each approximately 45 feet in length, will meet the design criteria. The roadway will need to be raised 8 feet. At 240 cfs, six (6) 48-inch CMPs, each approximately 35 feet in length, will meet the design criteria. For this scenario, the roadway will need to be raised 5 feet.

The Road 16 crossing of Loan Springs is currently a ford. Hydraulic analysis shows that at 10 cfs, a single 24-inch CMP, approximately 35 feet in length, will meet the design criteria. The roadway will need to be raised approximately 4 feet.

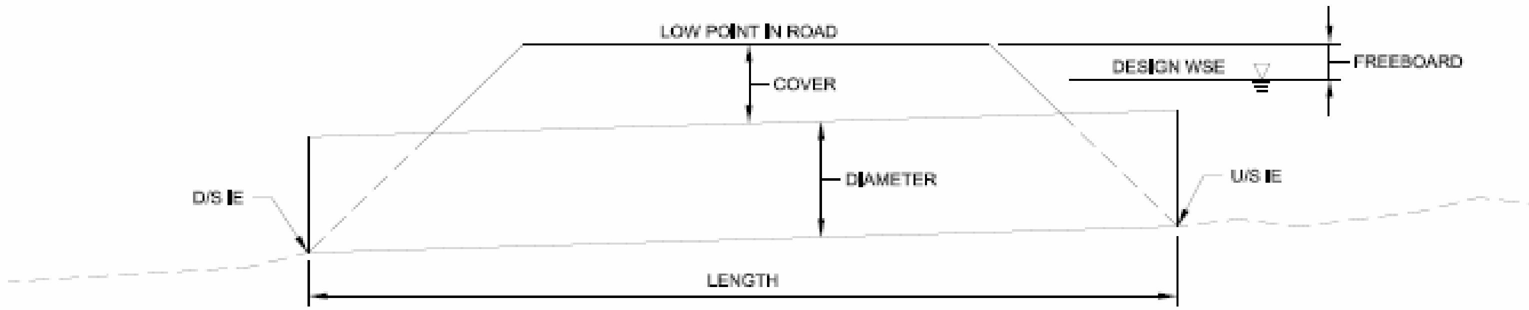
To ensure that the crossing will remain under higher flood flows (2400 cfs), the culverts were backfilled using unreinforced concrete.

West Crab Creek—Road 10 NE Crossing

This roadway is currently served by six (6) 48-inch CMPs that have a capacity to pass 800 cfs without surcharge and 3.9 feet of freeboard, and 900 cfs with 2.9 feet of surcharge and 1 foot of freeboard. The Road 10 culverts have adequate capacity to convey the design flow; therefore, no improvements are needed.

West Crab Creek—Walker Road Crossing

Walker Road currently has one 18-inch CMP. Hydraulic analysis shows that this culvert can pass 10 cfs before flows begin to over top the road.



ROAD/WATERWAY	DESIGN FLOW (CFS)	DIAMETER (INCHES)	# OF BARRELLS (#)	LENGTH (FEET)	U/S IE (FEET)	D/S IE (FEET)	FREEBOARD (NOTE 1) (FEET)	COVER (NOTE 2) (FEET)	DESIGN WSE (FEET)	LOW POINT IN ROAD (FEET)
WALKER ROAD/WEST CRAB CREEK	500	36	10	50	1100.3	1099.9	1.4	2.0	1102.2	1103.6
LOWER STRATFORD ROAD/WEST CRAB CREEK	500	42	10	70	1095.1	1094.8	0.9	2.0	1098.7	1099.6
RD 16/CRAB CREEK @ 850 CFS	850	72	6	46	1154.5	1152.0	0.3	2.0	1159.7	1160.0
RD 16/CRAB CREEK @ 240 CFS	240	48	6	35	1154.5	1152.0	0.4	1.0	1156.6	1157.0
ROAD 16/LOAN SPRINGS	10	24	1	35	1156.1	1155.7	1.1	1.0	1158.0	1159.4

1. FREEBOARD IS MEASURED FROM DESIGN WSE TO THE LOW POINT IN ROAD, WHICH IS NOT DIRECTLY ABOVE THE CULVERT.

2. COVER IS MEASURED FROM TOP OF PIPE TO THE TOP OF ROAD DIRECTLY ABOVE THE CULVERT.

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FIGURE 16
Culvert Design Summary

FIGURE 17
Road 16 Crossing Crab Creek and Loan Springs

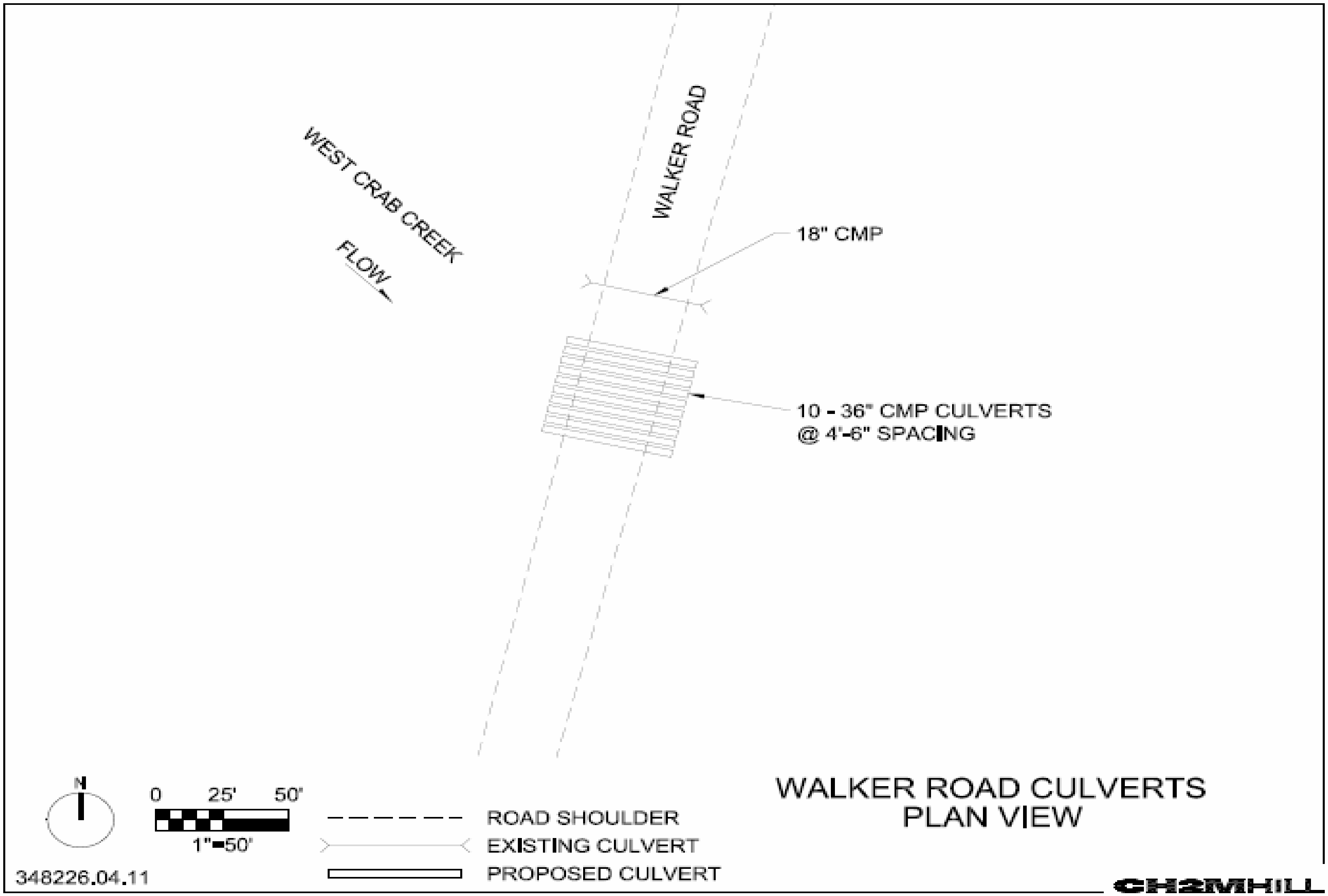

FIGURE 18
Walker Road Culverts Plan View

FIGURE 19
Barren Road Crossing Plan View

FIGURE 20
Lower Stratford Road Culverts Plan View

Hydraulic analysis shows that ten (10) 36-inch CMPs will meet the design criteria. The proposed location of these culverts is to the south of the existing culvert, which places the proposed culverts more in-line with the main channel according to the field survey data. A limited amount of site grading would be needed adjacent to the roadway.

West Crab Creek—Barren Road Crossing

Barren Road is a dirt road with no existing culverts. The roadway embankment is only 2 feet above the adjacent ground. Currently, water ponds behind the embankment and flows over the top of the roadway; backwater from Barren Road extends up to Walker Road.

The roadway needs to be raised approximately 2 to 3 feet, over several hundred feet, to accommodate a typical culvert crossing. Because Barren Road is infrequently used and does not appear to serve as the primary access to any residence, building, or facility, it is presumed acceptable to leave the crossing as a ford.

It is recommended that the roadway embankment located within the main channel be regraded to match the existing ground and finished with compacted gravel.

West Crab Creek—Lower Stratford Road Crossing

Currently there are two (2) 24-inch CMPs and one 18 inch CMP (placed with reverse slope) crossing Lower Stratford Road. These culverts can convey 50 cfs before water begins to overtop the road.

Hydraulic analysis shows that ten (10) 42-inch CMP culverts can convey the 500 cfs design flow while satisfying the other design criteria. The culverts would be flowing full at the design flow and are capable of passing 800 cfs before overtopping the roadway.

The proposed crossing location is located south of the existing culvert crossing. The proposed location lines up better with the main channel, and routes flows away from the solid waste transfer station. Recent information indicated that removal of the solid waste transfer station is planned during this next year. The alignment of these culverts should be re-evaluated during final design.

Cost Estimate

The cost estimates for the Crab Creek road crossings are identified in Table 11. Note that the Road 10 culverts have adequate capacity to convey the design flow; therefore, no improvements are needed.

TABLE 11
Supplemental Feed Route for Potholes Reservoir
West Crab Creek Proposed Culverts Upgrades Cost Estimate

Item Description	Item Quantity	Unit	Unit Cost	Cost
Road 16 Modifications at Loan Springs				
24” Diameter Culvert & Installation	35	LF	$81	$2,819
Culvert Backfill to Finished Road Grade w/Hauling	15	CY	$400	$6000
Guard Rail and Installation	220	LF	$25	$5,500
Subtotal				**$14,319**

TABLE 11
Supplemental Feed Route for Potholes Reservoir
West Crab Creek Proposed Culverts Upgrades Cost Estimate

Item Description	Item Quantity	Unit	Unit Cost	Cost
Road 16 Modifications at Crab Creek - 850 cfs				
72" Diameter Culverts: (6) @ 46-ft Each & Installation	276	LF	$147	$40,578
Culvert Backfill with Concrete to Finished Road Grade	625	CY	$400	$250,000
Guard Rail and Installation	800	LF	$25	$20,000
Subtotal				**$310,578**
Walker Road Modifications				
36" Diameter Culverts: (10) @ 50-ft Each & Installation	500	LF	$96	$47,880
Culvert Excavation	445	CY	$10	$4,450
Culvert Backfill to Finished Road Grade	340	CY	$15	$5,100
Channel and Spoil Grading	1	LS	$3,000	$3,000
Guard Rail and Installation	120	LF	$25	$3,000
Subtotal				**$63,430**
Barren Road Modifications				
Regrading Existing Road and Channel w/Spoil	280	CY	$12	$3,360
Crushed Surfacing Base Course	55	CY	$13	$715
Crushed Surfacing Base Course Installation	55	CY	$15	$825
Subtotal				**$4,900**
Lower Stratford Road Modifications				
42" Diameter Culverts: (10) @ 70-ft Each & Installation	700	LF	$113	$78,940
Culvert Excavation	565	CY	$10	$5,650
Culvert Backfill to Base Course Subgrade	324	CY	$15	$4,860
Crushed Surfacing Base Course	38	CY	$13	$494
Crushed Surfacing Base Course Installation to Asphalt Subgrade	38	CY	$15	$570
Asphalt Road Patch	2,054	SF	$7	$14,378
Channel and Spoil Grading	1	LS	$3,000	$3,000
Guard Rail and Installation	134	LF	$25	$3,350
Subtotal				**$111,242**
Total				**$504,469**
Contingency			25%	$126,117
Total Estimated Construction Cost				$630,586
Bonds/Insurance			2%	$12,612
Mobilization			2%	$12,612
WA State Sales Tax			8.0%	$50,447
Engineering, Legal and Administration Fees			20%	$126,117
Total Estimated Project Cost				$832,374

Table 12 identifies the cost associated with the Road 16 modifications at Crab Creek using a flow of 240 cfs as opposed to the previous cost estimate that used a flow of 850 cfs.

TABLE 12
Supplemental Feed Route for Potholes Reservoir
West Crab Creek Proposed Culverts Upgrades Cost Estimate

Item Description	Item Quantity	Unit	Unit Cost	Cost
Road 16 Modifications at Crab Creek - 240 cfs				
48" Diameter Culverts: (6) @ 35-ft Each & Installation	210	LF	$120	$25,116
Culvert Backfill with Concrete to Finished Road Grade	130	CY	$400	$52,000
Guard Rail and Installation	400	LF	$25	$10,000
Total				$87,116
Contingency			25%	$21,779
Total Estimated Construction Cost				$108,895
Bonds/Insurance			2%	$2,178
Mobilization			2%	$2,178
WA State Sales Tax			8.0%	$8,712
Engineering, Legal and Administration Fees			20%	$21,779
Total Estimated Project Cost				$143,741

Pinto Dam and Brook Lake Outlet Modifications

Background

The test flow in summer/fall 2006 presented an opportunity to observe impacts on the area at the Pinto Dam outlet, effects around Brook Lake, and effects of water discharging from Brook Lake into Crab Creek. The 1,000-cfs test release from the Pinto Dam outlet (considered to approximate the maximum possible release from the outlet) eroded a large scour pool in the silty soils adjacent to the existing plunge pool. In addition, the Brook Lake elevation eventually rose above the invert of the Pinto Dam outlet pipe and inundated the Pinto Dam toe drain weirs.

The erosion and significant impacts from backwater below Pinto Dam in Brook Lake must be addressed for Crab Creek to be a viable supplemental feed route option. Spillway improvements to minimize erosion at the Pinto Dam outlet and a Brook Lake discharge structure to control the elevation of Brook Lake were evaluated. In addition, there is a desire to measure the discharge from Brook Lake to manage releases down Crab Creek. Measuring the combined flow of the Pinto Dam outlet and the natural flow from Crab Creek below Brook Lake is critical to the proper management of supplement feed releases.

This evaluation includes a conceptual design for a spillway located at the Pinto Dam outlet pipe discharge, a Brook Lake discharge structure that incorporates flow measuring capability, a brief assessment of the hydraulic capacity of the upper end of Crab Creek, and a current estimate of costs associated with the modifications discussed in this evaluation.

Data Collection

Reclamation provided Reclamation drawings identifying construction details for Pinto Dam, hydraulic capacity of the Pinto Dam outlet sluice gate, detailed survey data identifying topography at 1-ft contour intervals for most of Brook Lake and the upper end of Crab Creek, and survey data for underwater topography at the Pinto Dam outlet pipe discharge. In addition, data were collected during site visits.

In August 2006, CH2M HILL and Knudsen Land Surveying generated survey data at the discharge of the Pinto Dam outlet pipe, Pinto Dam toe drains, and the outlet of Brook Lake to provide topography sufficient to support conceptual design of a spillway structure at the Pinto Dam outlet and a flow measuring discharge structure at the Brook Lake outlet.

Existing Facilities Description

General

The Pinto Dam outlet works include a 7-ft, 6-inch diameter outlet pipe installed through the base of Pinto Dam. Flow through the outlet pipe is controlled by a manually operated 4-ft^2 slide gate installed in a gate chamber at the approximate midpoint of the outlet pipe. The outlet pipe discharges water from Billy Clap Lake into the north end of Brook Lake. The slide gate capacity is 1060 cfs at a maximum Billy Clap Lake water surface elevation of 1,346.0 feet.

Brook Lake is typically fed from Crab Creek, which discharges into the southeast end of Brook Lake. When the water elevation in Brook Lake rises high enough, it discharges from the southwest end of the lake into Crab Creek just north of the Highway 28 bridge over Crab Creek. This reach of Crab Creek on the downstream side of Brook Lake has rarely carried significant flow over approximately the last 10 years. Crab Creek continues in a southerly direction, eventually discharging into Moses Lake. Crab Creek typically does not flow out of Brook Lake except during high runoff as a result of storm events or flooding. Flood flows as high as approximately 12,000 cfs have been reported through Brook Lake and into Crab Creek.

Pinto Dam Outlet

The Pinto Dam outlet pipe discharges into a channel that flows into Brook Lake. Visual observations of the abovegrade material indicate that the east side of the channel is comprised of a mixture of vertical basalt rock tapering to silty soils as the ground surface approaches Brook Lake. The west side of the channel is primarily silty soils. As previously noted, past releases from the Pinto Dam outlet have eroded soils forming a scour pool on the northwest side of the channel. The erosion has raised concerns that continuous releases of water at the anticipated supplemental feed rate of 1,000 cfs could impact the long-term stability of the Pinto Dam toe. In addition, some of the Pinto Dam toe drains have been inundated from the Pinto Dam outlet as a result of Brook Lake backwater even during long-term releases of only 150 cfs.

Brook Lake

Brook Lake has a surface area that historically ranges from approximately 340 acres to 430 acres depending on the water level. Observations during site visits of the area around Brook Lake indicate evidence that water in Brook Lake has been used for irrigation. Remnants of abandoned pumping facilities can be seen along the southwest shoreline. In recent years however, return flows into Brook Lake have probably not raised the water level high enough to facilitate pumping. An existing man-made rock dam located just north of the Highway 28 bridge crossing over Crab Creek is another remnant of a facility that was apparently used at one time to raise the level of Brook Lake to facilitate pumping. This rock dam continues to control the level of Brook Lake to some extent, as discussed in the following text.

The Brook Lake water surface elevation was 1,236.2 feet before water test releases from the Pinto Dam outlet pipe that started in August 2006. Brook Lake gradually filled at a long-term flow rate of approximately 145 cfs for several weeks. Brook Lake flowed over the rock dam at an elevation of approximately 1,242 feet, releasing water into Crab Creek. Additional rock dams, debris, and the minimal slope of Crab Creek for approximately five miles downstream of Brook Lake contributed to a gradual increase in the water level of Crab Creek and Brook Lake. Eventually, the backwater in Brook Lake rose to an elevation of approximately 1,245 feet, inundating the Pinto Dam outlet pipe invert and toe drain weirs at elevations of 1,242.3 feet and approximately 1,245 feet, respectively. Higher discharges into Brook Lake will further raise the elevation of Brook Lake.

Proposed Facilities

Pinto Dam Outlet

The evaluation of improvements necessary to eliminate erosion at the Pinto Dam outlet pipe discharge channel considered several alternatives for energy dissipation. Alternatives included a riprap plunge pool, manmade erosion protection, or a concrete spillway. A concrete spillway with energy dissipaters was determined to be the preferred alternative because of the certainty that it will be effective, familiarity with standard Reclamation design guidelines for proven spillway designs, and some uncertainty as to the availability of large-sized riprap. In addition, a concrete spillway provides a conservative safety factor that is critical considering the close proximity of the outlet structure to Pinto Dam.

The Pinto Dam outlet channel modifications also include a trapezoidal shaped riprap channel downstream of the spillway to further reduce the velocity of the water as it enters Brook Lake.

The following assumptions were made for the conceptual design of the spillway:

- The maximum flowrate from the Pinto Dam outlet pipe will be 1,060 cfs.
- A weir will be constructed at the discharge of Brook Lake to keep the maximum water surface elevation of Brook Lake at 1,241.0 feet, below Pinto Dam toe drain weirs and outlet pipe invert.
- Spillway floor slab will be 24-inches thick.
- Spillway walls will be 18-inches thick.
- Riprap will be filled in behind constructed walls.
- 1998 era Pinto Dam outlet pipe discharge channel topography below water surface is acceptable for conceptual design, as recent scour pool and channel erosion data is not available.
- Uplift pressures on the spillway structure will not be greater than the weight of the structure.

The conceptual design of the Pinto Dam outlet spillway was based on methodology presented in the Reclamation publication *Design of Small Dams*. Three different sections make up the spillway. The first section is a rectangular trough to transition the high-velocity discharge from the outlet pipe to a lower velocity and more uniform flow. The second section is the spillway chute that diverges as it drops in elevation. The third section is the stilling basin that includes energy dissipating blocks and is the planned location of the hydraulic jump. According to *Design of Small Dams*, the Froude number of the water in the chute just before flowing into the stilling basin dictates the type of stilling basin configuration. The Froude number for the proposed spillway chute is 9.8, which corresponds to a “Type 3” stilling basin. See Attachment K for detailed calculations identifying the process used to size the stilling basin. The stilling basin then transitions into a trapezoidal-shaped riprap channel that discharges into Brook Lake.

See Attachment L for conceptual design drawings of the proposed spillway and riprap channel. Note that the spillway dimensions and slopes were optimized to take into consideration the existing location of an exposed basalt cliff, and existing grades to minimize rock excavation and reduce cavitation at transition locations.

The design of the spillway structure requires further hydraulic calculations and modeling to verify dimensions, structural calculations will be necessary to verify concrete thickness, and survey data and subsurface soils investigations will likely impact the spillway configuration once detailed information on the extent of channel erosion and subsurface rock locations are known. In addition, the spillway will not function effectively if the water elevation of Brook Lake does not match the water surface elevation shown on Attachment L.

Brook Lake Discharge Structure

The Brook Lake discharge structure is necessary to ensure the Pinto Dam outlet spillway works properly and also to provide a method of monitoring flow from Brook Lake into Crab Creek.

The Pinto Dam outlet spillway elevations are located so that the spillway will function effectively without inundating the Pinto Dam outlet pipe and toe drain weirs. The Brook Lake discharge structure should control the maximum normal water surface of Brook Lake such that it does not exceed approximately 1,241 feet, otherwise the spillway will not work as efficiently, and the toe drain weirs could be inundated. The maximum normal water surface elevation provides a buffer of approximately 1.3 feet between the Pinto Dam outlet pipe invert and Brook Lake water surface.

Flow through the Pinto Dam outlet pipe can be approximated from the slide gate position, therefore flow monitoring at the discharge of Brook Lake will provide a method of calculating the approximate return flows into Brook Lake. If return flows are known, Reclamation can reduce the discharge flow rate at the Pinto Dam outlet pipe accordingly.

A broad-crested weir, located at the site of the existing rock dam at the southwest corner of Brook Lake, meets the requirements of the Brook Lake discharge structure. Conceptual design drawings for a broad-crested weir are shown in Attachment M. Calculations indicate that a 100-ft wide submerged broad-crested weir at an elevation of 1,238 feet with 2.75 feet of head over the weir and a 1-ft elevation drop on the downstream side of the weir can pass 1,000 cfs. The conceptual design includes 2.25 feet of freeboard above 1,000 cfs water surface corresponding to a maximum measurable flow rate of approximately 2,200 cfs, depending on downstream water surface elevations. High runoff or flood flows in excess of 2,200 cfs would overtop the weir. However, design of the weir could be robust enough to withstand overtopping during typical flood flows without significant damage.

