Chehalis Basin Strategy

Combined Dam and Fish Passage

Supplemental Design Report

FRE Dam Alternative

Reducing Flood Damage and
Restoring Aquatic Species Habitat

Updated Sep 2018

Prepared for: State of Washington Recreation and Conservation Office and Chehalis Basin Work Group

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ACRONYMS AND ABBREVIATIONS LIST

AACE	Association for the Advancement of Cost Engineering
ACI	American Concrete Institute
AEP	annual exceedance probability
AF	Acre Feet
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ASR	alkali-silica reactivity
AWS	auxiliary water supply/American Welding Society
CBFS	Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species Project
CFD	Computational fluid dynamics
cfs	cubic feet per second
CHTR	collection, handling, transport, and release
cm/sec	centimeters per second
CMCE	Controlling Maximum Credible Earthquake
CM	Construction Management
CMS	conditional mean spectrum/spectra
CSZ	Cascadia Subduction Zone
D/S	Downstream
DNR	Department of Natural Resources
DSHA	deterministic seismic hazard analysis
DSO	Dam Safety Office
EIS	Environmental Impact Statement
EM	engineering manual
ER	engineering report
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FMPC	fixed multi-port collector
fps	feet per second

FOS	factor(s) of safety
FRFA	Flood Retention Flow Augmentation
FRO	Flood Retention Only
FRE	Flood Retention Expandable
FRE-FC	Flood Retention Expandable-Future Construction
FSC	floating surface collector
FTE	full-time equivalent
ft	foot/feet
ft/sec, fps	foot/feet per second
G	gravity
GERCC	grout-enriched roller compacted concrete
HDC	Hydraulic Design Criteria
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
HEC-ResSim	Hydrologic Engineering Center Reservoir System Simulation
HMR	Hydrometeorological Report
I-5	Interstate 5
ICOLD	International Commission on Large Dams
IDF	Inflow design flood
IEEE	Institute of Electrical and Electronics Engineers
JS	joint set
km	kilometer(s)
MCE	Maximum Credible Earthquake
MCRCC	medium cementitious roller compacted concrete
min	minimum
mm	millimeter(s)
msa	maximum-size aggregate
msl	mean sea level
Mw	Megawatt
NEC	National Electrical Code
NEMA	National Electrical Manufacturers' Association
NEPA	National Environmental Policy Act

NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NMFS	National Marine Fisheries Service
NOHRSC	National Operational Hydrologic Remote Sensing Center
NRCS	Natural Resources Conservation Service
NTS	net transition structure
NWMLS	Northwest Multiple Listing Service
NWS	National Weather Service
O&M	operations and maintenance
OBE	operating basis earthquake
OFM	Office of Financial Management
OPCC	opinion of probable construction cost
OSHA	Occupational Safety and Health Organization
pcf	pounds per cubic foot
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PSHA	probabilistic seismic hazard analysis
psi	pounds per square inch
Qa	(modern) Quarternary alluvium
Qao	(older) Quarternary alluvium
RCC	roller compacted concrete
RCW	Revised Code of Washington
RMR	Rock Mass Rating
ROW	river outlet works
RQD	Rock Quality Designation
SEPA	State Environmental Policy Act
SPF	standard project flood
SR	State Route
SSD	saturated surface dry
Tcb	pillow basalt
Tcs	Crescent Formation siltstone/claystone
TM	Technical Memorandum

U/S	upstream
UHS	uniform hazard spectrum
UL	Underwriters Laboratories, Inc.
USACE	United States Army Corps of Engineers
USBUREC	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WA	Washington
WDFW	Washington Department of Fish and Wildlife
Work Group	Chehalis Basin Work Group
WSDOT	Washington State Department of Transportation
WSE	Watershed Science & Engineering
WSEL	water surface elevation

EXECUTIVE SUMMARY

This supplemental report has been prepared to document the development of an additional expandable Flood Control dam option for the Chehalis Basin Flood Strategy Project (CBFS Project). The type of dam that has been selected for Environmental Impact Statement (EIS) analysis is known as a Flood Retention Expandable (FRE) facility, which consists of a dam with a temporary reservoir. The FRE dam would temporarily retain water in the event of a major flood. The river would flow normally during regular conditions or smaller floods. The dam would only transition to flood retention operations during a major flood. Specific flow release operations would depend on inflow and the need to hold water to relieve downstream flooding as flood water recedes.

The FRE dam is considered to be expandable because it is proposed to be built with a foundation and hydraulic structures capable of supporting future construction of a larger dam with up to 130,000 acre-feet of storage; Flood Retention Expandable-Future Construction (FRE-FC). This future expansion, which may or may be constructed, would be subject to a separate National Environmental Policy Act (NEPA) and State Environmental Policy Act (SEPA) process and permitting, if pursued in the future.

The FRE project is not presented in the Conceptual Dam and Fish Passage Report (HDR, 2017a). That report contains complete descriptions of the Flood Retention Only (FRO), and Flood Retention and Flow Augmentation (FRFA) alternative Roller Compacted Concrete (RCC) dam configurations. FRO and FRFA dams have been under development since October 2013 and were identified as the preferred dam types and configurations as documented by HDR (2014a). This report contains only information and discussions specifically related to the FRE (expandable) dam option including both the FRE and FRE-FC configurations. See the Conceptual Dam and Fish Passage Report (HDR, 2017a) for detailed information related to the FRO and FRFA alternatives.

The FRO and FRFA RCC dam configurations with alternative fishways, fish collector, and experimental exit structures identified during the 2014 study are still viable options for achieving CBFS Project objectives

An updated opinion of probable construction cost (OPCC) and total project development costs, with appropriate planning contingencies for all options, are provided within an appendix to this report. A summary of the estimated total direct projects costs for the FRE and fish passage systems is provided in Table ES-1. The cost estimate is for direct construction costs, including final design engineering construction permitting, but does not include costs for EIS and Endangered Species Act (ESA) related studies and agreements or mitigation design and construction costs.

Table ES-1
Estimated Total Direct Project Costs for FRE Option

FEATURE	LOWER BOUND COST ($ MILLION)	WEIGHTED/MIDDLE COST ($ MILLION)	UPPER BOUND COST ($ MILLION)
FRE RCC Dam	$307	$358	$419
Upstream Fish Passage: CHTR Facility	$32	$43	$65
Downstream Fish Passage	Integral to dam construction		
Total	$339	**$401**	$484

Note: Includes OPCC, June 2017 dollars

Drawings and descriptions of the FRE are provided in Appendix H. Recommendations are provided for completing the next steps of project development during preliminary design. The completion of the main report and this supplemental report is intended to support selection of a preferred alternative. Based on the design team's experience with other large dam and fish passage facilities, it is anticipated that the time required to complete final design and construction would be 6 to 11 years.

Operation and maintenance (O&M) costs for the FRE and FRE-FC alternatives are expected to be similar to the costs for the FRO and FRFA, respectively, which are presented in more detail in the Combined Dam and Fish Passage report (HDR, 2017a). Those costs were developed with consideration of the requirements for replacement of dam components that are subject to wear and trash and sediment removal, as well as staffing and equipment needed for the dam and fish passage facilities. The estimated annual O&M cost (2017 dollars) are as follows:

- FRE: $628,000 per year
- FRE-FC: $2,178,000 per year

1 INTRODUCTION

1.1 Project Background

The conceptual design and opinion of probable construction costs (OPCC) for the Flood Retention Only (FRO) and Flood Retention Flow Augmentation (FRFA) dams and fish passage configurations at the proposed dam site are documented in HDR's Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a). That report, along with the Phase 2 Site Characterization Report (HDR, 2017b), document additional site characterization and engineering evaluations that were recommended in HDR's 2014 Combined Dam and Fish Passage Alternatives Technical Memorandum (HDR, 2014a) to reduce design uncertainty, refine estimated project costs, and support selection of a preferred alternative.

Subsequent to the issuance of the 2017 Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a), a third dam and fish passage configuration option was conceived as the Flood Retention Expandable (FRE) option, which has been selected for Environmental Impact Statement (EIS) analysis. The FRE dam is considered to be expandable because it is proposed to be built with a foundation and hydraulic structure capable of supporting future construction of a larger dam with up to 130,000 acre feet of storage. This future expansion, which may or may not be constructed, would be subject to a separate NEPA and SEPA process and permitting if pursued in the future and is described as the FRE future construction (FRE-FC).

The FRE dam would allow the river to flow normally during regular conditions or in smaller floods. The dam would only transition to flood retention operations during a major flood. Specific flow release operations would depend on inflow and the need to hold water to relieve downstream flooding as flood water recedes. Figure 1-1 shows the FRE dam site and the expected 100-year flood pool inundation pool limit.

The FRE project is not presented in the Conceptual Dam and Fish Passage Report (HDR, 2017). That report contains complete descriptions of the Flood Retention Only (FRO), and Flood Retention and Flow Augmentation (FRFA) alternative Roller Compacted Concrete (RCC) dam configurations that have been under development since October 2013 and have been identified as the preferred dam types and configurations as documented by HDR (2014a). This report contains only information and discussions specifically related to the FRE (expandable) dam option. The FRE-FC configuration is included in the discussion to describe the potential design conditions for the larger storage dam. Refer to the Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a) for detailed information related to the FRO and FRFA alternatives.

The design storage volumes and corresponding estimated water storage elevations for the FRE and FRE-FC configurations are summarized in Table 1-1. The storage volumes and corresponding dam heights and inundation areas are subject to change as climate change and operation studies advance through the planning process.

Figure 1-1
FRE Dam Site Location and Expected 100-Year Flood Inundation Limits

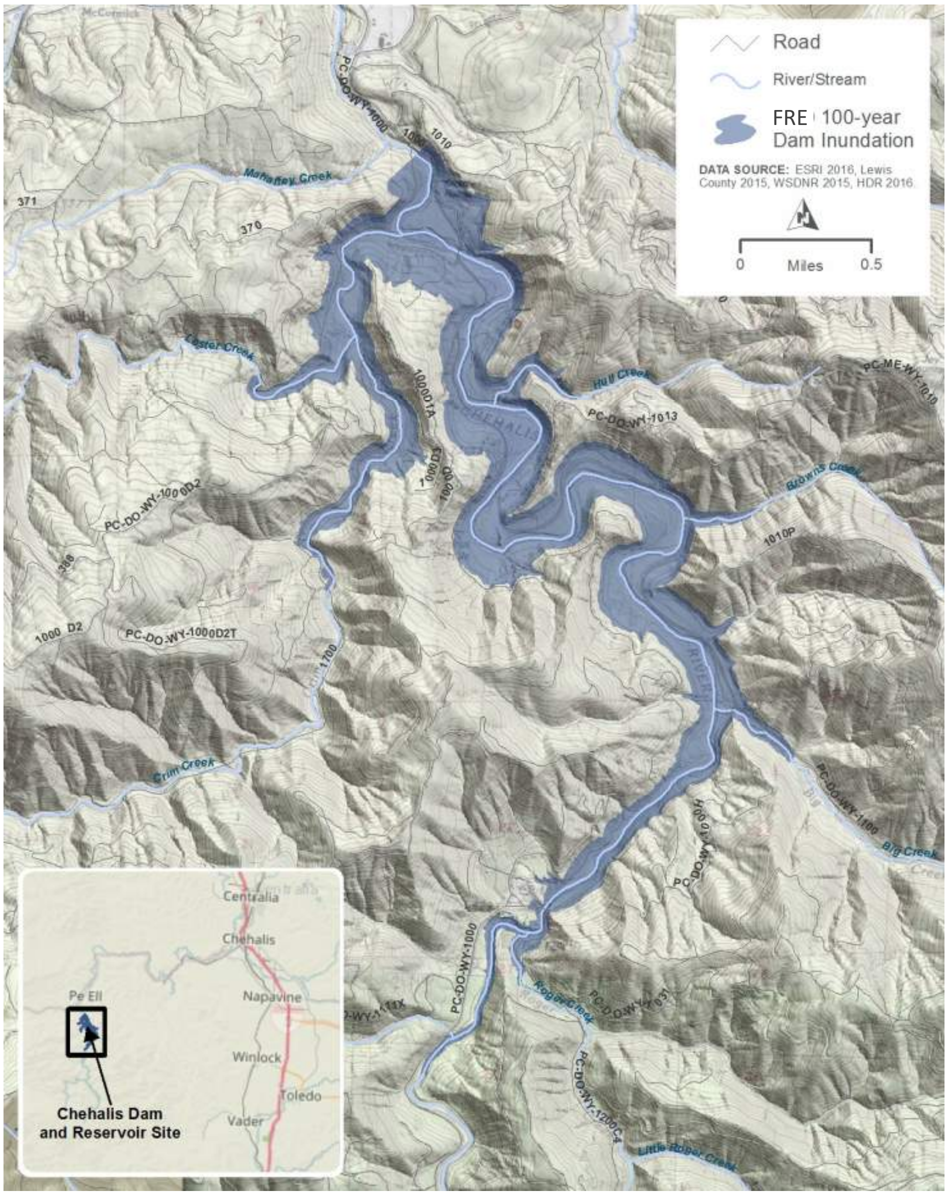


Table 1-1
Summary of Dam Storage Volumes and Maximum Water Surface Elevations

CONFIGURATION	WATER STORAGE VOLUME (ACRE FEET)	FLOOD STORAGE VOLUME (ACRE FEET)	MAXIMUM WATER STORAGE ELEVATION (FEET)	DESIGN FLOOD STORAGE ELEVATION (FEET)
FRE	0	65,000	-	628
FRE-FC	65,000	65,000	628	687

Note:
Design flood storage volumes and elevations are to spillway crest and include the routed volume for the 2007 design flood event. The flood storage volume and elevations do not include flood routing capacity between the design flood event (2007) and the Probable Maximum Flood (PMF).

1.2 Purpose and Objectives

This report is a supplement to the Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a). The primary objectives of this supplemental report are:

1. Describe and document the FRE dam option and associated fish passage configuration.
2. Present updated estimates of total project direct costs for the FRE. The updated cost estimates have a 2017 cost basis and include additional engineering and design refinements completed since issue of the Combined Dam and Fish Passage Conceptual Design Report in late 2017.
3. Describe only the specific hydraulic, structural, and cost details of the FRE that are significantly different from the FRO and FRFA options.

Detailed evaluations of design topics specific to the FRE option are included in the following attached Appendices:

- Appendix H – Maps and Drawings
- Appendix I – Hydraulic Design
- Appendix J – Construction Cost Opinion

This report is presented for consideration and review by the technical committees working on the project.

1.3 Scope of Services

The scope of work for this report included the following tasks:

- Development of the dam and fish passage facility conceptual design configuration for FRE configuration.

- Evaluation of foundation excavation and treatment requirements for the refined and relocated collection, handling, transport, and release (CHTR) and fish ladder facilities.
- Hydraulic analyses to support the FRE configuration and construction approach, including the conduits, spillway, water quality outlet works, and stilling basin.
- Development of the FRE dam and fish passage configuration drawings
- Development of preliminary design-level estimates of probable construction costs for the FRE project alternative.
- Development of recommendations for the next steps in project development.
- Preparation of documentation (this report) summarizing the above information.

1.4 Project Team

The following HDR personnel were involved in the various evaluations required to complete the updated conceptual designs:

Project Manager:	Beth Peterson, P.E.
Technical Manager and Lead Civil Engineer:	Keith Moen, P.E.
Lead Dam Engineer:	Keith A. Ferguson, P.E.
Lead Geotechnical Engineer:	Dan Osmun, P.E.
Geological Engineers:	Andrew Little, E.I.T. John Charlton, P.Geologist
Lead Hydraulic Engineer:	Ed Zapel, P.E.
Lead Fish Passage Designer:	Michael Garello, P.E.
Constructability and Cost Estimating:	Jeffrey Allen, P.E.
Project Support:	Carl Mannheim, P.E., Senior Civil/Hydraulic Engineer Ali Reza Firoozfar, E.I.T., Civil/Hydraulic Engineer Gokhan Inci, Ph.D., P.E. Geotechnical Engineer Mathew Prociv, P.E., Fish Passage Design Shaun Bevan, P.E., Fish Passage Design John Ferguson, Ph.D., Fish Passage Biology (Anchor QEA) John Hess, P.E. Materials Engineering Paul Oxborrow, CADD Paul Kowalki, CADD, Civil 3D Michael Austin, CADD

Additional technical staff for the project has been provided by Anchor QEA and Shannon & Wilson along with other members of the Anchor QEA consulting team for the project.

2 FRE DAM

2.1 FRE Configuration and Operational Approach

Both the FRE and FRE-FC configurations have been designed to meet downstream flood protection objectives. Each configuration has different dam hydraulic heights, operational approach, and potential flow augmentation storage volumes. The FRE is configured to only store flood flows as identified under the current flood control objectives at the Grand Mound gage. Most of the time, the dam outlet works would remain fully open and river flows would be unregulated. The FRE-FC is configured to provide additional storage that can be used in some combination of increased flood protection that reflects hydrologic changes (e.g. effects of global warming), or as a permanent storage pool for augmentation of downstream river flows for fish and aquatic habitat enhancement. The hydraulic configuration including the permanent pool elevation (and resulting storage volume) of the FRE-FC could vary depending on annual hydrology and future water management objectives. For the purpose of this report, we have assumed that FRE-FC would use up to half the total storage capacity below the spillway crest for permanent storage and the other half for flood control.

More detailed descriptions of the operational approach of each FRE dam is presented in a separate document (Anchor QEA, 2014).

2.2 FRE

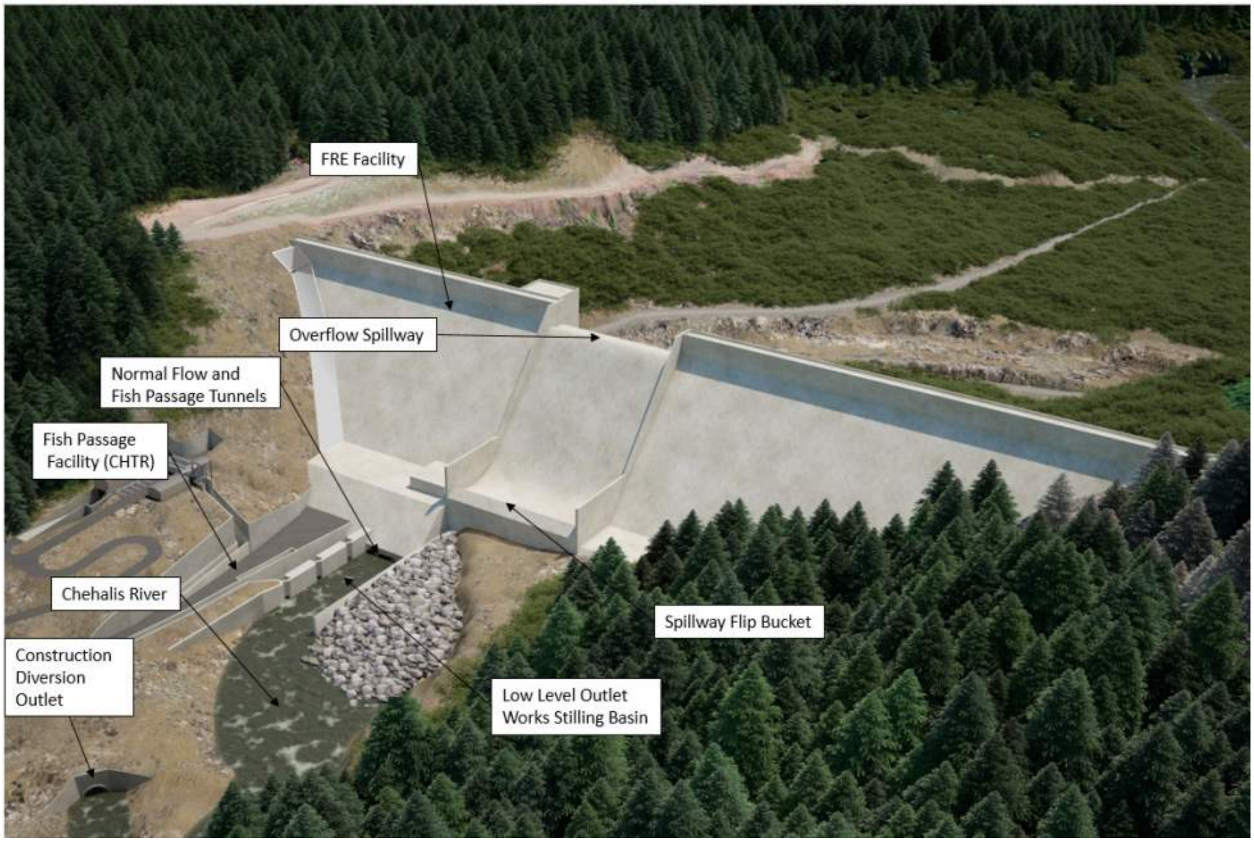
The FRE reservoir would be impounded with a primary roller compacted concrete (RCC) gravity dam structure. The configuration includes a right abutment construction (and backup normal operation) diversion tunnel, low-level fish passage and flood control outlet works, an emergency spillway, and supplemental fish passage facilities. The dam would be designed to temporarily store floodwater only when the downstream gage at Grand Mound is forecasted to rise above 38,000 cubic feet per second (cfs) within 48 hours. Such temporary storage events are estimated to have only a one in seven-year recurrence interval. After flood regulation operations are commenced and the outlet works begin regulating outflows, fish passage through the outlet works would no longer be available. Debris management operational plans and potential operational modifications associated with climate change scenarios have necessitated consideration of redundant fish passage facilities that would be operated during periods of flood retention and subsequent debris removal. At all other times, the project is expected to retain no water and to allow all river flows to pass, with only minor restriction of river flow and pool accumulation at the upstream face of the dam.

Primary components of FRE would be the following:

- An RCC dam sized for 65,000 acre feet of flood storage with estimated maximum dam structural height of 254 to 270 feet depending on final foundation elevation.
- A dam crest length of approximately 1,550 feet.
- A dam foundation excavation and treatment that would be completed to the ultimate FRE-FC configuration so that no redundant but expanded foundation treatments for the foundation grout curtain, foundation and dam drainage systems, dam jointing, dam facing systems, or dam gallery and access provisions would be required. Exposed portions of the foundation excavation for the future FRE-FC would be protected by an RCC cover.
- An overflow spillway, designed to pass flood flow up to and including the Probable Maximum Flood (PMF) without dam overtopping. The spillway includes a crest control structure, a spillway chute, flip bucket, and plunge pool. The location and configuration of the lower portion of the spillway chute, flip bucket (including pedestal) would be the same as required for the FRE-FC configuration to eliminate the need for demolition and reconstruction of these features.
- Diversion tunnel to handle flows during construction.
- Outlet works, including and low-level outlets for flood regulation and fish passage purposes.
- Fish passage facilities designed for free passage upstream and downstream prior to and after flood operations, and trap and haul during flood regulation periods.

The FRE visualization is shown in Figure 2-1. Additional conceptual design drawings of the initial construction of the FRE are included in Appendix H.

Figure 2-1
FRE Facility Visualization



2.3 FRE-FC

The FRE-FC reservoir would be impounded with a primary roller compacted concrete (RCC) gravity dam structure constructed over the FRE structure and small upper right abutment central earth core rockfill saddle dam embankment. The configuration would maintain the construction diversion tunnel constructed for the FRE along with the low-level flood control outlets. Multilevel water quality outlets would be completed for discharge to the flood control outlet stilling basin. The spillway crest for the FRE would be demolished and raised to the new level below the crest of the FRE-FC dam. All other features of the FRE would be retained and operated according to new FRE-FC objectives and procedures. The increased storage of the FRE-FC would be used to provide either additional flood storage, a permanent pool for flow augmentation, or some combination thereof. As currently configured, the FRE-FC dam would maintain a permanent pool behind the dam with a storage volume of about 65,000 acre feet and would be designed to provide water storage and releases for flow augmentation from the permanent pool to enhance certain aquatic species habitat, and a flood management pool with storage volume of 65,000 acre feet above the designated permanent pool and below the spillway crest for flood operations.

The primary components of the FRE-FC would include the following:

- A dam and reservoir sized for the combined flood and water quality storage with an estimated dam structural height of 313 to 330 feet depending on final foundation elevation.
- An RCC dam crest length of approximately 1,680 feet.
- A central earthcore rockfill embankment saddle dam on the right abutment that is approximately 850 feet long.
- An overflow crest control spillway structure designed to pass PMF without dam overtopping, including a spillway chute, flip bucket, and plunge pool.
- Multiple outlet works including a water quality inlet/outlet that draws water from multiple levels within the reservoir and a low-level flood regulation outlet.
- A recommended upstream fish passage by trap and haul or fishway; a recommended downstream fish passage by trap and haul.
- A permanent reservoir pool of up to 65,000 acre feet to be used for flow augmentation in late summer and fall prior to the winter rainy season to enhance fish and certain aquatic species habitat.
- A minimum of 65,000 acre feet of flood storage volume to be activated in flood events larger than the estimated 7-year recurrence interval event.

Additional conceptual-design drawings of the FRE-FC dam and appurtenant structures configuration are included in Appendix H.

3 DESIGN CRITERIA

3.1 FRE Dam Design Criteria and Requirements

The following summarizes the hydrologic and hydraulic design criteria and requirements that are specific to the FRE configuration. For additional details, including structural, electrical, mechanical, and geotechnical design guidelines and requirements, see the Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a).

The hydrologic study performed by WSE (WSE, 2016) and the hydrologic modeling of flood storage attenuation by Anchor QEA (Anchor QEA, 2014) form the basis for hydraulic design of the FRE alternative. The following hydraulic criteria apply to both the FRE and FRE-FC configurations:

- The maximum inflow for the project inflow design flood (IDF) is the PMF, which is estimated to be 69,800 cfs (NOTE: this value is based on the recent estimate of PMF which is less than 75,000 cfs used for the design of spillways for the FRO and FRFA alternatives)
- The spillway capacity will be equal to the PMF
- Flood storage equal to 65,000 acre-feet, approximately equal to the flood volume of the 2007 flood of record

The initial construction and raised dams will vary as follows:

FRE:

- Dam crest elevation is 651 feet msl (mean sea level)
- Estimated maximum routed PMF reservoir elevation is 650 feet msl
- Spillway crest elevation is 628 feet msl
- Minimum flood storage reservoir elevation is natural riverbed elevation
- Maximum flood storage elevation with no spillway flow is 628 feet msl
- Low-level flood regulation sluices design flow is 15,000 cfs

FRE-FC:

- Dam crest elevation is 710 feet msl
- Estimated maximum routed PMF reservoir elevation is 709 feet (msl)
- Spillway crest elevation is 687 feet msl
- Minimum flood storage reservoir elevation is 628 feet msl
- Maximum flood storage elevation with no spillway flow is 687 feet msl
- Maximum flow augmentation reservoir elevation is 628 feet msl

- Minimum flow augmentation reservoir elevation is 588 feet msl (585 feet msl with climate change scenario)
- Low-level flood regulation sluices design flow is 15,000 cfs

4 DAM FOUNDATION AND STRUCTURAL DESIGN

Design of concrete dams typically involves evaluation of a range of normal, flood (unusual), and seismic loading conditions (USACE, 1995). Suitable geotechnical and structural analyses were performed for the design of the foundation excavation objective, to set the cross-section properties for FRO and FRFA dam configurations. Specifically, the maximum design loading conditions and structural height of the dam associated with either the FRFA or FRE-FC with a maximum operating pool level were considered. Hence no additional geotechnical or structural analyses were required to establish the conceptual design level excavation and cross-section requirements for the FRE configurations. The excavation and cross-sections shown on the drawings provided in Figures FRE-S-1 and FRE-S-2 in Appendix H are therefore reasonable and conservative.

Additional geotechnical and structural analyses and modeling will be performed during preliminary design stage in order to further optimize design and construction requirements. In all cases, the designs will provide stable cross-sections for all applicable load conditions. See the Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a), and the Phase 2 Site Characterization Report (HDR, 2017b) for additional details related to the foundation and structural design for the alternative configurations.

5 HYDRAULIC DESIGN

5.1 Introduction

This section summarizes the hydraulic design criteria, reservoir storage and flow capacities, and the descriptions and hydraulic characterizations of the outlet structures: the spillway and the spillway chute; flip bucket and plunge pool; outlet works; and stilling basin.

More detailed information on the hydraulic design is included in Appendix I.

5.2 Design Criteria

Table 5-1 below summarizes the design criteria used for the hydraulic design of the FRE dam options.