The conceptual design for the broad-crested weir has been purposefully kept simple. Manual or automated control gates and trashracks have not been incorporated into the conceptual design because they do not offer any significant added value or purpose for achieving the intent of the weir. If flow monitoring capability of flood events above 2200 cfs is desired, a significantly larger weir would be required.

Similar to the Pinto Dam outlet spillway, the Brook Lake discharge weir will not function correctly if additional improvements are not made to reduce the backwater generated from Crab Creek.

It is also assumed that property ownership in the vicinity of the proposed Brook Lake discharge weir is not a concern, although vehicle access to the weir may require negotiations with local property owner(s) for an easement across private land.

Cost Estimates

Pinto Dam Outlet Spillway Cost Estimate

A cost estimate was developed for implementation of the proposed Pinto Dam outlet spillway. Current unit cost information was collected for the materials, as opposed to relying strictly on historical information. It was assumed that excavated volumes will overrun by approximately 25 percent, and riprap can be obtained locally in the vicinity of Pinto Dam. The cost estimate excludes impacts from tasks that have not been performed such as soils investigations.

TABLE 13
Proposed Improvements Cost Estimate, Pinto Dam Outlet Spillway

Item Description	Item Quantity	Unit	Unit Cost	Cost
Coffer Dam	1	LS	$20,000	$20,000
Dewatering	1	LS	$31,500	$31,500
Rock Excavation	228	CY	$12	$2,739
Excavation	4975	CY	$5	$24,874
Drain Rock Fill Under Spillway Slab	120	CY	$15	$1,800
Concrete (reinforcing steel and place)	490	CY	$600	$294,000
Riprap (local haul and place)	795	CY	$25	$19,875
Subtotal				$394,788
Contingency			25%	$98,697
Total Estimated Construction Cost				$493,485
Bonds/Insurance			2%	$9,870
Mobilization			2%	$9,870
WA State Sales Tax			8.0%	$39,479
Engineering, Legal and Administration Fees			20%	$98,697
Total Estimated Project Cost				**$651,400**

Brook Lake Outlet Weir Cost Estimate

A cost estimate was developed for implementation of the proposed Brook Lake outlet weir. Current unit cost information was collected for the materials, as opposed to relying strictly on historical information. The cost estimate excludes impacts from tasks that have not been performed such as soils investigations. In addition, easement costs, and temporary/ permanent roadway costs to access the site during construction were assumed to be estimated by the Reclamation.

TABLE 14
Proposed Improvements Cost Estimate, Brook Lake Outlet Weir

Item Description	Item Quantity	Unit	Unit Cost	Cost
Dewatering	1	LS	$7,350	$7,350
Excavation	6828	CY	$5	$34,138
Concrete (reinforcing steel and place)	68	CY	$600	$40,800
Grading	6828	CY	$10	$68,275
Subtotal				$150,563
Contingency			25%	$37,641
Total Estimated Construction Cost				$188,203
Bonds/Insurance			2%	$3,764
Mobilization			2%	$3,764
WA State Sales Tax			8.0%	$15,056
Engineering, Legal and Administration Fees			20%	$37,641
Total Estimated Project Cost				**$248,428**

Dieringer Dairy Wastewater Improvements

Introduction

This third section examines what modifications are required to the dairy operations if flows were to be increased in Crab Creek. This section describes existing conditions at the 1,000 cow operation and how the water levels and flow paths changed during the test releases in summer/fall 2006. It includes recommendations and a cost estimate for four improvements that are required to allow the dairy to continue operating in its current location if standing or flowing water were present in the swale south of the dairy barns (as occurred during the test releases).

Background

The Dieringer family operates a dairy north of Moses Lake, Washington. It is a well-established operation that includes 1,000 cows of which 500 are lactating. The calves are housed offsite at a separate location to the west of the dairy. A waste management plan has been developed for the dairy by the Natural Resources Conservation Service (NRCS) in accordance with NRCS and State of Washington rules.

The solid waste and wastewater is passed through a solids separator, and the wastewater is pumped through a 4-inch PVC pipeline to an 8-million-gallon (two 4-million-gallon cells) unlined storage lagoon located south of a swale that runs through the property south of the dairy barns. (Figure 21) Some of the clarified wastewater is pumped back from the lagoon and recycled to the barns and used for manure flushing. The excess liquid and solid waste is hauled by tank truck and land applied to farm land owned by the Dieringers west of the dairy. The land is used to grow corn for cattle feed. Because the swale south of the dairy is normally dry and not connected to any streams (such as Crab Creek) except during large flood events, there are no provisions to keep excess stormwater or snow melt from entering the swale. The swale is used for pasture and has at times been used to grow corn. There is a small amount of irrigated pasture between the dairy barns and the swale. The pasture is irrigated from a limited amount of water pumped from a shallow pond east of the pasture. The land does not have irrigation water from the nearby irrigation district.

According to the property owners, the increased test flows in Crab Creek that occurred last summer (2006) created changes in water levels and flow paths that do not normally occur. As soon as the flow was increased in Crab Creek, the swale on the Dieringer property south of the dairy began to fill with water. When the test flow was stopped, the water level quickly receded. There was no observed overland flow that contributed to the water in the swale.

The Dieringers have expressed concerns about operating the dairy in its current configuration adjacent to standing or flowing water such as was experienced during the Crab Creek test flows.

Proposed Improvements

The scope of this evaluation is limited to identification of improvements that would allow the dairy to continue operating in its current location when there is standing or flowing water in the swale south of the dairy barns. Wastewater and stormwater runoff from the dairy will need to be contained and routed to storage lagoons. When water is in the swale, the existing lagoons are not accessible and not practical to operate. To overcome these problems the following work is needed:

1. Construct two lined 4,000,000-gallon lagoons to replace the existing ones.
2. Construct a protective earth berm to isolate the dairy and irrigated land from the adjacent, future water body.
3. Construct two pump stations and a pipeline to convey wastewater from the dairy to and from the storage lagoons.
4. Construct a stormwater collection and pumping system to convey water to the lagoons.

The location of the proposed improvements is shown on Figure 21.

FIGURE 21
Dieringer Dairy Site Map

Storage Lagoons

Two 4,000,000-gallon lagoons are needed to settle solids and store wastewater during the nonirrigation season. For efficiency, the two lagoons would be located adjacent to each other and be partially below ground level but above the water table level. From onsite observations, it was estimated that the lagoon bottoms could be approximately 3 feet below the existing ground level. The site chosen for the lagoons is outside the area currently irrigated with a center pivot machine but still on the Dieringer property. The lagoons would have a plastic membrane liner (possibly 40-mil PVC) with a protective layer of crushed rock.

With a capacity of 8,000,000 gallons (approximately 25-acre feet), the lagoons would be under the review and jurisdiction of the Washington State Department of Ecology, Dam Safety Section. Considering the lack of uncontrolled stormwater inflow and low density development in the area, obtaining approval for the lagoons appears to be possible.

Protective Berm

A compacted earth berm is needed to prevent nutrients and turbidity from the dairy and irrigated pasture from entering the future adjacent water body by way of surface flows. This berm needs to extend from the dairy barn area, along the edge of the currently irrigated area, and end near the storage lagoons. It is estimated that the soils in the area are of insufficient quantity and of an unsuitable quality to construct the berm. Allowance in the cost estimate has been made to import this soil.

Wastewater Pump Stations

The dairy operations and the site topography will require water to be pumped from the dairy barns to the lagoons. After the solids have settled, the water can be pumped back to the dairy barns for reuse. Ultimately, the wastewater is used for irrigation. Pumping facilities will be required at both locations. One pipeline can be used to alternately carry the water both directions. The existing 4-inch pipeline is adequate for the current operations but will be submerged and is not in the appropriate location for future use.

Stormwater Collection

A shallow drainage channel located at the uphill toe of the protective berm could be used to collect stormwater and snow melt water so that it could be pumped to the storage lagoons. Due to the slope of the land, it is probable that two small float activated pump stations may be needed. The amount of stormwater produced from the site is minimal.

Cost Estimate

The conceptual cost of the work to handle the wastewater and stormwater has been estimated to be in the order of $2,600,000. This estimate does not include the value of the land that would be taken out of service, the cost of closing the existing lagoons, or the cost of various permits and approvals that will be required. A summary of the costs of the components is shown in Table 15.

TABLE 15
Cost Estimate April 10, 2007, Dieringer Dairy Wastewater Management Improvements

Item Description	Item Quantity	Unit	Unit Cost	Cost
3,300-ft long Earth Berm	12,700	CY	$25	$317,500
Two 4,000,000-gallon Storage Lagoons				
Earth Berms	20,600	CY	$20	$412,000
Excavation	13,900	CY	$2	$27,800
Membrane Liner	180,000	SF	$2	$360,000
Rock Cover Over Liner	13,400	CY	$20	$268,000
Concrete Control Structures & Valves	1	LS	$25,000	$25,000
4” PR 200 PVC Pipe	3,600	LF	$14	$50,400
Solids Handling Pumps, Sumps, Electrical	2	EA	$25,000	$50,000
Stormwater Collection System & Pump	1	EA	$25,000	$25,000
Fencing	5,000	LF	$5	$25,000
Subtotal				$1,560,700
Contingency			25%	$390,175
Total Estimated Construction Cost				$1,950,875
Bonds/Insurance			2%	$39,018
Mobilization			5%	$97,544
WA State Sales Tax			8%	$156,070
Engineering, Legal and Administration Fees			20%	$390,175
Total Estimated Project Cost				**$2,633,681**

Additional Work

The facilities described would allow the dairy to continue operating as it is currently run. No allowance is made for regulatory changes or expansion. Before decisions are made to proceed with the improvements, it is suggested that additional planning work be done as follows:

- Determine if there are plans for expansion of the dairy.
- Determine the proper size of the storage lagoons.
- Determine the design capacity of the pumping equipment and pipeline.
- Evaluate the onsite soils, groundwater levels, and sources of materials.
- Establish the future water level adjacent to the dairy.

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Attachment A

Field Observations

ATTACHMENT A

Field Observations

On July 19-21, 2006, Steve Clayton and Joe Young from CH2M HILL met with WDFW staff that manage the Gloyd Seeps Wildlife Area, Greg Fitzgerald (Refuge Manager) and Robert Fink (former Refuge Manager, now retired). Roger Sonnichsen (Reclamation) also provided a short field tour of the reach between Pinto Dam and Road 20.

Key field observations include the following (from upstream to downstream):

- Crab Creek was dry from Brook Lake to Road 20.
- Crab Creek passes through a field on either side of the Upper Stratford crossing, and Crab Creek itself is treated as part of the field (fully tilled).
- Adrian Sink seems to be located above the Adrian crossing according to a local landowner who has lived in the area for many years.
- A man-made levee on the right bank downstream of Adrian and upstream of the Burlington Northern Santa Fe (BNSF) Railway crossing is eroding at the toe of the slope along a short reach; this levee routes Crab Creek away from what appears to have been its natural historic path out into "Adrian Lake," which is now a field with a center pivot.
- Irrigation return flow was entering Crab Creek at Road 20, but the channel dried up a short distance downstream (approximately 0.5-mile north of the Abandoned Structure).
- The Abandoned Structure is located near the upper end of the wildlife area and is part of a man-made levee.
- The Upper Wildlife Structure is located just north of Willow Lake at the inlet to a short reach of channel blasted into bedrock. The bedrock spans the valley width and appears to have acted as historic sediment control, given the fine material deposited upstream of it. Locally, the area upstream of this structure is known as "Flood Flat."
- Willow Lake was dry.
- The Spring (Loan Creek) located south of Willow Lake appears to enter the east outlet of Willow Lake above Road 16.
- The east outlet of Willow Lake appears to be the primary channel, although it was difficult to determine in the field. The west outlet of Willow Lake was dry.
- Just upstream, the east outlet of Willow Lake is joined by the first spring.
- The east and west outlets of Willow Lake converge south of Road 16.
- From Road 16 to Moses Lake, Crab Creek appears to be a perennial, slowly flowing channel/string of ponds.

- A wide, deeper channel exists north of the area known as the “Spud Field” (between Road 15 and Road 12). The Spud Field is currently tilled and erodible.
- The Lower Structure is located immediately south of the Spud Field. The bedrock spans most of the valley width and appears to have acted as historic sediment control. Similar to Structure #2, Structure #3 appears to be blasted into bedrock.
- What appears to be the largest pond on Crab Creek is located North of Road 13.
- A wide, deeper channel exists just north of Road 12.
- The feed lot located near Road 12 appears to be a tributary of Crab Creek.
- Some of the channel below Road 12 appears within the backwater influence of Moses Lake.
- There is 1 to 2 feet of fine sediment spanning the channel width for an undetermined distance upstream, immediately upstream of the Road 7 crossing.
- The eroded streambank, identified by Reclamation and WDFW south of Road 7, could not be located within 50 meters of the provided coordinates, despite discussions with two landowners.

On October 18, 2006, Jeff Barry (CH2M HILL) and Pat Pope (Reclamation) initiated the sediment and water discharge sampling.

TABLE A-1
July 2006 Site Visit Field Notes Including Geomorphic Observations and GPS Points

Crab Creek July Site Visit Field Notes

Site	Stop 1	Abandoned Structure	Stop 3	Stop 4	Stop 5	Upper Wildlife Structure	Stop 6	Stop 7	Stop 8	Stop 9	Stop 10	Stop 11	Stop 12	Stop 13
Site ID #	ST1	STR1	ST3	ST4	ST5	STR2	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13
Date	7/19/2006	7/19/2006	7/19/2006	7/19/2006	7/19/2006	7/19/2006	7/19/2006	7/19/2006	7/20/2006	7/20/2006	7/20/2006	7/20/2006	7/20/2006	7/20/2006
Time	12:00	13:50	15:00		16:35	17:30	18:15		10:45	12:00	12:30			15:05
# photos	7	8	6	6	7	5	9	4	14	6	7	12	7	10
Channel defined?	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes
Structure present [a]	6	4	6	6	6	5	6	6	1	3	2	6	6	3
Wetted width (ft)	* 13.5	dry	dry	dry	20	dry	dry	dry		dry	dry	dry	dry	dry
Wetted depth (ft)	1.5	dry	dry	dry	1	dry	dry	dry		dry	dry	dry	dry	dry
Terrace width (ft)	75	450	150	95	120	35	25	100	130	75	150	160	220	150
Terrace depth (ft)	6	8	7	6	5.5	17	4	6	20	10	15	5.5	4	10
Veg width (ft)	41		7	6	120				80	75				6
Veg depth (ft)	3		2	1.5	5.5				2	0				
Veg description [b]	1,5	2,3	2,3	2,3		6		2,3	1,2,5	6	2,3	1,2,3	2,3	
Roughness (summer) [c]	2	5	4	3	4	3	4	5	2	5	4	3	3	3
Roughness (winter) [c]	3	5	4	4	5	3	5	5	3	5	4	3	3	3
Erodibility [c]	4	4	4	3	2	5	2	5	2	5	2	4	4	4
Substrate Surface [d]	8,9,2	7,8		9,6,7	3,9,7,6		5,6,7	1,10	9,7		8	9,2	7,6,5,4,3,2	
Substrate Sub-surface [d]	4,5,6	7,8	12	11,13	7,13		5,6,7	1	9,7		8	3,4,5,6,7	7,6,5,4,3,2	
Soil sample type [e]	3	1	1	2	1	3	1	3	1	3	1	2	2	2

Site	Stop 14	Stop 15	Stop 16	Stop 17	Stop 18	Stop 19	Lower Wildlife Structure	Stop 20	Stop 21	Stop 22	Stop 23	Stop 24	Feed Lot	Stop 26	Stop 27
Site ID #	ST14	ST15	ST16	ST17	ST18	ST19	STR3	ST20	ST21	ST22	ST23	ST24	ST25	ST26	ST27
Date	7/20/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006	7/21/2006
Time	16:10		7:20							12:00	13:15				
# photos	12	6	7	6	5	3	10	4	3	3	5	3	7	5	5
Channel defined?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes		yes	yes
Structure present [a]	2	6	6	6	6	6	5	6	6	6	6	6	3	1	1
Wetted width (ft)	dry	dry	dry	dry	25	35	25	50	150	35		20		60	65
Wetted depth (ft)	dry	dry	dry	dry	1	3	2	1.5	8	3.5		3.5		1.5	2
Terrace width (ft)	175	40	280	100	200	300	50	2600	200	80		150			
Terrace depth (ft)	12	6	6	6	12	8	16	4	13	8		10			
Veg width (ft)		40		25											
Veg depth (ft)		1.5		4											
Veg description [b]	2,3	2,3	1,2,3	1,3	1,5	1,3						1,3			
Roughness (summer) [c]	3	4	4	2	2	5	4	4	5	5		2		3	4
Roughness (winter) [c]	3	5	4	2	3	5	4	4	5	5		2		4	4
Erodibility [c]	5	3	4	4	3	3	4	2	4	4		4		4	4
Substrate Surface [d]	2,3,4,5,6,7	9,7	10,9,13	9,10	9,10	9	9,7	9,7		9		9,10			
Substrate Sub-surface [d]	2,3,4,5,6,7	6,5,4,12	10,9,13	1	6,7	5,6,4	1	7,13		3,4		12			
Soil sample type [e]	2	2	1	3	1	2	3	1	3	3	3	2	3	3	3

* Water in channel due to irrigation return flow not springs/seeps per conversation w/ Roger Sonnichsen (7/20/06)
[a] 1-bridge (road crossing), 2-bridge (rail crossing), 3-culverts (road crossing), 4-abandoned in-stream, 5-not abandoned in-stream, 6-no structure
[b] 1-riparian, 2-upland, 3-herbacious, 4-woody, 5-both, 6-none
[c] 1-very high, 2-high, 3-medium, 4-low, 5-very low
[d] 1-bedrock, 2-basketball, 3-softball, 4-baseball, 5-golf ball, 6-marble, 7-sand, 8-loam, 9-silt and organics, 10-root layer, 11-ash, 12-hard layer, 13-clay
[e] 1-bag sample, 2-bucket sample, 3-no sample

Crab Creek GPS Coordinates
WGS84

ID	Northing (°)	Westing (°)	Description
ST1	47.37579	119.38178	Just below Rd 20 crossing
ST2	47.36376	119.381	Abandoned structure
ST3	47.36687	119.37702	
ST4	47.36994	119.37554	Near transition of wet to dry from irrigation runoff
ST5	47.35311	119.38593	
ST6	47.34531	119.38171	
ST7	47.33998	119.37661	
ST8	47.42736	119.27312	Highway 28 crossing
ST9	47.42422	119.28278	Upper Stratford Culverts
ST10	47.41685	119.32614	BNSF Railway Crossing below Round Lake
ST11	47.40757	119.35819	Dowstream of blowoff siphon (40 cfs origin)
ST12	47.40271	119.36819	Jim's property
ST13	47.39248	119.37493	Adrian Rd crossing
ST14	47.38741	119.38911	
ST14D1	47.38832	119.38697	Dike near BNSF Railway Crossing (channel makes 90 bend)
ST14D2	47.3863	119.39049	Dike near BNSF Railway Crossing (channel makes 90 bend)
ST15	47.33448	119.36568	East outlet of Willow Lake
ST16	47.32686	119.36487	West arm of Willow Lake near Willow Lake
ST17	47.32182	119.35786	West arm of Willow Lake near Rd 16
ST18	47.32282	119.35663	East arm of Willow Lake near Rd 16
ST19	47.31986	119.35673	Just below confluence of east and west arm of Willow Lake
ST20	47.29554	119.3476	Bottom of spud field

ID	Northing (°)	Westing (°)	Description
ST21	47.30361	119.34901	Above top of spud field
ST22	47.31044	119.34407	
ST23	47.2656	119.32374	
ST24	47.26489	119.31702	Outlet to lake
ST25	47.23388	119.29682	Feed lot crossing
ST26	47.22504	119.2776	Lower Stratford bridge
ST27	47.18965	119.26567	Road 7 bridge
R20	47.38279	119.38436	Road 20 crossing
WL	47.33682	119.36892	Willow Lake panaramic view-point
WLIN	47.33805	119.37168	Willow Lake inlet
WLRD	47.33877	119.37358	Willow Lake Road Crossing
WTR	47.37103	119.37615	Transition from wet to dry between ST1 and ST4
EWC	47.32047	119.35728	Willow Lake east west confluence
BE1	47.38879	119.38397	Bank erosion site
STR1_1	47.36257	119.38067	Abandoned Structure
STR1_2	47.36285	119.38084	Abandoned Structure
STR1_3	47.36371	119.38139	Abandoned Structure
STR1_4	47.36399	119.38155	Abandoned Structure
STR1_5	47.36401	119.38175	Abandoned Structure
STR1_6	47.36428	119.38196	Abandoned Structure
STR2	47.34258	119.38137	Structure where rattlesnake was found (upper wildlife structure)
STR3	47.29412	119.34542	Structure below spud field (lower wildlife structure)

Attachment B

Hydraulic Modeling

ATTACHMENT B

Hydraulic Modeling

Model Development

The model network (alignment) and cross section geometry were extracted from the generated DEM using MIKE11 geographic information system (GIS). Refer to Section 4.1 for further details regarding the methodology and data used to generate the DEM surface.

The 23-mile study reach of Crab Creek was modeled as a single, continuous reach. The cross section layout was determined using aerial photography, various forms of survey data, and information gathered during the site visit. Cross section locations were selected to best capture breakpoints in topography and positioned perpendicular to expected flow lines based on topography and engineering judgment. On average, cross sections are located approximately every 1,000 feet and immediately upstream and downstream of all hydraulic structures. In all, there are 171 cross sections, 6 bridges, and 2 culvert crossings.

In locations where the area of expected inundation could extend beyond the cross section, the 10-m public domain data were used to supplement the original data set by extending the cross section to include the full width of the functional floodplain. The 10-m data are coarser than the original data set but provides a better basis for predicting the area of inundation and improves the accuracy of the sediment transport analysis.

All cross sections below Willow Lake were reviewed and modified because the channel in this reach was inundated at the time the aerial photos were taken, and these aerials provided the basis for the photogrammetry survey from Reclamation.

A systematic approach for reviewing and editing cross sections was developed to provide consistency throughout the process. First, a database was assembled that contained the section ID, wetted top width, distance from thalweg to the left end point, and estimated average depth. All data were collected using aerial photography, photogrammetry data, 1930s contours, and data collected during field investigations. Once the database was complete, the sections were reviewed one by one and the channel (section underwater during the photogrammetry survey) modified based on the assembled database. The channel was modified by identifying the top of the bank and adjusting the channel geometry to match the measured width and depth as closely as possible given the available data. The shape of the cross section below water was determined based on the width to depth (b/y) ratio. If the b/y ratio was greater than 20 (wide channel assumption where R~y), a rectangular channel was used, for all other cases, a trapezoidal channel shape was assumed.

Further modification was made to 8 of the 171 cross sections based on field survey data collected while taking discharge measurements during the October field visit. The 8 cross sections reflect more accurately the true channel topography and were used as reference during the hydraulic model calibration.

The effective flow area through each cross section was carefully defined for each cross section by evaluating the topography and aerial photos. Proper definition of the effective flow area prevents the 1-D model from calculating conveyance through portions on the channel that are purely backwater or completely disconnected from the channel. The effective flow area is defined in MIKE11 using "marks." A typical cross section is shown in Figure B-1.

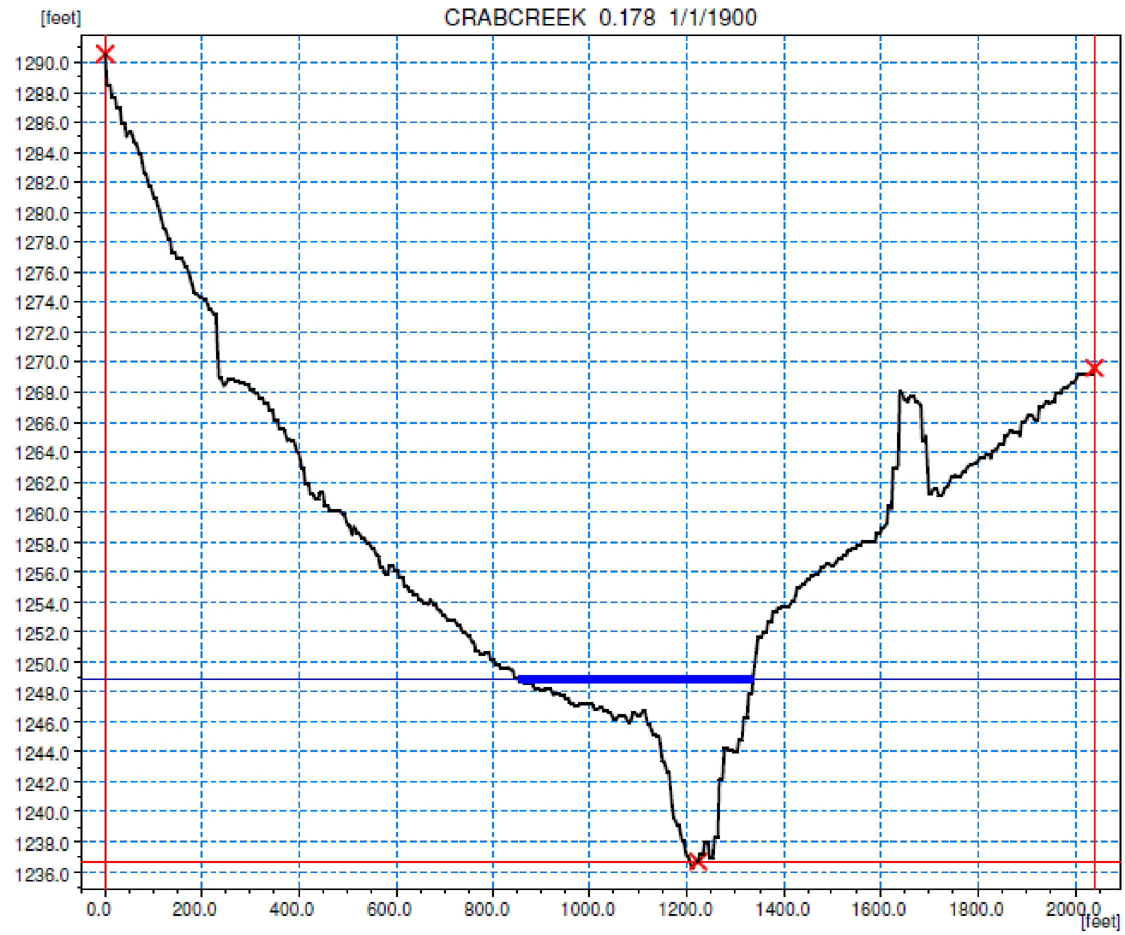


FIGURE B-1
Model Schematic of Crab_Creek_existing.xns11

Hydraulic structures, including bridges and culvert crossings, were defined using a combination of field measurements, surface topography, and photos. Hydraulics through the structures were modeled using the Federal Highway Administration (FHWA) Water Surface Pro (WSPRO) method, a commonly used set of equations to characterize bridge hydraulics. Typical values were used for loss coefficients because none of the structures appear to have extreme contractions or expansions. The flow to head relationship through the culverts was modeled using the energy equation, continuity equation, Manning's equations, the orifice equation (from the submerged condition), and the weir equation to account for flow over the roadway. MIKE11 computes the Q-h relations for each crossing using an iterative process.

Friction losses throughout the reach were calculated using Manning's equation with a uniform *n*-value across the entire section.

The water surface of Moses Lake defines the downstream boundary condition (fixed water surface). This water surface elevation was estimated using surface topography to be approximately 1,046 feet National Geodetic Vertical Datum (NGVD) just below Highway 17.

A constant flow rate defines the upstream boundary condition. The constant flow rate assumption, as opposed to removing flow based on seepage estimates, will produce a more conservative estimate of the total sediment load expected to deposit in Moses Lake. All seepage and inflow losses were ignored as part of this study. It should be noted that these factors should be considered at a later time, if further project consideration is warranted, to more accurately define the inundation area.

Model Calibration

The availability of calibration data is extremely limited and only moderately reliable in terms of its known accuracy. However, the available data provides a basis for determining the relative accuracy and the associated confidence in the model results. The objective is to achieve a level of accuracy consistent with that of the model input data (that is, surface topography, estimated flows, hydraulic structure parameters, etc.) and meet the objectives of the intended use of the model. In this case, the primary use of the model is to determine the general hydraulic characteristics, which are then used to evaluate the sediment transport characteristics at a planning level.

The best available data for model calibration are from a historic event that occurred February 29, 1980. A daily mean of 1,860 cfs was recorded at USGS gage #12467000, Upper Crab Creek at Moses Lake, located at Road 7. Oblique aerial photos were documented during the event for the entire study reach. Calibration data were extracted from these oblique photos by comparing the inundated area, at locations where physical features could be easily referenced (that is, bridges, road, telephone poles, houses, etc.), to the orthorectified aerial photos in which the wetted width could be measured and the water surface elevation (WSE) estimated using the DEM surface. There are a total of 11 locations where measurements could be obtained, most of which are near a bridge or other hydraulic structure.

Model calibration was conducted by initially setting up the model parameters based on professional judgment. Initial model results, specifically WSEs, were compared to measured calibration data. The initial results provide insight into which sections of the reach need to be modified to more accurately match the observed conditions. Determining which parameters are the most appropriate to modify depends on the magnitude of the error, the spatial location where the comparison is being made, and the accuracy of the model input data at that location. In this case, most of the calibration points are near hydraulic structures, the initial magnitude of model error was rather high, and the accuracy of the model inputs for the hydraulic structures is rather coarse. Therefore, the most appropriate parameters to adjust are the horizontal placement of the structure, which is only approximately known and significantly affects the Q-h relationship, the size of the opening if it was generally approximated (at a few locations), and the loss coefficients through each structure. At locations other than hydraulic structures, the Manning's roughness coefficient was adjusted within a reasonable range to increase or decrease the WSE.

Table B-1 summarizes the results of the calibration and shows the model error is reasonable and consistent with the accuracy of model inputs and the measured calibration data.

TABLE B-1

Summary of Calibration Results at Flow of Water Surface Elevation

Chainage (ft)	Average Elevation (ft)	Differences in WSE (ft)
15516	1245.5	-1.5
33314	1208.4	-4.1
37481	1193.7	0.7
37831	1193.7	0.7
37999	1193.4	0.4
39812	1190.3	-2.7
39922	1190.3	-2.7
81259	1153.9	0.9
82665	1153.8	0.8
120481	1096.1	-0.9
135440	1074.8	-0.2

Sources of model error include discrepancies between the generated topographic surface (DEM) and the real world topography, estimated geometry of hydraulic structures, limited accuracy of a 1-D model, the difference between estimated flow rate and actual flow rate, and assumptions inherent in any numeric computer model.

The model is suitable for the use in providing general hydraulic characteristics and evaluating the sediment transport characteristics at a planning level.

Future Model Use

This model was developed specifically for the needs of this project; therefore, its application to other projects may or may not be appropriate. Future users should review the model documentation in this report and all model inputs to ensure the model is suitable for a particular application.

If there is a need to do more detailed inundation mapping, in addition to the work that has already been performed by Reclamation, more work will need to be completed to both the model and the generated surface (DEM). This work includes detailed definition of floodplain features (that is, lakes, roadways, buildings, etc.) on the DEM surface. Further, a two-dimensional (2-D) model will be used to create the computed water surface at specific locations of interest. There is no need to switch software platforms, as MIKE11 contains a 2-D module.

Attachment C

Sediment Transport Modeling

ATTACHMENT C

Sediment Transport Modeling

Model Development

Several methods were used to estimate suspended sediment transport to Moses Lake under three different flow conditions (335, 580, and 875 cfs). Hydraulic output from the MIKE11 model was used to estimate suspended sediment transport rates into Moses Lake using four common sediment transport equations: Lane and Kalinske (1941), Einstein (1950), Brooks (1963), and van Rijn (1984).

Initial estimates were made using flow hydraulics measured at the time the suspended sediment sample was collected at 86 cfs. Based on the relative performance of these four equations (that is, predicted transport rates compared to observed transport rates), only the equations of Lane and Kalinske (1941) and van Rijn (1984) were used for all subsequent analysis. The analysis presented in this technical memorandum focuses on the most downstream location (Road 7), which is closest to the inlet of Moses Lake and considered the most representative location to estimate short- and long-term delivery rates to the lake. By calibrating the transport equations to the observed suspended sediment transport rate collected at the Road 7 Bridge, the upstream variability was incorporated into the sediment supply and transport capacity at this flow. The equations are applied as calibrated to observed sediment transport rates at 86 cfs to predict transport rates at 335, 580, and 875 cfs.

Other methods for predicting sediment transport rates are based on an analysis of observed suspended sediment data collected within the Crab Creek watershed and an extensive set of suspended sediment observations collected in Idaho.

Initial Parameter Settings

The Grant County Soil Survey (SCS, 1984) was used to determine the surface sediments available for transport. The Road 7 Crossing of Crab Creek is within the Starbuck soil type. The median surface size (d_{50}) (that is, the particle size, of which 50 percent of the sample is smaller) is between 0.074 mm and 0.42 mm. The d_{84} and d_{16} particle sizes varied between 0.42 and 2 mm and 0.074 and 0.04 mm, respectively. The initial d_{50} was set equal to 0.074 mm for both the Lane and Kalinske (1941) and van Rijn (1984) equations.

The Lane and Kalinske (1941) equation requires an estimate of the suspended sediment concentration, C_a, at a known elevation above the bed, *a*. C_a was initially set equal to the percent concentration measured at Road 7 on October 19, 2006 (0.0008 percent). The elevation was initially set equal to 1 percent of the flow depth. In addition, Lane and Kalinske (1941) developed a relationship between the ratio of particle fall velocity to shear velocity and the P_L ratio (the ratio between the depth integrated sediment concentration and C_a). The P_L ratio was initially set equal to 0.6.

Similarly, the van Rijn (1984) equation requires the calculation of a reference elevation, *a*, below which all sediment is transported as bedload. As previously discussed, this elevation was initially set equal to 1 percent of the flow depth. The van Rijn (1984) equation also requires the calculation of a critical shear velocity, $u'_{f,cr}$. This value is a function of the sediment size (that is, d_{50}) and was initially set equal to 0.02 ft/sec and 0.05 ft/sec for a d_{50} equal to 0.074 mm and 0.4 mm, respectively.

Model Calibration

The Lane and Kalinske (1941) and van Rijn (1984) equations were calibrated to the observed suspended sediment transport data collected at 86 cfs, immediately upstream of the Road 7 Bridge. Before calibration, these equations predicted 1.0 and 7.1 tons per day, respectively (compared to the observed value of 1.6 tons per day). (Table C-1) These calibrated equations were then used to estimate suspended sediment transport rates at 335, 580, and 875 cfs assuming two different sediment sizes taken from the Grant County Soil Survey (SCS, 1984) (that is, 0.074 mm and 0.42 mm). The principal variables that are adjusted in the Lane and Kalinske (1941) and van Rijn (1984) equations are the suspended sediment concentration at a known elevation above the bed, C_a, and the critical shear velocity, $u'_{f,cr}$. To reproduce the observed suspended sediment transport rate at the Road 7 sample site, the parameter C_a was increased by an order of magnitude, from 0.0007 percent to 0.0011 percent. Similarly, the critical shear velocity, $u'_{f,cr}$ in the van Rijn (1984) equation was increased by approximately 25 percent, from 0.02 ft/sec to 0.025 ft/sec, assuming the d_{50} is 0.074 mm. Given the hydraulics at 86.3 cfs, the van Rijn (1984) equation predicts zero suspended sediment transport if the d_{50} is 0.4 mm.

TABLE C-1
Comparison of Predicted and Observed (86.3 cfs on October 19, 2006) Suspended Sediment Transport Rates at Road 7 Before Calibration

Equation	Observed Suspended Sediment Transport (tons/day)	Predicted Suspended Sediment Transport (tons/day)
Lane and Kalinske (1941)	1.63	0.99
van Rijn (1984)	1.63	7.14

Additional Methods for Estimating Suspended Sediment Transport Rates

The second method for estimating suspended sediment transport is based on analyzing the suspended sediment data collected at Crab Creek at Rocky Ford Road (USGS Gage #12464770) and in the Frenchman Hills Wasteway (USGS Gage #12471090) over a range of flows. At the Crab Creek at Rocky Ford Road site, 120 suspended sediment observations were collected between 1994 and 2004 at flows ranging from 3.7 cfs to 1,880 cfs. (Figure C-1) At the Frenchman Hills Wasteway site, 13 suspended sediment observations were collected between 1993 and 1995 at flows ranging from 123 cfs to 598 cfs. (Figure C-2). The suspended sediment rating curves developed from this data set are shown in Figure C-3 and were used to estimate suspended sediment transport rates at 335, 580, and 875 cfs. For example, at 580 cfs, the estimated suspended sediment transport rate in the Frenchman Hills Wasteway is approximately 27 tons per day. However, at this same flow, the Crab Creek at Rocky Ford Road rating curve predicts approximately 281 tons per day of suspended sediment transport.

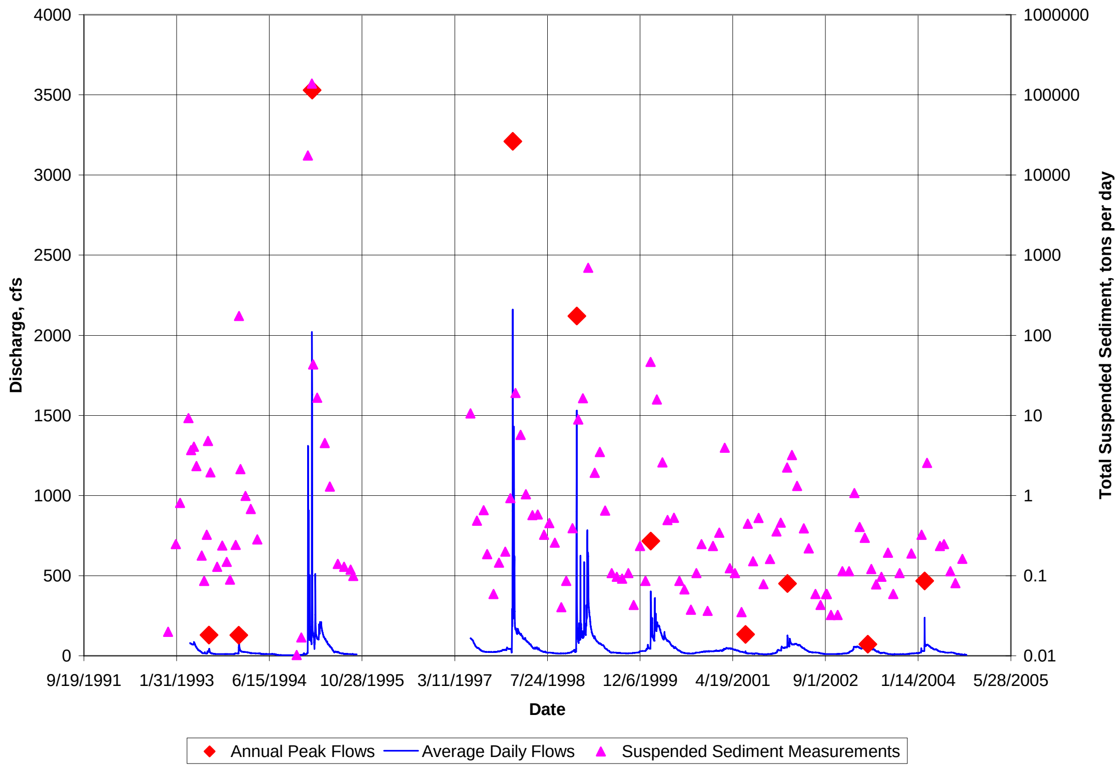


FIGURE C-1
Stream Flow and Suspended Sediment Transport Data Collected at the Crab Creek at Rocky Ford Road (USGS Gage #12464770).

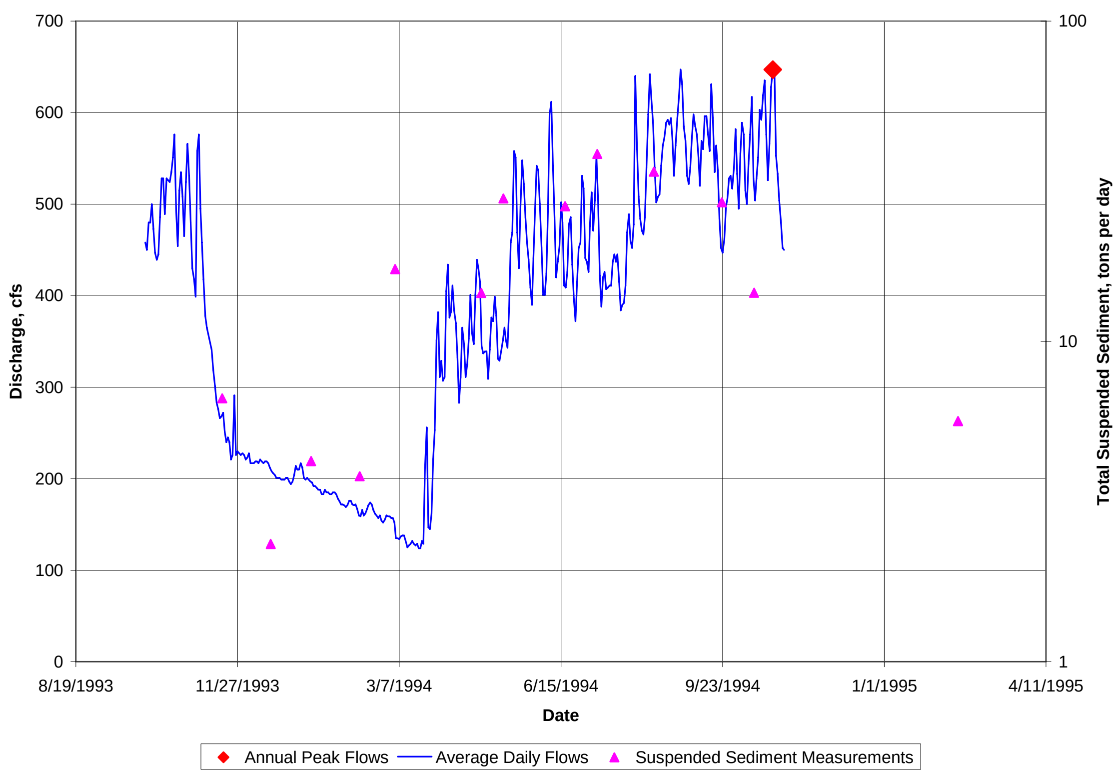


FIGURE C-2
Stream Flow and Suspended Sediment Transport Data Collected at the Frenchman Hills Wasteway (USGS Gage #12471090).

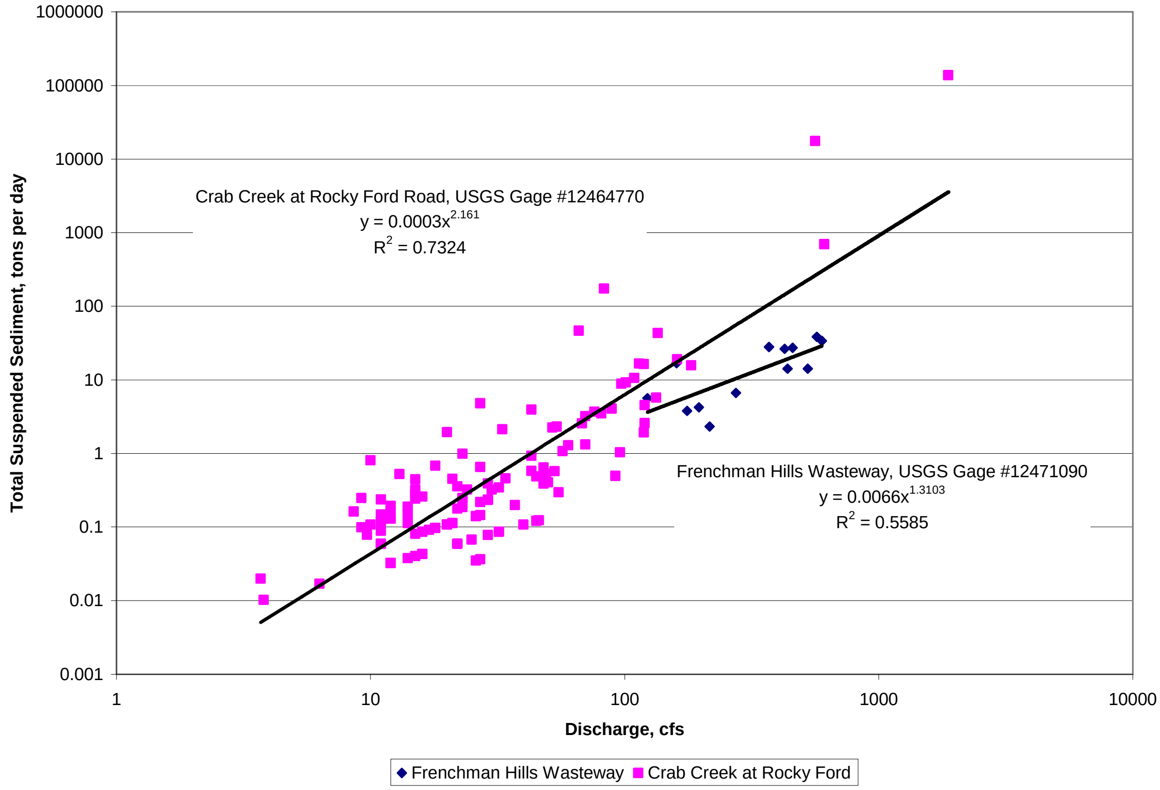


FIGURE C-3
Suspended Sediment Rating Curves at Crab Creek at Rocky Ford Road (USGS Gage #12464770) and at the Frenchman Hills Wasteway (USGS Gage #12471090).

A third method to estimate suspended sediment transport at Crab Creek at the Road 7 Bridge is based on extrapolating the relationship between the unit suspended sediment transport and drainage area collected at 33 sites in Idaho (Idaho data downloaded from http://www.fs.fed.us/rm/boise/research/watershed/BAT/index.shtml) (Figure C-4 graphs 86 cfs, Figure C-5 graphs 375 cfs, Figure C-6 graphs 580 cfs, and Figure C-7 graphs 875 cfs).