Table 5-1
Hydraulic Design Criteria

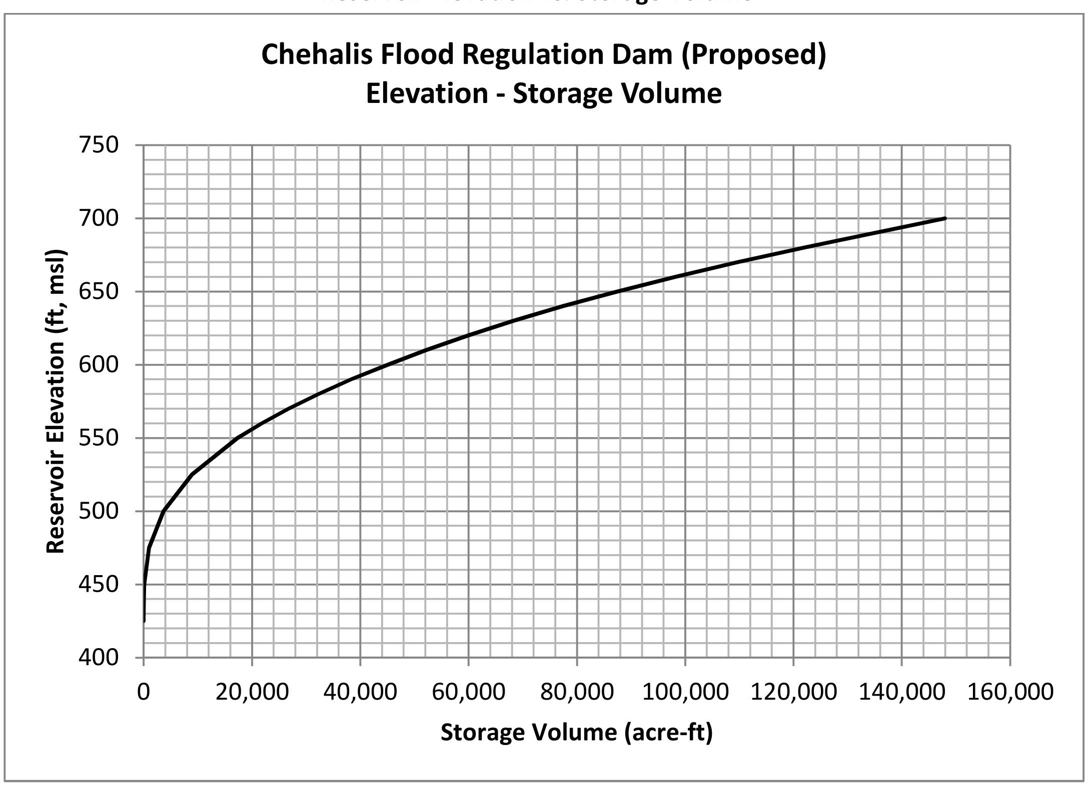
PARAMETER	DESIGN CRITERION	COMMENT/REFERENCE
Spillway Design Flood	69,800 cfs	PMF, as required by Washington State Dam Safety Guidelines (WSE, 2016)
Flood Regulation Storage	65,000 AF	The equivalent flood volume of the December 2007 flood event of record (Anchor QEA, 2014)
Flow Augmentation Storage	FRE: 0 AF FRE-FC: 65,000 AF	(Anchor QEA, 2014)
Low Level Flood Regulation Outlet Works Minimum Total Flow	15,000 cfs at reservoir EL 550; total for all five conduits	Minimum flow capacity of low level flood control outlets needed to release the full equivalent flood storage volume of the 2007 flood of record hydrograph back into the river within one week
Maximum Fish Passage Flow	2,000 cfs	5 % exceedance flow; unrestricted fish passage for all flows up to 2,000 cfs
Minimum Fish Passage Flow	30 cfs	95 % exceedance flow
Minimum Water Quality Outlet Works Flow	500 cfs	Each outlet must be capable of discharging 500 cfs with a minimum of 35 feet of submergence.
Stilling Basin Design Flow	15,000 cfs	Flow at reservoir flood elevation (FRE = 628 feet; FRE-FC = 687 feet)

5.3 Flow Capacities and Reservoir Storage

The spillway design flow for both the initial construction FRE dam (FRE) and the raised FRE dam (FRE-FC) is the estimated maximum reservoir inflow during a PMF that is estimated to be 69,800 cfs (WSE, 2016), as required under the Washington State Dam Safety Office guidelines. The total required flood regulation storage reservoir volume is 65,000 acre feet. The flood storage capacity is the equivalent volume of the hydrograph of the December 2007 flood event of record at the Doty gage site, the recurrence interval of which has been estimated to be between 300 and 1,000 years.

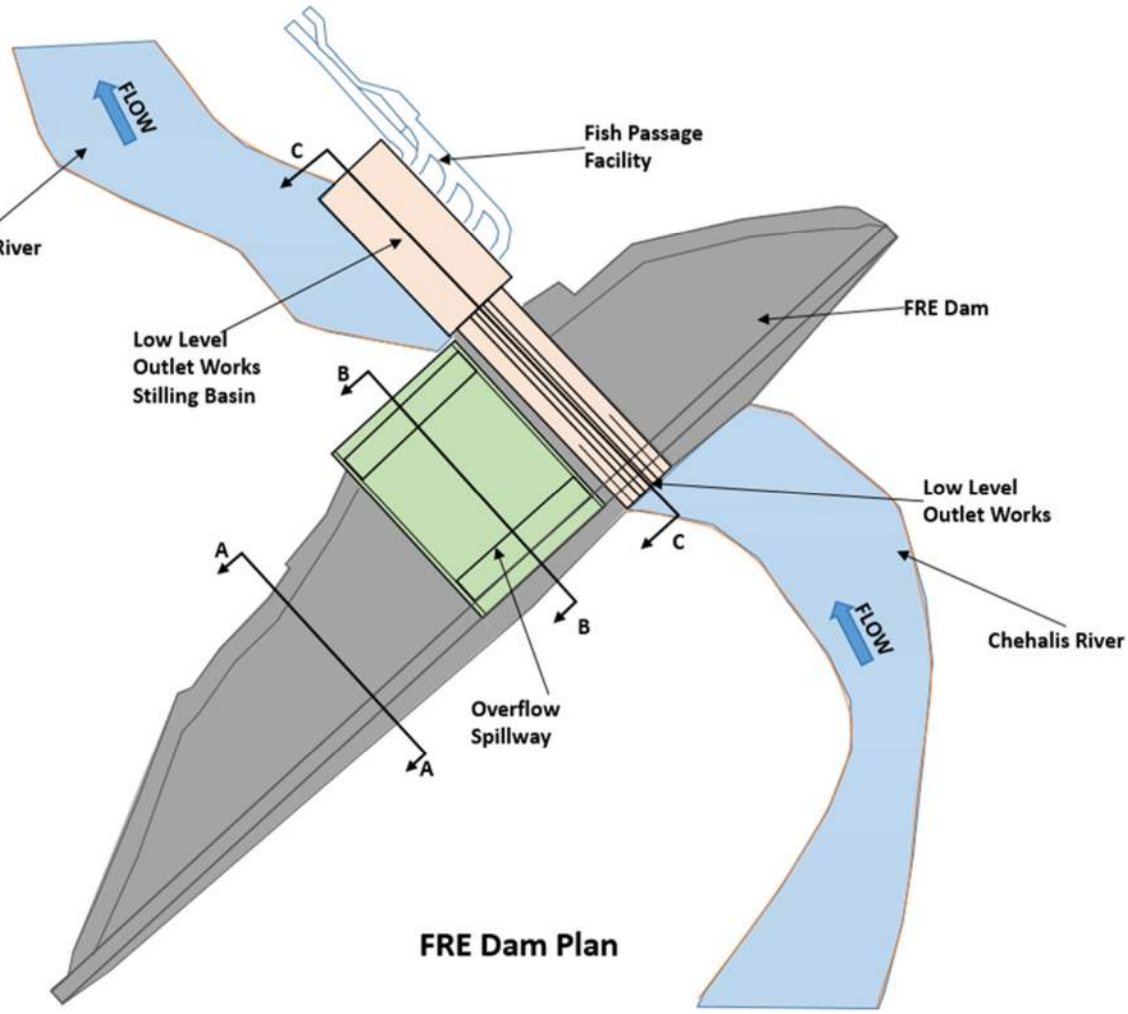
The FRE reservoir will normally be "dry"; that is, there will normally be no reservoir behind the dam, and the river flows will pass unimpeded through the dam sluices at all times until and unless a flood regulation operation is initiated. Flood storage is provided between the existing river water surface elevation and the emergency spillway crest at elevation 628 feet. The raised FRE-FC dam includes a permanent storage pool of up to 65,000 acre-feet (at elev. 628 feet) for flow augmentation and the required flood storage of 65,000 acre-feet from the reservoir elevation of 628 feet to the spillway crest elevation of 687 feet. Figure 5-1 shows the Reservoir Elevation vs. Storage Volume relationship, and Figure 5-2 illustrates how storage is provided in the FRE and FRE-FC dam alternatives.

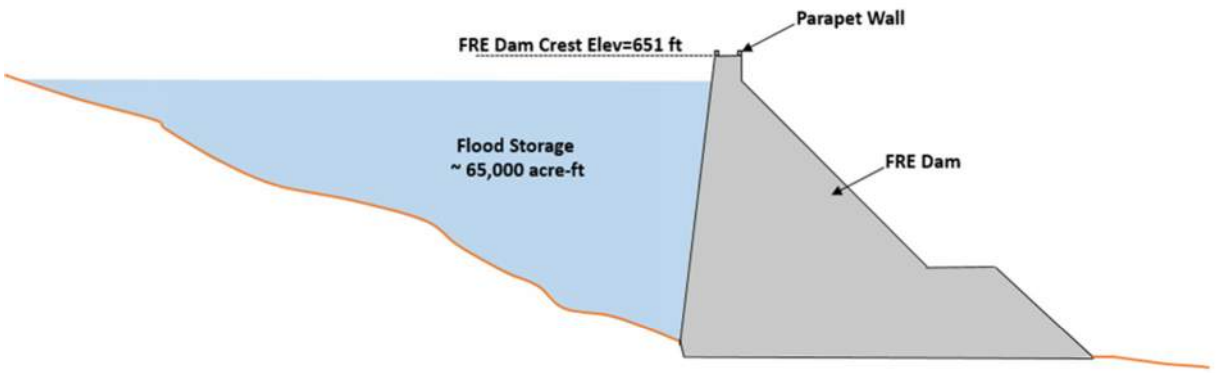
Figure 5-1
Reservoir Elevation vs. Storage Volume



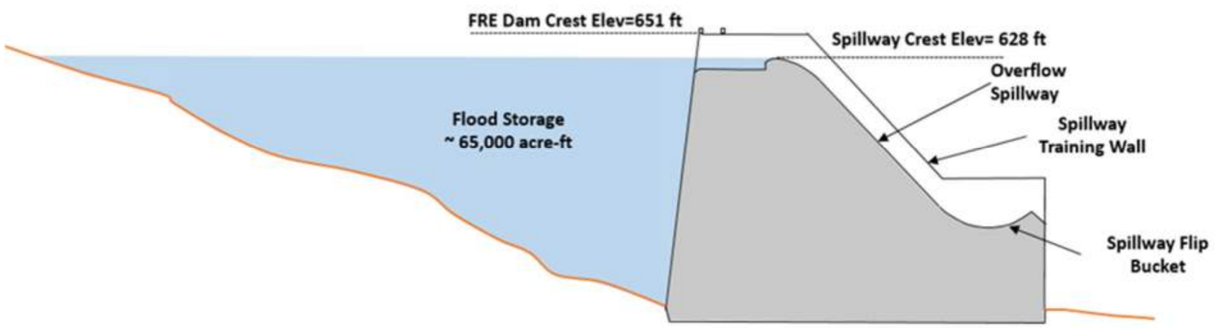
Source: Anchor QEA, 2017

Figure 5-2
FRE Schematic Layout

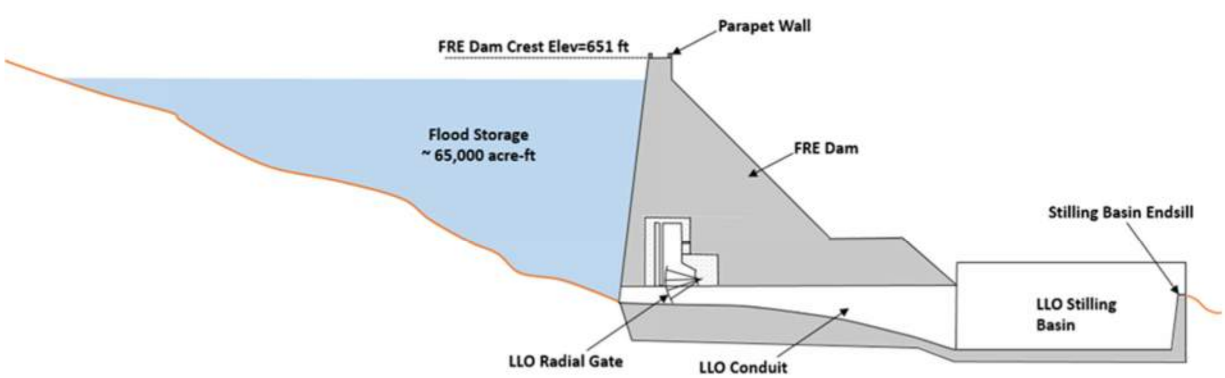




Section A-A
FRE Dam Non-Overflow Section



Section B-B
FRE Dam Overflow Spillway



Section C-C
FRE Dam Low Level Outlet Works (LLO)

The FRE dam would typically allow water from all minor high-flow events up to about 12,500 cfs to be passed through the dam with the sluice gates fully open, unless the flood regulation operation is commenced in response to larger flooding concerns downstream. All sediment and most small debris would pass through the dam unimpeded. The sluices have been designed to provide sufficient capacity at these smaller flow events to prevent developing backwater upstream of the sluices for flows up to and above a required high fish passage flow (2,000 cfs). Additionally, the low-level outlet works for both FRE and FRE-FC dams are sized to release the full equivalent flood storage volume of the 2007 flood of record hydrograph back into the river at a rate that would restore full flood storage capacity within one week.

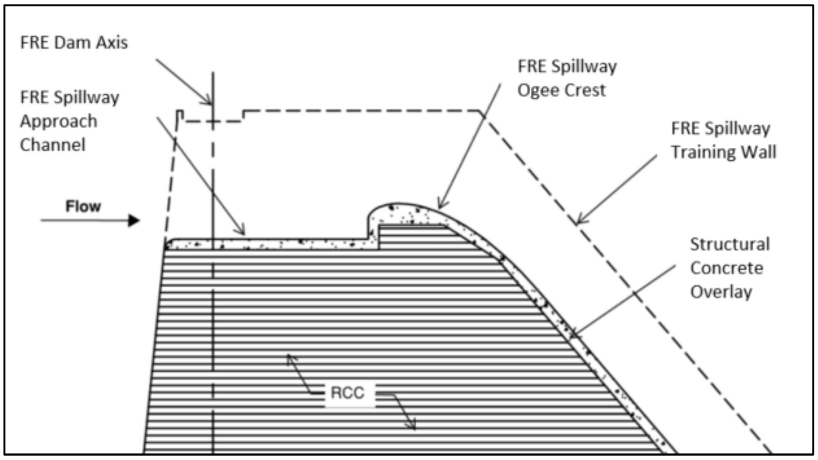
Similar to the FRFA dam alternative, the multiport water quality outlet works for the FRE-FC alternative is designed to pass up to 500 cfs from any reservoir level within the flow augmentation pool. Each of the four 48-inch-diameter conduits can discharge over 500 cfs with a minimum of 35 feet of submergence. The water quality outlet works are designed to accommodate withdrawal from multiple depths within the flow augmentation pool as needed to manage downstream release water temperatures. A larger, 84-inch diameter low-level port with a capacity of 800 cfs is included at the lowest level of the flow augmentation reservoir pool, in case additional quantities of cool stored water are required to meet downstream water temperature needs. The multiport water quality outlet works would be built during construction of the FRE, however, they will only be operational after completion of the FRE-FC.

5.4 Spillway and Spillway Chute

The spillways for the FRE and FRE-FC would be uncontrolled ogee crests, discharging to smooth-faced conventional concrete chutes cast over the top of the RCC mass dam section. Design guidance utilized in the design of the crest shape included USACE EM 1110-2-1603, Hydraulic Design of Spillways; the USACE Hydraulic Design Criteria (HDC); and the USBUREC Design of Small Dams.

The FRE spillway crest is set at elevation 628 feet with a width of 200 feet, and is designed to pass up to 69,800 cfs with 4.3 feet of freeboard to the top of the upstream crest parapet wall. The equivalent unit discharge at full design capacity is 349 cfs per linear foot. The design discharge capacity has been conservatively estimated using a slightly lower discharge coefficient (C_d = 3.73) than is typically found for smooth ogee designs, to ensure adequate capacity without risk of overtopping. The FRE spillway is designed with a relatively short and shallow approach channel which positions the ogee crest approximately 50 feet downstream of the dam axis. This design and construction of the spillway chute and flip bucket structures conforms to the geometric requirements of the potential future FRE-FC dam, hence minimizing the construction effort and costs for expanding this portion of the dam. Figure 5-3 shows a schematic section view of the FRE spillway crest design.

Figure 5-3
Schematic view of FRE Spillway Crest and Chute Design



The FRE-FC spillway crest is set at elevation 687 feet with a width of 200 feet, and is designed to pass up to 69,800 cfs with 5 feet of freeboard to the top of the upstream dam parapet wall. The equivalent unit discharge at full design capacity is 349 cfs per linear foot. The design discharge capacity has been conservatively estimated using a slightly lower discharge coefficient (C_d = 3.84) than is typically found for smooth ogee designs, to ensure adequate capacity without risk of overtopping. To construct the FRE-FC spillway, the FRE spillway crest will be demolished while the flip bucket structure and a significant portion of the spillway chute will remain in place. Then, the RCC construction will proceed in lifts to facilitate the construction of the FRE-FC spillway. Figure 5-4 shows a schematic section view of the FRE-FC spillway design and construction.

Like that of the FRFA and FRO, the FRE and FRE-FC crest shapes have been designed with a design head (H_d) of 30 feet, though the maximum anticipated actual (effective) head (H_e) under the PMF event is only 22 feet. This "overdesign" permits the ogee shape to be cast on top of the underlying RCC structural outline and reach tangency with the overall downstream dam structure slope with approximately 3 feet of concrete overlay. This simplifies the dam construction process by allowing continuous RCC placement to finish the non-overflow section of the dam followed by conventional concrete overlay to construct the spillway. The crest shape shown on Figure 5-5 is used for both FRE and FRE-FC spillway designs. For this evaluation, it is assumed that the RCC construction will proceed in lifts of approximately 1 foot, which would leave a finished concrete face with 1-foot steps at the design downstream face slope of 0.85H:1V. The chute design assumes a structural overlay of concrete on the ogee crest and the face of the chute. Doweling and structural reinforcement would be required to securely anchor the structural concrete overlay to the RCC dam structure (Figure 5-3 and Figure 5-4).

Figure 5-4
FRE-FC Spillway Crest and Chute Design

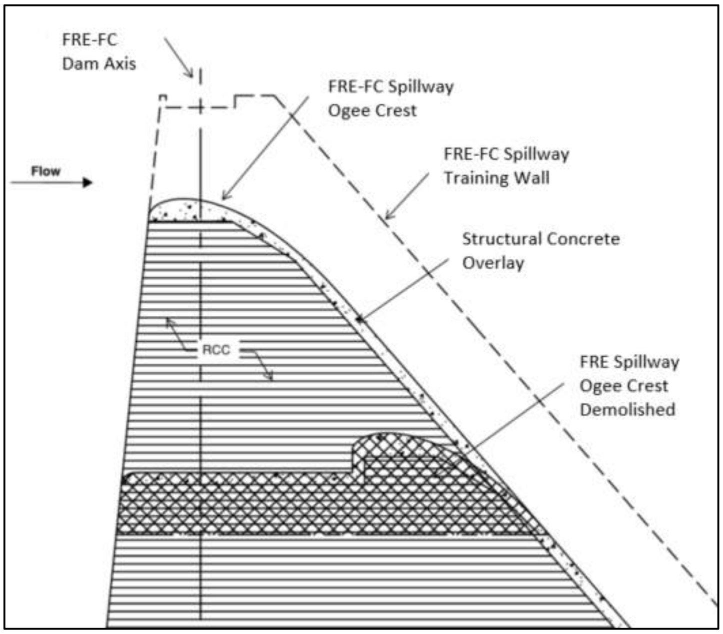
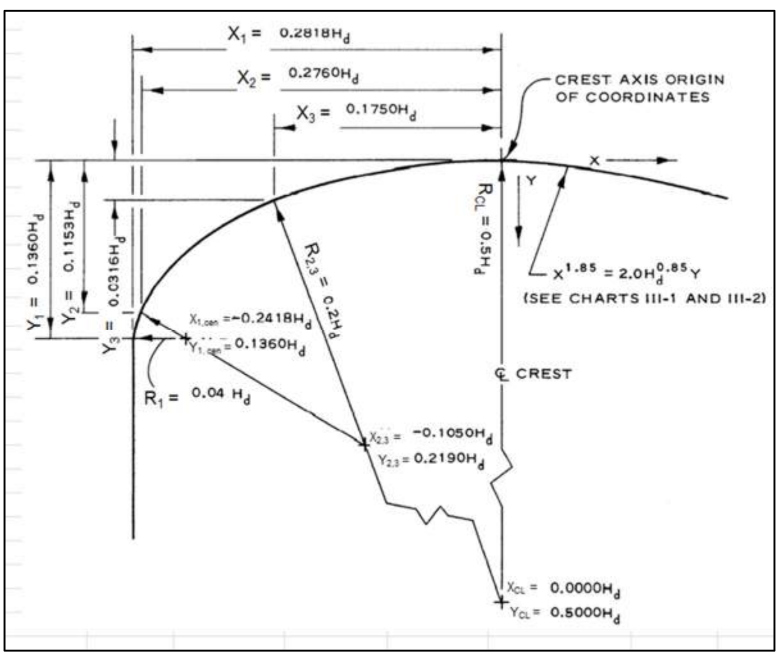


Figure 5-5
USACE Hydraulic Design Criteria 111-2/1 Design of Ogee Crest Shape



5.5 Flip Bucket and Plunge Pool

Similar to the FRO and FRFA alternatives, the FRE and FRE-FC alternatives spillway is expected to be used very rarely, and for events of very short duration. Therefore, no spillway stilling basin is provided. Rather, a flip bucket will be constructed to launch the spillway flow a safe distance downstream of the dam and to dissipate the energy in the river channel. Based on the geology of the site, the downstream rock within the flow impact area appears to be of sufficient quality and strength to provide occasional spillway flow dissipation and resist significant erosion, but that should be confirmed by geotechnical investigations prior to final design. The reservoir modeling conducted to date indicates that spill events are likely to occur with recurrence of 300 to 1000 years. Small spill discharges would be expected to cascade from the lip of the flip bucket and fall onto the rockfill material at the spillway toe adjacent to the sluice outlet stilling basin structure. Additional design refinement in the next phase of the project may include a more detailed evaluation of erosion protection for the rockfill adjacent to the sluice stilling basin. At this stage, a low containment wall about 3 to 5 feet high directs these minor spillway flows across the rockfill material adjacent to the stilling basin and to the river channel below.

For both the FRE and FRE-FC spillways, the flip bucket design is based on a unit discharge of 349 cfs/foot of width at the maximum spillway flow, with the bucket invert at elevation 475 feet and the lip at elevation 489.6 feet. The flip bucket was designed according to guidance provided in USACE EM 1110-2-1603, Hydraulic Design of Spillways, as shown on Figure 5-6 below. The flow depth at the flip bucket toe was estimated for the spillway design flow by two methods with comparable results: the first method using boundary layer development theory, and the second using the potential energy of the available hydraulic head from the reservoir level to the flip bucket toe. For the FRE, the maximum flow depth at the bucket toe is about 3.7 feet with a design flow velocity of about 100 feet per second, resulting in a minimum design bucket radius of 40.4 feet. For the FRE-FC, the maximum flow depth at the bucket toe is about 3.2 feet with a design flow velocity of about 118 feet per second, yielding a minimum design bucket radius of 47.6 feet. A bucket radius of 50 feet was selected for both the FRE and FRE-FC configurations. Simple trajectory calculations based on the USACE guidance indicated an impact location approximately 350 feet and 500 feet downstream of the lip for the FRE and FRE-FC, respectively. For unit discharges less than about 50 cfs per linear foot, energy losses down the chute would become significant and would reduce the flow velocity at the chute toe appreciably, resulting in an impact zone closer to the dam. The rockfill design in the channel downstream of the flip bucket would accommodate unit discharges of perhaps 30 to 50 cfs per foot without entrainment of stone and plucking or erosion. The specific gradation requirements for the stone surface material that will resist erosion under these flow conditions has not been determined in this conceptual design. Analysis to estimate the required riprap protection should be included as a refinement during the preliminary design phase.

Figure 5-6
Spillway Flip Bucket Design

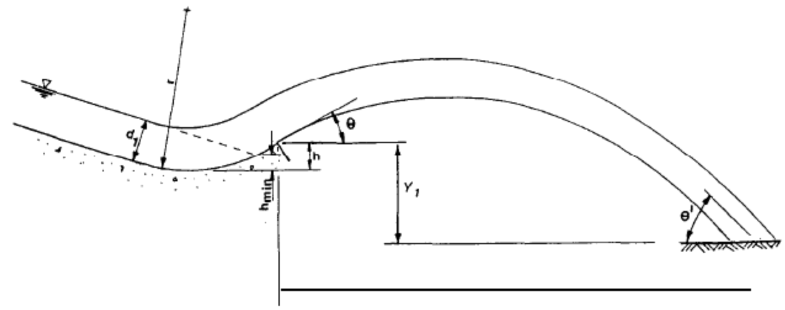


Figure 7-2. Parameters used in the design of a flip bucket

Source: USACE EM 1110-2-1603, Hydraulic Design of Spillways

5.6 Outlet Works

The FRE alternative design has five low-level sluice outlets: a single larger 12-feet-wide by 20-feet-high sluice at invert elevation 408 feet and two pairs of 10-feet-wide by 16-feet-high sluices at invert elevation 411 feet, one pair on each side of the larger center sluice. A large, full height trashrack extending from the riverbed to the dam crest will exclude most large trees from the sluice conduits and provide excess open area under all reservoir elevations to pass the desired project outflows. The larger sluice outlet in the center will be used to pass the majority of bedload sediment in the river, as well as most small debris. Some sediment is expected to pass through the smaller sluice outlets as well, but the center sluice with a lower invert elevation will intentionally receive the most wear from sediment passage over time. It is expected that repairs to the sluice floor would be required every few years to bring the sacrificial concrete floor surface back to original grade.

The two pairs of 10 foot by 16 foot sluice gates pass flow into parallel conduits separated by a center dividing wall terminating about 100 feet downstream of the gate seats. Downstream of the divider wall, the outflows from both gates combine into a 22-feet-wide by 16-feet-high single conduit. A parabolic drop of about 31 feet in the floor elevation of the sluice conduit transitions the discharge into the downstream stilling basin floor at an elevation of 377 feet.

The large 12-feet-wide by 20-feet-high center sluice is equipped with a radial gate with a radius of about 44 feet. The four smaller 10-feet-wide by 16-feet-high sluices have radial gates with a radius of about 35 feet. Hydraulic cylinder operators for each gate would provide positive closure under all flow conditions. Gate sealing would be accomplished using either inflatable (using reservoir static water pressure) side seals and top seals, or the gate trunnion would be provided with an eccentric rotator to compress the top seal. Both sealing types have been used with success in high head applications such as this. Similar to FRO and FRFA, radial gates were selected for the FRE dams for several reasons:

- They reduce the gate operator load by transmitting the hydrostatic forces to the trunnion.
- They eliminate gate slots, which, in a sediment- and debris-rich environment, can cause problems in fully seating the gate.
- They are more reliably and positively controlled than cable-hung vertical gates at these heads.
- They do not suffer from pressure regime shifts resulting from the jet attachment and detachment from the gate lip at small gate openings as do vertical gates.

Each sluice conduit is provided with an emergency bulkhead gate a few feet upstream of the radial gate, and dewatering bulkheads at the inlet and the outlet to the sluice. The emergency bulkhead gate would be a vertical panel, likely a roller gate with hydraulic operator, and would be designed to close under full flow at maximum reservoir elevation. The upstream and downstream dewatering bulkheads are simple vertically hung panels that are designed to close under no flow. They are provided to isolate and dewater each sluice conduit so that inspections and repairs can be accomplished in safe working conditions.

For the FRE dam, with all five low-level flood regulation sluice gates fully open, up to approximately 12,500 cfs can be passed through the sluices without transitioning to orifice or pressurized conduit flow in any of the sluice outlet conduits. For reservoir elevations greater than 430 feet, the sluice entrances would become submerged and flow control would shift to orifice flow, unless the radial gates are used to control the flow. The minimum required total low level flood release flow of 15,000 cfs can be discharged entirely through one pair of the 10 by 16 sluices at reservoir elevations greater than about 580 feet. Typical flood regulation operation would initiate closure of the large center sluice at any time the pool level exceeds reservoir elevation 500 feet to prevent excessive wear on the invert due to sediment entrained in high flow velocity. The two pairs of smaller sluices are expected to entrain considerably less sediment, though the specific elevation details to confirm this and establish the final higher sluice gate seat elevation would have to be evaluated using a physical laboratory scale model. Following the closure of the large center sluice gate, one pair of the smaller sluice gates would also initiate closure and the flood would only be regulated through one pair of the smaller sluices. Mud Mountain Dam on the White River in western Washington (owned by USACE) is designed similarly, and its three outlet sluices operate much like that proposed for the FRE design alternative.

At full flood storage reservoir elevation of 628 feet, each of the smaller sluice gates at 75 percent open can pass up to about 9,500 cfs, and the larger gate can pass up to about 14,200 cfs alone. The paired design of the two smaller gates was selected to ensure that finely controlled flood regulation would be available with a single gate as needed, given that the larger gate will likely be closed. Adjustment of a single 10-foot-wide gate in 6-inch typical lift increments gives just 380 cfs per increment at the maximum flood regulation reservoir elevation of 628 feet. Incremental control over downstream flows will allow the dam operator to achieve gradual increases and decreases to flow rates (ramping rates as required by the dam operations plan). Flood regulation operation would include operation of the sluices at reservoir elevations up to the spillway crest of 628 feet. At reservoir elevation above the spillway crest, sluice operation may be curtailed to avoid adverse flow conditions within the stilling basin.

The low-level outlet works constructed for the FRE would be used for the FRE-FC dam. The only modification to the outlet works for FRE-FC dam would be the extension of the large trashrack in front of the outlet works to the full height of the FRE-FC dam. The low-level flood regulation sluices would accommodate the same flow capacities as the FRE, with a maximum controlled discharge of 15,000 cfs at any reservoir elevation within the full operating range of the project (reservoir elevation 588 to 687).