Figure C-4 suggests that the amount of suspended sediment transport collected at approximately 86 cfs, normalized by drainage area, decreases as the drainage area goes up at the 33 Idaho sites. The measured data at the three eastern Washington sites (including the Road 7 observation) show a similar decreasing trend. However, this data also indicates that, at low flows, both Crab Creek and the Frenchman Hills Wasteway sites transport more sediment than similarly sized watersheds in Idaho. Graphs taken from flows of 335, 580, and 875 cfs indicate that this trend continues at the Frenchman Hills and Crab Creek at Rocky Ford Road site. (Figure C-5-7)

No high-flow observations have been collected at Road 7 to include in this analysis, however, based on the Frenchman Hills and Rocky Ford Road results, we suggest that at high flows, Crab Creek continues to transport more sediment past the Road 7 Bridge than a similarly sized watershed would produce in Idaho (based on 33 sites where data is available). This third method is based on multiplying the unit suspended sediment transport rate estimated from the observed trend in the Idaho data by the drainage area of

Crab Creek at Road 7 (2,228 square miles). For example, at 875 cfs, the trend in the Idaho data suggests that the high end of the unit transport rate at Crab Creek at Road 7, with a drainage area of 2,228 square miles, is approximately 0.03 tons/day/square mile. (Figure C-7) This would translate into approximately 71 tons per day of suspended sediment transport during this high flow.

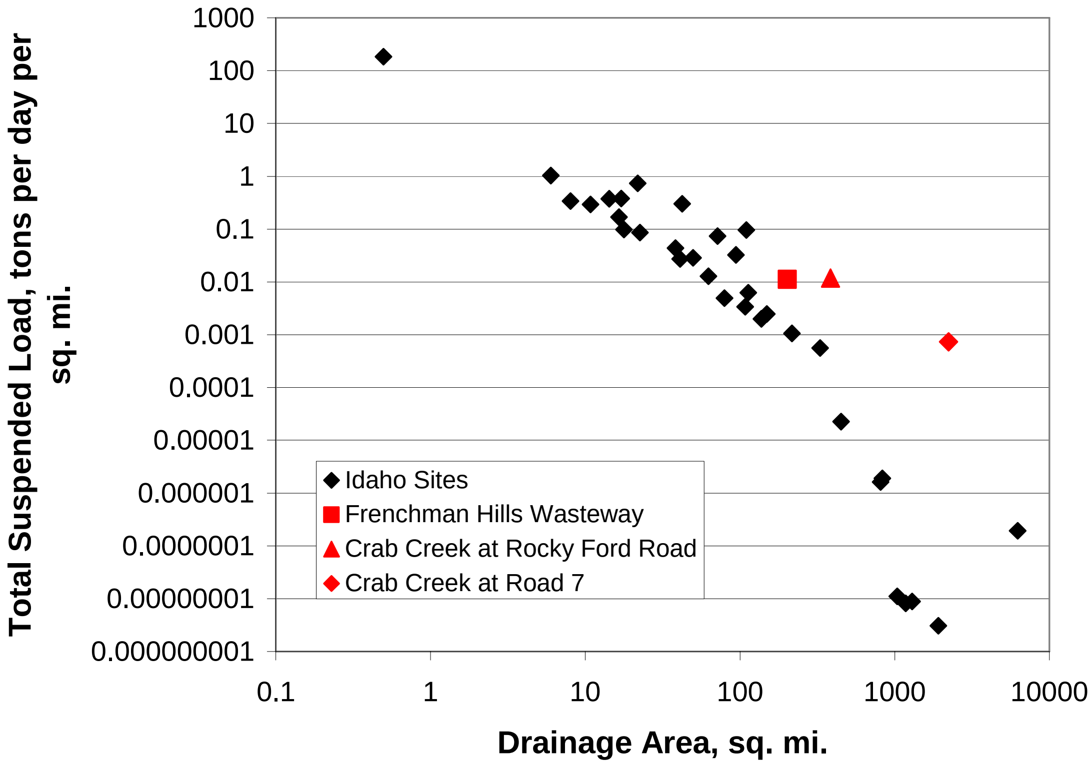


FIGURE C-4
Estimated Suspended Sediment Transport Rates at 86 cfs from 33 Sites in Idaho and Three USGS Gages Near Moses Lake, Including the USGS Gage on Crab Creek at Road 7.

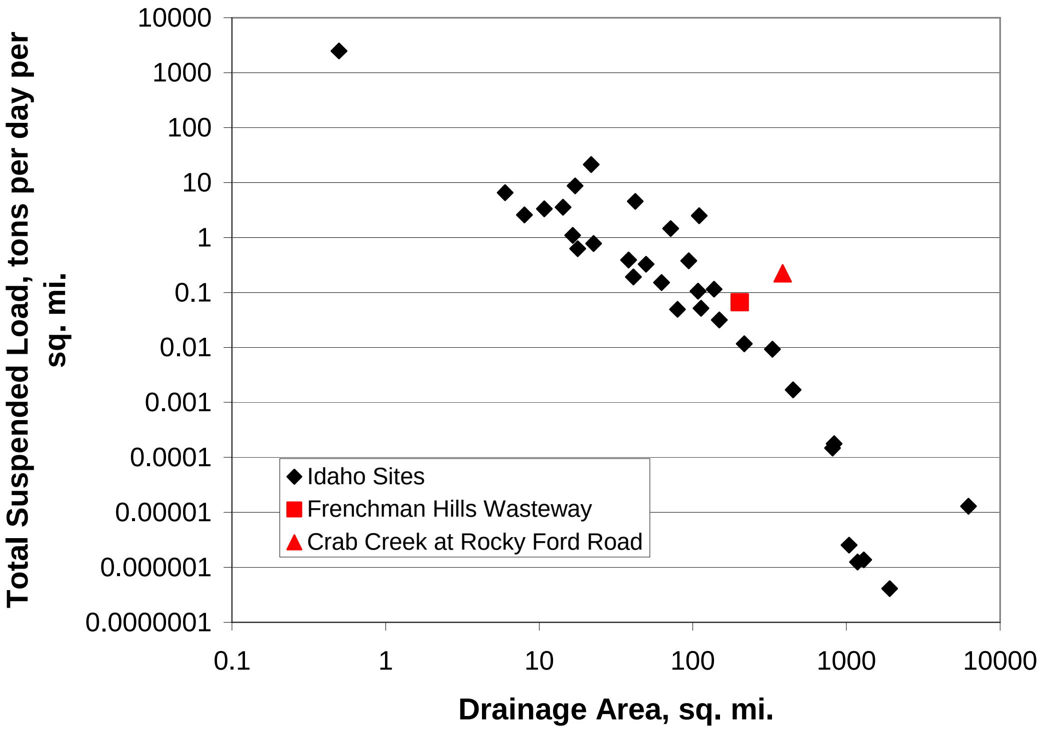


FIGURE C-5
Estimated Suspended Sediment Transport Rates at 335 cfs from 33 Sites in Idaho and Two USGS Gages Near Moses Lake. The USGS gage on Crab Creek at Road 7 is not included in this Data Set.

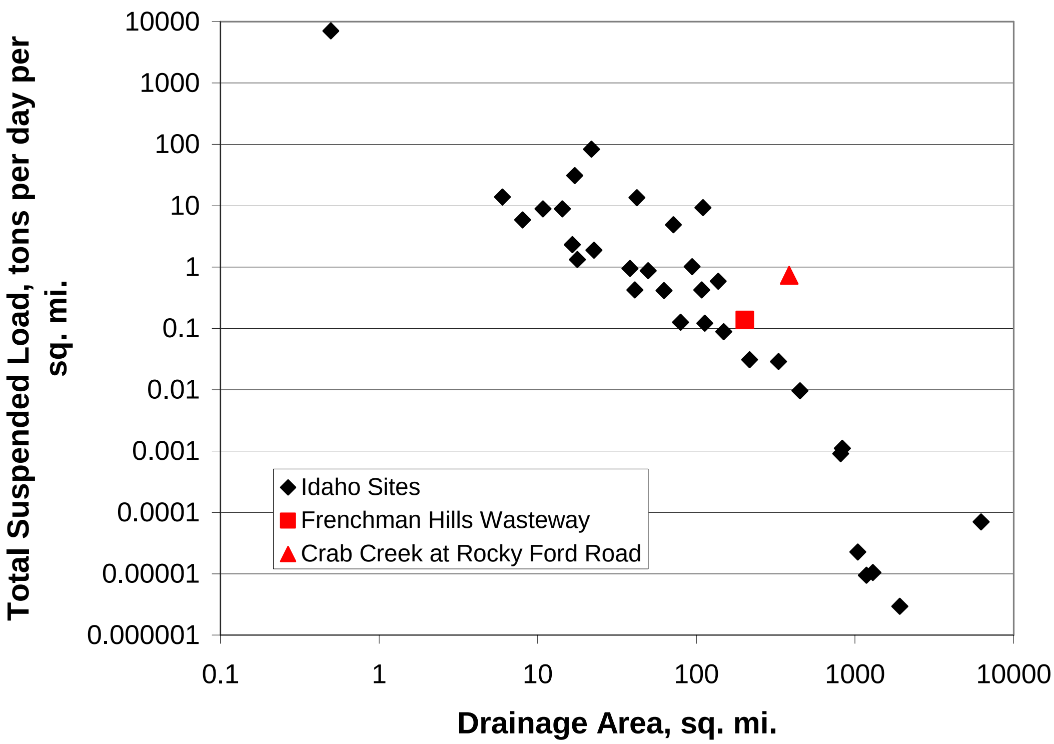


FIGURE C-6
Estimated Suspended Sediment Transport Rates at 580 cfs from 33 Sites in Idaho and Two USGS Gages Near Moses Lake. The USGS gage on Crab Creek at Road 7 is not included in this Data Set.

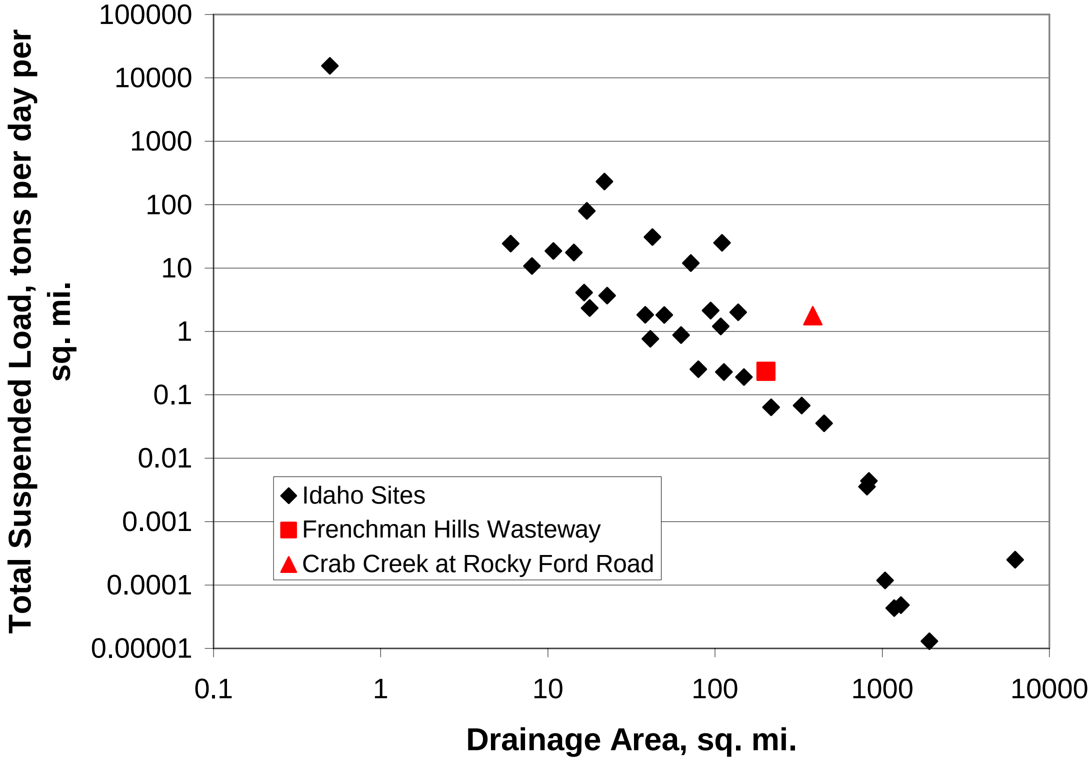


FIGURE C-7
Estimated Suspended Sediment Transport Rates at 875 cfs from 33 Sites in Idaho and Two USGS Gages Near Moses Lake. The USGS gage on Crab Creek at Road 7 is not included in this Data Set.

The fourth method is based on applying the difference in the unit suspended sediment transport rates between Crab Creek at Rocky Ford Road and Crab Creek at Road 7 observed at 86 cfs (Figure C-4) to the observed unit suspended sediment transport rates at the Rock Ford site at 335, 580, and 875 cfs. (Figures C-5, C-6, and C-7) For example, the Road 7 unit transport rate at 86 cfs is approximately an order of magnitude less than the Rocky Ford transport rate (that is, 0.0008 tons/day/square mile versus 0.007 tons/day/square mile). Applying this same difference to the observed Rocky Ford unit transport rate at 580 cfs (that is, 0.73 tons/day/square mile), the estimated unit transport rate at Road 7 is 0.084 tons/day/square mile. Given that the Road 7 drainage area is 2,228 square miles, this translates into an estimated transport rate of approximately 187 tons per day.

Attachment D

Inundation Maps

Attachment E

Example Photos from Field at Test Release Flow

Attachment F

Additional Survey Data Collected by Reclamation January 31 to February 13, 2007

ATTACHMENT F

Additional Survey Data Collected by Reclamation January 31 to February 13, 2007

Supplemental Feed Route, Potholes Reservoir, WA
Crab Creek Additional Field Survey

To assist in the model development to support the Crab Creek Alternative for the Potholes Reservoir Supplemental Feed Route Study, additional field surveying is needed. The Contractor plans to use this survey data, along with discharge data provided by Roger Sonnichsen, to calibrate a hydraulic model.

The following list of survey needs is organized by the primary tasks described in Modification 4 to the original scope of work.

Upper Crab Creek (Task 1B):

1. Brook Lake outlet:
   - WSE (or apparent normal water surface elevation from recent test flows)
2. Crab Creek channel from Brook Lake outlet to East Low Siphon:
   - At all bridge crossings (Highway 28, Upper Stratford Road, Railroad crossing (both), and Private Bridge), the following features:
     - Abutments and piers (location, type, and short description)
     - Low chord elevation
     - Roadway elevation
     - High flow features (ice outcrops, water stains, vegetation displacement, etc.)
     - Geometry of the Private Rock weir located downstream of Round Lake

Willow Lake and Loan Springs Area (Tasks 2A and 2C):

3. Loan Springs channel from 1,000-ft downstream of its lower confluence with Crab Creek up to Willow Lake:
   - At least every 200 to 300 feet (or more frequently at distinct breaks in the profile), the following profiles:
     - Thalweg (invert)
     - High flow elevation marks such as ice outcrops, water stains, vegetation displacement, etc. (Roger Sonnichsen has example photos)

Road 10 NE, Walker Road, and the Stratford Road Crossings of West Branch Crab Creek (Task 3A)

4. West branch of Crab Creek from its upstream confluence at Farm Unit Lake, just north of Road 10, to the downstream confluence near the solid waste transfer site, south of lower Stratford Road:
   - At least every 500 feet (or more frequently at distinct breaks in the profile), the following profiles:
     - Thalweg (invert)
     - High flow elevation marks such as ice outcrops, water stains, vegetation displacement, etc. (Roger Sonnichsen has example photos)
   - At least every 1,000 feet (or more frequently at distinct breaks in the profile), the following profiles:
     - Cross sections (extend approximately 500 feet to the east and west of the channel). All cross sections must be perpendicular to the channel (estimated direction of flow). These sections should be spaced to complement those described in the next bullet.
   - At each of three roadway crossings (Road 10, Walker Road, Barren, and Stratford Road), cross sections at the following locations:
     - Approximately 300-ft upstream of the crossing, perpendicular to the channel
     - At the upstream toe of the roadway embankment, parallel to the road
     - At the downstream toe of the roadway embankment
     - Along the top of the roadway (along the shoulder is acceptable if easier to obtain)
     - Approximately 300-ft downstream of the crossing perpendicular to the channel
     - Inverts and configuration of existing culverts
   - Berm located in the Feed Lot
5. On Crab Creek approximately 200-ft upstream of Road 7:
   - One cross section

Road 16 Area (Tasks 2A & 2B):

1. Crab Creek channel for 500-ft upstream and downstream of the Road 16 crossing (and at the crossing itself):
   - Thalweg profile (plus high water/ice marks) least every 50 feet (or more frequently at distinct breaks in the profile)
   - Two cross sections: (1) 50-ft upstream of Road 16, (2) 50-ft downstream of Road 16

2. Profile along the centerline of Road 16 extending at least 200-ft beyond the banks of Crab Creek and Loan Springs

   Note: These two waterways cross Road 16 at different locations, please carry a continuous profile that includes both crossings.

3. Loan Springs channel at Road 16:

   - Two cross sections: (1) 50-ft upstream of Road 16, (2) 50-ft downstream of Road 16

4. A few photos of each crossing

Attachment G

Initial Analysis of Bank Stabilization Alternatives

ATTACHMENT G

Initial Analysis of Bank Stabilization Alternatives

To meet the expedited schedule, CH2M HILL worked concurrently on several components of Task 1B before receiving the request to stop work. This work included an initial assessment of streambank stability under existing conditions and an initial analysis of several bank stabilization alternatives that may be appropriate for reaches of Crab Creek.

Initial Assessment of Bank Stability under Existing Conditions

As part of the initial assessment, CH2M HILL estimated the bank stability under existing conditions for the five subreaches. Subreaches were grouped into one of two categories: stable or erosion-prone. This initial assessment was based primarily on field observations from July 2006 and January 2007 and preliminary results from the initial hydraulic modeling. Table G-1 summarizes hydraulic model results of average velocity and shear stress by subreach. This assessment is based solely on existing conditions and does not address potential changes in bank stability that may be associated with modifications to increase channel conveyance.

Stable Reaches

Of the five subreaches, Reach 1E is considered to be the most stable (that is, least susceptible to erosion). Subreaches 1B and 1C were considered to have some potential for erosion, but were considered stable under existing conditions.

Erosion-prone Reaches

Two subreaches were considered to have high potential for erosion, Subreaches 1A and 1D, caused by the soil composition, presence of vertical banks, and lack of vegetative cover.

Example Treatment Alternatives

A wide range of resources are available for conceptual planning of streambank stabilization treatments. For the Crab Creek project in central Washington, CH2M HILL included three examples from the Integrated Streambank Protection Guidelines (ISPG), published by WDFW (2003). The ISPG document includes conceptual drawings, cost estimates, and monitoring and maintenance recommendations.

A typical herbaceous planting scheme may be appropriate in areas that are currently stable but lack habitat benefits. (Figure G-1) For more erosion-prone reaches, woody plantings, such as shrubs and trees, may be appropriate. (Figure G-2) As seen in both Figures G-1 and G-2, varied heights of cover within riparian zones provide wildlife habitat as well as future recruitment of woody material (ISPG, 2003).

Reaches most susceptible to erosion, especially those in which the primary mechanism of failure is toe erosion, may require treatments designed to redirect flow. Barbs constructed of rock and/or large woody debris are a treatment typically used in the Pacific Northwest (Figure G-3).