At a full flood storage reservoir elevation of 687 feet, the larger and each of the smaller sluice gates at 75 percent open gate position can pass up to about 16,100 cfa and 10,700 cfs, respectively. FRE-FC flood regulation operation would include operation of the sluices at reservoir elevations up to the spillway crest of 687 feet. Similar to the FRE discussion above, at a reservoir elevation above the spillway crest, sluice operation may be curtailed to avoid adverse flow conditions within the stilling basin.

5.7 Stilling Basin

The outlet works stilling basin for the FRE alternative designs dissipates the energy in the flow from the five low-level sluice outlets. The design of the stilling basin is based on the maximum energy dissipation requirement for FRE-FC, which, due to the higher flood reservoir level, is greater than for the FRE. The stilling basin is sized to dissipate a total sluice outlet works discharge of 15,000 cfs at a reservoir level of 687 ft.

Assuming two 10-feet-wide by 16-feet-high sluices are discharging 15,000 cfs (7,500 cfs per sluice) under the flood reservoir elevation of 687 feet (FRE-FC), the flow velocity entering the basin would be approximately 140 feet per second, with a Froude number of about 12.6. Following USACE design guidelines for stilling basin design (Engineer Manual EM 1110-2-1603), a baffled stilling basin length of approximately 230 feet and a width of 102 feet would be required.

For the FRE-FC dam, the multiport low-flow outlet conduits would discharge through individual valves into the stilling basin from a valve located above the maximum expected regulating flow stilling basin water surface elevation of 433.5 feet. It is anticipated these valves would likely be of the hollow cone type, such as Howell-Bunger design, or perhaps fixed-cone valves. The design of the discharge valves for the multiport outlets will be refined in the next phase of designs. For cost estimation purposes, we have assumed Howell-Bunger valves will be selected.

5.8 FRE Hydraulic Characterization

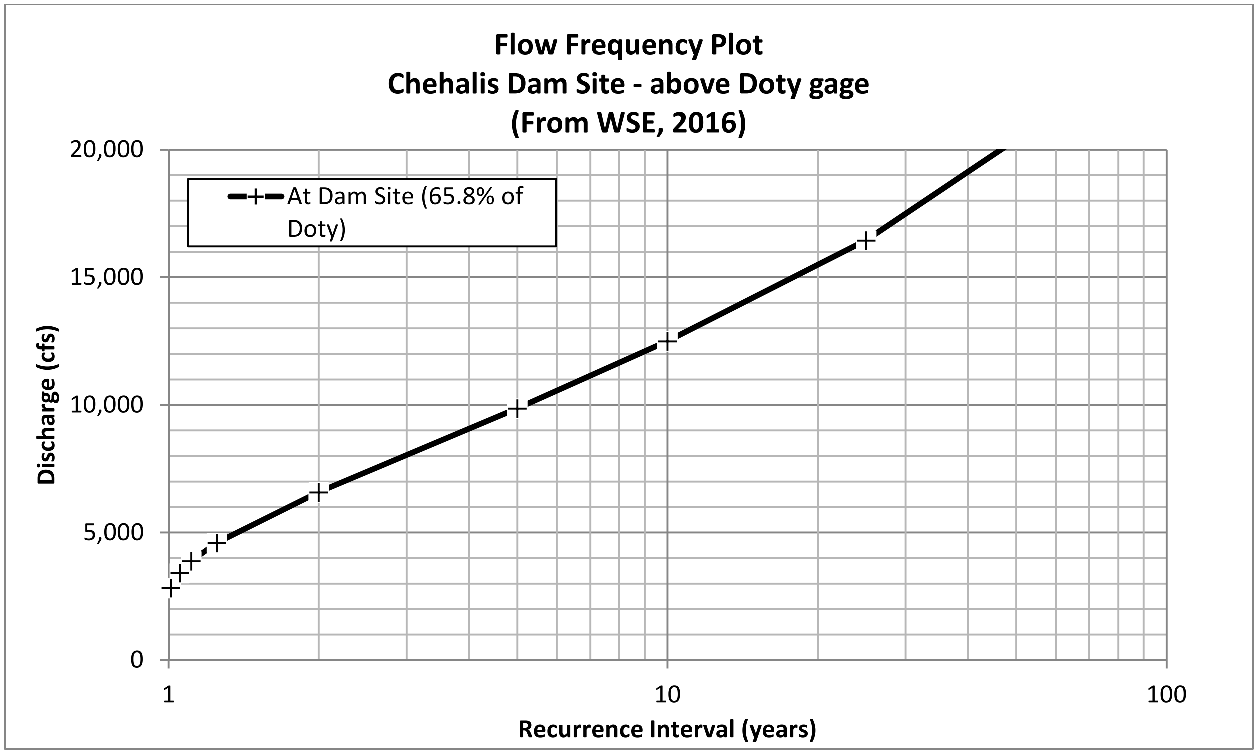
Similar to the FRO dam alternative, the FRE dam alternative is designed as a free-flowing run-of-the-river facility, where all the low level sluice gates are held fully open nearly all the time, except when forecast flood flows in the mainstem Chehalis River are expected to rise above 38,000 cfs within 48 hours. In holding all sluices fully open most of the time, and only regulating flow during events larger than approximately a 1 in 7 year recurrence interval flood event provides that most of the natural regime processes will be maintained through the dam reach. Sediment is expected to freely pass through the dam, and upstream and downstream fish passage is expected to be uninterrupted. To maintain these processes in the FRE dam design, the location, number, and size of the low level sluice outlets were refined to allow replication of the typical channel conveyance, velocity, depth, and transport capacity of the natural channel to the extent possible. The previously developed FRO design, though largely replicating the natural channel conditions upstream and downstream of the dam site, did not meet the desired fish passage design criteria.

5.8.1 Velocity and Depth Characterization

The existing channel reach extending roughly 1700 feet above the proposed dam site is relatively steep and comprised of bedrock step pools and has little evidence of deposition. The depth and velocity regime through this reach is unchanged with the FRE dam alternative, with the exception of minor flow transitions in the vicinity of the sluice gates and stilling basin, as there is no permanent impoundment to trap bedload materials. Most debris will either be passed through the sluice conduits or removed from the trashracks and hauled downstream to be released back into the river. Similarly, the natural depth and velocity through the reach downstream of the proposed dam is also a steep, bedrock channel with some step pools and minimal sediment deposition. Since most flows will be passed directly through the dam's fully open sluices, the flow depth and velocities are expected to be similar to the natural channel downstream of the dam.

During a large flood event of a magnitude significant enough to trigger flood regulation operations, the sluice gates would be closed and floodwaters would be impounded behind the dam. The natural flow regime is generally driven by flows between the average annual flood and the 2-year recurrence interval flood event which corresponds to roughly between 3,000 and 6,000 cfs (Figure 5-7). The hydraulic analysis of the reach in the vicinity of the proposed dam site was conducted on flows less than 4,000 cfs, since the fish passage criteria maximum flow is just 2,250 cfs (see discussion in Section 5.8.3 below). Hence, the most important comparisons to be made are at those sections represented within the dam and stilling basin and a limited distance upstream and downstream. The basic hydraulics through the dam reach was assessed using a 1D HEC-RAS, a one-dimensional computer water surface profile modeling tool created by the USACE Hydrologic Engineering Center, and in common use throughout the engineering discipline for flow modeling.

Figure 5-7
Flow Frequency Plot for the Proposed Chehalis Dam Site



Source: WSE, 2016

The results of 1D-HEC-RAS modeling showed that under natural and proposed conditions, the flow depth and velocity at river discharges of 250 to 2,250 cfs range from 3 to 8 feet per second in the reaches above and below the dam site. Through the dam footprint, the natural channel velocity varies from about 1 to 5 fps across that same range of flows, while the velocities through the sluices of the FRE dam varies from about 0.5 to 1.5 fps over the same range of flows. The previously evaluated FRO dam alternative produced somewhat higher flow velocities, ranging from about 0.5 to 2 fps. The results generally show that the FRE dam alternative, with its five low level sluice outlets, provides lower flow velocities across the range of low to moderate flows than the existing channel, and also improves on the natural channel flow velocity. From a fish passage perspective, the FRE would be expected to provide easier passage for fish through the dam than the existing channel, and an improvement over the previously evaluated FRO alternative. Without intervention such as that occurring when the sluices are regulated for floods, the lower flow velocities within the sluices would likely lead to sediment deposition inside the dam conduits. Comprehensive results of the modeling analysis are provided in Appendix I (Section 2.5.1).

5.8.2 Sediment Transport Capacity and Performance

Sediment transport modeling was conducted for the existing channel condition, the FRO dam alternative with 3 sluice configuration, and the FRE with five sluice configuration. Bed shear stress of the FRO dam sluice conduits and the FRE sluice conduits were compared against the shear stress of the natural channel reach. The bed sediment transport over time was also compared (proposed vs natural conditions) by applying the natural river flow hydrograph from 1990 to 1994 to the 1-D HEC-RAS model running the Meyer-Peter Mueller (MPM) transport function and the observed bed sediment gradations from samples collected at Cross Section 108.532 about 2,000 feet upstream of the dam site in a depositional reach (Dube, 2016). The MPM method provides the best agreement between calculated and observed transport rates and deposition/scour areas noted in the natural channel, and is generally best suited for rivers in which the bed substrate is dominated by gravel, as noted in the literature.

The results of the sediment transport analysis using 1D HEC-RAS reveals that the channel through the narrow scoured bedrock gorge at the proposed dam site will likely scour deeply and refill with sediment during flood events in which the substrate is mobilized. The results of the sediment transport analysis also show that the deep stilling basin downstream of the sluice conduits will similarly fill with and be scoured of sediment, particularly at the sluice outlets. The resultant river reach bed profile for the existing channel condition, FRO with three sluices configuration and FRFA with five sluices configuration following four years of hydrologic hydrograph from 1990 to 1994 are provided in Appendix I Section (2.5.2).

Through all river discharges in which the sluice gates are held fully open (i.e. no flood regulation operations), sediment will deposit throughout the sluice conduits and fill most of the stilling basin. This would represent the average condition, from a natural process and fish passage perspective. However, during a flood event in which the sluice gates would be closed or otherwise used to regulate dam discharges, any sediment that had deposited within the sluice conduits would be expected to be swept through the dam and deposited in the stilling basin or downstream in the natural channel. The action of closing the gates causes a high velocity flow jet to form immediately downstream of the gates, which would quickly clear the sluices of sediment deposits. Evaluation of the range of expected conditions within the sluice conduits indicates that the scoured areas at the cleared sluices will be much deeper than the existing natural channel, with commensurately lower flow velocities following the event. Anticipated bed sediment profiles following sluice gate regulation operations are provided in Appendix I Section 2.5.2. It should be noted that these sediment transport analyses are approximations of what should be expected. More accurate and quantifiable sediment transport, deposition, scour, and performance information would be obtained from a physical scale model of the entire dam and appurtenant outlet works that would be conducted during the next phase of design.

5.8.3 Fish Passage Considerations

Fish passage is a required objective of the Chehalis Dam project for all alternatives, including the FRE and FRE-FC Dam Alternatives covered in this Supplemental Report. The goal of the FRO Dam Alternative previously evaluated was to replicate, to the extent possible, the same hydraulic characteristics as the existing natural channel for all river flows up to about 2,250 cfs. These characteristics included flow velocity and depth (see Section 5.8.1 above), and sediment deposition (see Section 5.8.2 above), to the extent that sediment deposits and scour directly affect the lower flow velocity and depth. The original design criteria included a maximum velocity of 2 fps through all flows up to 2,250 cfs, or equal to or less than that of the existing channel. Modeling indicates that the FRE would not appreciably change the velocities and depths in the natural channel reaches upstream and downstream of the dam and stilling basin through this range of flows (up to 2,250 cfs). However, the flow characteristics in the low level flood regulating sluices will be different than that of the existing channel, given the concrete sluice geometries.

Previous modeling evaluations indicated that the FRO dam alternative would meet fish passage objectives for the project. Further analysis has been conducted using a 1-dimensional HEC-RAS model, to evaluate general hydraulic characteristics of the FRE dam design. This work built upon the earlier work completed on the FRO Dam Alternative. This additional study shows that the fish passage performance of the FRO alternative could be performed. In particular, the post-sedimentation flow velocity could be decreased by adding one or more additional sluice conduits, while maintaining similar flow depths. A second pair of 10-feet-wide by 16-feet-high sluice gates and conduits has been added to the FRO alternative (and is present in the FRE alternative) to provide the additional capacity by expanding the width of the intake trashrack about 40 feet, including a second pair of sluices to the left (facing downstream) of the large 12-feet-wide by 20-feet-high sluice, and widening the stilling basin to about 100 feet to accommodate the additional sluice discharge. The elevation of the second pair of 10-feet-wide by 16-feet-high sluice conduits on the left side of the outlet works is the same as the right pair of 10-feet-wide by 16-feet-high sluice conduits (elevation 411.0 ft msl), while the larger 12-feet-wide by 20-feet-high sluice elevation remains the same (elevation 408.0 ft msl). The HEC-RAS model was used to compare various hydraulic parameters over the range of fish passage flows from 25 cfs to 2,250 cfs, including flow velocity and depth, before and after the 4 years of the hydrologic record was applied to evaluate sediment transport processes, and with the or without clearing the sluices of sediment.

In addition to the 1-dimensional HEC-RAS modeling, a Computational Fluid Dynamic (CFD) model of the FRE geometry was developed using FLOW3D software (product of Flow Science, Inc.), with upstream boundary at the interior side of the intake trashrack and downstream boundary below the stilling basin control sill. The CFD model mapped the bed bathymetry calculated with the HEC-RAS sediment transport model following the 4 year hydrograph discussed above (1990 – 1994). The upstream boundary condition was assumed to be uniform flow, which is appropriate given that the intake trashrack would tend to distribute inflows uniformly as a result of the head loss induced across the width of the trashrack. The downstream boundary condition was assumed to be simply a conservation of mass criterion, passing flow equal to the inflow boundary. The CFD model was run in steady state condition for ten flows across the range of fish passage river discharges (100 cfs, 250 cfs, 500 cfs, 750 cfs, 1,000 cfs, 1,250 cfs, 1,500 cfs, 1,750 cfs, 2,000 cfs, and 2,200 cfs). CFD model results are provided in Appendix I Section (2.5.3).

5.9 FRE-FC Hydraulic Characterization

The FRE-FC Dam Alternative is, as discussed above, very similar to the FRFA Dam Alternative evaluated previously, with the exception that there are two additional low level flood regulation sluices, and all of the sluices are set lower in elevation than the FRFA Dam Alternative. As with the FRFA Dam Alternative, a permanent reservoir would be formed behind the FRE-FC Dam. Since a reservoir would be formed, bed sediment transport processes would be largely eliminated through the dam structure, though suspended sediment load would likely pass through the dam. The previously conducted hydraulic evaluation of the FRFA dam was used to inform design of the FRE-FC alternative. Additional detailed evaluation has not been performed for development of the FRE-FC alternative due to similarities with the FRFA configuration. If the FRE-FC Dam modification is implemented, it is likely that the second pair of 10-feet-wide by 16-feet-high sluice gates would be permanently closed and bulkheads would be placed at the sluice entrance opening, and the only operable gates would be the single large 12-feet-wide by 20-feet-high gate and the right side pair of 10-feet-wide by 16-feet-high gates. Please refer to the main report (HDR, 2017a) for specific details on the general hydraulic characteristics and performance of the FRFA, and by similarity the FRE-FC Dam Alternative.

6 CONSTRUCTION CONSIDERATIONS

6.1 Introduction

This section describes the specific construction considerations to allow future expansion of the FRE dam to a larger FRE-FC dam configuration. Typical construction considerations for the FRE, such as construction phase flood risks and flow diversion, are similar to constructing either the FRO or FRFA options and are described in the Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a). They are, therefore, not covered herein.

The main differences related to construction of the FRE dam option compared to the FRO or the FRFA options are related to configuring the FRE in a manner that is favorable for the construction of the FRE-FC enlargement at a later time. Descriptions of those specific construction issues are described below. Some additional refinements of the access and staging, compared to the FRO and FRFA, have been identified and are described in Sections 6.4 and 6.5.

6.2 FRE Construction

From a constructability and cost standpoint, the FRE dam configuration includes a number of the final FRE-FC configuration elements: 1) excavation and treatment of the FRE-FC dam footprint; 2) coverage and protection of the excavation between the limits of the FRE dam and the FRE-FC excavation up to the flood level elevation of 430 feet; 3) completion of the flood control sluice outlet works, water quality outlet penetrations through the dam, the outlet works stilling basin and basin walls, lower portion of the spillway chute and the flip bucket, and the chute training walls below elevation 651 feet.

The FRE needs greater dam and foundation seepage control than the FRO does, because the FRE must consider future construction of FRE-FC with additional storage with higher head. The FRO may allow for a lesser grout curtain, foundation drainage, or upstream facing system. If a dam raise will be considered for the FRO in the future, retrofitting the FRO foundation or dam seepage controls to accommodate the higher head raised dam might be quite costly due to limited options for performing this retrofit.

The FRE configuration would depend on the scope and extent of the FRE-FC. In the event the FRE alternative is the preferred alternative and is selected for final design and construction, the following items would need to be evaluated at the FRE and FRE-FC design stage to ensure the future FRE-FC is constructed appropriately:

- Foundation blanket or consolidation grouting
- Abutment termination details
- RCC mix strength and cured properties

- RCC mix and placed temperature control
- Dam joint spacing and construction details
- Upstream facing elements for seepage barrier
- FRE-FC downstream facing elements
- FRE downstream face treatment or preparation
- Spillway chute anchorage
- Training wall height and design
- Diversion or cofferdam requirements; tailwater, intake, and flood routing

6.3 FRE-FC Construction

The FRE-FC design configuration considers that the foundation excavation, materials, and structures are completed during the development of the FRE to allow an efficient expansion that does not require development of a new diversion, significant structure remediation, and repeated structure construction. The FRE-FC construction complexity, and, therefore, also schedule and risk, are minimized.

Constructing the FRE-FC introduces some work that is not necessary for the FRO or FRFA alternatives. Similarly, some work required in both the FRO and FRFA alternatives is parsed and reconfigured in the FRE and the FRE-FC, introducing varying degrees of construction inefficiency and additional cost.

Construction of the FRE-FC includes:

- Demolition of FRE concrete; crest parapets; ogee crest; and possibly concrete related to raising the intake/trashrack structure
- Preparation of the existing downstream face and possible anchorage between the FRE and FRE-FC
- Coverage of the FRE downstream facing that required vertical and other dam formwork as well as higher cost materials to create the dam facing.

Other factors that affect the RCC, unit prices, and related work and total project costs include:

- Quarry and aggregate development split into two projects; increasing fixed cost contribution to unit prices (i.e. mobilization, setup, access)
- RCC production fixed costs similarly increasing the RCC unit pricing for each project
- Widely different RCC lift configurations and volumes as evident on the illustrations included in the cost appendix.
- Increased percentages of other work controlling or dictating daily RCC production rates; multiple starting locations and times, learning curves, higher percentages of formwork per cubic yard of RCC; and a higher percentage of narrower and longer lifts.

6.4 Access and Staging

Construction access and staging for the FRE will essentially look the same as for the FRO or FRFA. With the FRE in operation, and depending upon how much time has passed, the initial access and staging development may generally be intact, needing a degree of clearing, resurfacing, or other activities to support FRE-FC construction. Access to the left side of the dam may have to be re-established with temporary upstream or downstream crossings, or perhaps even over the FRE spillway.

6.5 Diversion during Construction

Completion of the FRE including the downstream RCC cover materials as previously described will limit downstream dam raise work to above elevation 430. This elevation should be above typical flood tailwater levels limiting construction flooding risks to the downstream work. The FRE-FC sequencing does not involve construction within the spillway until late in RCC placement. Also, flood routing through the FRE low-level sluice outlet works should minimize the risk of spill during the FRE-FC construction to more than acceptable levels (> 100-year recurrence flow). Trashrack and intake structure design should likewise seek to allow FRE-FC buildout that does not require sustained construction access to the intake tower below the FRE crest.

6.6 Concrete Aggregate

Both the FRE and FRE-FC require enough aggregate to result in favorable economies of scale and pricing for site-based production.

6.7 Construction Risk

Construction risk is very similar for the FRFA, FRO, and FRE alternatives. However, the FRE-FC construction risks are greatly reduced by essentially eliminating foundation and construction flood diversion risks, since those will already have been addressed in the design and construction of the FRE. The construction risks for the FRE-FC are reduced to those risks generally applicable to plant and heavy-civil construction, such as: safety; commercial material supply; market interest; contract form and terms; external sequencing or schedule demands; and seasonal factors.

7 FISH PASSAGE OPTIONS

7.1 Fish Passage During Operation

The fish passage options for all the FRE and FRE-FC are similar to the FRO and the FRFA fish passage alternatives, respectively. These options are described in more detail in the main Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017a) and are included herein by reference.

The FRE and FRE-FC presented in this document, and the costs used for fish passage, show a refined Collection, Handling, Transport, and Release (CHTR) facility fish passage alternative, which has been updated based on new design information since the issuance of the original draft report. The specific details of the refined CHTR are presented in the CHTR Conceptual Design Report (HDR, 2017c). A figure of the CHTR is included in Appendix H.

7.2 Fish Passage During Construction

Fish passage is required during construction of the FRE dam to reduce adverse impacts to fisheries recourses present in the Chehalis River and is required by federal and state agencies such as USFWS, NMFS, WDFW, and WA DOE and other stakeholders including the Quinault tribe. Construction for the FRE dam is expected to require diversion of the entire river for a possible construction duration of approximately 5 years. Failing to provide fish passage for the target fish species on the Chehalis River (e.g. – Chinook, coho, and steelhead) would eliminate at least two full rearing and spawning cycles upstream of the dam location, resulting in significant adverse impacts to the populations of these species present in the river. USFWS, NMFS, WDFW, WA DOE, and the Quinault Tribe, have all expressed their position in stakeholder coordination meetings over the last several years, indicating their desire for fish passage during construction mainly for this reason. Due to the extended period of diversion and the impact to salmon populations, for the following fish passage alternatives during construction, it is assumed that the full fish passage criteria required by NMFS and WDFW must be met for the entire period of construction.

7.2.1 Alternative 1: Diversion Tunnel

One potential alternative for fish passage past the project area during construction for the FRE dam is via the construction diversion tunnel. The tunnel is anticipated to be a 20 foot by 20 foot, horseshoe-shaped, concrete lined tunnel drilled and blasted through rock. It is expected to be approximately 1,630 feet long at a slope of about 1%. Fish passage is required by the governing state and federal agencies to be between the 95% and 5% exceedance flows (16 cfs to 2,200 cfs) for the river. At these flows the anticipated flow velocity within a smooth hydraulically efficient tunnel would be expected to range from 4 feet per second (fps) to 25 fps, respectively. These velocities are well above the 2 fps maximum flow velocity criteria required by NMFS for safe, timely, and effective upstream fish passage through a tunnel structure of this nature. However, the fish passage technical committee agreed in 2016 that the final design of conduits through the dam may exceed the 2 fps criteria as long as they mimicked the flow characteristics of the natural channel in this reach. If this criteria were applied to the diversion tunnel a maximum flow velocity of about 6 fps would be acceptable. A flow velocity of 6 fps corresponds to a river flow of about 50 cfs. Even with the greater allowable flow velocity, the range of river flows that would meet fish passage requirements is a small fraction of what is required, making an unmodified alternative infeasible for upstream fish passage during construction.

To make the diversion tunnel fish passage, the tunnel must be designed to approximate the natural channel in this section of river. The design of the diversion tunnel may be modified to better match the flow conditions of the natural river channel. Modifications required would likely include some or all of the following:

- Larger tunnel with lower magnitude gradient (slope).
- Multiple smaller tunnels instead of the single tunnel currently shown.
- Flow control gates for each tunnel.
- A stilling basin or other means of providing a backwater effect to the tunnels.
- Lighting to mimic the daylight during the day.
- Pools, weirs, or other means of producing velocity refugia (means of producing low velocity pools to provide resting areas for migrating fish).

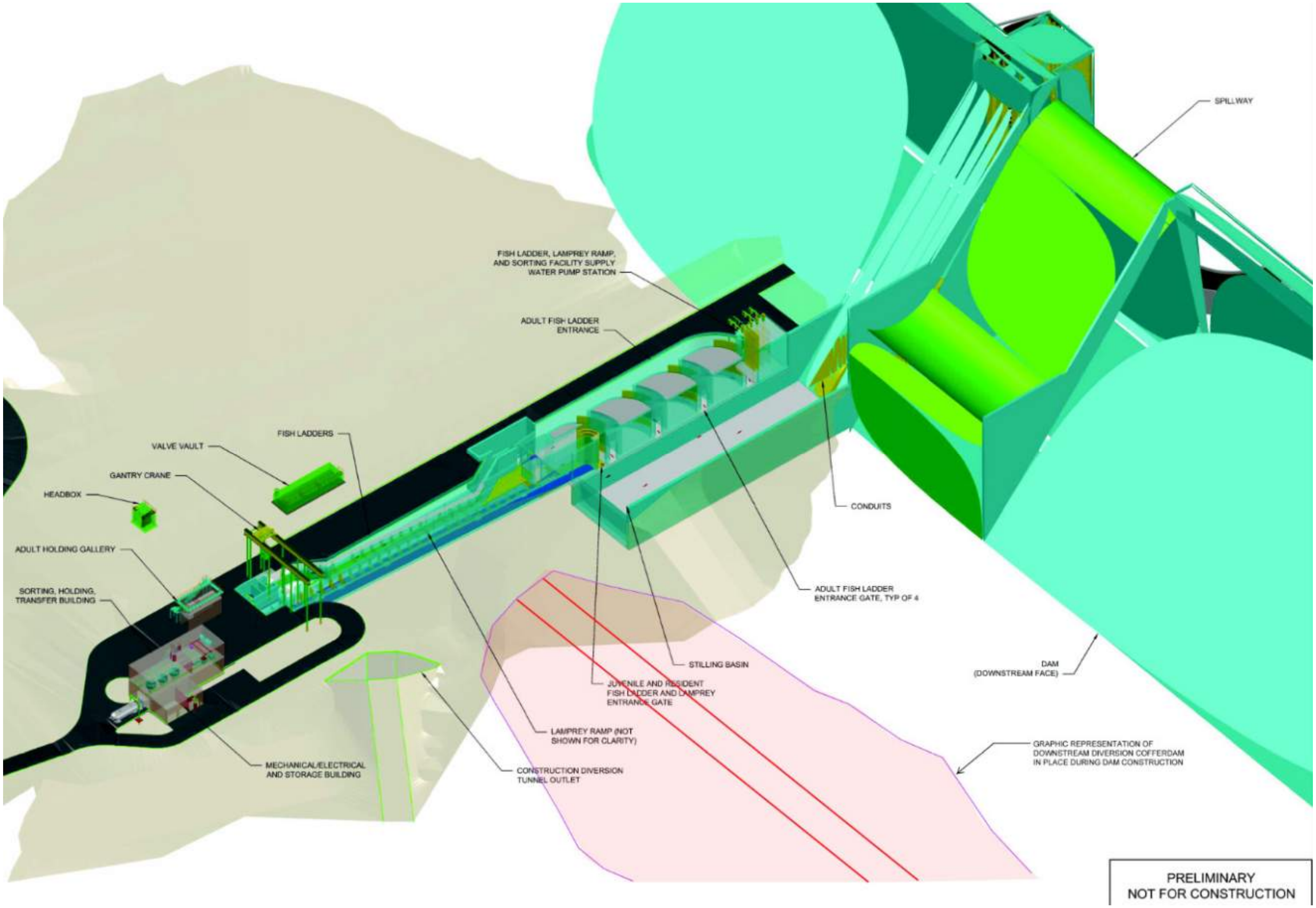
Downstream fish passage through the diversion tunnel appears feasible, although significant modifications to the tunnel design may be required to ensure flow velocities within the 95% to 5% exceedance of mean daily flow does not exceed fish passage guidance while still accommodating the conveyance target required for dam construction.

7.2.2 Alternative 2: Permanent CHTR Facility

Another alternative to provide fish passage during construction of the dam is to construct the permanent Collect, Handle, Transfer, and Release (CHTR) Facility prior to beginning dewatering and construction of the dam. This alternative provides the advantage of not constructing any additional or temporary facilities as the permanent facility would be constructed and operated during dewatering and dam construction. Unfortunately, upon preliminary examination, this alternative appears infeasible for the following reasons:

- The downstream cofferdam is located between the diversion tunnel and fish ladder entrance, preventing fish from accessing the CHTR facility.
- The flow patterns and velocities from the outlet of the diversion tunnel would adversely affect fish attraction and passage to the CHTR facility.
- The excavation footprint for the dam foundation extends well into the footprint of the CHTR facility, preventing the CHTR facility from being constructed before the dam.

Figure 7-1: Alternative 2 - CHTR Facility



7.2.3 Alternative 3: Temporary Trap and Transport Facility

Temporary trap and transport (T&T) facilities are common to provide fish passage for projects that require extensive in-water work for long duration, such as what will be required for the FRE dam. The temporary T&T facility would be installed and begin operation prior to any other in-water work. The facility would be located far enough downstream of the diversion tunnel outlet such that river flow approaching the facility would be as calm and uniform as practicable. A temporary trap and transport facility would likely consist of a temporary barrier such as picket weirs or an inflatable dam with a fish ladder on the left bank that led to holding ponds or holding tanks at the top of the bank where they could be easily accessed by transport trucks. Auxiliary water would be provided to a technical fish ladder entrance via a pumping system. The pumping system would likely consist of an intake on the right bank meeting fish screening criteria, a series of vertical turbine pumps, and pipelines that would supply water from the river directly to the holding ponds or tanks, the top of the fish ladder, and the auxiliary water system. This pumping system would operate 24-hours a day, 7-days a week for the full period of construction, until normal operation of the dam began. Once normal operation began, the temporary facilities in the river would be removed and the facilities above a to-be-determined high water elevation would be abandoned or removed. Based on the duration of construction and potential flood events the facility may experience, the temporary barrier would likely be primarily of concrete construction, well anchored to the river bottom, with abutments firmly keyed into the right and left banks of the river.