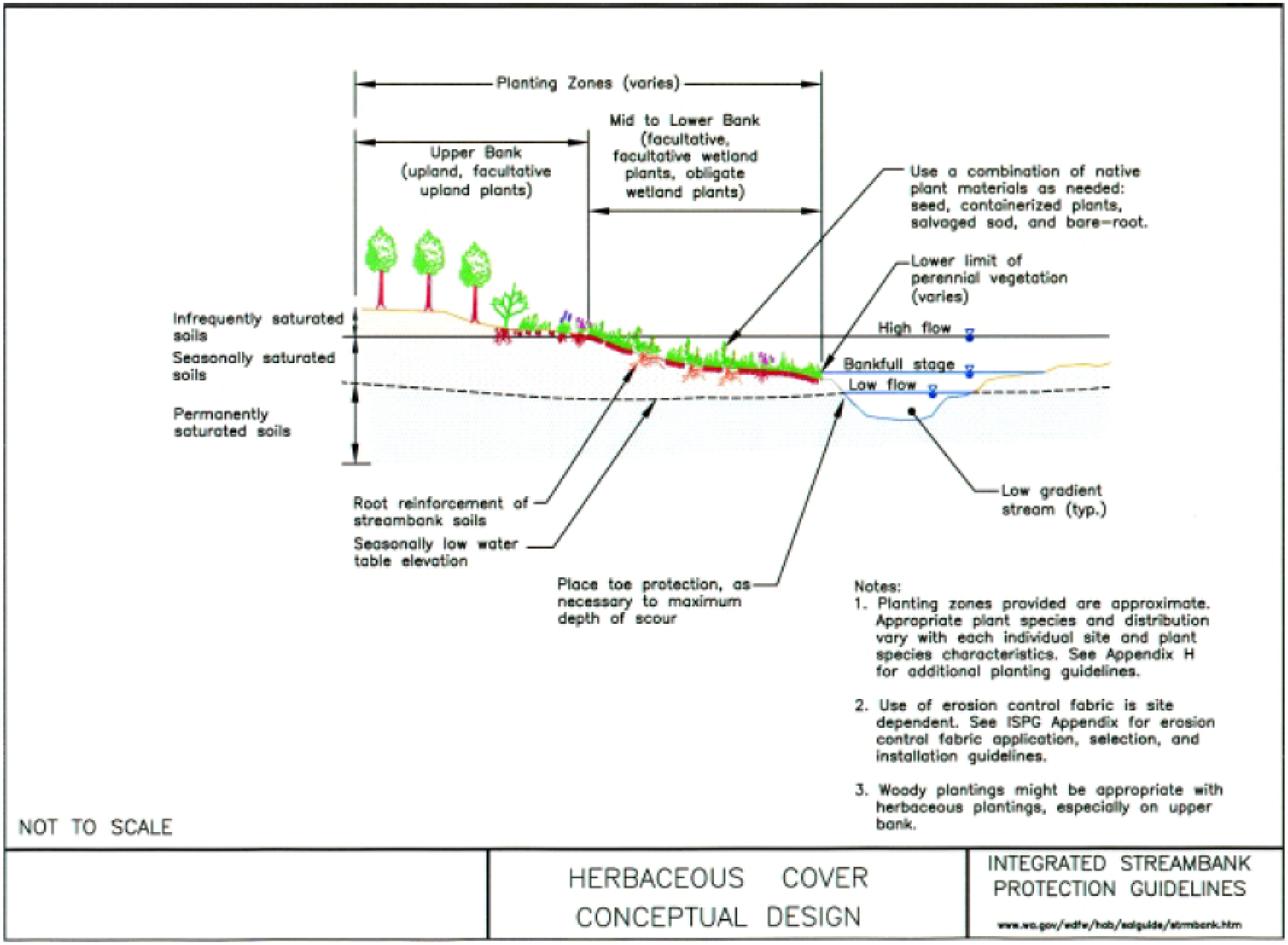


FIGURE G-1
Herbaceous Cover

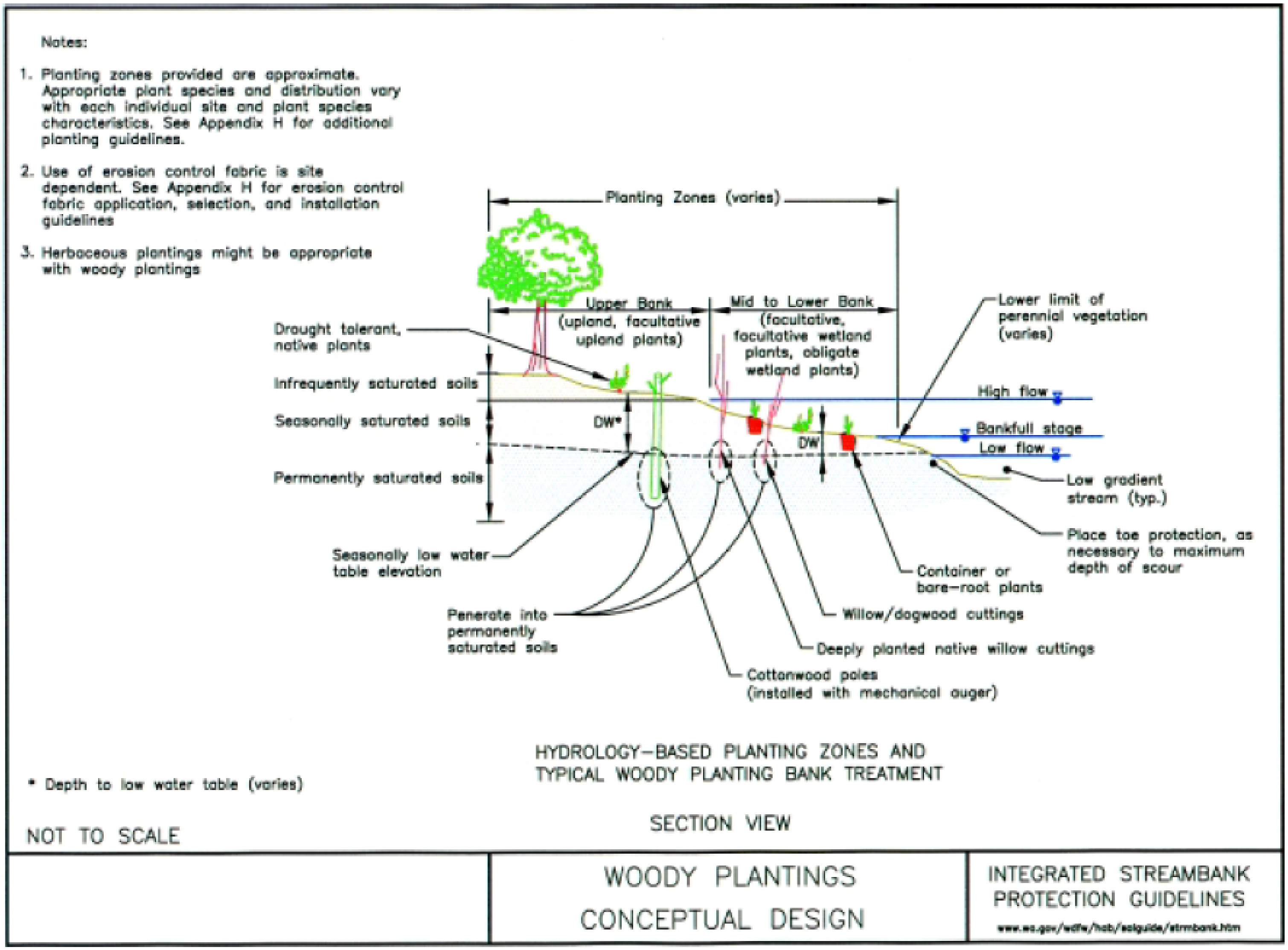


FIGURE G-2
Woody Plantings

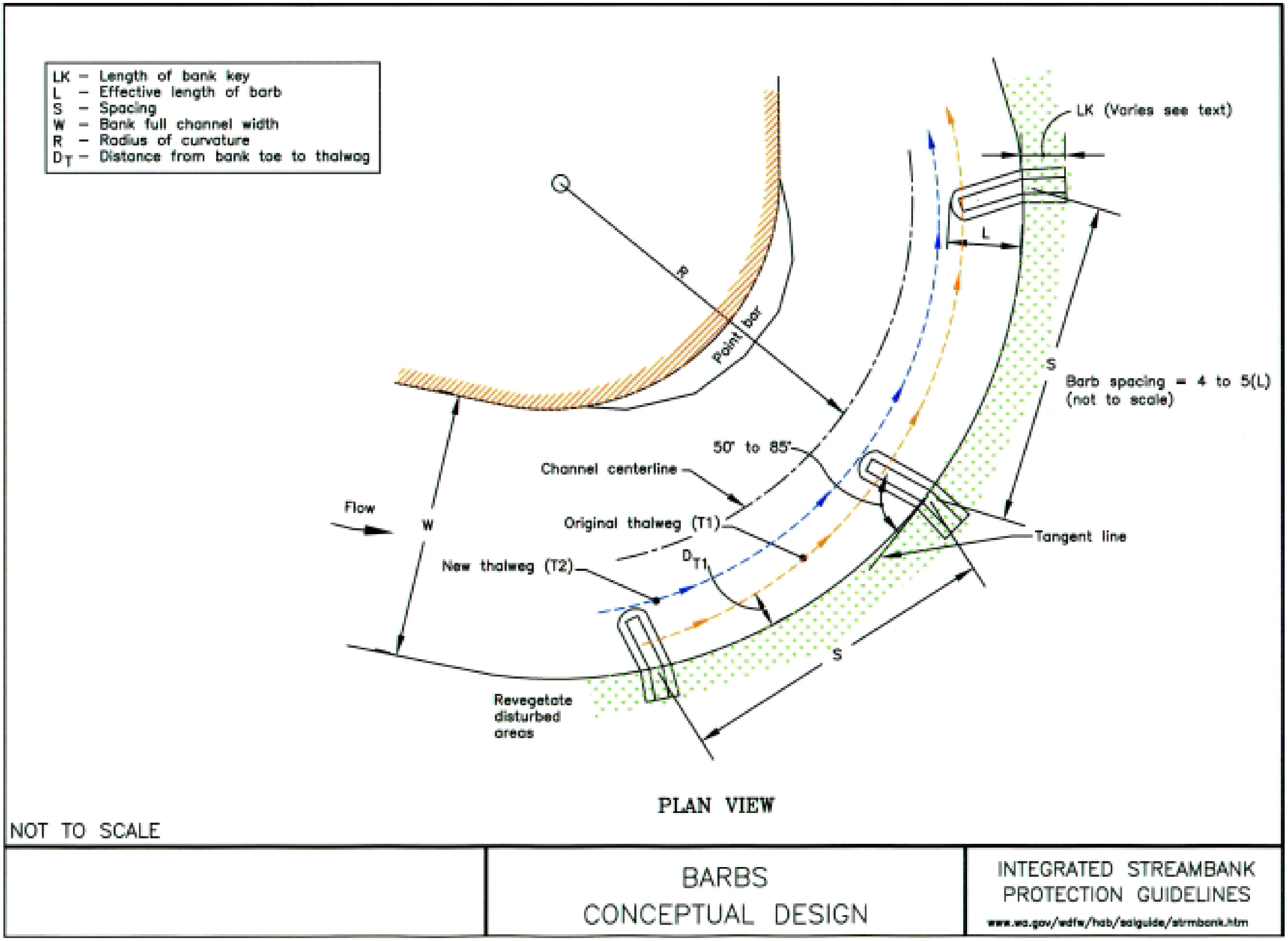


FIGURE G-3
Barbs

Cost Estimate

CH2M HILL was in the process of preparing a template to summarize the conceptual level cost estimates for bank stabilization treatments in Reach 1 when the stop work request was received. The outline of that portion of the work is included here as a starting point in case Reclamation decides to continue at a future date.

Cost estimates for each subreach are partitioned into three major categories, as itemized in Table G-1:

1) Design costs – engineering and construction drawings (lump sum)
2) Construction and material costs – fill material and excavation (per cubic yard)
3) Bank-protection techniques – planting, armoring, monitoring (per linear foot)

Design costs were to be based upon the level of detail provided in this report without further analysis or additional detail caused by permitting requirements. Construction and material costs were to have included earthwork excavation. Bank-protection techniques were to have included revegetation and planting costs, bank-protection armoring costs, and monitoring and maintenance costs.

TABLE G-1
Cost Estimate by Subreach of Crab Creek Reach 1

		Crab Creek Reach 1 Subreaches				
		1A	**1B**	**1C**	**1D**	**1E**
Design Cost						
Engineering	*lump sum*					
Construction drawings	*lump sum*					
Construction & Material Cost						
Material						
Rock	*cubic yard*					
Soil	*cubic yard*					
Fabric	*square yard*					
Artificial	*each*					
Rootwad	*each*					
Miscellaneous	*each*					
Excavation						
Excavator	*day*					
Hauling	*day*					
Bank Protection Techniques						
Planting and revegetation						
live cuttings	*linear foot*					
grass seed	*linear foot*					
hydromulching	*linear foot*					
Shrubs	*linear foot*					
trees	*each*					

TABLE G-1
Cost Estimate by Subreach of Crab Creek Reach 1

		Crab Creek Reach 1 Subreaches				
		1A	**1B**	**1C**	**1D**	**1E**
Bank armoring						
Instream flow-redirection						
groin (rock)	*each*					
barb (rock)	*each*					
log jam	*each*					
Structural treatments						
Riprap	*linear foot*					
roughness trees	*linear foot*					
Biotechnical techniques						
soil reinforcement	*linear foot*					
bank reshaping	*linear foot*					
Monitoring and maintenance	*lump sum*					

Attachment H

Hydraulic Modeling for Upper Reach

ATTACHMENT H

Hydraulic Modeling for Upper Reach

Model Development

The model was constructed using the existing topographic surface described in the December 11, 2006, draft Technical Memorandum, supplemented with the field survey data. The software package InRoads was used to extract the cross section geometry to be imported to HEC-RAS.

The model begins at the East Low Siphon and extends upstream to Brook Lake. In total, there are 82 cross sections. Hydraulic structures (bridges, culverts, and weirs) were defined using the geometry obtained during the additional field survey data collection.

Results

This section summarizes the primary findings related to the hydraulic modeling. The model produces stable and reasonable results for a flow rate of 1,860 cfs, as described in the December 11, 2006, draft Technical Memorandum. Figures H-1 to H-3 depict water surface elevation, left and right bank (dashed and solid lines), and channel bed elevation from the Brook Lake Outlet (chainage = 0 feet) to just below Highway 17 at Moses Lake (chainage = 156,501 feet). Table H-1 summarizes average depth and velocity at 9 of 10 October discharge measurement site locations. Table H-2 summarizes the model results for a flow rate of 1,000 cfs.

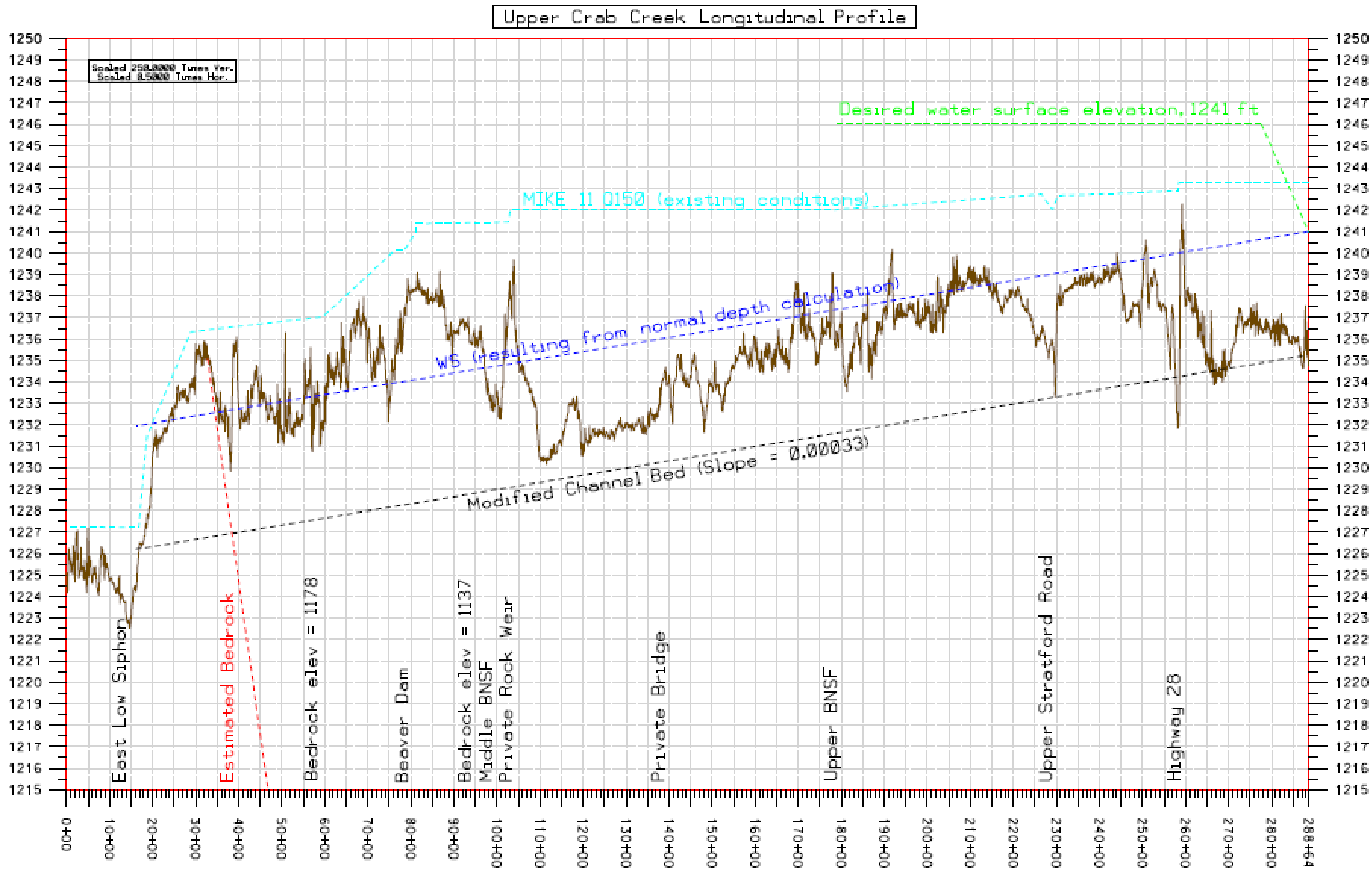


FIGURE H-1
Longitudinal Profile of Reach 1 Channel Bed Elevation and Water Surfaces

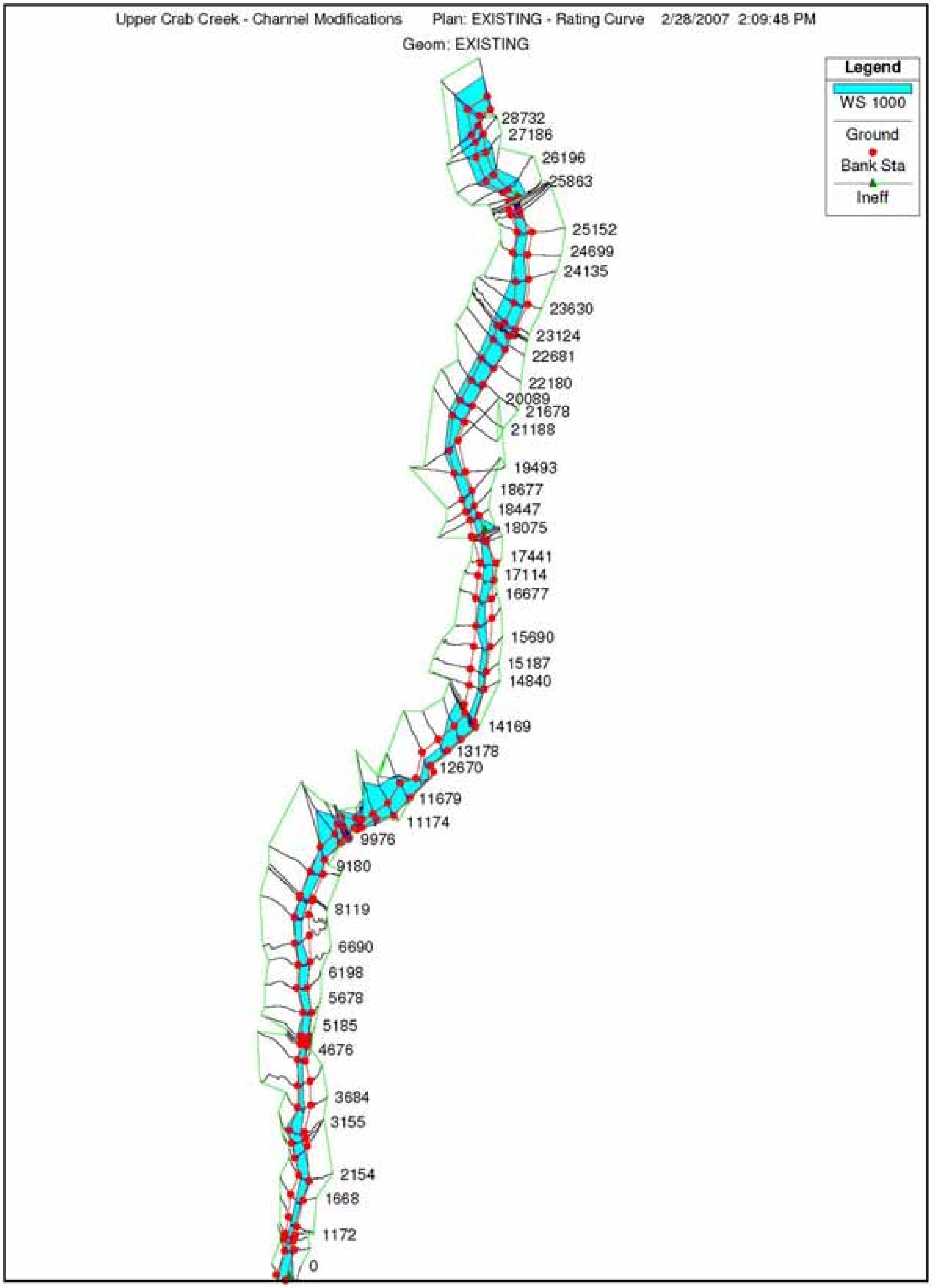


FIGURE H-2
Plan View of Reach 1 at 1,000 cfs

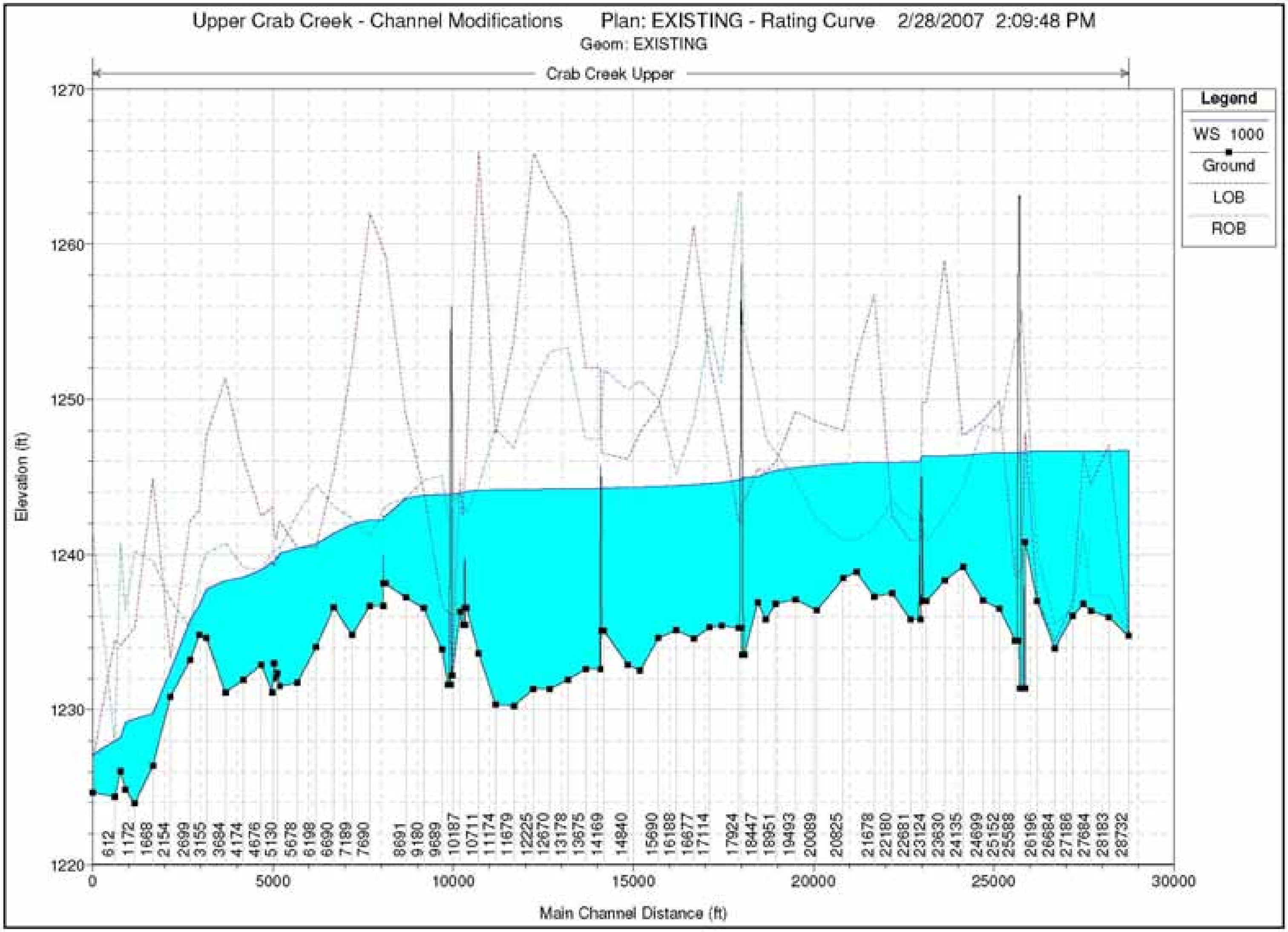


FIGURE H-3
Profile View of Reach 1 at 1,000 cfs

TABLE H-1
Average Depth and Velocity Identified by Chainage and October Discharge Measurement Site Location

Chainage	Average Velocity (ft/s)	Avg. Depth (ft)	Flow Site*
24999.0	2.6	5.9	Siphon Blow-off Valve
33444.0	3.1	4.4	Adrian Road Crossing
37481.6	0.7	5.5	BNSF Railway above Road 20
44788.4	1.8	4.4	Abandoned Structure
57768.7	14.9	4.3	Upper Wildlife Structure
70542.6	0.1	4.5	Willow Lake Main Outlet (West Channel)
83401.0	1.4	7.5	Lower Wildlife Structure
119987.0	1.2	4.3	Lower Stratford Crossing
135440.0	0.7	3.6	Road 7 Crossing

*October discharge measurement site

Limitations

The model produces results suitable for general interpretation of the hydraulic conditions in Crab Creek. Because the model considers the channel to have 1-D flow and parameters are uniform throughout the entire wetted channel area, the model is more appropriate for use in estimating water surface elevations, inundation widths, and reach-scale velocities than for site-specific velocities.