The trap and transport facility would provide upstream passage for the same species as the permanent CHTR facility. Aquatic species collected in the facility would be transported to release points upstream of the upstream cofferdam. Downstream fish passage would be provided via the diversion tunnel (see Alternative 1).

8 OPERATIONS AND MAINTENANCE

Operation and maintenance (O&M) costs for the FRE and FRE-FC alternatives are expected to be similar to the costs for the FRO and FRFA, respectively, which are presented in more detail in the main report (HDR, 2017a). Those costs were developed with consideration of the requirements for replacement of dam components that are subject to wear and trash and sediment removal, as well as staffing and equipment needed for the dam and fish passage facilities. The estimated annual O&M costs (2016 dollars) are as follows:

- FRE: $628,000 per year
- FRE-FC: $2,178,000 per year

9 OPINION OF PROBABLE COSTS

9.1 Introduction

This section summarizes the opinion of probable construction costs (OPCC) for the FRE option. The cost basis for the FRE-FC option is in most respects similar to the FRFA option, since the FRE includes the footprint of the FRFA. Therefore, not included herein are descriptions of the cost development for roads; land and land rights; transmission lines and substations equipment; sales tax; contingencies; engineering and construction management assistance; permitting costs; operation and maintenance; and property tax and insurance. For details on the development of those subject costs, see the main report (HDR, 2017a). The cost estimate is for direct construction costs including final design engineering construction permitting but does not include costs for EIS and ESA related studies and agreements or mitigation design and construction costs.

It should also be noted that the CHTR fish passage facility presented herein for the FRE option represents further design development compared to the CHTR facility cost presented with the FRO option. The fish passage costs for the FRE dam options include the updated estimated costs for the CHTR. More details of the updated CHTR are presented in the updated Fish Passage Report (HDR, 2017c).

9.2 Cost Summary

Table 9-1 summarizes the opinion of probable construction costs (OPCC) for both FRE and FRE-FC, not including the fish passage facilities. Appendix J provides additional detailed information on the estimated costs of the FRE; OPC worksheets; dam placement production and sequence illustrations; RCC unit cost development; and quantity takeoffs.

Table 9-1

Concept-level Estimate of Total Direct Project Costs

	FRE	FRE-FC
Total Likely Project Cost	358,000,000	129,000,000
Low End Project Cost	307,000,000	110,000,000
High End Project Cost	419,000,000	154,000,000
Project Cost Range from Total Likely	82 % - 118 %	82 % - 118 %
Driving RCC Quantity	892,000 CY	467,000 CY
RCC Unit Bid – Likely	$ 103.50	$ 111.00
RCC Unit Bid Range	$ 88.00 - $ 119.00	$ 94.00 - $ 127.00
RCC - as % of Contractor Bid	39 %	61 %

Note: including OPCC, June 2017 dollars

The document 'Guidelines for Construction Cost Estimating for Dam Engineers and Owners' (USSD, 2012) provides a description of varying cost estimating "levels" for dam projects. Levels provide an indication as to the degree of uncertainty associated with an estimate. Significant effort has been expended on evaluating RCC materials availability, design, and construction considerations. Accordingly, the RCC portion of the dam project has a higher degree of certainty than other portions of the project. The estimate completed for the RCC portion of work is consistent with a "reconnaissance-level" OPCC. This type of estimate is generally in compliance with an Association for the Advancement of Cost Engineering (AACE) Class 3 estimate. The non-RCC components (such as clearing and grubbing, excavating, diversion tunnel, earthwork, piping, concrete, utility, and other site civil work) of the estimate are generally consistent with a "feasibility-level" OPCC. This type of estimate is generally in compliance with an AACE Class 4 estimate.

9.3 FRE Dam Construction Cost Implications

Construction of the FRE prepared for a potential future expansion introduces important cost implications as discussed below.

9.3.1 Diversion

The FRE, FRO, and FRFA options all bear nearly the same diversion requirements and risk, varying only slightly in terms of the months of diversion exposure. Constructing the full foundation and the full lower limits of RCC for the FRE, however, significantly reduces any diversion requirement for the FRE-FC. During FRE-FC construction there will be a brief period when the raise takes the FRE spillway out of service, exposing the construction to only the most extreme flood events that could not be routed through the low-level sluice outlets. A small amount of costs for nuisance dewatering and unforeseen water handling has been included in the estimated costs for the FRE-FC.

9.3.2 Hydraulic Structures, Concrete Scope and Efficiencies

FRE concept provides the majority of the concrete infrastructure required for the FRE-FC, including the spillway chute and flip bucket and outlet works systems built to the FRE-FC extents. These massive structural concrete components can be built efficiently in the FRE, leaving only the new upper spillway, upper intake structure, and dam crest for the FRE-FC. Furnishing and installing the water quality outlets in the FRE-FC is the only mechanical dam component not completed in the FRE, contributing to a simpler and more singular focus (RCC raise) of the FRE-FC construction.

In addition, the full upstream face of the FRE is now conventional concrete whereas the FRO considered a less robust grout-enriched RCC (GERCC) for the upstream facing element.

9.3.3 RCC Scope and Efficiencies

Both the FRO and FRFA have cross sections and configurations that favor RCC delivery and placement. The broad upper right abutment provides good area for staging RCC operations and a top-to-bottom delivery approach, which can benefit projects and keep RCC unit costs low. The estimated RCC unit costs for the FRE ($103.50) and FRE-FC ($111) are higher than the FRO ($93) and the FRFA ($99) for the following reasons:

- The RCC quantities are significant in both FRE and FRE-FC, but the FRE includes a higher percentage of non-RCC costs, and both include a higher percentage of non-RCC production drivers, slowing the overall pace and increasing costs.
- Increased vertical or near-vertical formwork
- More delivery resets and placement starts and stops
- Smaller and generally narrower lifts

All factors above combine to slow production and increase the unit costs. Nevertheless, both FRE and FRE-FC projects are tall and massive enough for RCC to remain economical. The RCC Quantity and Placement Summary in Appendix J provides an illustration of the lift shapes as vertical progress is made.

9.3.4 FRE Additional Costs

Temporary backfill has been added to the FRE to lightly cover the downstream RCC until the FRE-FC contract would remove it, thereby adding those costs to the FRE. Assuming a vertical chimney section for the FRE, downstream vertical formwork will be needed for construction, along with facing system concrete. These portions of the FRE work will ultimately be covered by the FRE-FC cross section. Demolition of the FRE spillway approach and ogee crest has been added to the FRE-FC estimate. Anticipating a need for adhesion of the second stage of RCC, the FRE-FC estimate includes fully treating and potentially anchoring the downstream face prior to the RCC placement. The same level of foundation grouting as the FRFA has been included for the FRE which is more robust than the grouting included and priced for the FRO. An allowance has been added to the FRE-FC for grouting to address the concept-level foundation and design uncertainty associated with the foundation near the transition from RCC to the central earth core rockfill section.

9.3.5 Contingencies and Other Factors

All estimates maintain the same below-the-line cost factors of 25 %. All costs, including the FRO and FRFA, are now presented in 2017 dollars.

10 CONSTRUCTION SCHEDULE

10.1 Construction Sequence

It is anticipated that the FRE project would have a very similar duration to the FRO and potentially the FRFA which have been considered at 6 and 7 years of design and construction, respectively. While shorter schedules for each are plausible, the important reality is that the access development, tunnel and diversion systems, aggregate development, foundation features, early hydraulic structures, and the dam are all very similar between the FRO, FRFA, and FRE. It is unlikely a schedule difference greater than 1 year could be generated between the options. Regarding the FRE-FC, which would benefit from the earlier access and staging development, earlier quarry development, and foundation completion, its construction could reasonably be completed in two years, perhaps less. Due to similarities in scheduling requirements, new construction schedules have not been developed specifically for either the FRE or FRE-FC designs.

11 ALTERNATIVES COMPARISON AND RECOMMENDATIONS

11.1 Alternatives Comparison

The evaluation performed in support of this report did not identify any fatal flaws associated with the FRO, FRFA, or FRE dam configurations. A summary of the main features of the alternative dam configurations is provided in Table 11-1. The selection of the preferred alternative will need to be based on considerations cost, risk, selected fisheries objectives, and identified environmental objectives and permitting constraints.

Table 11-1
Summary Comparison of FRO, FRFA, and FRE Alternatives

COMBINED ALTERNATIVE	FRO	FRFA	FRE	FRE-FC*
Purpose	Flood Retention Only	Flood Retention and Flow Augmentation	Flood Retention Only	Flood Retention and Flow Augmentation
Dam Type	Gravity - RCC	Gravity - RCC	Gravity - RCC	Gravity – RCC
Dam Structural Height (feet)	254	313	254	313
Water Storage Elevation (Spillway Crest Elevation, feet)	628	687	628	687
Emergency Spillway Type	Over Dam Crest	Over Dam crest	Over Dam Crest	Over Dam crest
Total Reservoir Storage Volume (1,000 AF)	65	130	65	130
Recommended Upstream Fish Passage	Flow through outlet sluices and CHTR facility	CHTR	Flow through outlet sluices and CHTR facility	CHTR
Recommended Downstream Fish Passage	Flow through outlet sluices	Floating Surface Collector	Flow through outlet sluices	Floating Surface Collector
Construction Period (years)	2.5 – 3.5	3 – 4	3 - 4	1 – 1.5

COMBINED ALTERNATIVE	FRO	FRFA	FRE	FRE-FC*
Estimated Dam and Fish Passage Project Costs (6/2017)	$341,000,000	$544,000,000	$401,000,000	$215,000,000
Estimated Annual O&M Costs ($2016)	$628,000	$2,178,000	$628,000	$2,178,000

Notes: AF = acre-feet, CHTR = collection, handling, transport, release, RCC = roller compacted concrete, NA = Not applicable O&M = operations and maintenance
* Additional cost to build FRE-FC once FRE is completed, in 2017 dollars.

11.2 Conclusions

An additional dam and fish passage configuration (FRE) has been developed and presented in this report. This alternative would construct a large foundation and a low dam, with the potential for future expansion if additional water storage for flow augmentation was desired. The benefits of this configuration include:

1. Potential for adaptation of project objectives to address uncertainties associated with climate change on flood storage and routing requirements.
2. Potential for further optimization of flow augmentation requirements and deliveries in response to better understanding of environmental changes and needs that are occurring in the basin below the dam.

12 REFERENCES

Anchor QEA, 2014. Revised Operations for Flood Retention Only Dam, Seattle, Washington.

Association for the Advancement of Cost Engineering (AACE), 2011. Recommended Practice No. 18R-97.

EES Consulting, Anchor QEA, LLC, Millen, LLC, Watershed Science & Engineering, and Shannon & Wilson, Inc., 2012. Chehalis River Basin Flood Retention Structure 8-Year Project Planning Document, Final.

Dube, 2016. Sediment sample gradation for HEC-RAS Cross Section 108.532.

HDR (HDR Engineering, Inc.), 2014a. *Draft Dam Design Technical Memorandum.* Bellevue, Washington.

HDR, 2014b. *Fish Passage Briefing, Interim Report.* Bellevue, Washington.

HDR, 2014c. *Revised Assessment of Fish Passage and Anticipated Operations of Proposed Dam Structure Alternatives*. Gig Harbor, Washington.

HDR, 2017a. *Combined Dam and Fish Passage Conceptual Design Report*. Bellevue, Washington.

HDR, 2017b. Phase 2 Site Characterization Technical Memorandum.

HDR, 2017c. CHTR Conceptual Design Report. Bellevue, Washington.

Frizell, K., No Date. *Hydraulics of Stepped Spillways for RCC Dams and Dam Rehabilitation*. USBUREC, Denver.

Gonzalez, A., Chanson, H., 2005. *Design of Stepped Spillways and Downstream Energy Dissipaters for Embankment Dams.* University of Queensland. Brisbane, Australia.

Kantoush, S. Sumi, T. Meshkati, M, 2011. *Eco-friendly Hydraulic Design of In-stream Flood Mitigation Dams.* Kyoto University.

Sarfaraz, M., Attari, J., 2011. *Selection of Empirical Formulae for Design of Stepped Spillways on RCC Dams.* World Environmental and Water Resources Congress. ASCE 2011.

S&W (Shannon & Wilson), 2009a. *Geologic Reconnaissance Study Proposed Chehalis River and South Fork Dam Sites.* Seattle, Washington.

S&W, 2009b. *Reconnaissance-Level Geotechnical Report Proposed Chehalis River and South Fork Dam Sites.* Seattle, Washington.

S&W, 2010. *Conceptual Plans and Profiles South Fork and Upper Chehalis Dams.* Lewis County, Washington.

Sumi, T., 2008. *Designing and Operating of Flood Retention 'Dry' Dams in Japan and USA*. Kyoto University, Japan.

USACE Buffalo District, 2013. *Mount Morris Lake and Dam*. Mount Morris, New York.

USACE, *Engineering Manual, EM1110-2-1602, Hydraulic Design of Reservoir Outlet Works*.

USSD (United States Society on Dams), 2012. *Guidelines for Construction Cost Estimating for Dam Engineers and Owners.*

Washington State, 1993. *Washington Dam Design and Construction Guidelines*. Washington State Department of Ecology.

WSE, 2014. Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species - Peer Review of December 2007 Peak and Hydrograph at Doty Gaging Station. Memorandum to H&H Technical Committee from Watershed Science and Engineering, dated 31 January, 2014.

WSE, 2016. Upper Chehalis Basin HEC-HMS Model Development. DRAFT Memorandum to Chehalis Basin Strategy Technical Team, dated 30 June, 2016.