Attachment I

Fish Passage Barrier Details

Insert Table (page 1 of 3)

Insert Table (page 2 of 3)

Insert Table (page 3 of 3)

Attachment J

Hydraulic Modeling for Road Crossings

ATTACHMENT J

Hydraulic Modeling for Road Crossings

HEC-RAS Inputs and Results—West Crab Creek

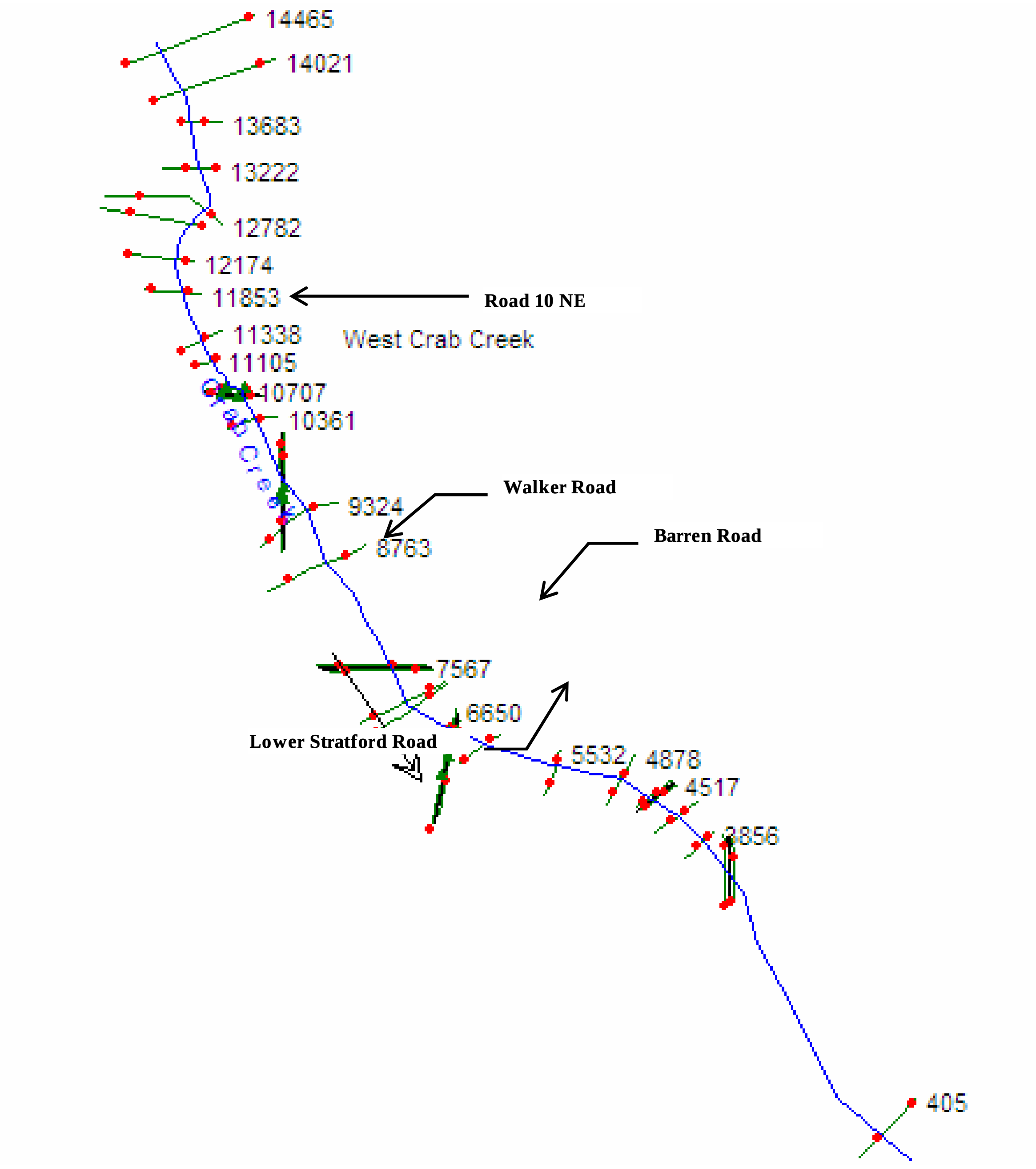


FIGURE J-1
Plan View Schematic of West Crab Creek

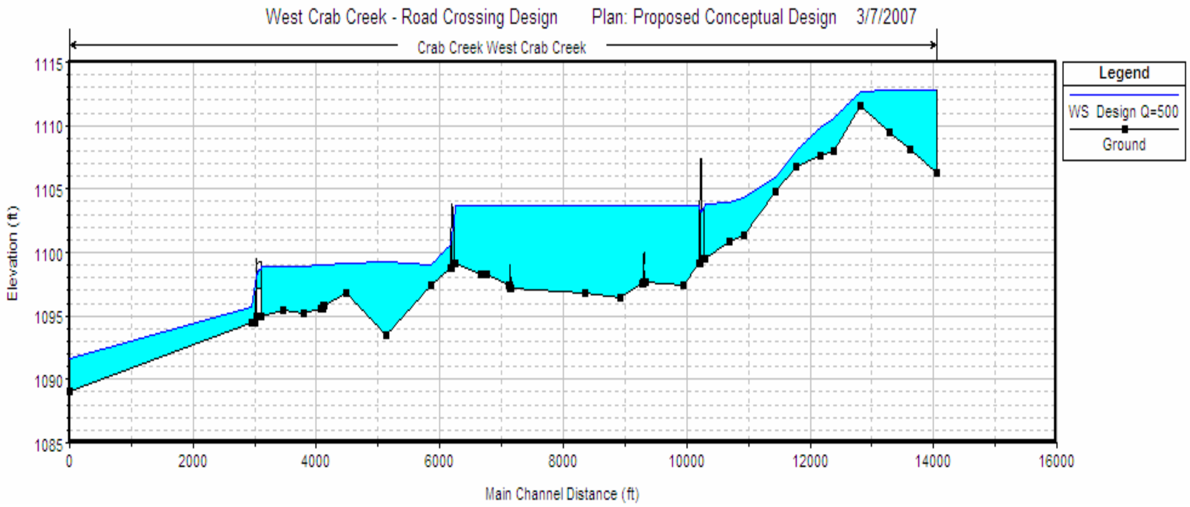


FIGURE J-2
Profile Schematic of West Crab Creek

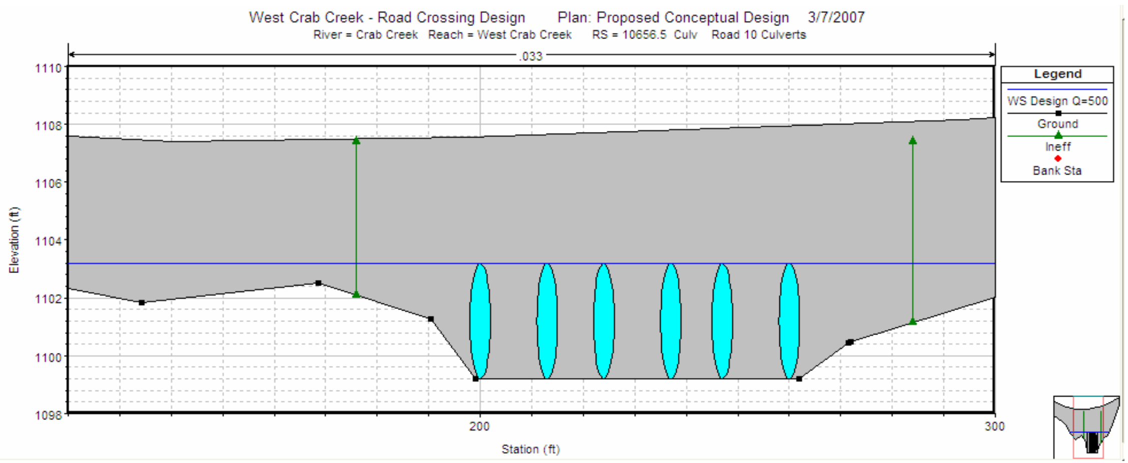


FIGURE J-3
Cross Section at Upstream Face of Road 10 NE

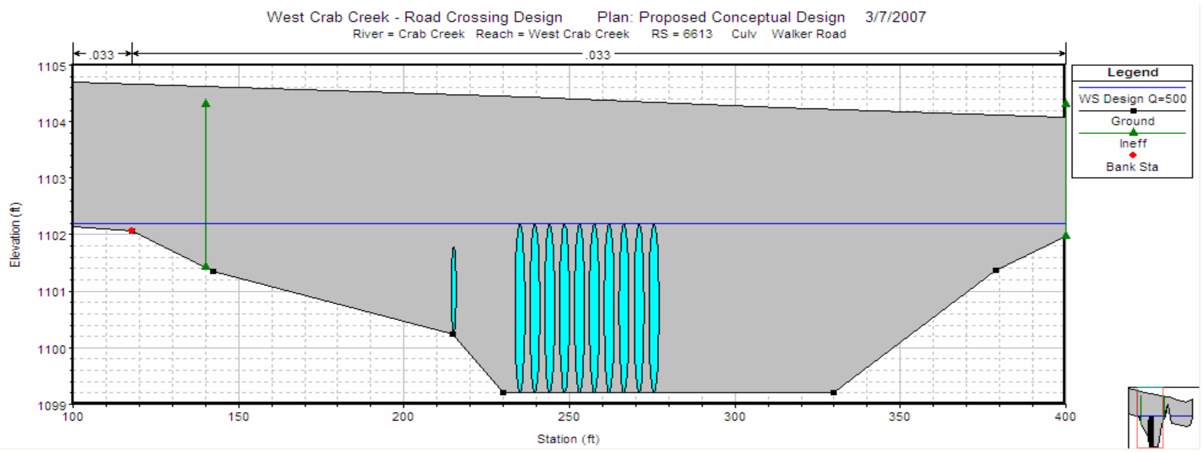


FIGURE J-4
Cross Section at Upstream Face of Walker Road

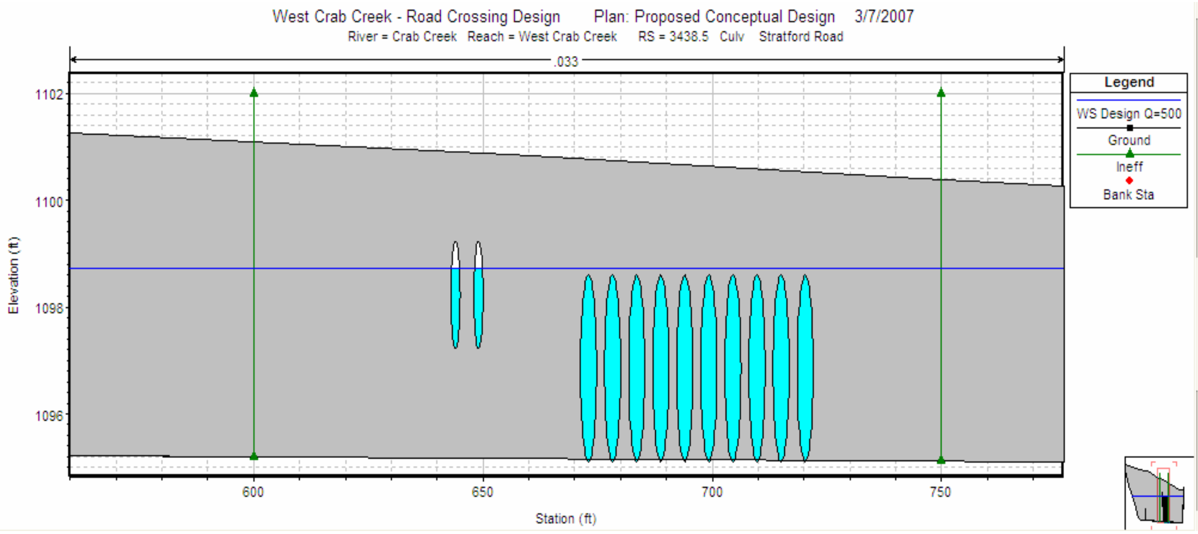


FIGURE J-5
Cross Section at Upstream Face of Lower Stratford Road

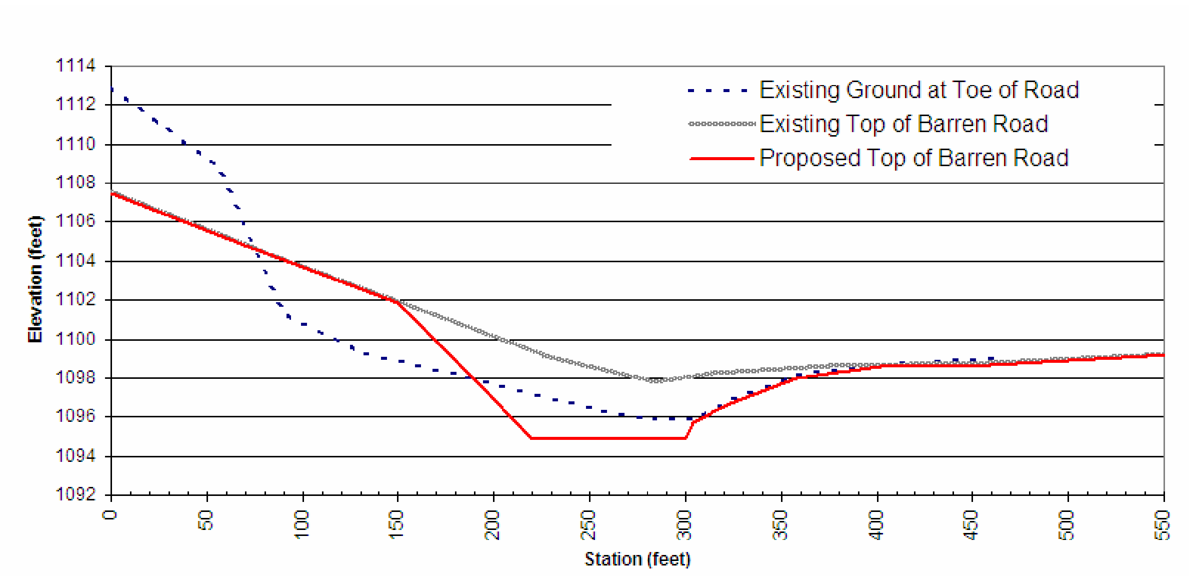


FIGURE J-6
Cross Section at Barren Road

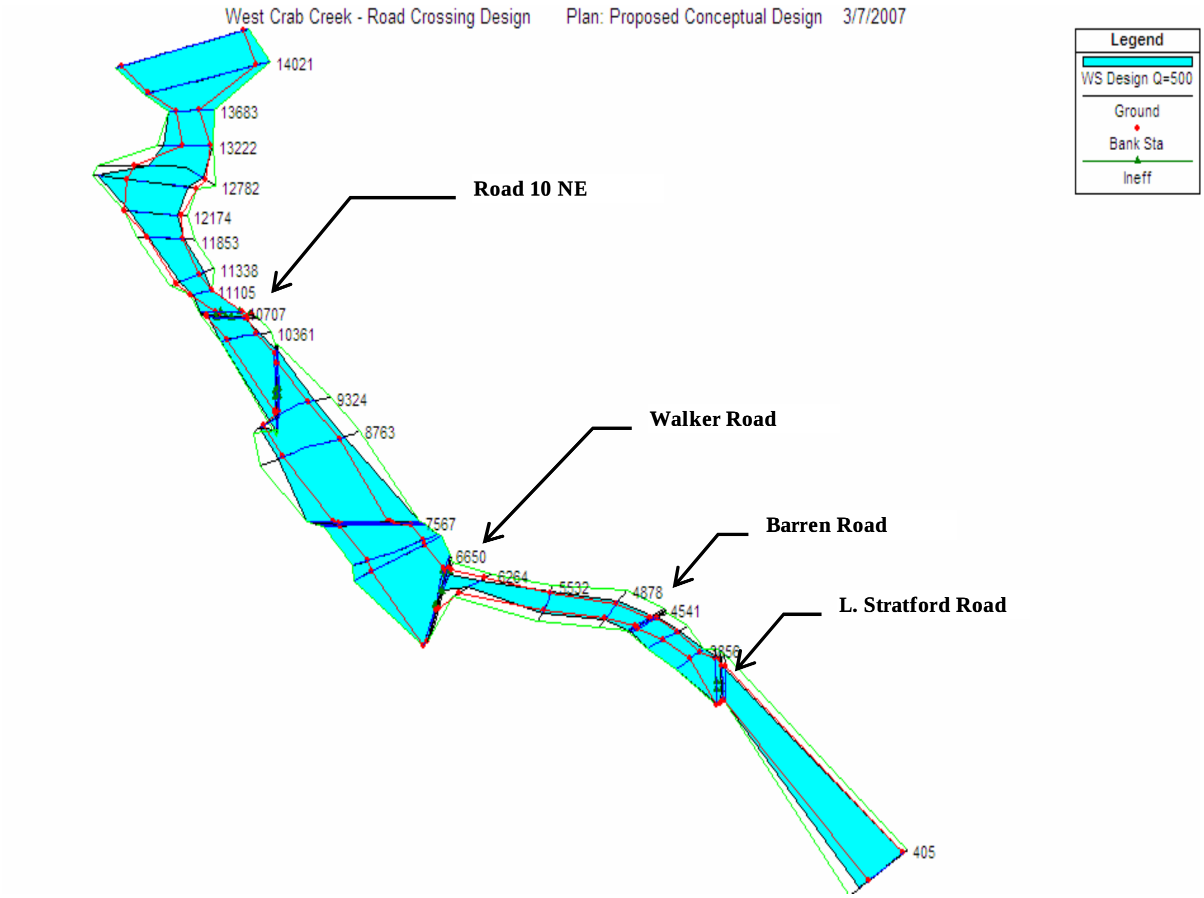


FIGURE J-7
West Crab Creek Approximate Inundation at Design Flow (Q- 500 cfs)

TABLE J-1
HEC-RAS Output for West Crab Creek

River Station (ft)	Descriptions	Flow (cfs)	W.S. Elev (ft)	E.G. Slope (ft/ft)	Max Chl Dpth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
14465	Farm Unit Lake	500	1112.7	0	6.5	0.1	6792	1403	0.01
14021		500	1112.7	0.0000	4.6	0.1	4287	1321	0.01
13683		500	1112.7	0.0000	3.2	0.5	1115	456	0.05
13222		500	1112.6	0.0037	1.1	2.3	235	453	0.46
12782		500	1110.5	0.0055	2.5	3.4	148	145	0.59
12579		500	1109.9	0.0024	2.2	2.6	202	181	0.41
12174		500	1108.0	0.0107	1.2	3.6	140	209	0.77
11853		500	1106.0	0.0043	1.1	2.7	188	224	0.51
11338		500	1104.3	0.0024	3.0	2.7	191	169	0.41
11105		500	1103.9	0.0016	3.0	2.5	200	120	0.34
10707		500	1103.8	0.0001	4.3	1.2	436	247	0.1
10656.5	Road 10 NE	500							
10609		500	1103.7	0.0001	4.5	1.2	417	248	0.11
10361		500	1103.7	0.0000	6.3	0.5	1071	278	0.04
9735		500	1103.7	0.0000	6.0	0.2	2712	734	0.02
9712		500							
9683		500	1103.7	0.0000	6.2	0.2	2976	740	0.01
9324		500	1103.7	0.0000	7.3	0.3	1832	439	0.02
8763		500	1103.7	0.0000	7.0	0.2	2503	494	0.01
7567		500	1103.7	0.0000	6.6	0.2	3172	737	0.01
7550	Berm in Dairy Farm								
7520		500	1103.7	0.0000	6.3	0.2	3380	713	0.01
7159		500	1103.7	0.0000	5.4	0.2	2763	676	0.02
7071		500	1103.7	0.0000	5.4	0.2	2483	725	0.02
6650		500	1103.7	0.0000	4.5	0.5	936	724	0.05
6613	Walker Road	500							
6576		500	1100.6	0.0019	1.8	2.6	193	126	0.37
6264		500	1099.0	0.0140	1.6	5.3	94	95	0.94
5532		500	1099.2	0.0000	5.7	0.7	706	189	0.06
4878		500	1099.1	0.0006	2.4	1.5	345	265	0.21
4541		500	1099.0	0.0003	3.2	1.3	431	317	0.15
4517	Barren Road								
4482		500	1099.0	0.0003	3.4	1.1	468	324	0.14
4199		500	1099.0	0.0001	3.7	1.0	554	392	0.11
3856		500	1098.9	0.0001	3.5	1.1	579	378	0.11
3521		500	1098.9	0.0000	3.9	0.2	3062	893	0.02
3438.5	L. Stratford Road	500							
3356		500	1095.7	0.0012	1.2	1.3	392	519	0.26
405		500	1091.7	0.0016	2.6	1.6	313	382	0.31