Appendix H
Maps and Drawings

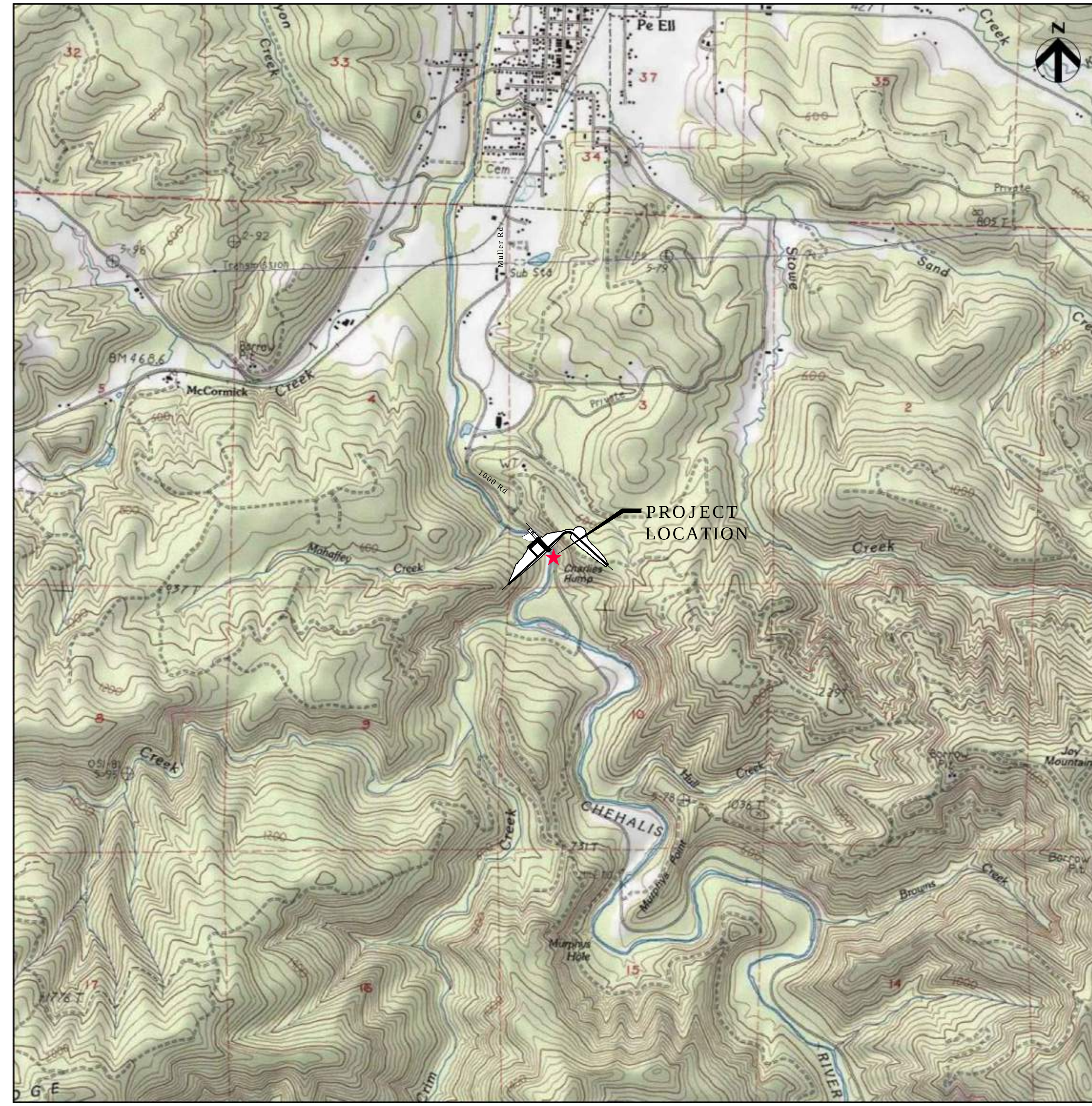
CHEHALIS BASIN STRATEGY
COMBINED DAM AND FISH PASSAGE
CONCEPTUAL DESIGN

WASHINGTON STATE

SCALE: 1" = 100 mi

PROJECT VICINITY

SCALE: 1" = 8 mi

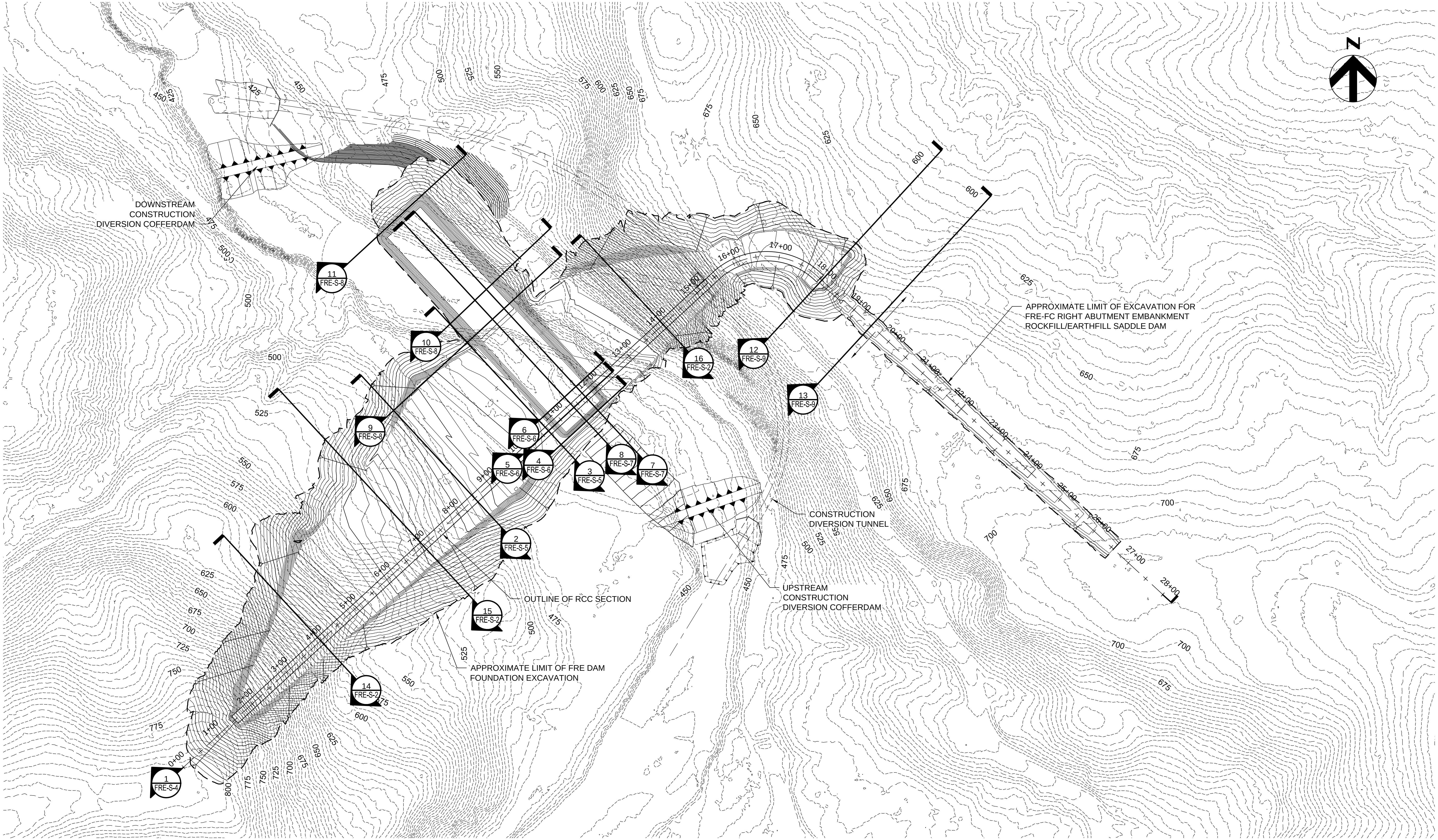


PROJECT LOCATION

SCALE: 1" = 0.5 mi

VICINITY AND LOCATION MAPS	DATE	SEPT 2018
CHEHALIS BASIN DAM	FIGURE	FRE-G-1

INDEX OF DRAWINGS



DAM EXCAVATION PLAN

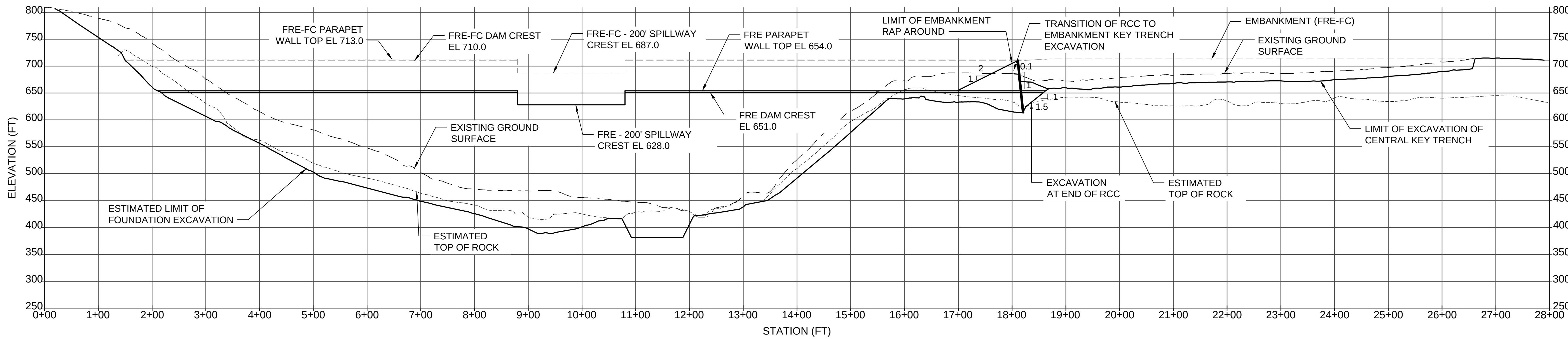
0 50 100 200
SCALE IN FEET

HDR

FRE DAM
DAM EXCAVATION AND FOUNDATION TREATMENT PLAN

CHEHALIS BASIN DAM

DATE	SEPT 2018
FIGURE	FRE-S-1

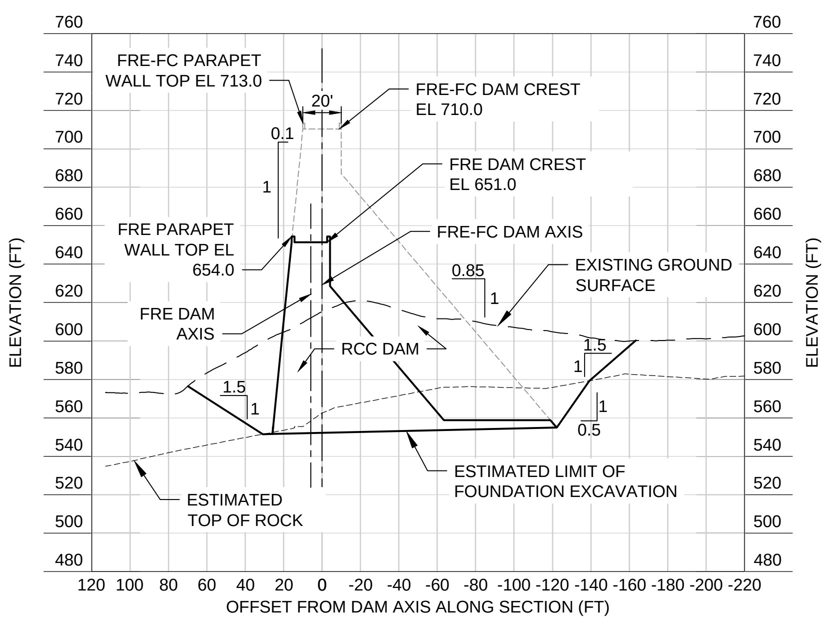


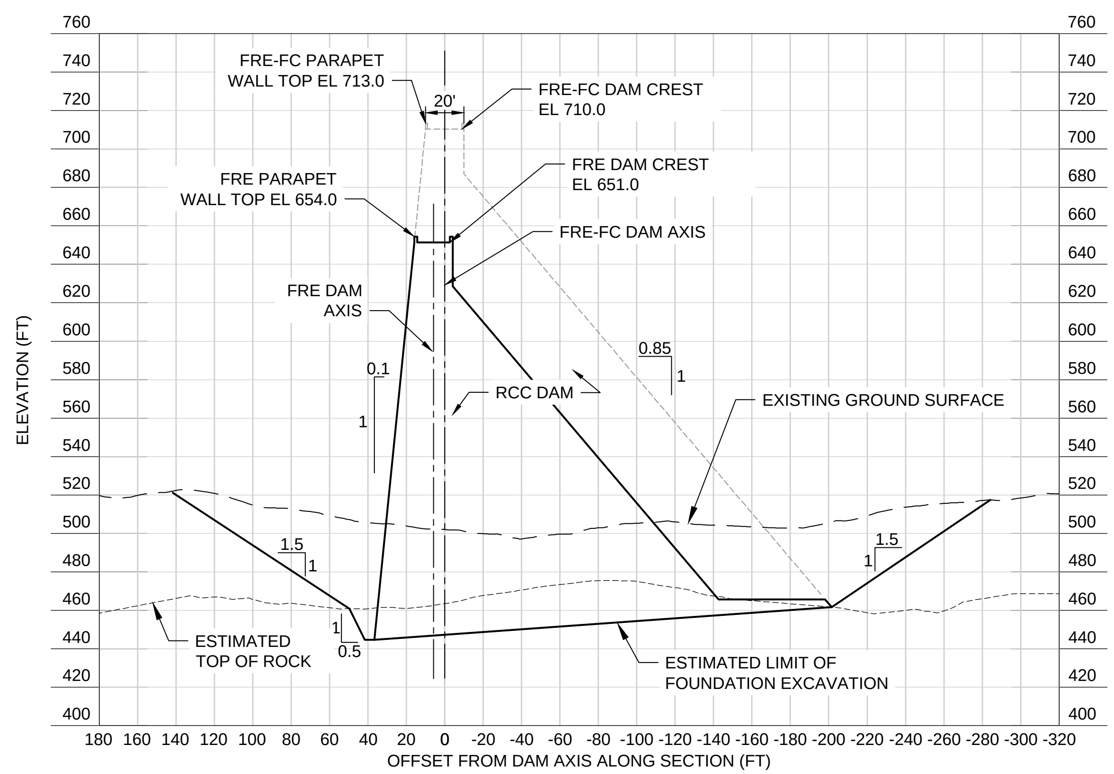
DAM EXCAVATION PROFILE

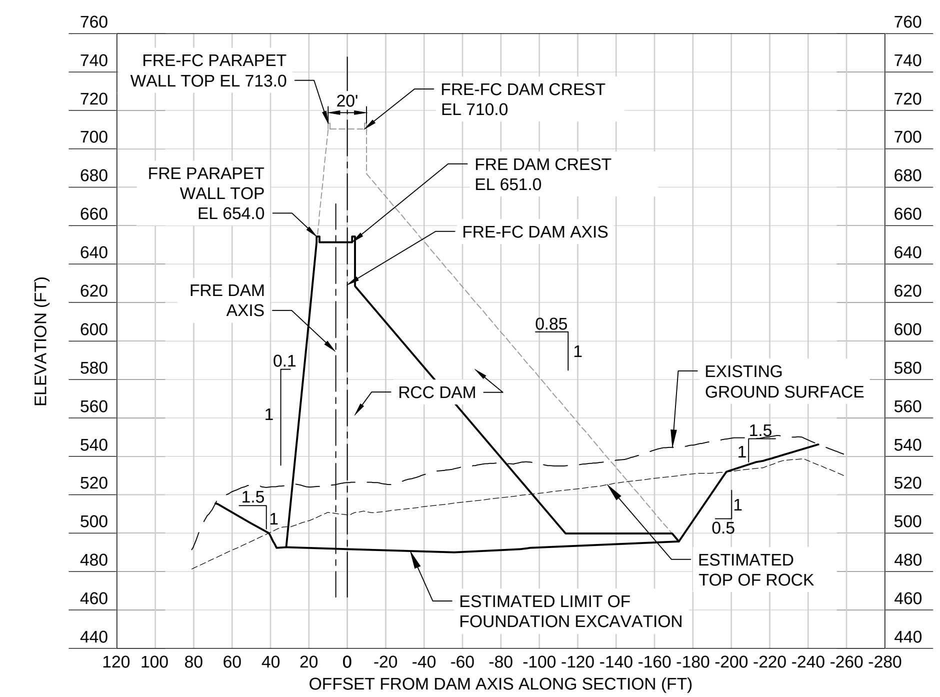
1 FRE-S-1

0 50 100 200

SCALE IN FEET







DAM EXCAVATION TYPICAL SECTION

14 FRE-S-1

0 25 50 100

SCALE IN FEET

DAM EXCAVATION TYPICAL SECTION

15 FRE-S-1

0 25 50 100

SCALE IN FEET

DAM EXCAVATION TYPICAL SECTION

16 FRE-S-1

0 25 50 100

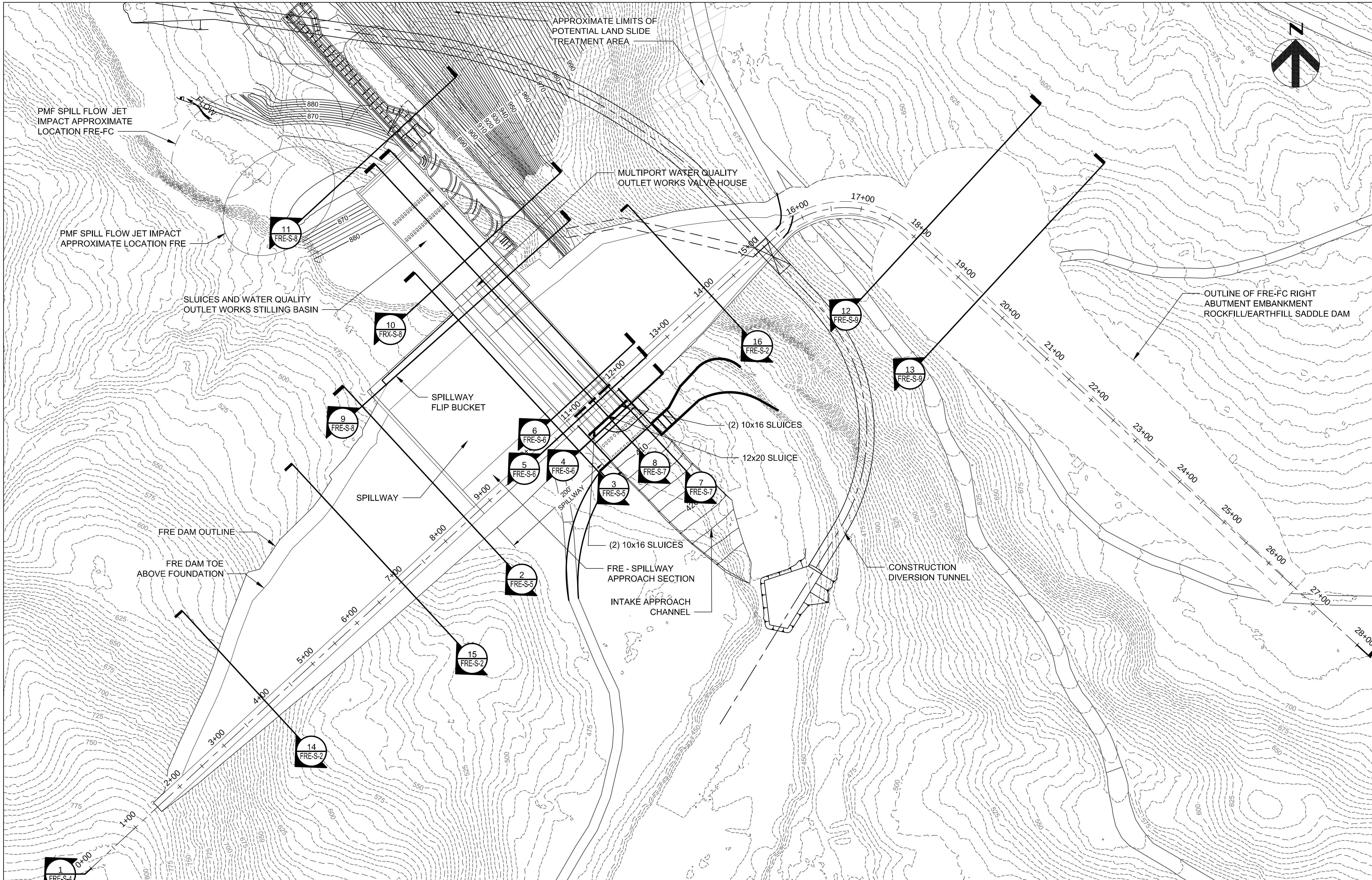
SCALE IN FEET

FRE DAM
DAM EXCAVATION PROFILE, AND TYPICAL SECTIONS 1, 14, 15, AND 16

CHEHALIS BASIN DAM

DATE SEPT 2018

FIGURE FRE-S-2



PLAN

0 40 80 160

SCALE IN FEET

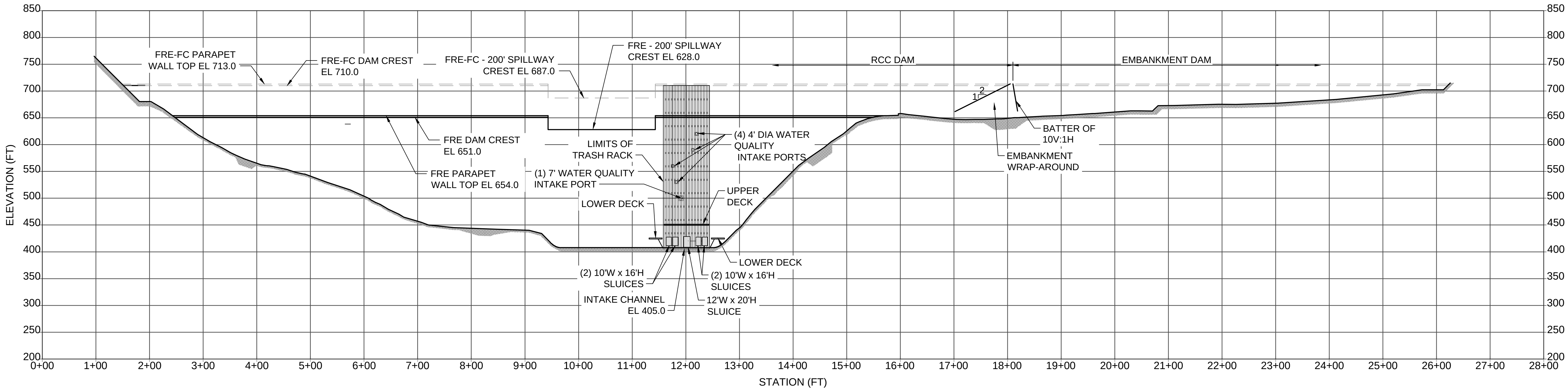
HDR

FRE DAM
DAM PLAN

CHEHALIS BASIN DAM

DATE SEPT 2018

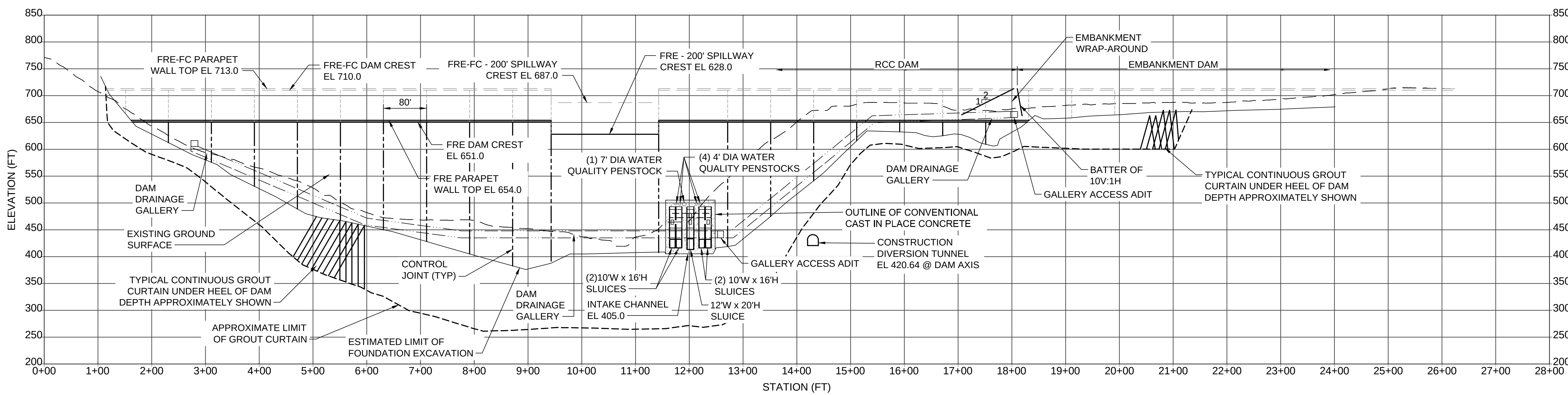
FIGURE FRE-S-3



DAM ELEVATION VIEW

1 FRE-S-3

0 50 100 200
SCALE IN FEET



SECTION ALONG DAM AXIS

1 FRE-S-3

0 50 100 200
SCALE IN FEET

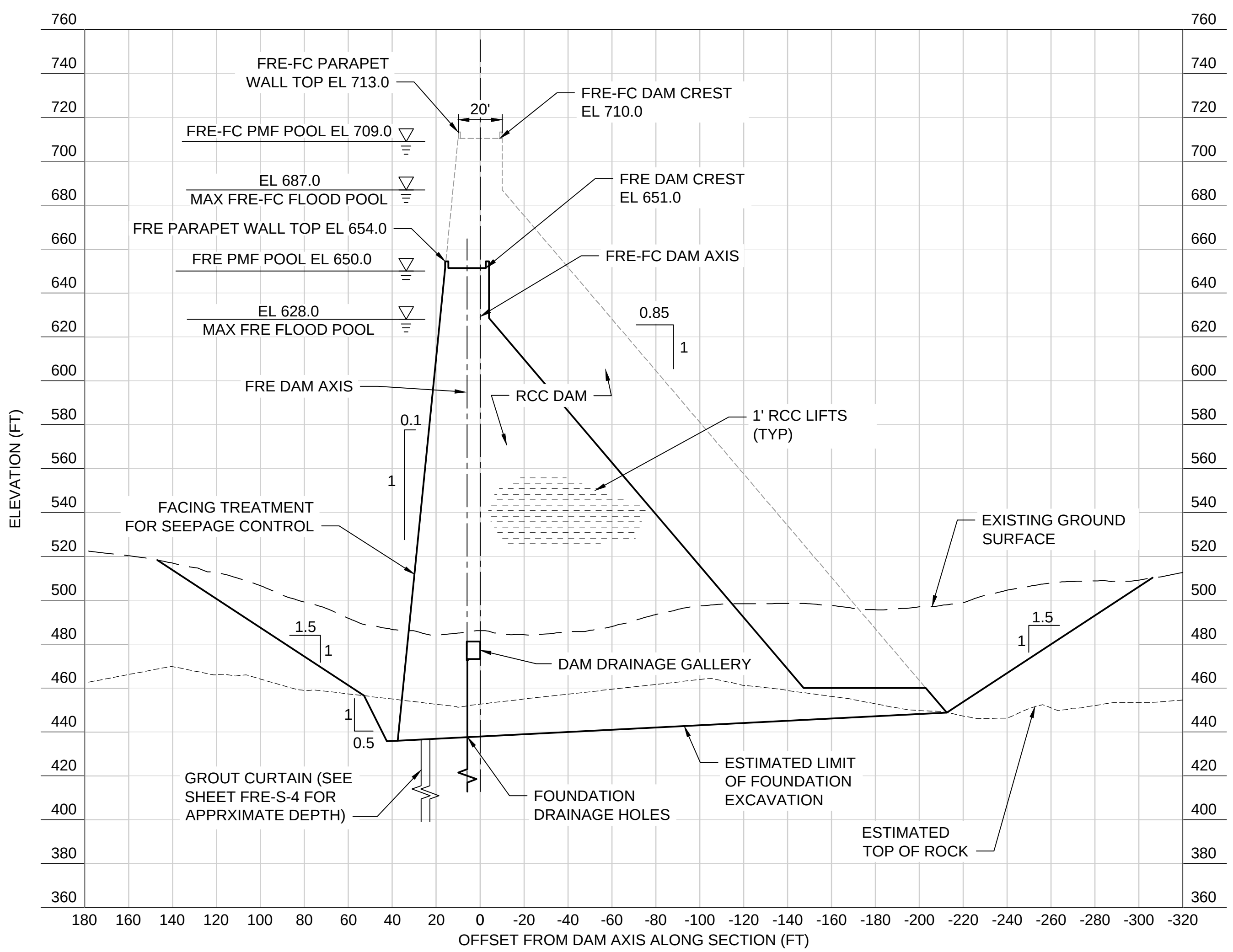
HDR

FRE DAM
DAM ELEVATION VIEW
AND DAM AXIS SECTION 1

CHEHALIS BASIN DAM

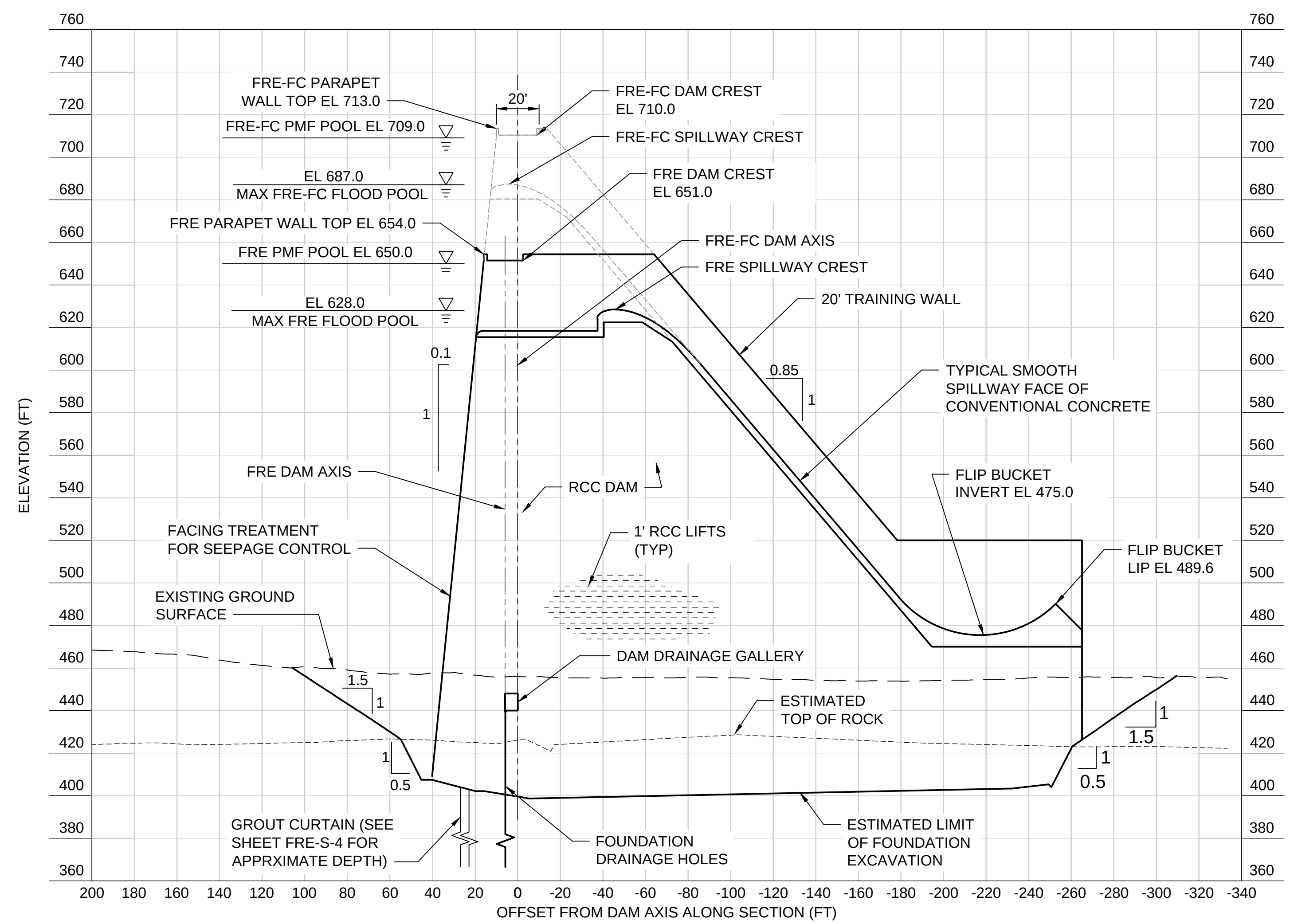
DATE
SEPT 2018

FIGURE
FRE-S-4



SECTION 2 FRE-S-3

0 20 40 80
SCALE IN FEET



SECTION 3 FRE-S-3

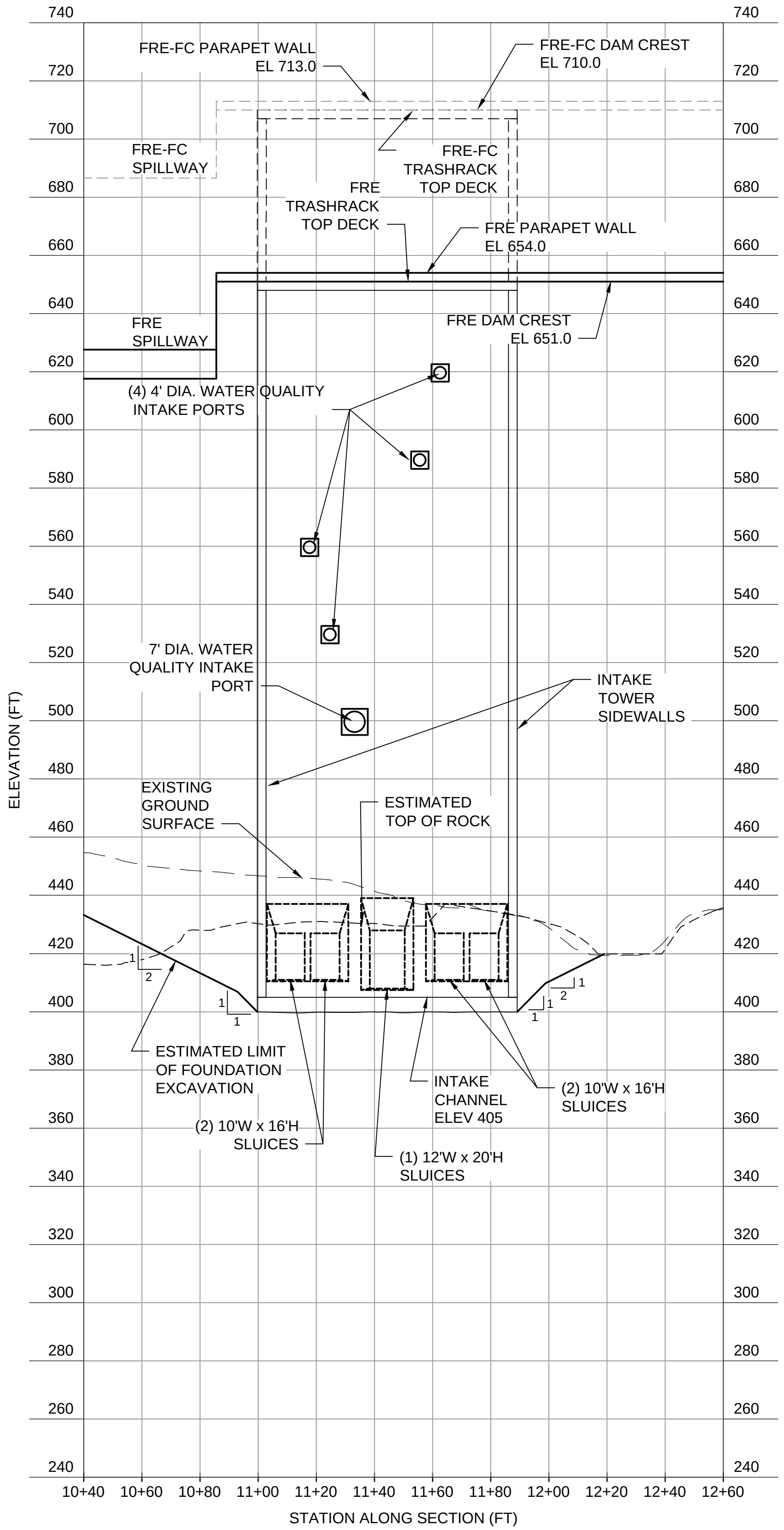
0 20 40 80
SCALE IN FEET

FRE DAM
TYPICAL DAM AND SPILLWAY
SECTIONS 2 AND 3

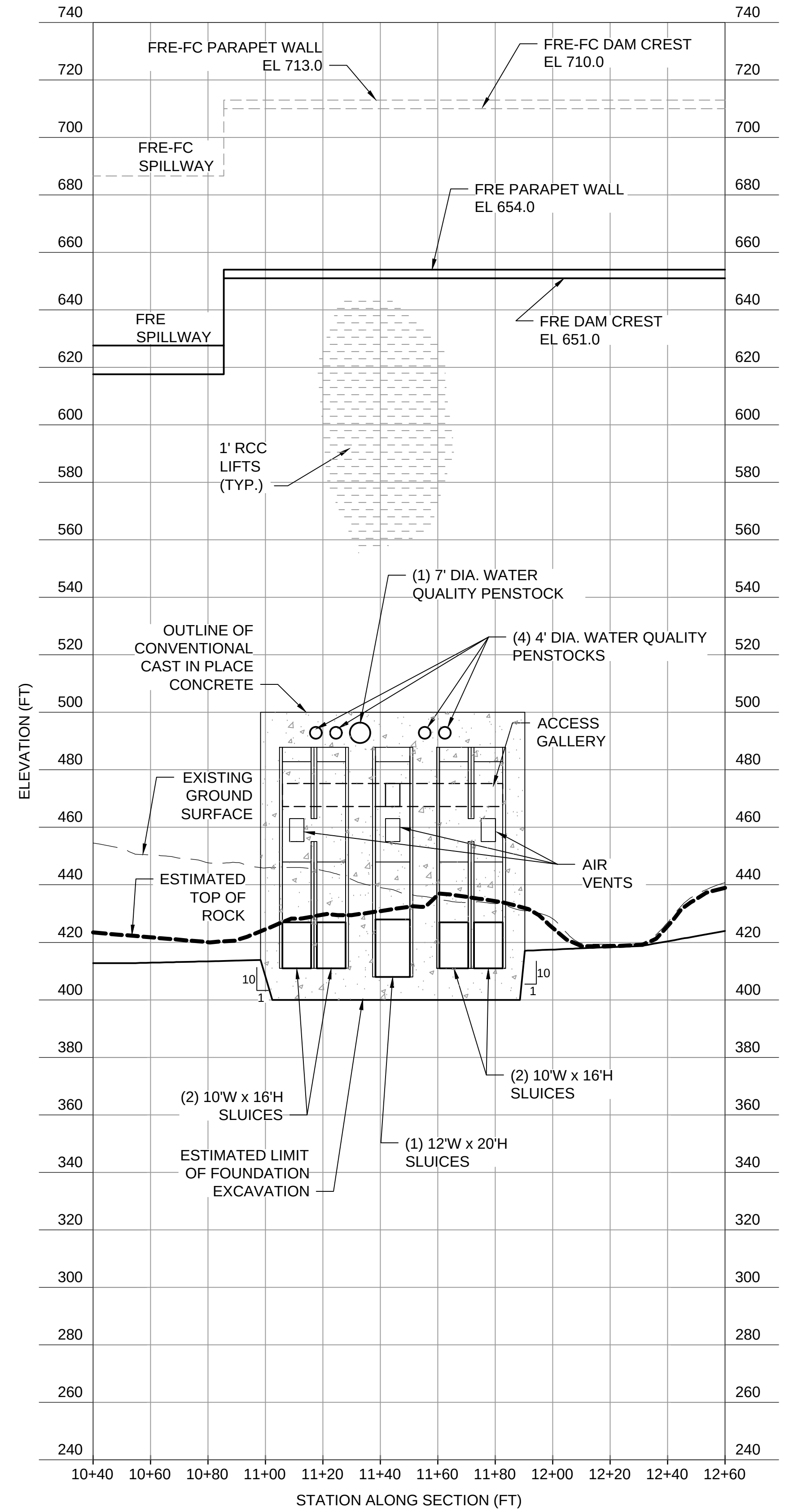
CHEHALIS BASIN DAM

DATE SEPT 2018

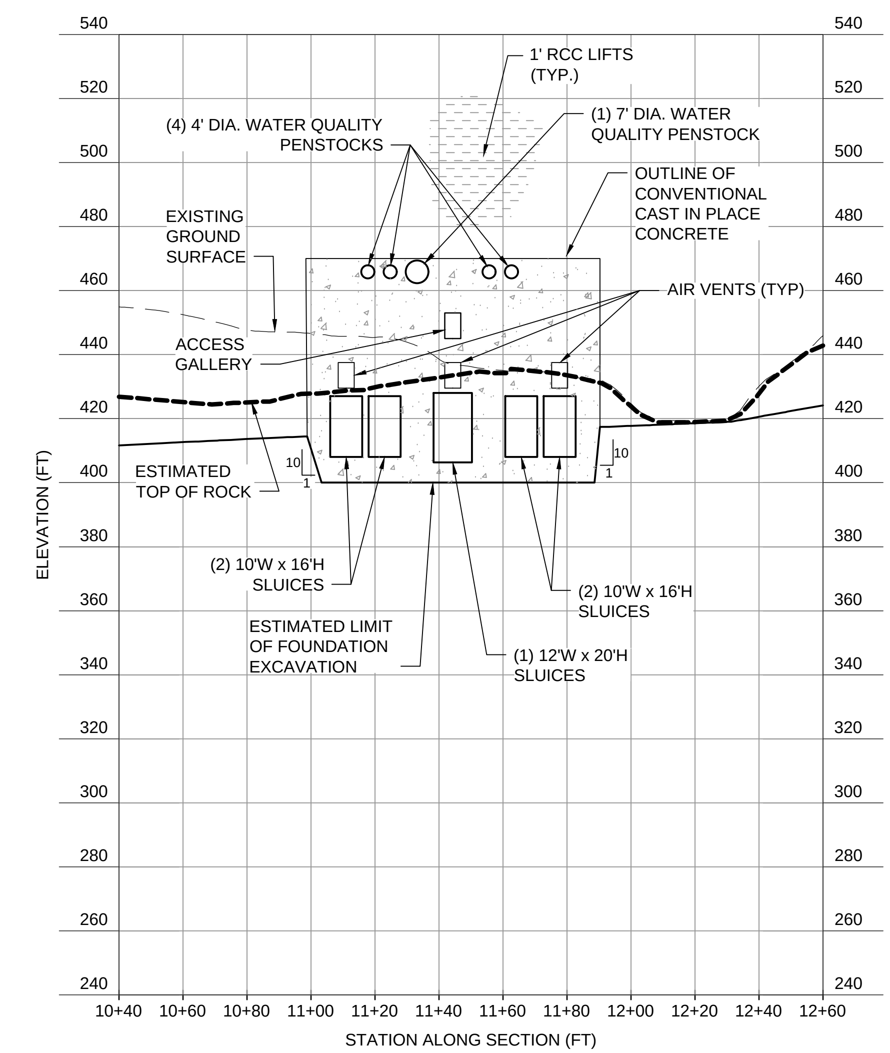
FIGURE FRE-S-5



SECTION 4 FRE-S-3



SECTION 5 FRE-S-3



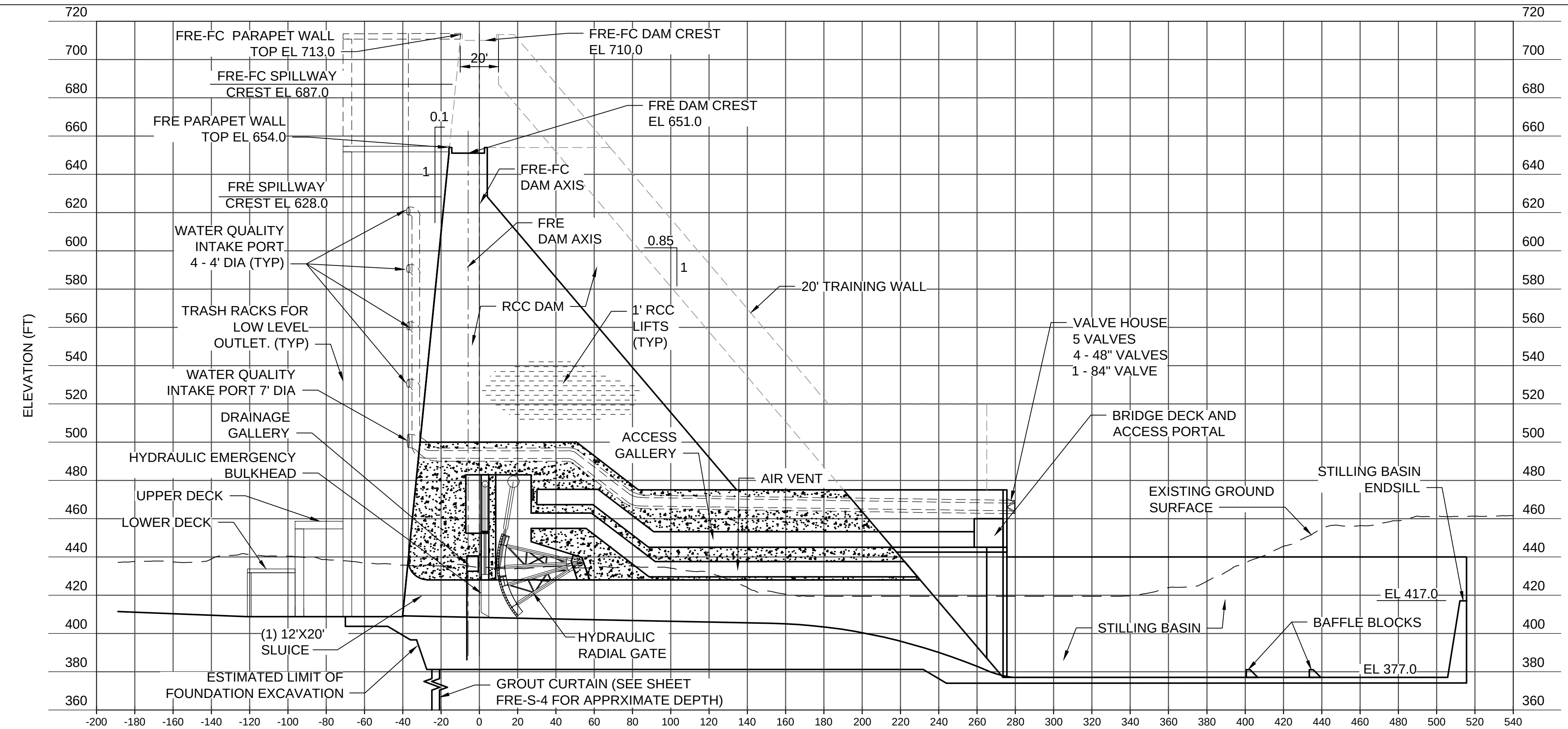
SECTION 6 FRE-S-3

0 25 50 100
SCALE IN FEET

FRE DAM
INTAKE TOWER AND SLUICES
SECTIONS 4, 5, AND 6

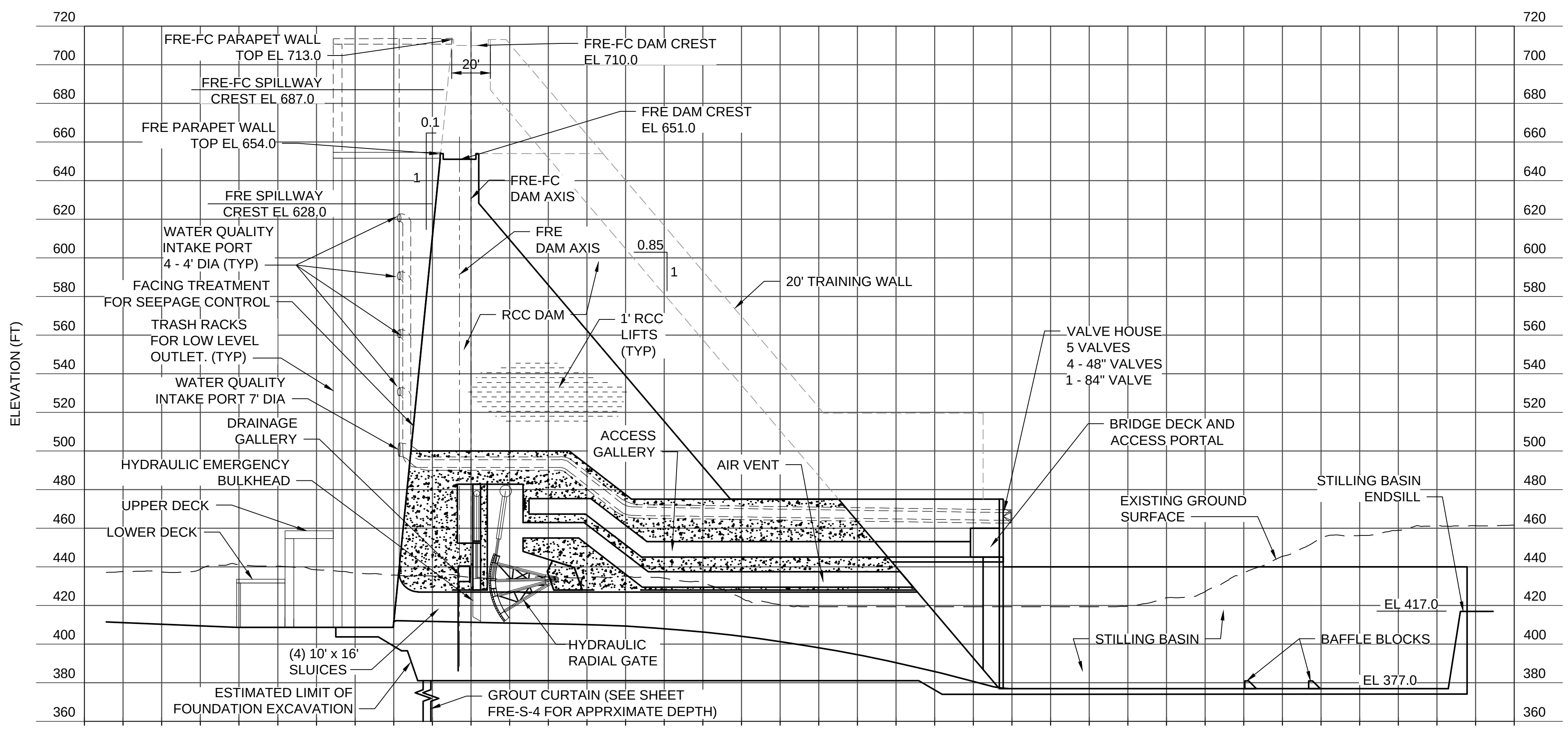
CHEHALIS BASIN DAM

DATE: SEPT 2018
FIGURE: FRE-S-6



SECTION - 12'W x 20'H SLUICE (8 / FRE-S-3)

0 20 40 80
SCALE IN FEET



SECTION - 10'Wx16'H SLUICE (7 / FRE-S-3)

0 20 40 80
SCALE IN FEET

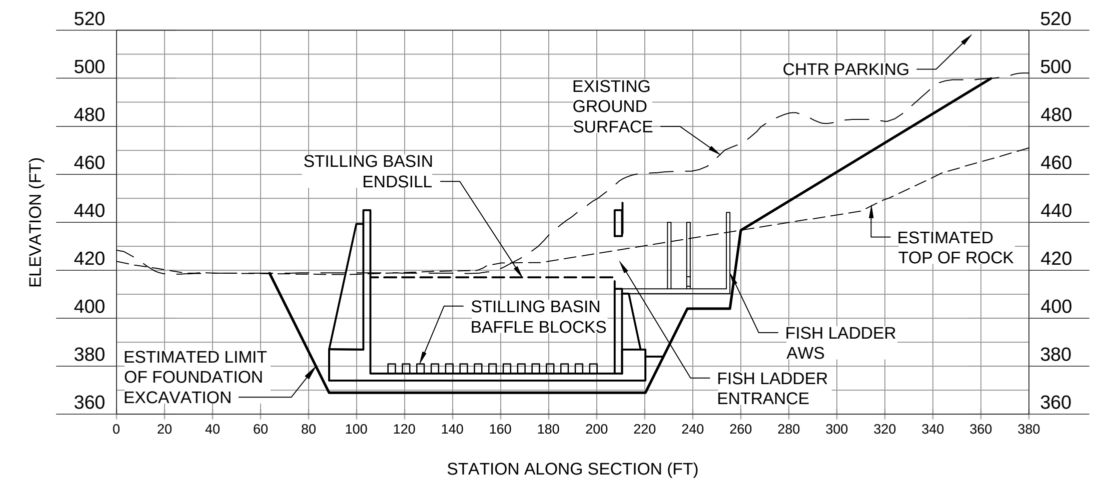
HDR

FRE DAM
LOW LEVEL SLUICES
LONGITUDINAL SECTIONS 7 AND 8

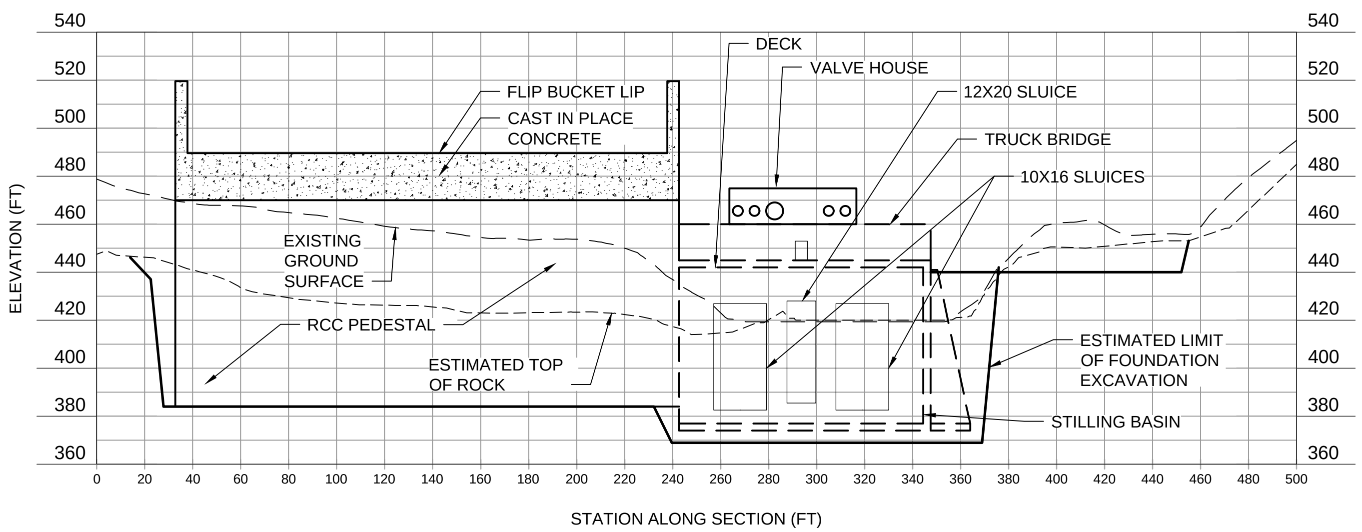
CHEHALIS BASIN DAM

DATE: SEPT 2018

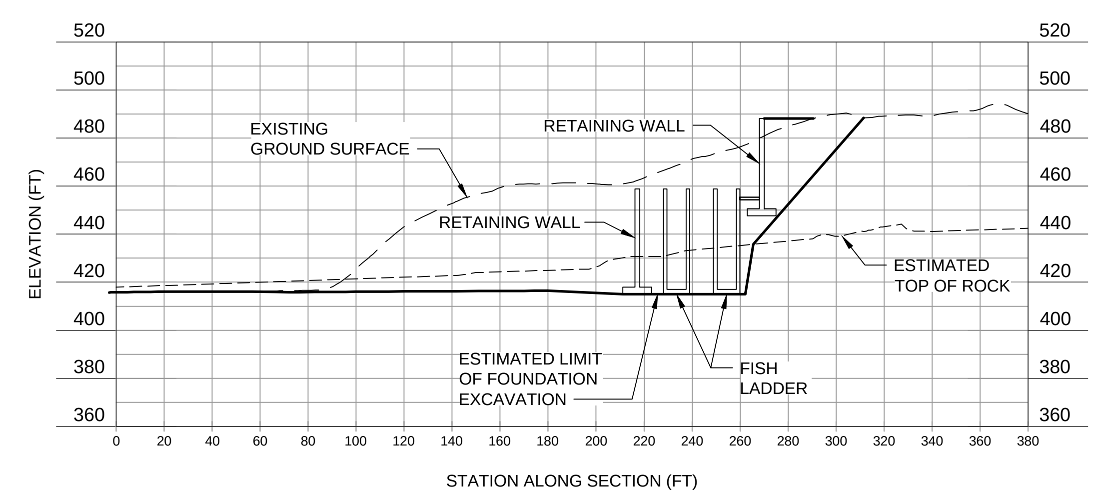
FIGURE: FRE-S-7



SECTION 10 FRE-S-3



SECTION 9 FRE-S-3



SECTION 11 FRE-S-3

NOTE:
1. REFER TO CHTR FACILITY DRAWINGS FOR DETAILED INFORMATION ON RIGHT BANK EXCAVATION AND STRUCTURES

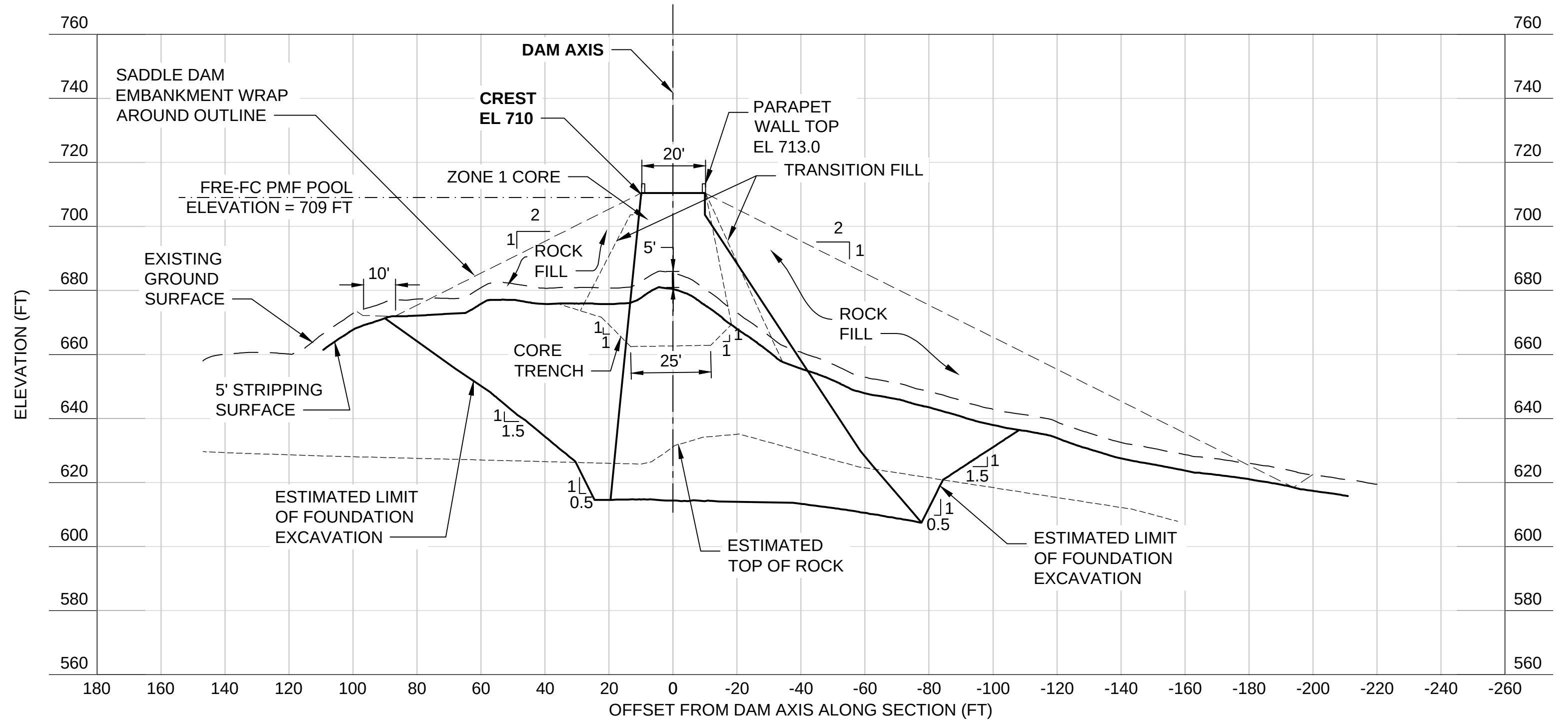
0 20 40 80
SCALE IN FEET

FRE DAM
STILLING BASIN
SECTIONS 9, 10, AND 11

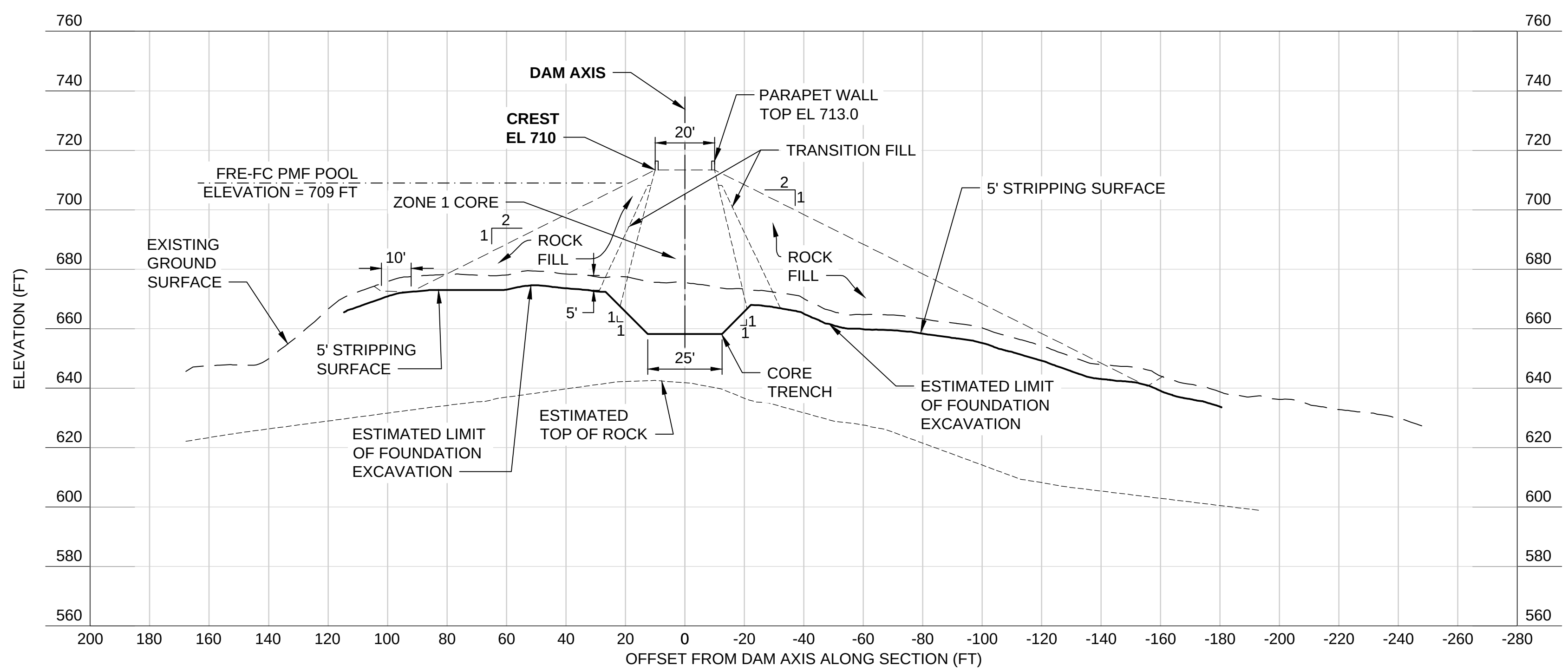
CHEHALIS BASIN DAM

DATE SEPT 2018

FIGURE FRE-S-8



SECTION 12 FRE-S-1



SECTION 13 FRE-S-1

0 15 30 60
SCALE IN FEET

FRE-FC DAM
RIGHT ABUTMENT
EMBANKMENT DAM TYPICAL SECTIONS
12 AND 13
CHEHALIS BASIN DAM

DATE: SEPT 2018
FIGURE: FRE-S-9

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PRELIMINARY
NOT FOR CONSTRUCTION

PROJECT MANAGER	
CHECKED BY	MATT PROCIV
CHECKED BY	
DRAWN BY	DON DADE
DESIGNED BY	DON DADE
DESIGNED BY	
PROJECT NUMBER	268421

ISSUE	DATE	DESCRIPTION

THE SEAL OF THE STATE OF WASHINGTON 1889

STATE OF WASHINGTON
OLYMPIA
CHEHALIS BASIN STRATEGY

FRO AND HYBRID DAMS
CHTR FISH PASAGE FACILITY

GENERAL

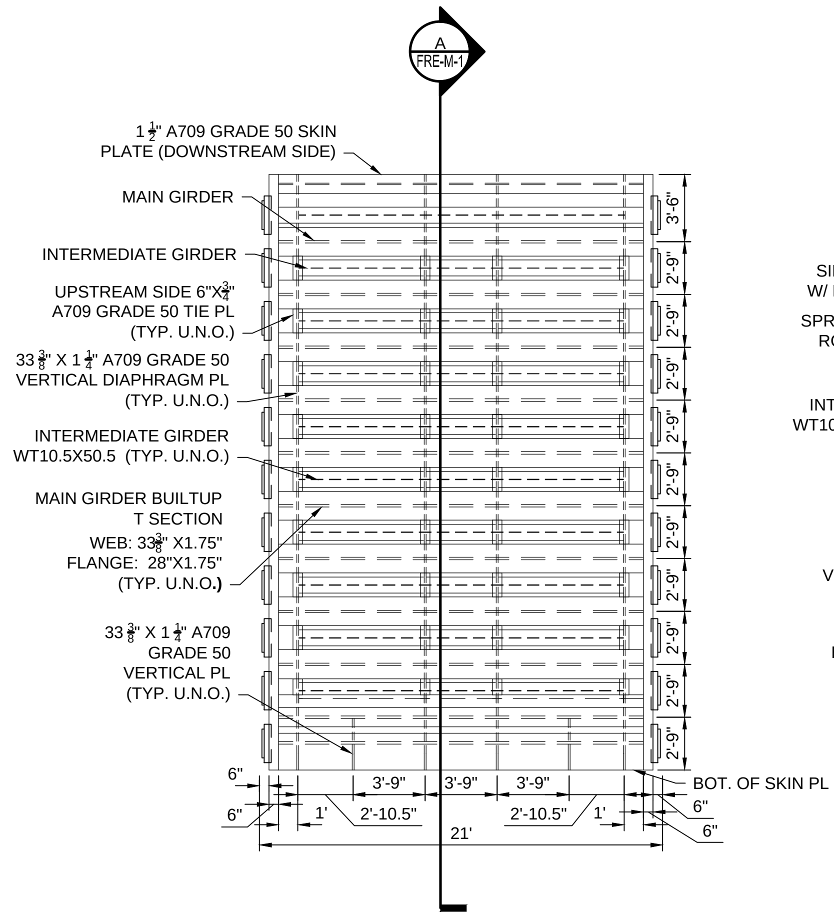
FACILITY ISOMETRIC - AERIAL

0 1" 2"