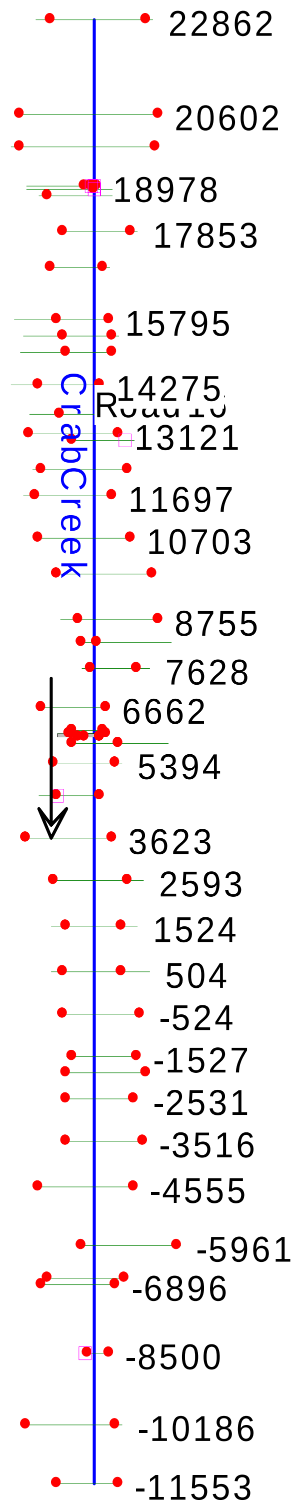


FIGURE J-8
Plan View Schematic of Crab Creek

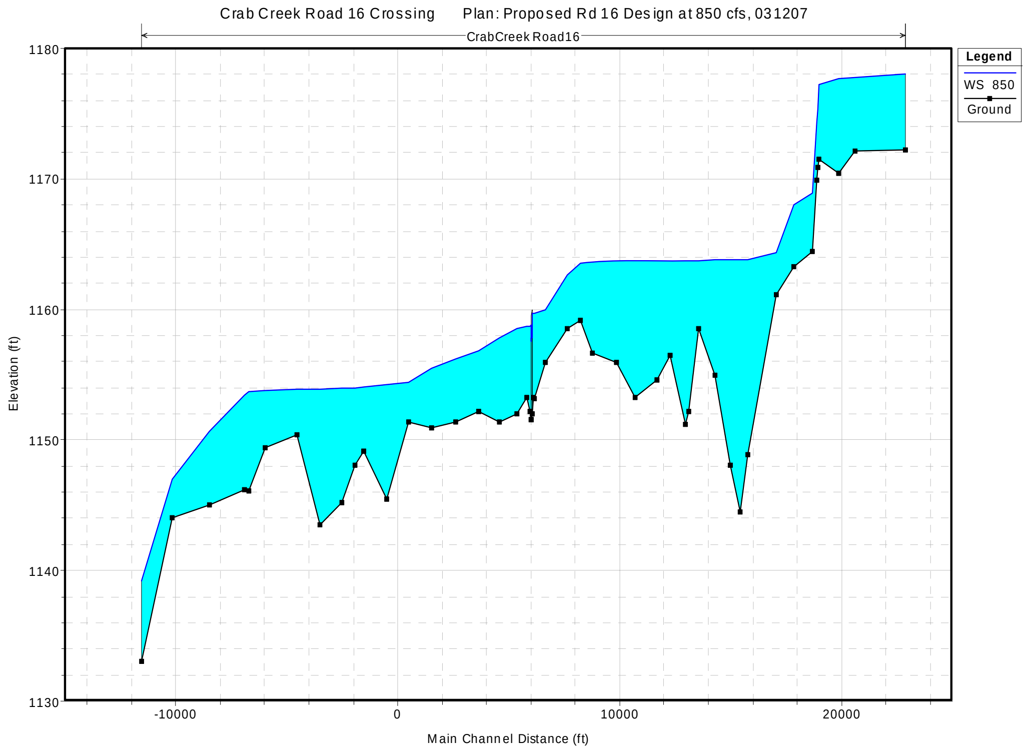


FIGURE J-9
Profile Schematic of Crab Creek at 850 cfs

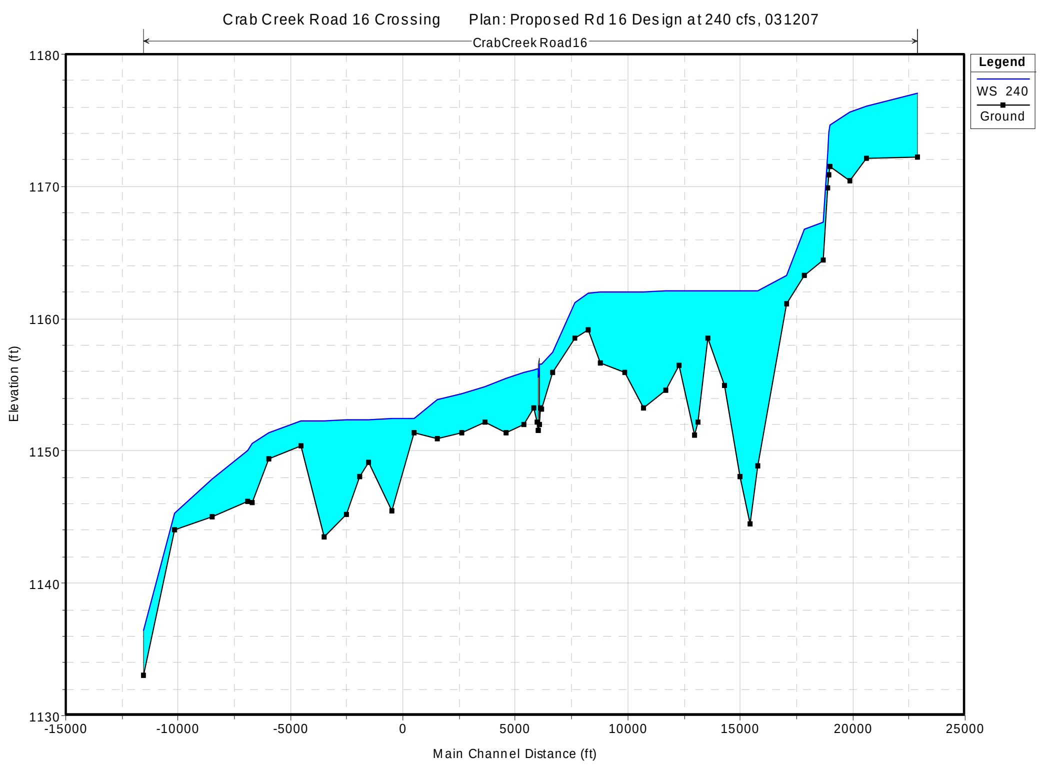


FIGURE J-10
Profile Schematic of Crab Creek at 240 cfs

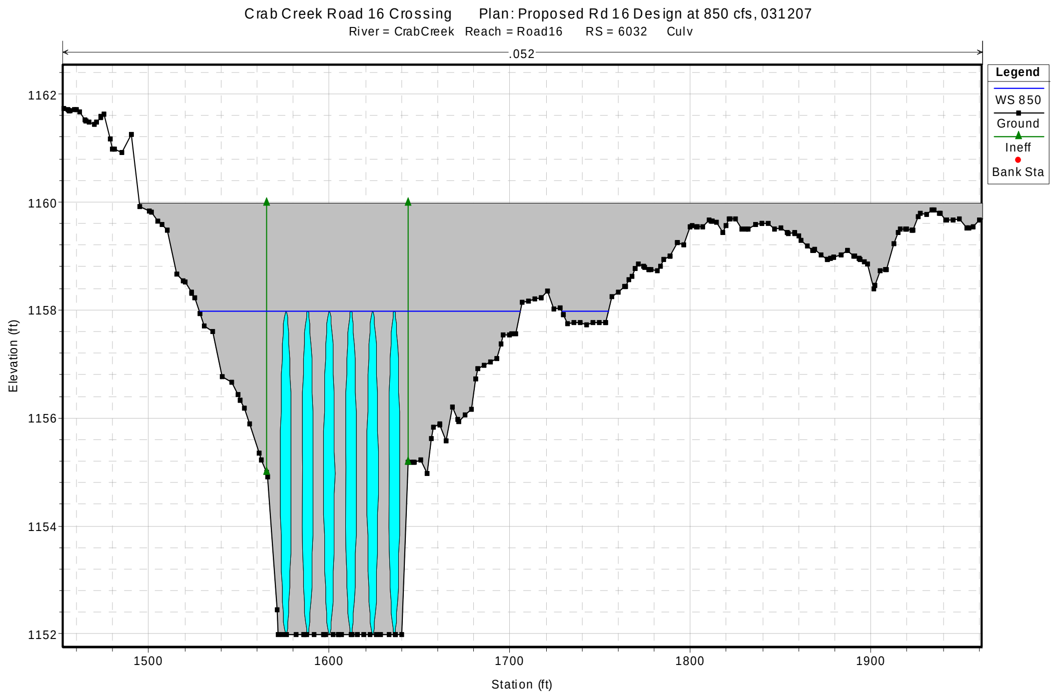


FIGURE J-11
Cross Section at Upstream Face of Road 16 at 850 cfs

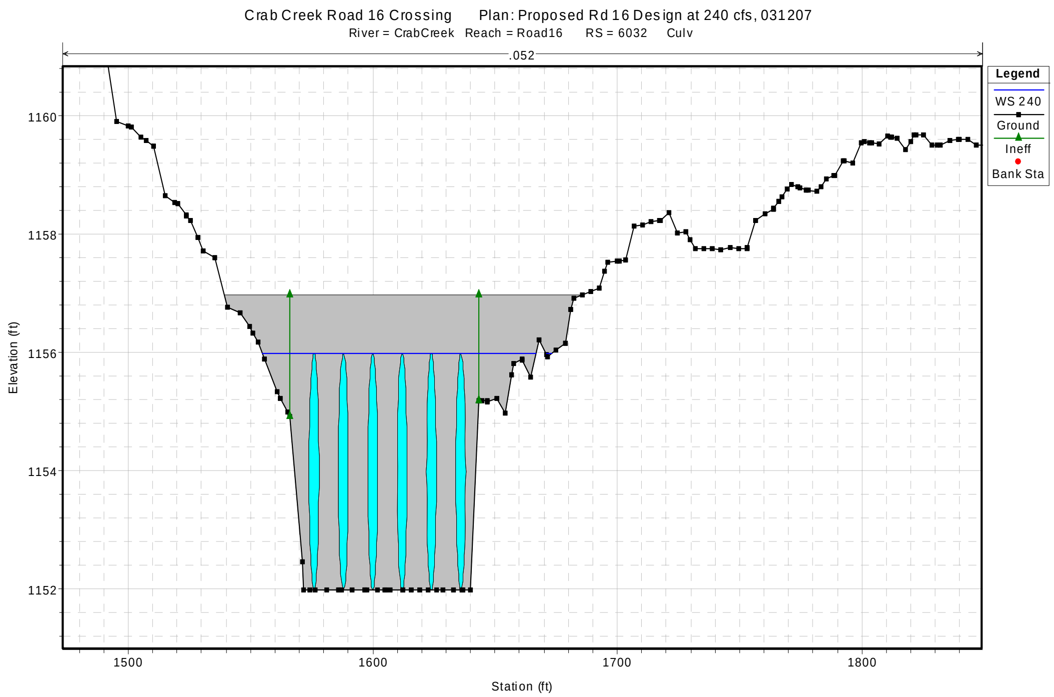


FIGURE J-12
Cross Section at Upstream Face of Road 16 at 240 cfs

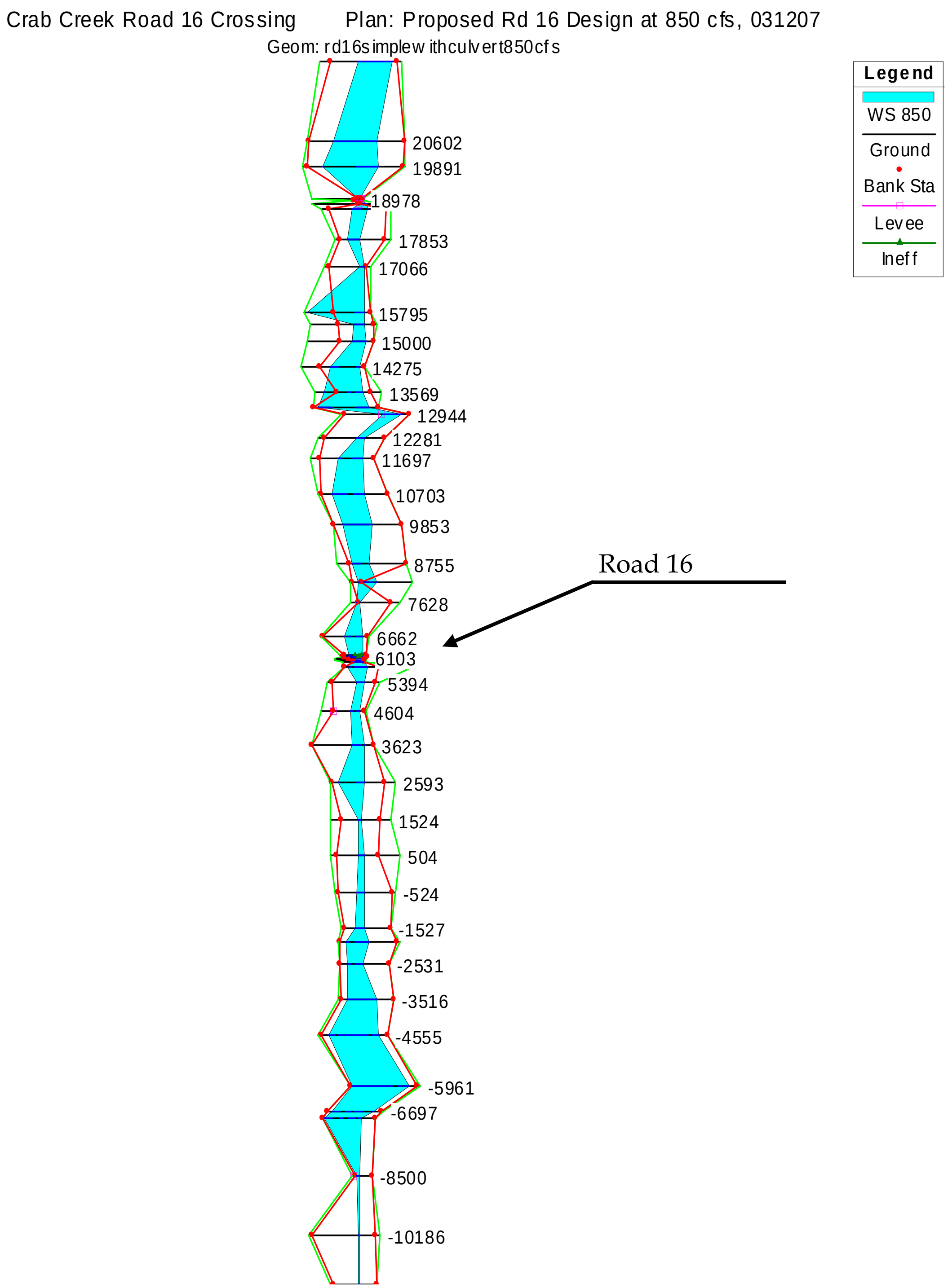


FIGURE J-13
Crab Creek Approximate Inundation at 850 cfs

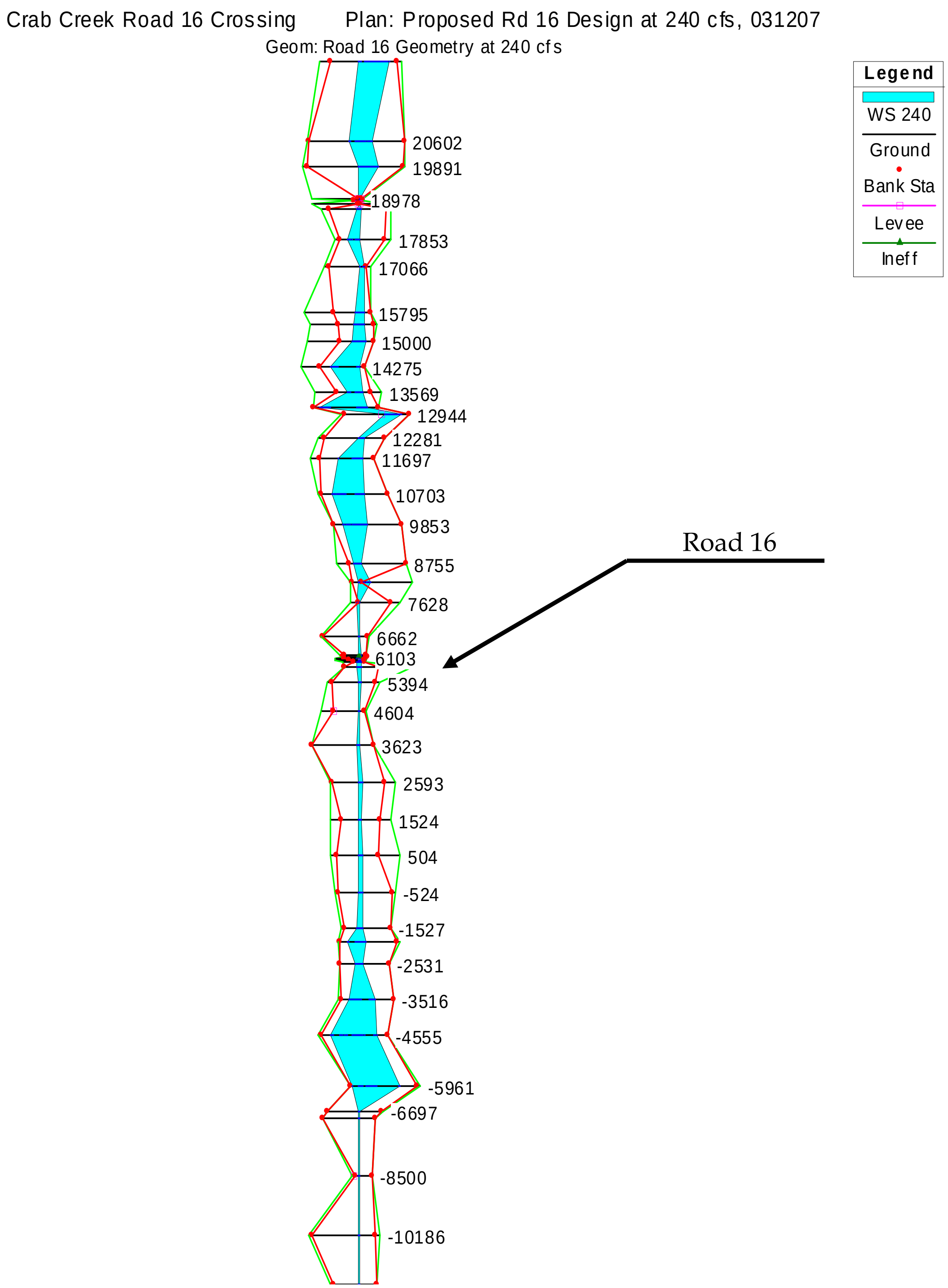


FIGURE J-14
Crab Creek Approximate Inundation at 240 cfs

TABLE J-2
HEC-RAS Output for Crab Creek Near Road 16 at 240 cfs

River Station (ft)	Descriptions	Flow (cfs)	W.S. Elev (ft)	E.G. Slope (ft/ft)	Max Chl Dpth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
22862		240.00	1177.04	0.000161	4.78	0.32	756.71	922.19	0.06
20602		240.00	1176.07	0.003114	3.96	0.92	261.25	596.30	0.24
19891		240.00	1175.60	0.000284	5.18	0.41	585.46	740.42	0.08
18978		240.00	1174.64	0.008117	3.15	3.66	65.57	37.23	0.49
18936		240.00	1174.12	0.010576	3.20	4.58	52.40	25.25	0.56
18872		240.00	1172.47	0.035406	3.62	7.18	33.43	20.57	0.99
18691		240.00	1167.33	0.000470	2.87	0.87	276.42	165.84	0.12
17853		240.00	1166.72	0.001275	3.43	1.06	227.27	212.62	0.18
17066		240.00	1163.30	0.048624	2.19	5.26	45.63	53.94	1.01
15795		240.00	1162.08	0.000001	13.17	0.12	2014.36	310.47	0.01
15456		240.00	1162.08	0.000000	17.60	0.05	4593.90	388.90	0.00
15000		240.00	1162.08	0.000000	13.99	0.04	5462.74	523.91	0.00
14275		240.00	1162.08	0.000004	7.09	0.14	1666.10	392.37	0.01
13569		240.00	1162.07	0.000028	3.55	0.27	894.28	377.64	0.03
13121		240.00	1162.07	0.000000	9.87	0.05	5176.37	838.78	0.00
12944		240.00	1162.07	0.000000	10.86	0.07	3647.47	581.07	0.00
12281		240.00	1162.07	0.000011	5.59	0.25	960.44	221.78	0.02
11697		240.00	1162.07	0.000004	7.43	0.15	1634.09	389.08	0.01
10703		240.00	1162.06	0.000007	8.83	0.13	1819.60	773.34	0.02
9853		240.00	1162.05	0.000012	6.08	0.16	1527.58	753.80	0.02
8755		240.00	1162.04	0.000021	5.39	0.28	863.72	273.73	0.03
8224		240.00	1161.98	0.001516	2.79	1.42	192.61	179.20	0.21
7628		240.00	1161.19	0.001148	3.38	1.36	175.94	102.29	0.18
6662		240.00	1157.44	0.042991	1.49	5.40	44.48	50.73	1.02
6162		240.00	1156.59	0.000528	3.42	1.30	184.32	118.15	0.18
6103		240.00	1156.58	0.000312	3.35	0.88	272.69	117.94	0.10
6062		240.00	1156.58	0.000086	4.60	0.70	341.58	133.24	0.06
6032	Road 16 Crossing	Culvert							
6002		240.00	1156.18	0.000120	4.64	0.64	372.93	123.34	0.07
5971		240.00	1156.17	0.000498	3.95	0.97	246.37	130.05	0.12
5821		240.00	1156.11	0.000378	2.85	0.83	287.80	155.98	0.11
5394		240.00	1155.90	0.000568	3.87	1.05	227.50	117.30	0.13
4604		240.00	1155.50	0.000448	4.08	1.12	214.72	84.05	0.12
3623		240.00	1154.91	0.000862	2.70	1.11	217.19	143.03	0.16
2593		240.00	1154.31	0.000425	2.91	0.80	300.59	190.24	0.11
1524		240.00	1153.85	0.000429	2.95	0.94	254.45	125.90	0.12
504		240.00	1152.43	0.017440	1.06	2.74	87.62	141.44	0.61
-524		240.00	1152.41	0.000026	6.94	0.34	699.53	190.64	0.03
-1527		240.00	1152.35	0.000173	3.23	0.57	418.68	221.45	0.07
-1924		240.00	1152.33	0.000026	4.27	0.25	950.57	419.92	0.03
-2531		240.00	1152.32	0.000012	7.09	0.25	967.47	238.01	0.02
-3516		240.00	1152.31	0.000017	8.83	0.19	1281.48	649.45	0.02
-4555		240.00	1152.26	0.000342	1.91	0.44	544.28	712.40	0.09
-5961		240.00	1151.42	0.001255	1.97	0.72	331.32	546.55	0.16

TABLE J-2
HEC-RAS Output for Crab Creek Near Road 16 at 240 cfs

River Station (ft)	Descriptions	Flow (cfs)	W.S. Elev (ft)	E.G. Slope (ft/ft)	Max Chl Dpth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
-6697		240.00	1150.55	0.001011	4.46	1.84	130.75	43.73	0.19
-6896		240.00	1150.03	0.004103	3.82	3.56	67.32	18.32	0.33
-8500		240.00	1147.89	0.000700	2.89	1.45	165.57	59.62	0.15
-10186		240.00	1145.31	0.005156	1.31	2.40	99.85	77.77	0.37
-11553		240.00	1136.42	0.008000	3.42	4.26	56.39	24.22	0.49

TABLE J-3
HEC-RAS Output for Crab Creek Near Road 16 at 850 cfs

River Station (ft)	Descriptions	Flow (cfs)	W.S. Elev (ft)	E.G. Slope (ft/ft)	Max Chl Dpth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
22862		850.00	1178.05	0.000144	5.79	0.47	1792.19	1098.85	0.07
20602		850.00	1177.76	0.000115	5.65	0.39	2178.86	1517.06	0.06
19891		850.00	1177.71	0.000048	7.29	0.38	2224.48	821.98	0.04
18978		850.00	1177.26	0.005705	5.77	4.23	201.11	71.23	0.44
18936		850.00	1175.34	0.031404	4.42	10.14	83.82	26.26	1.00
18872		850.00	1174.31	0.000316	5.46	0.93	802.91	298.16	0.10
18691		850.00	1168.88	0.000878	4.42	1.52	557.53	229.11	0.17
17853		850.00	1168.01	0.001265	4.72	1.29	660.85	459.08	0.19
17066		850.00	1164.36	0.039953	3.25	6.88	123.47	84.84	1.01
15795		850.00	1163.78	0.000009	14.87	0.33	2578.03	354.90	0.02
15456		850.00	1163.78	0.000001	19.30	0.16	5257.99	392.46	0.01
15000		850.00	1163.78	0.000001	15.69	0.13	6356.07	527.40	0.01
14275		850.00	1163.77	0.000017	8.78	0.36	2357.98	434.45	0.03
13569		850.00	1163.75	0.000063	5.23	0.54	1570.76	431.97	0.05
13121		850.00	1163.75	0.000001	11.55	0.13	6658.44	922.67	0.01
12944		850.00	1163.75	0.000003	12.54	0.18	4672.71	655.84	0.01
12281		850.00	1163.74	0.000054	7.26	0.61	1387.63	275.64	0.05
11697		850.00	1163.73	0.000019	9.09	0.36	2384.23	495.75	0.03
10703		850.00	1163.71	0.000016	10.48	0.26	3259.89	946.47	0.02
9853		850.00	1163.69	0.000023	7.72	0.28	3000.88	1019.30	0.03
8755		850.00	1163.65	0.000070	6.99	0.64	1322.05	299.12	0.05
8224		850.00	1163.53	0.000989	4.34	1.38	650.83	408.06	0.18
7628		850.00	1162.62	0.002167	4.81	2.60	341.97	130.72	0.27
6662		850.00	1159.92	0.003826	3.97	2.10	404.75	310.12	0.32
6162		850.00	1159.70	0.000195	6.52	1.05	813.03	345.35	0.12
6103		850.00	1159.69	0.000207	6.46	0.97	874.98	542.47	0.09
6062		850.00	1159.66	0.000183	7.68	1.45	585.24	434.06	0.09