DATE JUNE, 2017

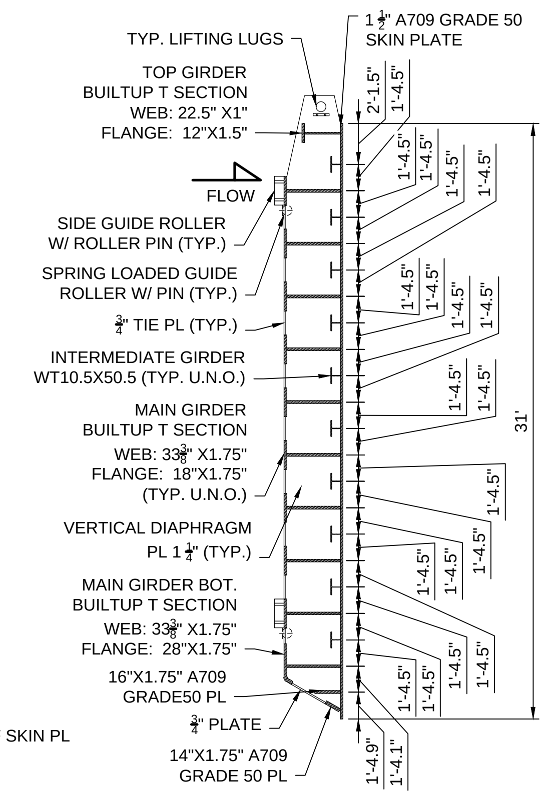
SCALE NTS

SHEET G-6



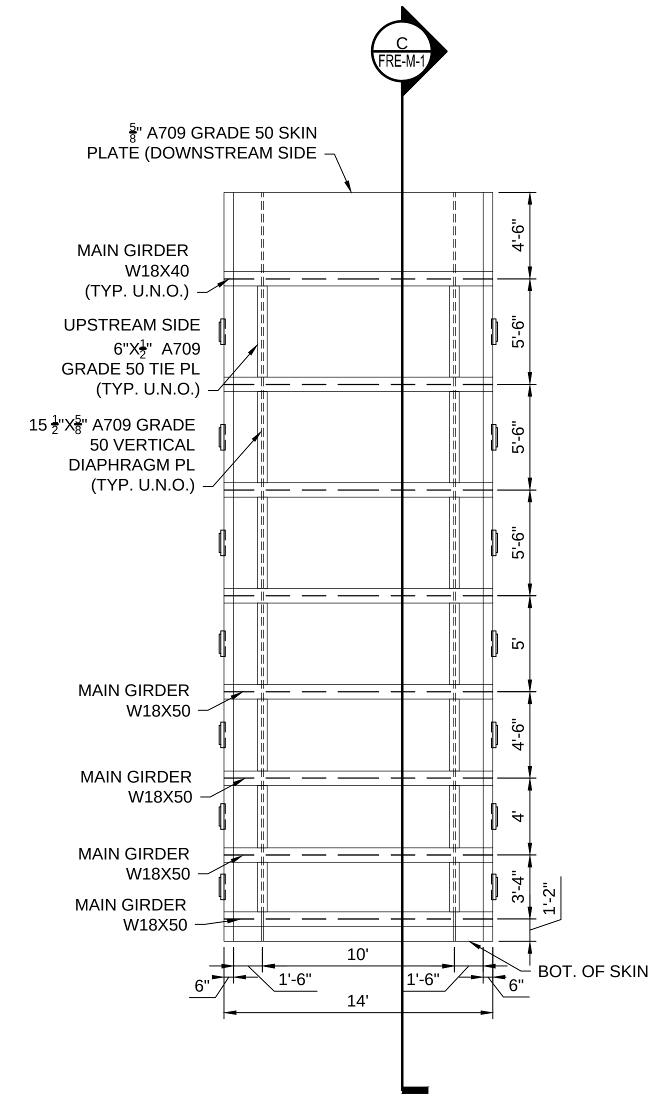
ELEVATION UPSTREAM DEWATERING BULKHEAD

1 FRE-M-1



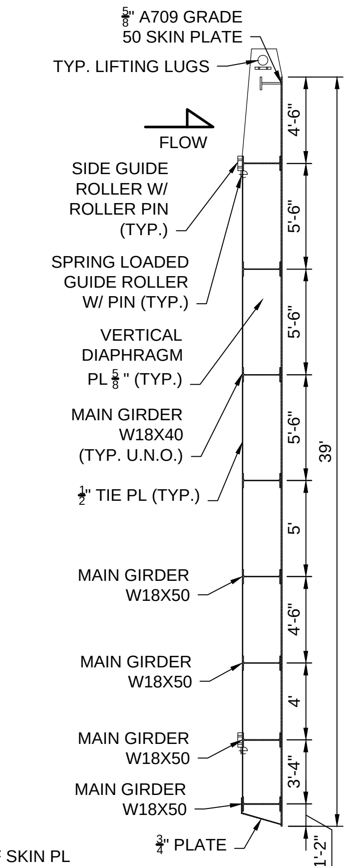
SECTION

A FRE-M-1



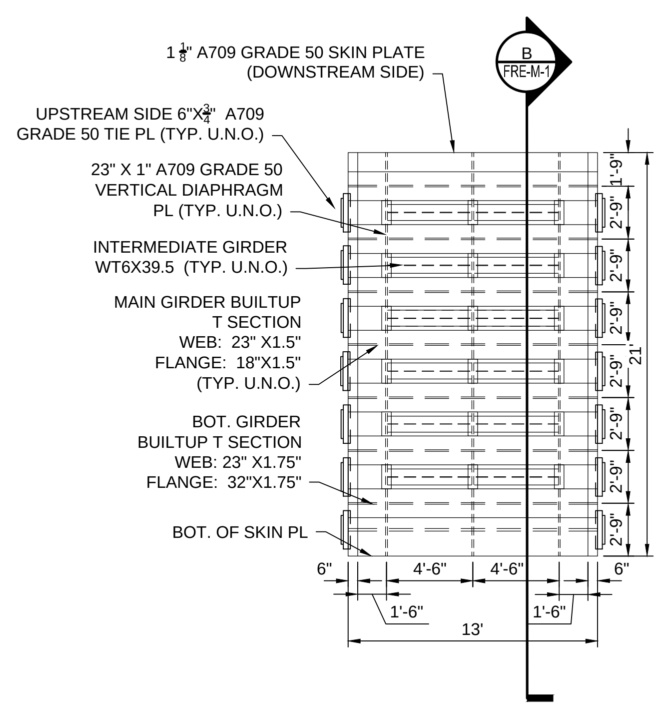
ELEVATION DOWNSTREAM DEWATERING BULKHEAD

3 FRE-M-1



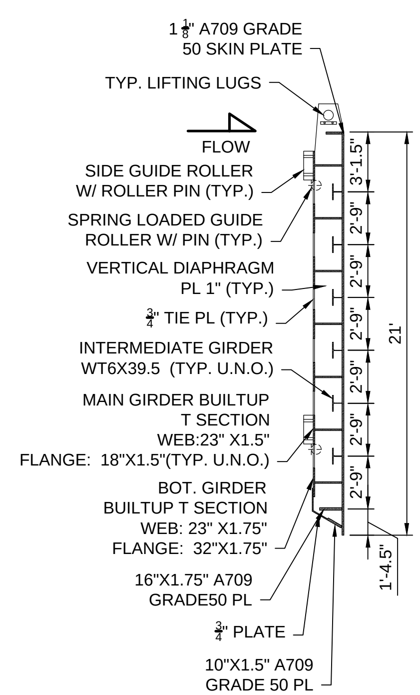
SECTION

C FRE-M-1



ELEVATION EMERGENCY CLOSURE GATE

3 FRE-M-1

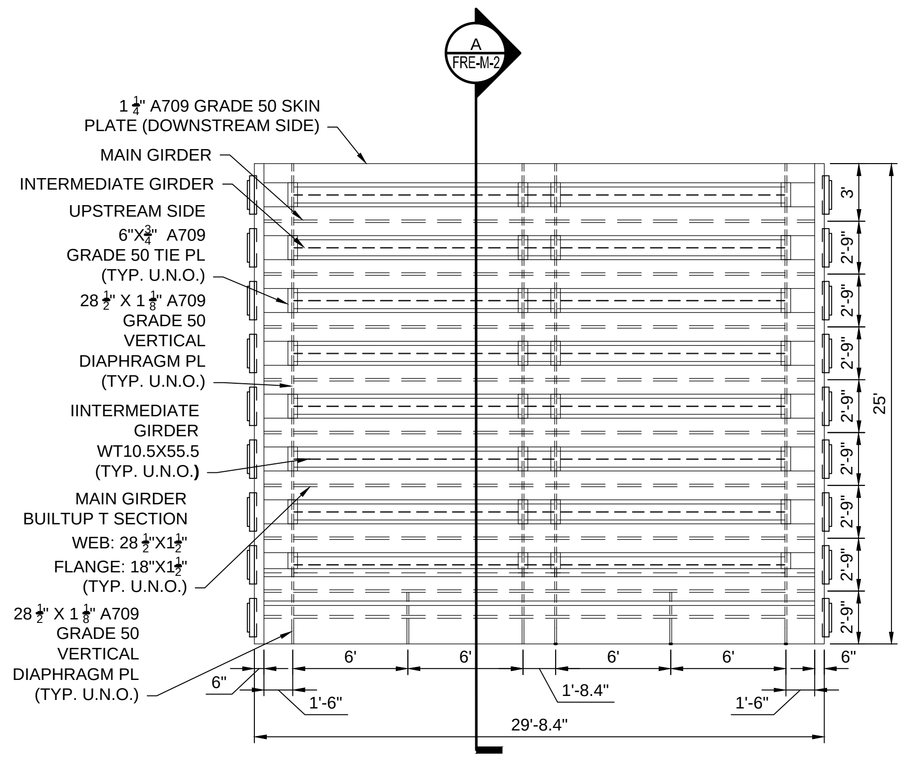


SECTION

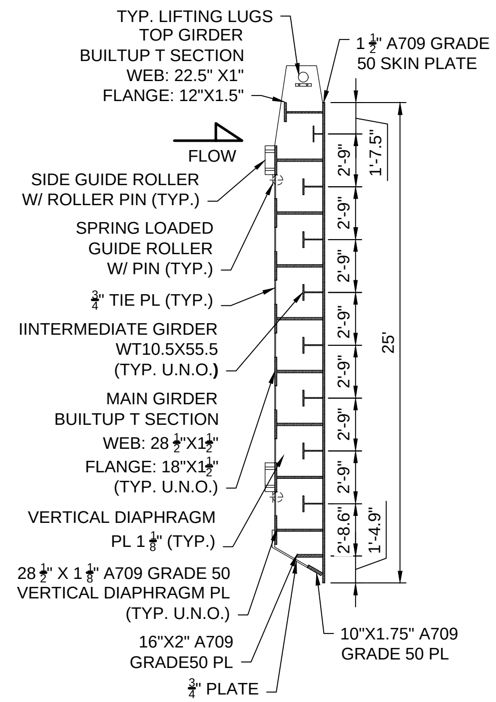
B FRE-M-1

0 2.5 5 10
SCALE IN FEET

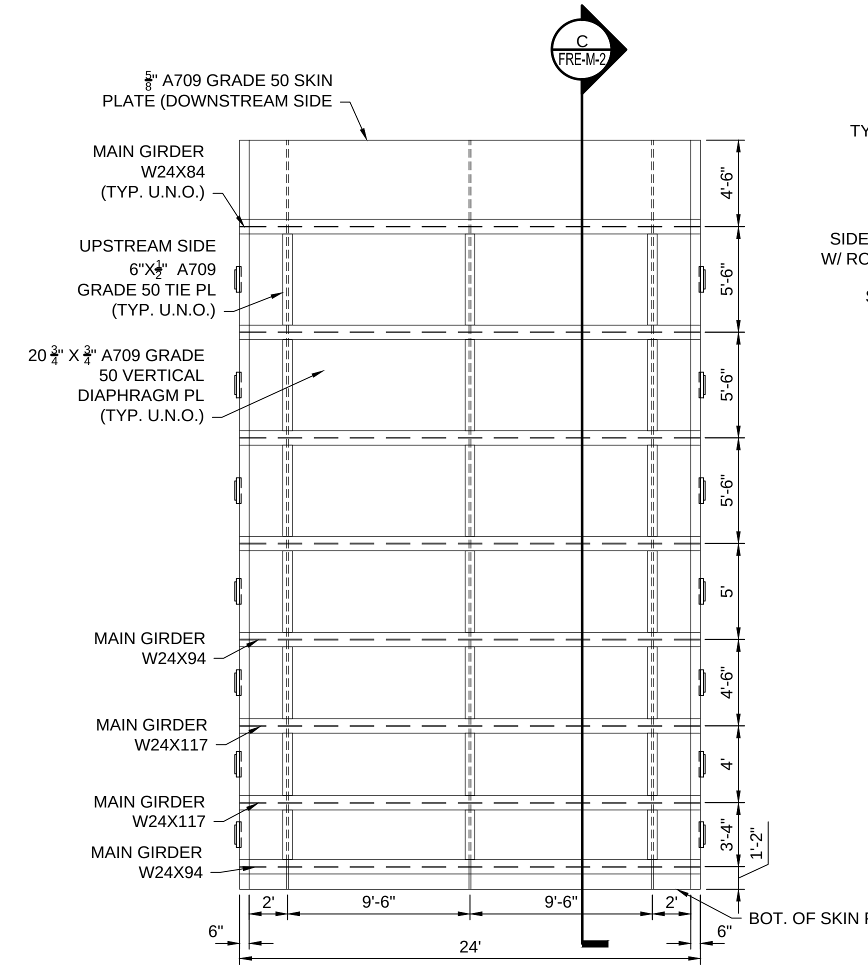
FRE DAM **LOW LEVEL SLUICES** **GATES AND BULKHEADS DETAILS** **12' x 20' SLUICE** CHEHALIS BASIN DAM	DATE SEPT 2018 FIGURE FRE-M-1



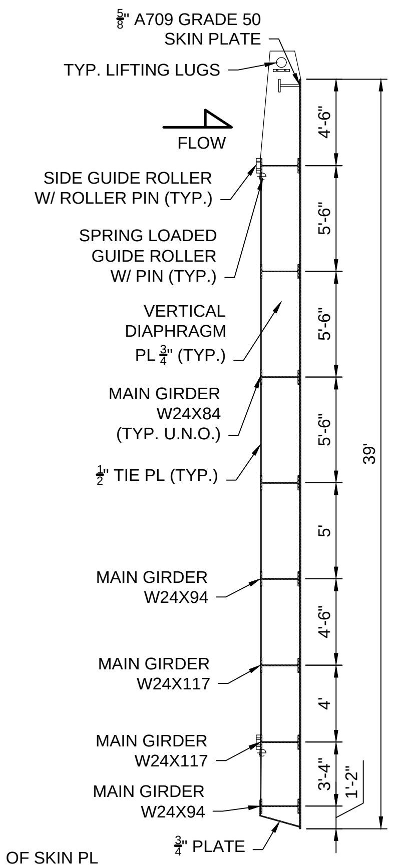
ELEVATION UPSTREAM DEWATERING BULKHEAD 1 FRE-M-2



SECTION A FRE-M-2



ELEVATION DOWNSTREAM DEWATERING BULKHEAD 3 FRE-M-2



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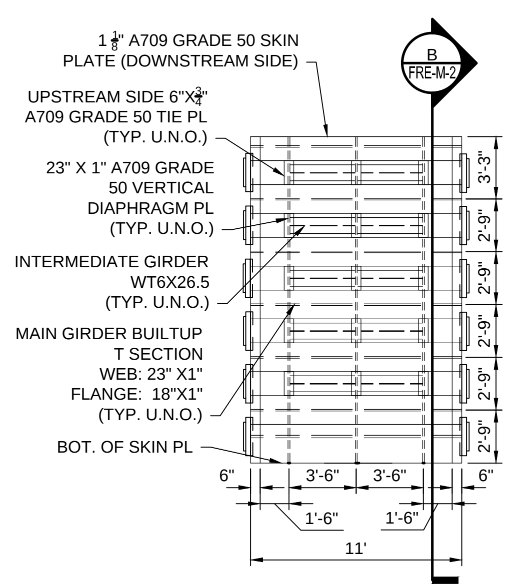

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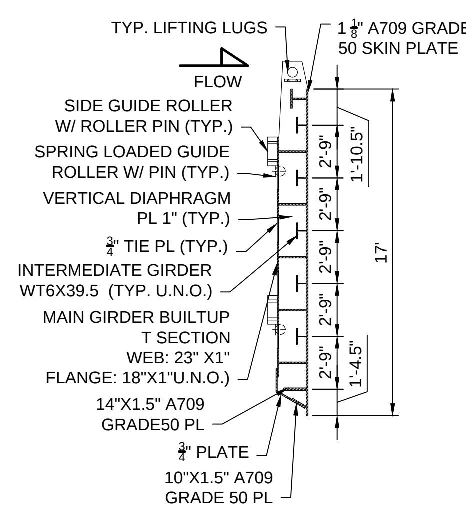


SECTION B FRE-M-2

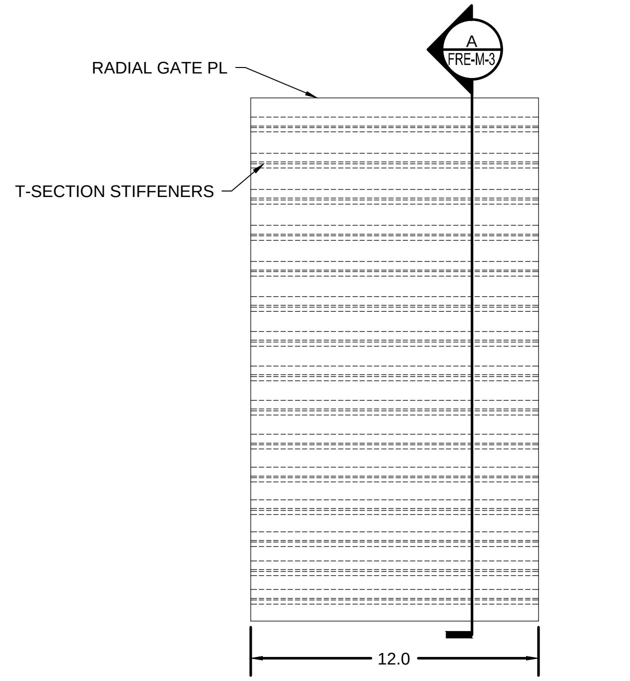
0 2.5 5 10
SCALE IN FEET

HDR

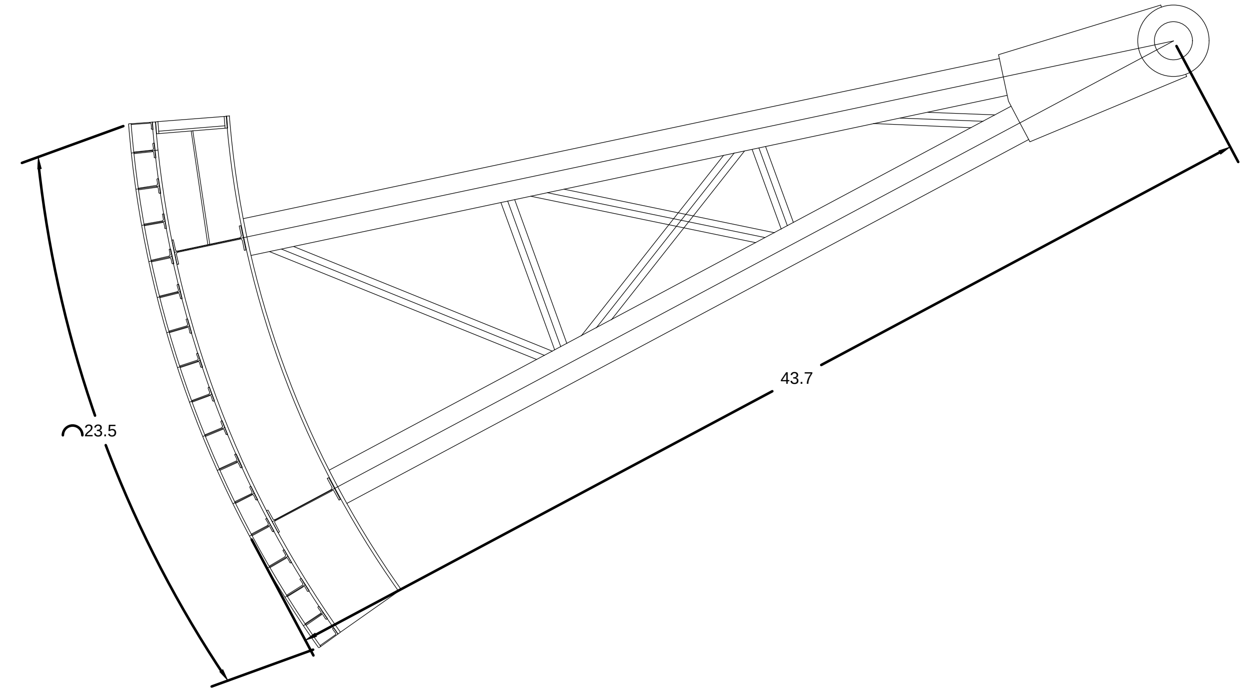
FRE DAM
LOW LEVEL SLUICES
GATES AND BULKHEADS DETAILS
10' x 16' SLUICE
CHEHALIS BASIN DAM

DATE: SEPT 2018

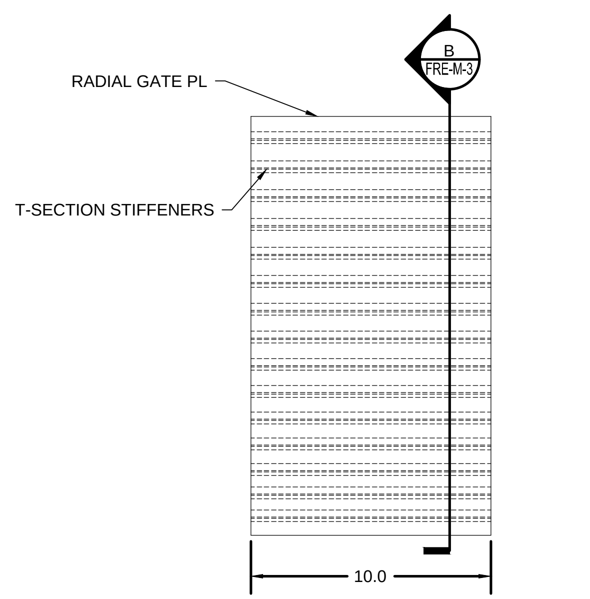
FIGURE: FRE-M-2



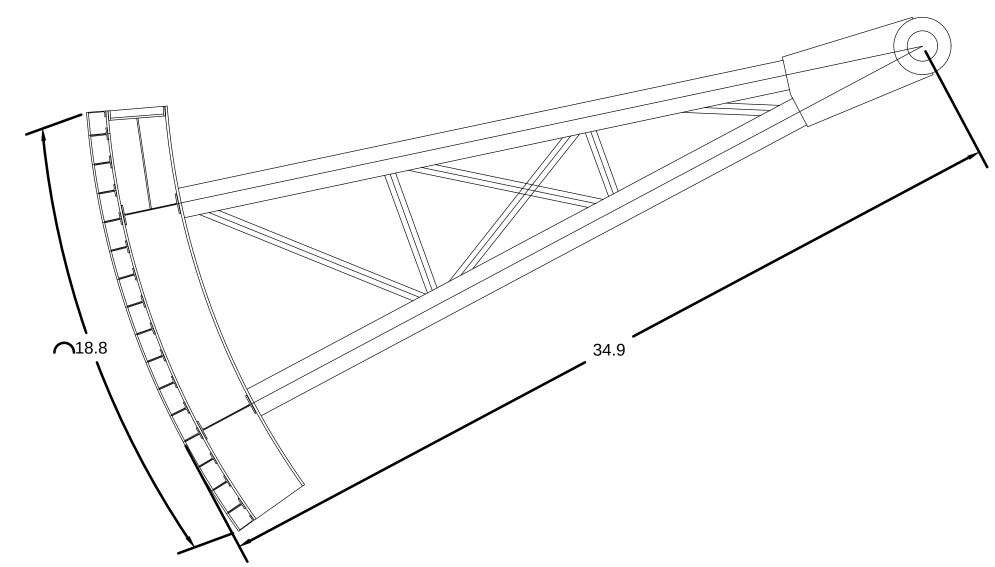
FRONT ELEVATION 12'X20'
RADIAL SLUICE GATE
1
FRE-M-3



SECTION
A
FRE-M-3



FRONT ELEVATION 10'X16'
RADIAL SLUICE GATE
2
FRE-M-3



SECTION
B
FRE-M-3

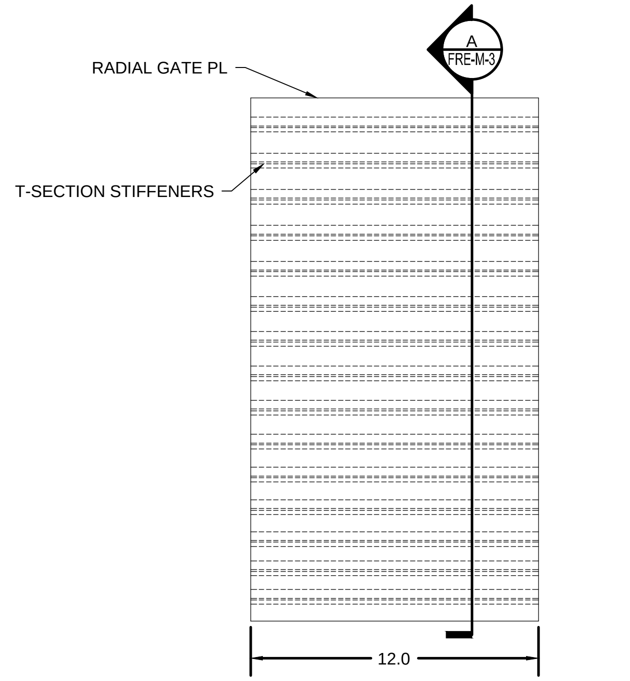
0 2 4 8
SCALE IN FEET

HDR

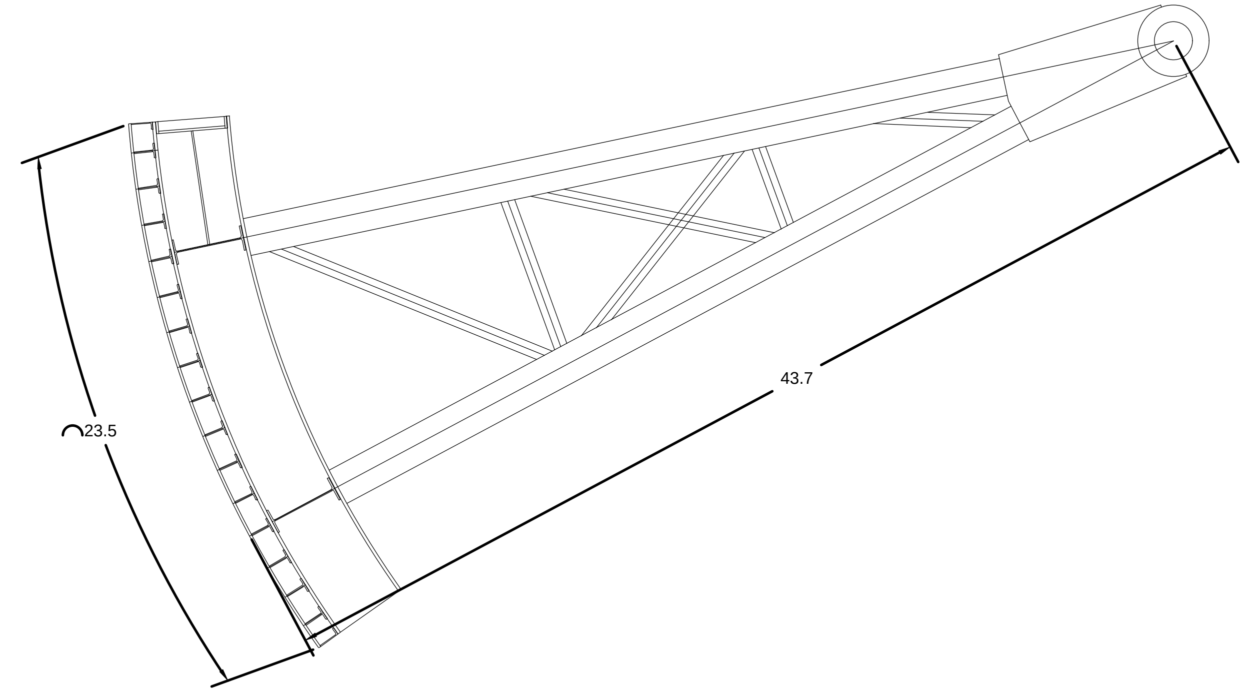
FRE DAM
LOW LEVEL SLUICES GATES DETAILS
12' x 20' AND 10' x 16' RADIAL GATES

CHEHALIS BASIN DAM

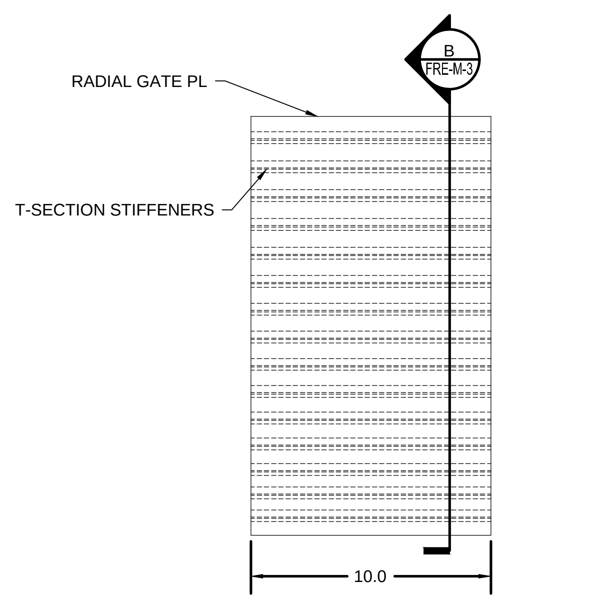
DATE	SEPT 2018
FIGURE	FRE-M-3



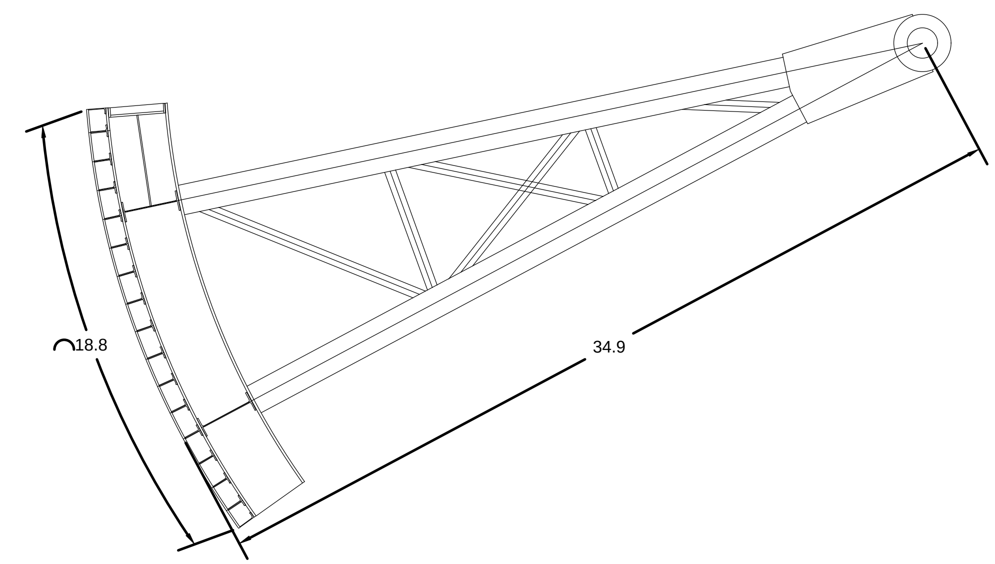
FRONT ELEVATION 12'X20'
RADIAL SLUICE GATE
1
FRE-M-3



SECTION
A
FRE-M-3



FRONT ELEVATION 10'X16'
RADIAL SLUICE GATE
2
FRE-M-3



SECTION
B
FRE-M-3

0 2 4 8
SCALE IN FEET

HDR

FRE DAM
LOW LEVEL SLUICES GATES DETAILS
12' x 20' AND 10' x 16' RADIAL GATES

CHEHALIS BASIN DAM

DATE
SEPT 2018

FIGURE
FRE-M-3

Appendix I
Hydraulic Design

Chehalis Basin Strategy

Appendix I

FRE Dam Alternative – Hydraulic Design

Reducing Flood Damage and
Restoring Aquatic Species Habitat

Updated September 2018

Prepared for: State of Washington Recreation and Conservation Office and Chehalis Basin Work Group

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ACRONYMS AND ABBREVIATIONS

AEP	annual exceedance probability
AW	Ackers-White
cfs	cubic feet per second
EM	engineering manual
ER	engineering report
FRFA	flood retention flow augmentation
FRO	flood retention only
FRE	flood retention expandable
FRE-FC	flood retention expandable-future configuration
ft	foot/feet
HDC	Hydraulic Design Criteria
HEC	Hydrologic Engineering Center
LiDAR	Light Detection and Ranging
msl	Mean sea level
MPM	Meyer-Peter-Mueller
PMF	probable maximum flood
PMP	Probable maximum precipitation
RCC	roller-compacted concrete
USACE	U.S. Army Corps of Engineers
USBUREC	U.S. Bureau of Reclamation
WSE	Watershed Science & Engineering

1 DAM ALTERNATIVE DESCRIPTION

1.1 Flood Retention Expandable (FRE) Alternative

The FRE dam and fish passage configuration was conceived from a combination of the Flood Retention Only (FRO) and Flood Retention and Flow Augmentation (FRFA) alternatives. The FRE is designed to facilitate potential future expansion of the dam, if desired. The future configuration is referred as FRE-FC in this report. The FRE and FRE-FC are both designed to provide downstream flood protection benefits, but have different dam heights, operational approach, and potential storage volumes. The FRE configuration would be constructed within the FRFA dam foundation footprint to the height of the FRO dam and fish passage configuration. The FRE-FC configuration would involve building upon the FRE dam to raise the dam to the full FRFA dam height and would allow the dam to function in accordance with the FRFA alternative. The FRE dam is designed to only store flood flows as needed to control downstream river flows to the desired Grand Mound gage control flow. The FRE-FC dam is designed to provide augmentation of downstream river flows during low flow periods for certain fish species and aquatic habitat enhancement as well. The specific control flow downstream of 38,000 cfs at the Grand Mound gage, or about a 1 in 7 year flood event, has been identified in preliminary assessments, but that value may change as the larger study progresses.

1.1.1 FRE Dam

Similar to the FRO alternative, the FRE dam would be a Roller Compacted Concrete (RCC) gravity dam. The Dam would typically not impound Chehalis River flows until and unless a large flood is forecasted to occur. The dam would be equipped with spillway structure, low level outlet works, stilling basin and fish passage facility. Under typical operation whenever flood flow regulation is not needed, there would be no reservoir impoundment, as the sluice gates would be held fully open to pass all inflows without retention. The low level sluices would be large in size to provide relatively unimpeded fish passage through the sluice conduits at all typical flows less than about 2,000 cfs. The FRE dam is designed to only store flood flows as needed to regulate downstream river flows to the desired Grand Mound gage control flow. The FRE dam operation is patterned after the Seattle District of the US Army Corps of Engineers' Mud Mountain Dam on the White River, near Enumclaw, Washington.

1.1.2 FRE-FC Dam

The FRE-FC will be constructed by raising the FRE dam through placement of additional roller compacted concrete to the height of the FRFA dam alternative. The FRE-FC dam is designed to provide a permanent storage pool to allow augmentation of downstream river flows during low flow periods for fish and aquatic habitat enhancement, while also providing additional storage volume above the permanent pool for floodwater storage to accommodate extreme precipitation and runoff events. The dam would be equipped with a spillway structure, low level outlet works, water quality outlet works, stilling basin and fish passage facilities.