TABLE J-3
HEC-RAS Output for Crab Creek Near Road 16 at 850 cfs

River Station (ft)	Descriptions	Flow (cfs)	W.S. Elev (ft)	E.G. Slope (ft/ft)	Max Chl Dpth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
6032	Road 16 Crossing	Culvert							
6002		850.00	1158.76	0.000295	7.22	0.95	891.75	326.10	0.10
5971		850.00	1158.75	0.000365	6.52	1.01	844.13	354.38	0.11
5821		850.00	1158.71	0.000203	5.45	0.73	1166.25	484.80	0.08
5394		850.00	1158.55	0.000643	6.52	1.37	619.14	235.30	0.15
4604		850.00	1157.84	0.001260	6.42	1.66	513.19	243.20	0.20
3623		850.00	1156.86	0.000830	4.65	1.35	631.50	300.76	0.16
2593		850.00	1156.21	0.000500	4.81	1.20	707.04	273.08	0.13
1524		850.00	1155.52	0.000767	4.62	1.78	476.48	139.89	0.17
504		850.00	1154.45	0.001527	3.08	1.72	495.17	259.11	0.22
-524		850.00	1154.22	0.000098	8.75	0.77	1106.66	244.99	0.06
-1527		850.00	1154.05	0.000309	4.93	0.95	898.14	346.44	0.10
-1924		850.00	1154.01	0.000063	5.95	0.48	1753.90	557.54	0.05
-2531		850.00	1153.97	0.000079	8.73	0.58	1463.49	421.38	0.05
-3516		850.00	1153.91	0.000040	10.43	0.33	2573.41	1035.48	0.04
-4555		850.00	1153.86	0.000076	3.51	0.35	2460.81	1503.75	0.05
-5961		850.00	1153.78	0.000041	4.33	0.27	3131.82	1719.77	0.04
-6697		850.00	1153.69	0.000942	7.60	0.97	874.82	746.05	0.16
-6896		850.00	1153.39	0.002302	7.19	1.38	613.73	590.27	0.24
-8500		850.00	1150.64	0.001269	5.64	2.51	338.39	81.85	0.22
-10186		850.00	1147.01	0.004015	3.01	3.61	235.77	81.63	0.37
-11553		850.00	1139.22	0.008015	6.22	5.34	159.14	48.99	0.52

Attachment K

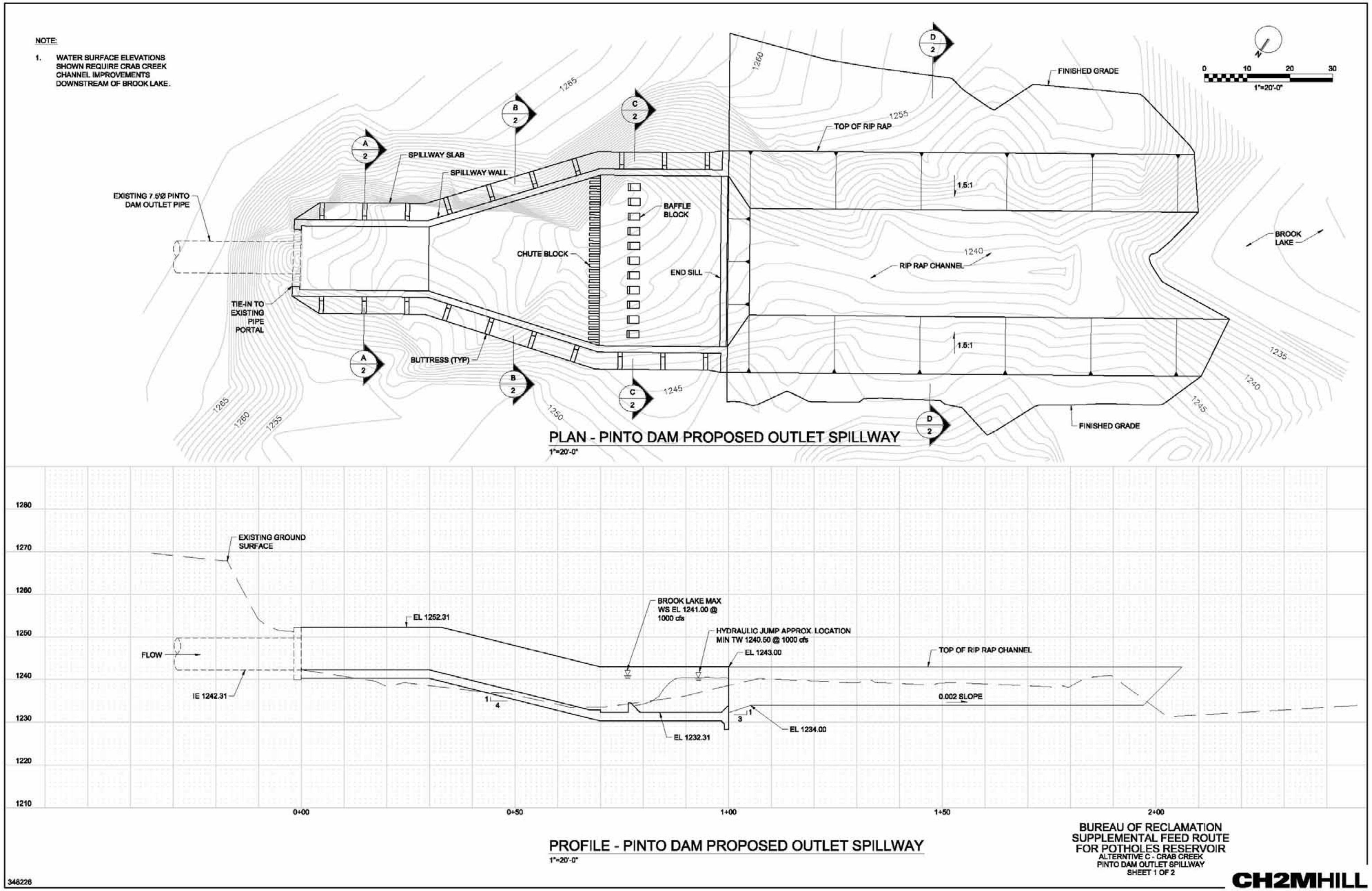
Pinto Dam Outlet Spillway Calculations

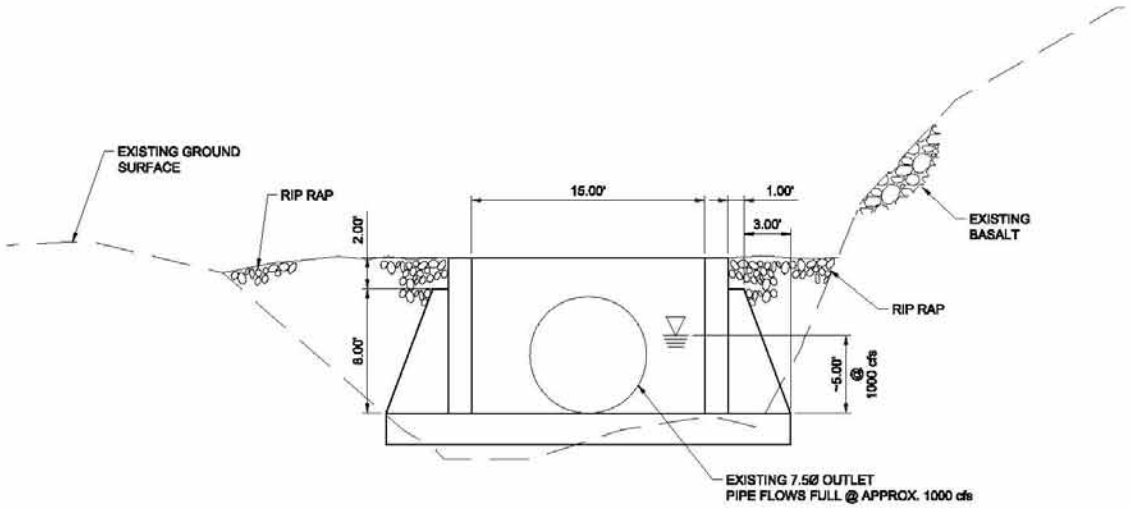
(this is a 5-page scanned PDF document)

Page 1 of 5

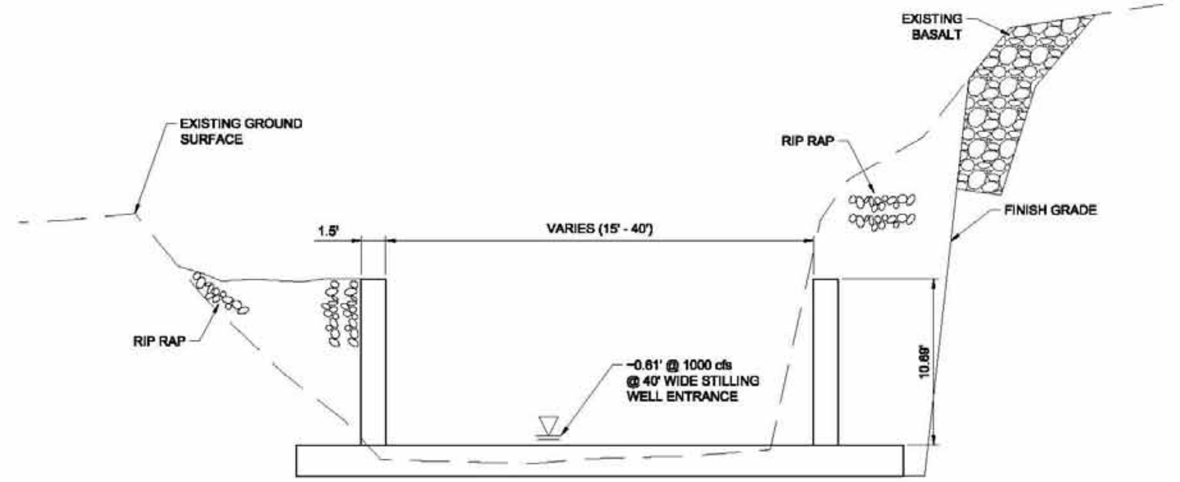
Attachment L

Pinto Dam Outlet Spillway—Conceptual Design Figures

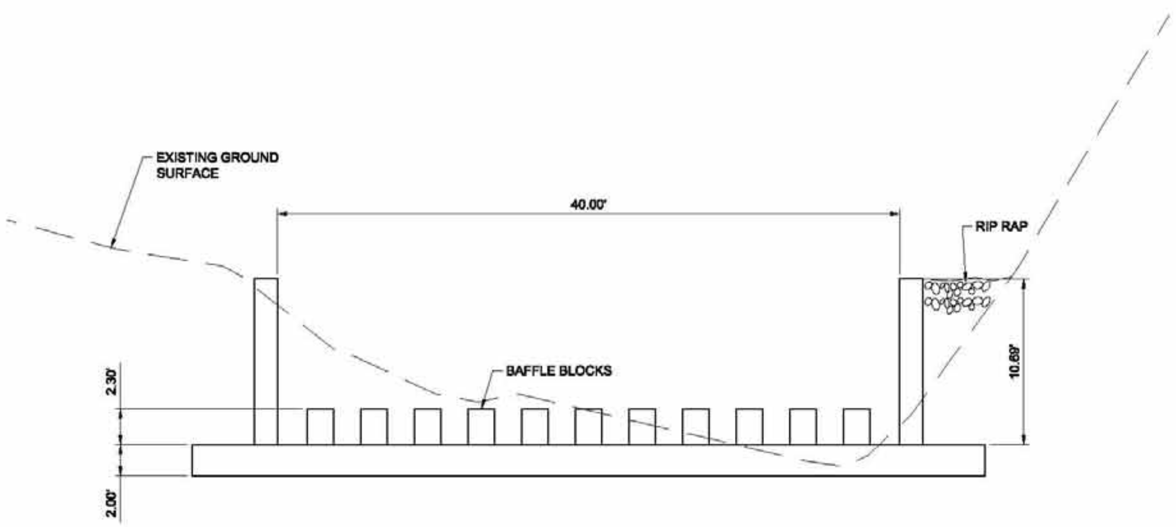

NOTE:
1. WATER SURFACE ELEVATIONS SHOWN REQUIRE CRAB CREEK CHANNEL IMPROVEMENTS DOWNSTREAM OF BROOK LAKE.
EXISTING 7.5'Ø PINTO DAM OUTLET PIPE
SPILLWAY SLAB
SPILLWAY WALL
BAFFLE BLOCK
CHUTE BLOCK
END SILL
TIE-IN TO EXISTING PIPE PORTAL
BUTTRESS (TYP)
TOP OF RIP RAP
RIP RAP CHANNEL
FINISHED GRADE
BROOK LAKE
1.5:1
1"=20'-0"
PLAN - PINTO DAM PROPOSED OUTLET SPILLWAY
1"=20'-0"
EXISTING GROUND SURFACE
FLOW
IE 1242.31
EL 1252.31
BROOK LAKE MAX WS EL 1241.00 @ 1000 cfs
HYDRAULIC JUMP APPROX. LOCATION MIN TW 1240.50 @ 1000 cfs
EL 1243.00
TOP OF RIP RAP CHANNEL
0.002 SLOPE
EL 1232.31
EL 1234.00
PROFILE - PINTO DAM PROPOSED OUTLET SPILLWAY
1"=20'-0"
BUREAU OF RECLAMATION
SUPPLEMENTAL FEED ROUTE
FOR POTHOLES RESERVOIR
ALTERNTIVE C - CRAB CREEK
PINTO DAM OUTLET SPILLWAY
SHEET 1 OF 2
CH2MHILL
348226



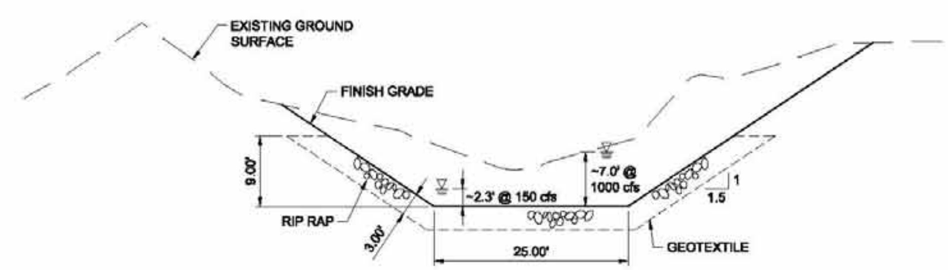
A SPILLWAY TROUGH SECTION
1"=10'-0"
1



B SPILLWAY CHUTE SECTION
1"=10'-0"
1



C STILLING BASIN SECTION
1"=10'-0"
1



D RIP RAP CHANNEL SECTION
1"=20'-0"
1

NOTE:

1. WATER SURFACE ELEVATIONS SHOWN REQUIRE CRAB CREEK CHANNEL IMPROVEMENTS DOWNSTREAM OF BROOK LAKE.

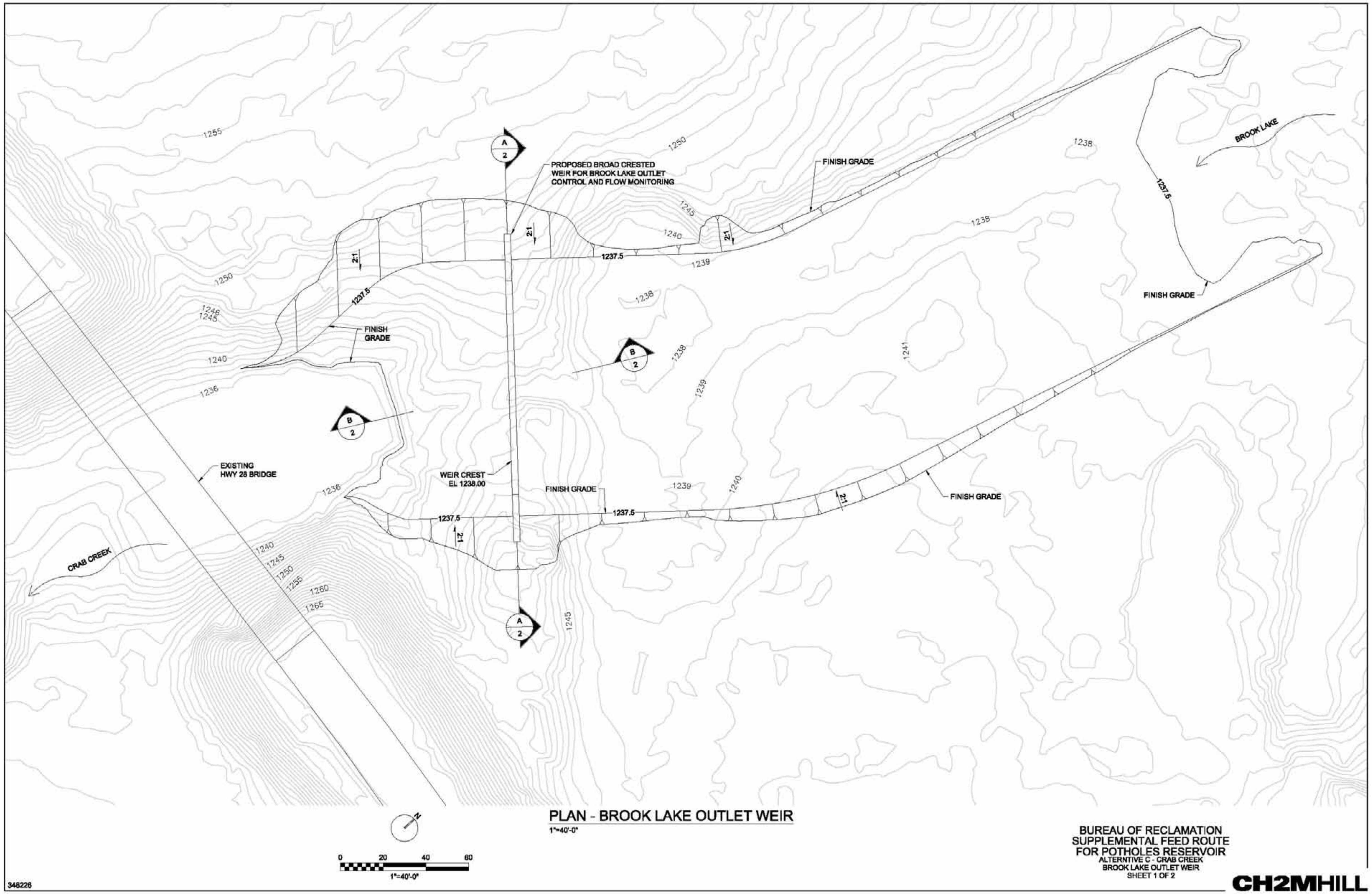
348226

BUREAU OF RECLAMATION
SUPPLEMENTAL FEED ROUTE
FOR POTHOLES RESERVOIR
ALTERNATIVE C - CRAB CREEK
PINTO DAM OUTLET SPILLWAY
SHEET 2 OF 2

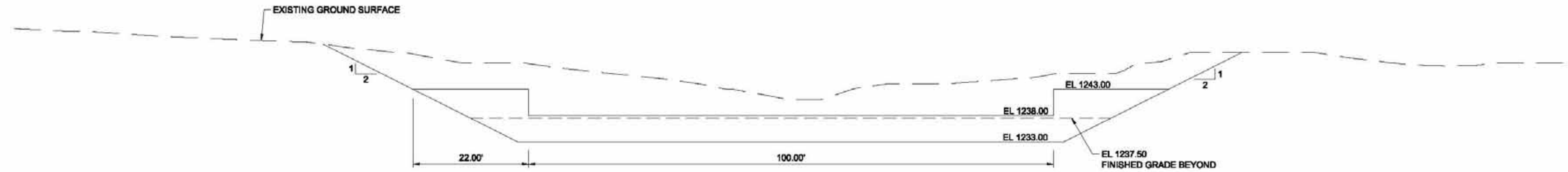
CH2MHILL

Attachment M

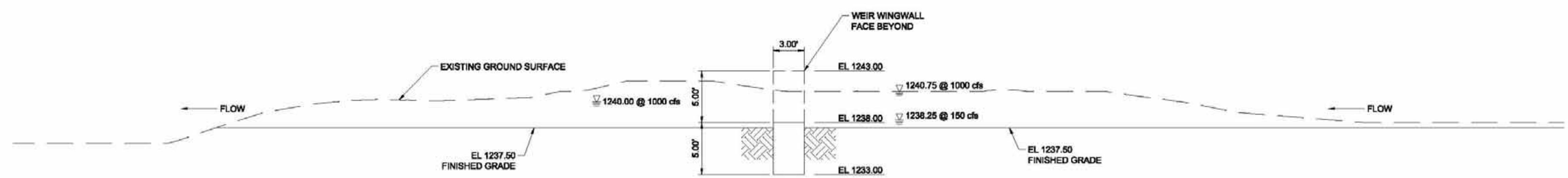
Brook Lake Outlet Weir—Conceptual Design Figures



PROPOSED BROAD CRESTED
WEIR FOR BROOK LAKE OUTLET
CONTROL AND FLOW MONITORING
FINISH GRADE
BROOK LAKE
CRAB CREEK
EXISTING
HWY 28 BRIDGE
WEIR CREST
EL 1238.00
1237.5
2:1
PLAN - BROOK LAKE OUTLET WEIR
1"=40'-0"
0 20 40 60
BUREAU OF RECLAMATION
SUPPLEMENTAL FEED ROUTE
FOR POTHOLES RESERVOIR
ALTERNTIVE C - CRAB CREEK
BROOK LAKE OUTLET WEIR
SHEET 1 OF 2
CH2MHILL
348226



A WEIR SECTION
1"=20'-0"
1



B WEIR SECTION
1"=10'-0"
1

NOTE:

1. WATER SURFACE ELEVATIONS SHOWN REQUIRE CRAB CREEK CHANNEL IMPROVEMENTS DOWNSTREAM OF BROOK LAKE.

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BUREAU OF RECLAMATION
SUPPLEMENTAL FEED ROUTE
FOR POTHOLES RESERVOIR
ALTERNTIVE C - CRAB CREEK
BROOK LAKE OUTLET WEIR
SHEET 2 OF 2

CH2MHILL