2 DAM ALTERNATIVE DESIGN

2.1 FRE Configuration

The currently envisioned FRE alternative's primary characteristics include the following:

- A Roller Compacted Concrete (RCC) dam of 254 to 270 feet estimated maximum dam structural height depending on final foundation elevation and a large foundation footprint to accommodate the potential future construction of FRE-FC
- Dam crest length of approximately 1,225 feet to span the Chehalis valley
- Uncontrolled overflow spillway approximately 200 ft wide, with crest elevation 628 ft designed to pass the Probable Maximum Flood (PMF) event, but expected to operate very infrequently
- Smooth spillway ogee and chute cast over the RCC dam section. Chute would have training/containment walls approximately 20 feet in height.
- Spillway terminus flip bucket to eject jet well out and away from the dam structure
- Spillway discharge plunge pool well downstream of the toe of the dam
- Single 12 ft wide by 20 ft high low level sluice to pass sediment and low head flood flows, with invert elevation approximately at existing river channel bed elevation. This sluice floor would be expected to be repaired regularly due to sediment abrasion and erosion, much like Mud Mountain Dam.
- Two pairs of large 10 ft wide by 16 ft high low level sluices to pass high head flood flows, with invert elevation about 3 feet higher than the existing river channel bed elevation. These would be used to pass flow when the reservoir exceeded about 50 feet of head and sediment would no longer be actively moving through the dam
- Multiport water quality inlets/outlets that draw water from multiple levels within the reservoir and a low-level flood control outlet. The water quality outlet work will be constructed during the FRE to simplify the future potential development to FRE-FC dam. The multiport outlet works could potentially be operated in FRE dam for flood regulation purposes, though, they are currently envisioned to only be functional in FRE-FC dam for water quality purposes.
- A full height trashrack upstream of the outlet works to capture large wooden debris. The lower 50 ft of trashrack is offset about 25 ft upstream of the upper portion to accommodate and simplify the debris removal process.
- Construction diversion tunnel about 20 ft in diameter through the right abutment. The tunnel floor would be lined with concrete to provide a smooth invert wear layer for sediment passage during construction, and would be plugged following completion of the low level outlet sluices but provided with a drain valve to evacuate the reservoir if needed

- Hydraulic jump-type energy dissipating stilling basin approximately 240 feet long by 100 ft wide and 40 feet deep with baffle blocks to contain and dissipate flow energy from the low level outlet sluices. The stilling basin would be concrete lined, and would have an end sill elevation roughly the same elevation as the downstream river channel
- Fish ladder and collection channel with entrances along the right wall of the stilling basin to attract and pass upstream migrating fish to the trap and haul facility
- Initial target flood storage pool volume of 65,000 acre-ft, to be activated in flood events larger than the estimated 7-year recurrence interval event. This value may change as the economic benefit-to-cost studies progress to identify the preferred storage volume

The flood regulation operation is achieved by radial sluice gates controlling sluice discharge when required under the prescribed operation plan. The reservoir would not be impounded unless the Chehalis River at the Grand Mound gage was forecasted to rise above 38,000 cfs, at which point the sluices would be gradually closed to retain flood flows. When the Grand Mound gage flow is predicted to fall below 38,000 cfs, the sluices would be gradually opened to draft the reservoir. Except during flood control operations, the sluice gates are to remain fully open, freely passing sediment, smaller woody debris that can readily pass through the trashrack, and fish both upstream and downstream. Larger woody debris that becomes lodged against the trashrack would be removed as needed to keep the channel clear and permit unfettered fish passage and maintain sediment transport continuity through the dam.

A good analogous existing dam would be the Mud Mountain Dam on the White River in western Washington State, owned and operated by the US Army Corps of Engineers in a very similar fashion. The Mud Mountain Dam on the White River in western Washington State, owned and operated by the US Army Corps of Engineers, has been operating successfully since the late 1940's and operates in a very similar fashion. Similar to the proposed FRE dam alternative for Chehalis River, the Mud Mountain dam is a run-of-river type dam which does not typically impound the river flows unless a large flood is forecasted to occur. In this case, the flood regulation operation will commence by closing the low level outlets, holding back water and slowly releasing water back into the river after the flood wave is dampened. However, unlike the FRE dam alternative, the Mud Mountain Dam does not pass upstream migrant fish through the low level outlet sluices, and instead utilizes a separate downstream low barrier weir and trap and haul facility operated continuously to collect and transport upstream migrating fish from all five species of Pacific salmonids to the extensive watershed habitat above the dam.

Similar to FRO, when flood regulation operation is commenced, the sluice gates would be throttled as needed to reduce mainstem flow sufficiently to hold the Grand Mound gage at or below 38,000 cfs. Once flood control operations begin, fish passage would be limited or temporarily suspended as a result of the high flow velocities within the low level sluice conduits. However, coincident with the commencement of flood regulation operation, the fish ladder would be opened and fish would be attracted to the ladder and collection facility instead of the low level sluices. A trap and haul facility would begin operations to move upstream migrating fish above the dam to a release point above the reservoir. Downstream fish passage would still be possible through the low level sluice conduits, though the rising reservoir would at some point cause the submergence of the sluices to be too excessive for downstream migrating fish to readily find it. Once the flood has passed and the reservoir is evacuated, downstream fish passage would resume as the submergence over the low level sluice outlets decreases. Upstream fish passage would be provided by the fish ladder and trap and haul facility until the reservoir was fully drained and woody debris and sediment could be cleared from the trashrack opening to permit free flow again. Larger flood events that carry significant volumes of debris to the reservoir may require that the pool to be maintained for a longer time than what is required for flood regulation to corral and move floating debris to containment areas before complete draw down.

2.2 FRE-FC Configuration

The currently envisioned FRE-FC alternative's primary characteristics include the following:

- An estimated maximum dam structural height of 313 to 330 feet depending on final foundation elevation
- Dam crest length of approximately 1,225 feet spanning the Chehalis valley, in addition to a right abutment RCC and rockfill section about 900 feet in length to carry the dam crest closure to high ground
- Uncontrolled overflow spillway approximately 200 ft wide, with crest elevation 687 ft designed to pass the PMF event, but expected to operate very infrequently
- Smooth spillway ogee and chute cast over the RCC dam section. Chute would have training/containment walls approximately 20 feet in height
- Spillway terminus flip bucket to eject the jet well out and away from the dam structure
- Spillway discharge plunge pool well downstream of the toe of the dam
- Single 12 ft wide by 20 ft high low level sluice with invert elevation approximately at existing river channel bed elevation.
- Two pairs of large 10 ft wide by 16 ft high low level sluices to pass flood flows, with invert elevation about 3 feet higher than the existing river channel bed elevation. These would be used to pass flow whenever the discharge requirements exceeded the capacity of the multilevel outlet ports, and could be used at any reservoir elevation.
- A full height trashrack upstream of the outlet works to capture large wooden debris.
- Construction diversion tunnel about 20 ft in diameter through the right abutment. The tunnel floor would be lined with concrete to provide a smooth invert wear layer for sediment passage during construction, and would be plugged following completion of the low level outlet sluices but provided with a drain valve to evacuate the reservoir if needed

- Hydraulic jump-type energy dissipating stilling basin approximately 240 feet long by 70 ft wide and 40 feet deep with baffle blocks to capture and dissipate flow energy from the low level outlet sluices. The stilling basin would be concrete lined, and would have an end sill elevation roughly the same elevation as the downstream river channel
- Multiport water quality outlet works that draw water from multiple levels within the reservoir
- Fish ladder and collection channel with entrances along the right wall of the stilling basin to attract and pass upstream migrating fish to the trap and haul facility
- Floating fish collection and dewatering screened facility in the reservoir to collect downstream migrating fish, transport and release in the river downstream of the dam
- A permanent reservoir pool of up to 65,000 acre-ft to be used for flow augmentation in late summer and fall prior to the winter rainy season to enhance fish habitat. This value may change as the biological benefit-to-cost studies progress to identify the preferred storage volume
- Up to 65,000 acre-ft of flood storage volume to be activated in flood events larger than the estimated 7-year recurrence interval event. This value may change as the economic benefit-to-cost studies progress to identify the preferred storage volume

Unlike FRE, the FRE-FC dam would maintain a permanent pool behind the dam and be designed to provide water storage and releases for flow augmentation from the permanent pool to enhance certain aquatic species habitat, and a flood management pool between the designated permanent pool level and the spillway crest for flood operations. During the flood control season, the low level sluices would typically be used to pass flows that could not be discharged through the smaller multiport outlets due to capacity limitations. A good analogous existing dam would be the Howard A. Hanson Dam on the Green River in western Washington State, owned and operated by the U.S. Army Corps of Engineers in a very similar fashion.

Similar to FRFA, seasonal operation of the FRE-FC dam would typically include adherence to an operational rule curve, which establishes a desired reservoir level during each part of the season, and includes reservoir drawdown and filling rates, as well as limitations on downstream rising and falling ramping rates to protect aquatic species and provide for human safety in the event of ramping operations. The FRFA seasonal operational approach is explained in Appendix B (Section 2.3) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017)

The permanent pool of the FRE-FC dam would entirely prevent the free passage of upstream- and downstream-migrating fish that is accommodated by the FRE alternative. Therefore separate upstream and downstream migrating fish passage facility are required for FRE-FC alternative. The upstream migrating fish passage facility constructed for the FRE would continue to be utilized to move fish to the upstream of the dam. This Collection, Handling, Transport, and Release (CHTR) system is comprised of a fish collection channel adjacent to the outlet works stilling basin, a short length of fish ladder leading to a sorting, holding, and transfer facility, and tank truck hauling operation to the upper watershed.

Downstream-migrating fish would be collected in the reservoir with a floating collection facility similar to the upper or lower Baker Lake floating collector, or any one of the several similar fish collectors deployed on a number of Pacific Northwest reservoirs.

2.3 Hydraulic Design Guidelines

Federal agencies have well established guidelines for developing the design of concrete gravity dams such as the Roller Compacted Concrete (RCC) dam structure proposed for the Chehalis Flood Storage Dam project. The US Army Corps of Engineers (USACE) and the US Bureau of Reclamation (USBUREC) provide the most applicable and comprehensive design guidance for large concrete gravity dams. Though the Federal Energy Regulatory Commission (FERC) provides additional dam safety guidance for hydropower dams, this project would not fall under FERC regulatory jurisdiction. If hydropower is added as a project feature in the future, the dam would fall under FERC's jurisdiction and those criteria would apply. Similarly, the Natural Resources Conservation Resources Service (NRCS) provides additional guidance for the design of dams. However, the NRCS guidance focuses primarily on embankment dams and is not particularly applicable to the Chehalis Flood Storage Dam project, and therefore the NRCS guidance was not used.

2.3.1 U.S. Army Corps of Engineers (USACE)

The US Army Corps of Engineers (USACE) has developed comprehensive design guidance in the form of Engineer Manuals (EMs) and Engineer Regulations (ERs) based on decades of experience and many empirical data sets collected at numerous projects around the United States. Those specifically used in this design evaluation of the dam hydraulic structures include those provided in Section 2.12 below.

2.3.2 U.S. Bureau of Reclamation (USBUREC)

In addition to publishing numerous dam design texts and guidelines, the US Bureau of Reclamation (USBUREC) has been a leader in developing and incorporating risk-informed dam safety and design methods and guidelines. As for the USACE guidance, the USBUREC guidance is based on many decades of direct experience and many constructed dam projects around the United States. Those specifically used in this design evaluation of the dam hydraulic structures include those provided in Section 2.12 below.

2.4 Hydrologic Conditions

2.4.1 Basin Hydrology

The hydrologic analysis supporting the development of the Chehalis dam alternatives was conducted by Watershed Science & Engineering (WSE). This information was provided in three cited sources (WSE, 2014; WSE, 2016a; WSE, 2016b). Also, a summary discussion of these three reports has been provided in the Appendix B (Section 2.5.1) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

2.4.2 Spillway Design Flood

Since the FRE dam and fish passage configuration was conceived from a combination of the FRO and FRFA at the same site representing a phased approach, the spillway hydraulic design criteria is similar to FRO and FRFA which is explained in detail in Appendix B (Section 2.5.2) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

2.4.3 Hydrologic Modeling of Flood Regulation Operations

Modeling of the reservoir operations was conducted by Anchor QEA, and is briefly summarized in Appendix B (Section 2.5.3) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017). More detailed information is provided in Anchor's report (Anchor QEA, 2016).

2.5 FRE Hydraulic Characterization

An important consideration of the alternatives designs is the hydraulic flow characteristics and sediment transport processes in the Chehalis River upstream, downstream and through the dam. Sediment gradations and incoming bed load transport data were provided by others (Dube, 2016), based on sampling data from gravel bars exposed in the vicinity of River Mile 108.532. The FRE dam alternative is designed to pass all flow, suspended and bed sediment through the open sluices without delay at all times until and unless the sluice gates are regulating flow and a reservoir forms. On the other hand, the FRE-FC dam design retains a permanent reservoir and will prevent the continuity of bed load sediment transport through the dam. It is likely that suspended sediments will largely pass through the dam during the winter flood months as a consequence of the smaller reservoir volume and rapid transit time.

The primary focus on the dam low level outlet works hydraulic modeling and sediment transport analysis was exclusively on the sediment transport and fish passage characteristics of flow through the FRE dam when no reservoir is impounded. The analysis focuses on the near-dam reach hydraulic and sediment transport processes between River Mile 108.532 above the dam site and River Mile 107.62 below the dam site. The results of hydraulic and sediment transport simulations are discussed in the following sections.

2.5.1 Velocity and Depth Characterization

The hydraulic modeling analysis was conducted using a combination of tools, including analytical evaluation of outlet works capacity, velocity, gate operation, sediment throughput, as well as computational numerical modeling tools. Similar to FRO dam alternative, the basic hydraulics through the dam reach was assessed using 1D HEC-RAS, a one-dimensional computer water surface profile modeling tool created by the US Army Corps of Engineers' (USACE) Hydrologic Engineering Center, and in common use throughout the engineering discipline for flow modeling in preliminary design evaluations. The model geometry construction and calibration process is discussed in detail in Appendix B (Section 2.6.1) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

Figure 2-1 and Figure 2-2 show the cross section location and topography of the reach utilized to construct the 1D HEC-RAS model geometry.

Figure 2-1
Sediment Sample Location, HEC-RAS Cross Sections (Dam Axis Shown as Red Line)

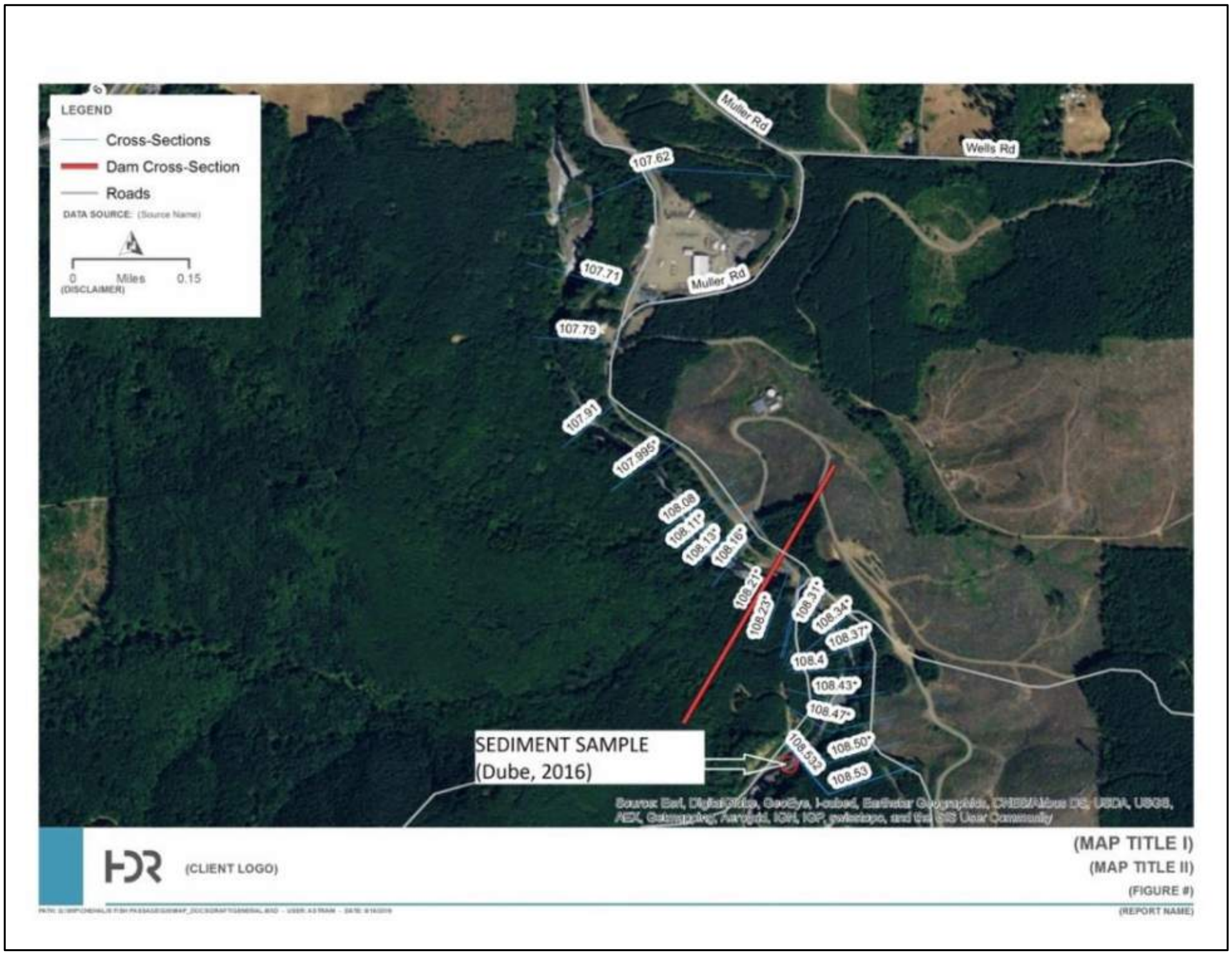
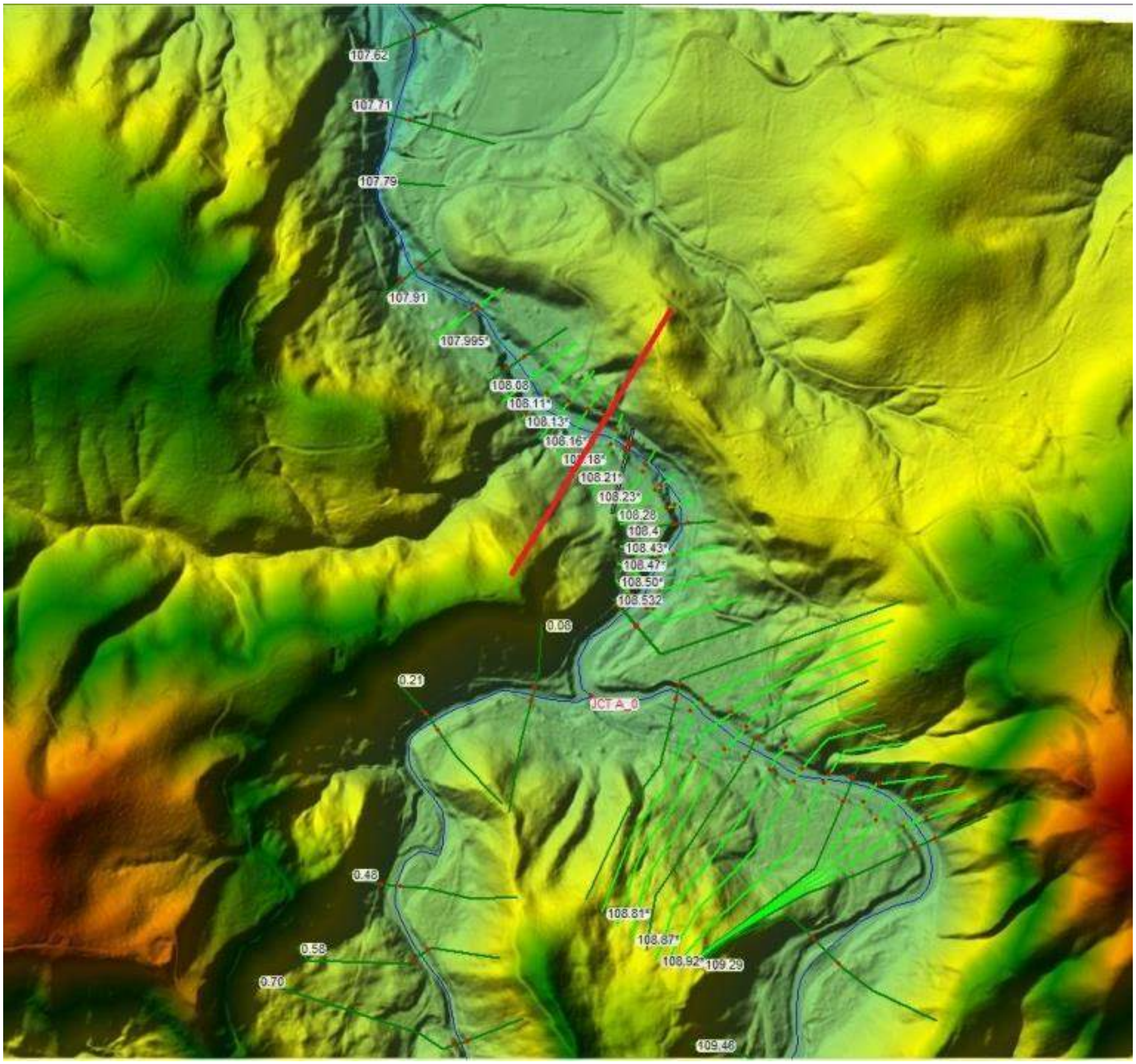


Figure 2-2
LiDAR Topography with HEC-RAS Sections (Dam Axis Shown as Red Line)



The results of 1D HEC-RAS model generally showed that the FRE dam alternative, with its five low level sluice outlets, provides lower flow velocity across the range of low to moderate flows than the existing channel. From a fish passage perspective, the FRE would be expected to provide slower flow passage for fish through the dam than the existing channel, and an improvement over the previously evaluated FRO alternative with three sluices configuration. Without intervention such as that occurring when the sluices are regulated for floods, the lower flow velocities within the sluices would likely lead to sediment deposition inside the dam. A sample comparison of the flow velocity and depth for existing channel condition, FRO alternative with three sluices configuration (a single larger 12’Wx20’H sluice at elevation

408 ft and a pair of 10’Wx16’H at invert elevation 411 ft) and FRE alternative with five sluices configuration (a single larger 12’Wx20’H sluice at elevation 408 ft and two pairs of 10’Wx16’H at invert elevation 411 ft) is presented in Figure 2-3 And Figure 2-4.

The comprehensive results of 1D HEC-RAS modeling (flow velocity and depth) for existing channel condition, FRO alternative with three sluices configuration and FRE alternative with five sluices configuration for all the cross sections are provided in Section 3.1.1 in Figure 3-1 through Figure 3-14.

Figure 2-3

Comparison of Flow Velocity at Cross Section 108.30 under Typical Conditions, about Midway through the Flood Regulating Sluices

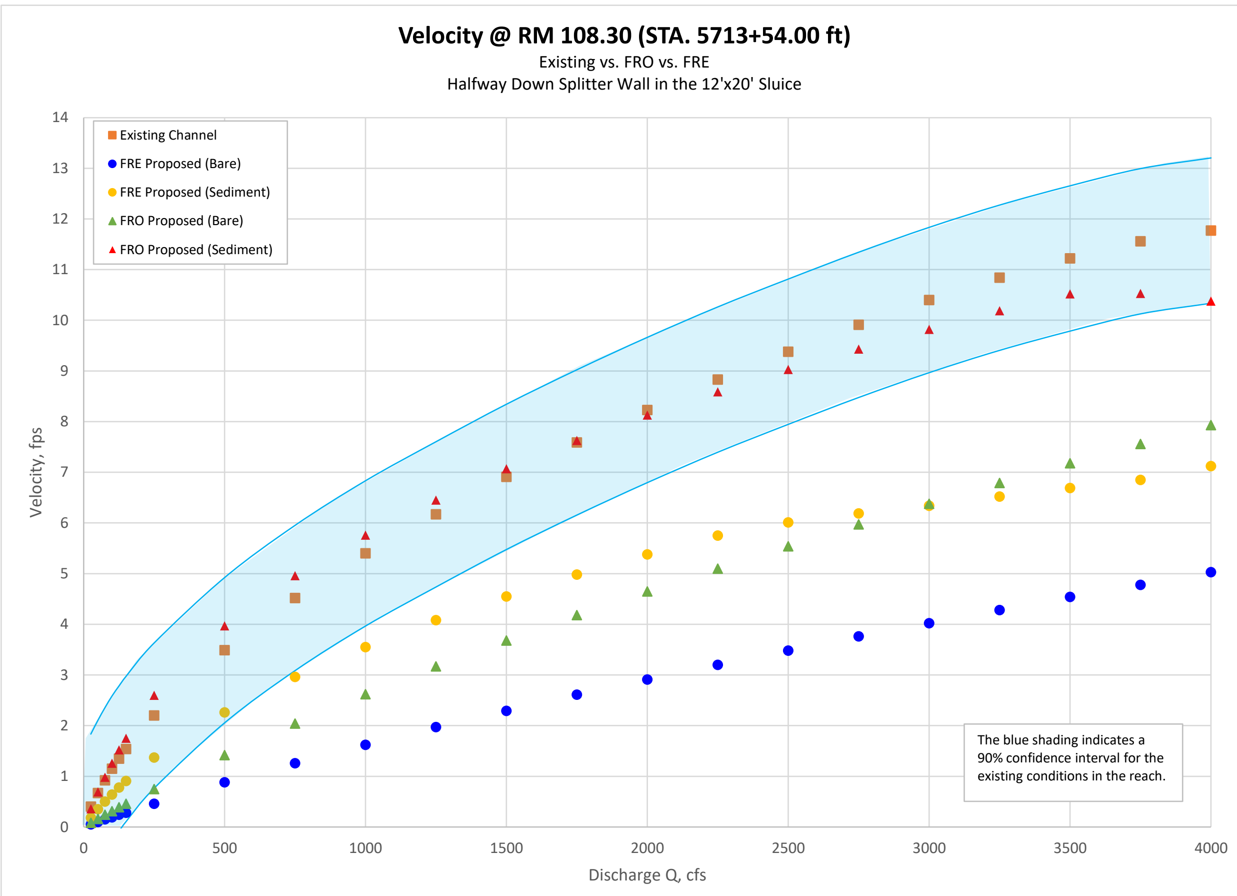
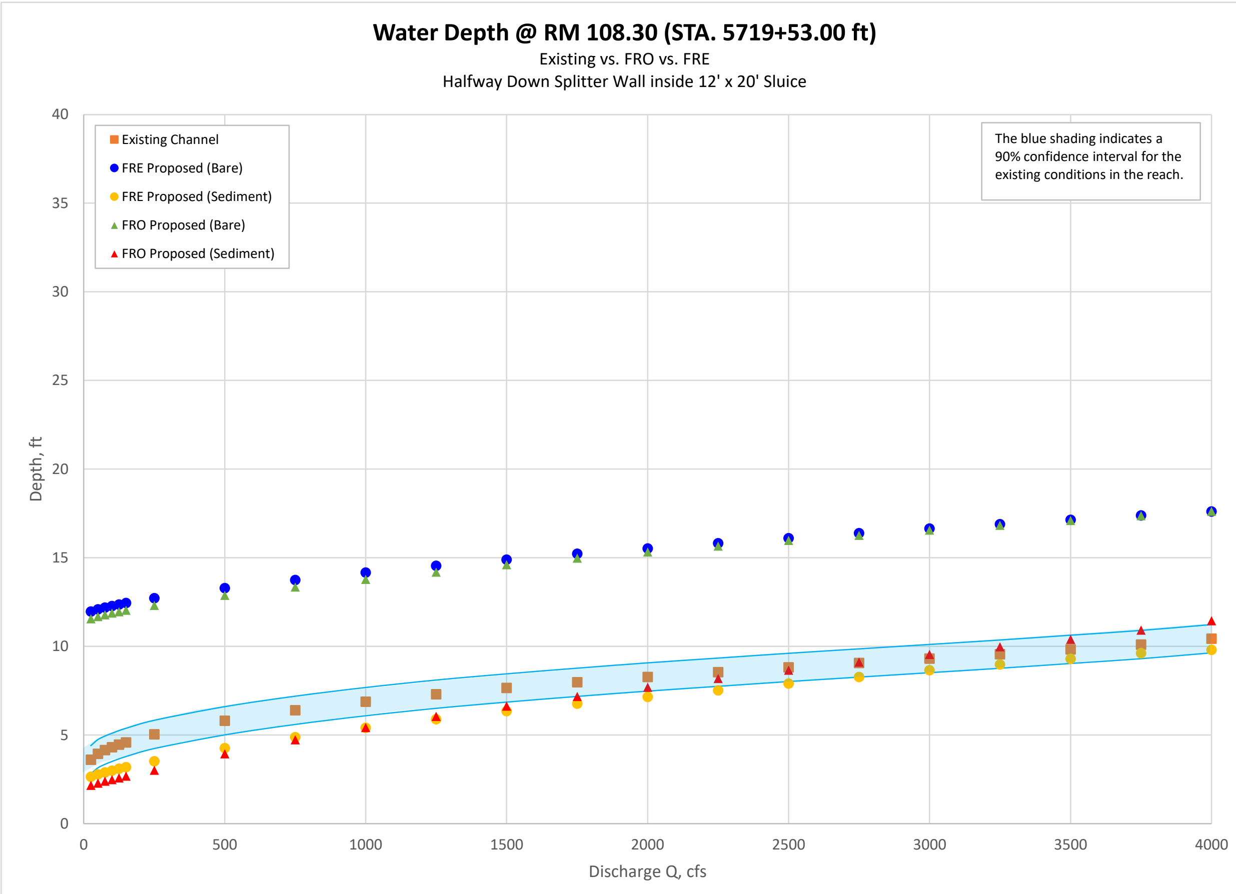


Figure 2-4
Comparison of Flow Depth at Cross Section 108.30 under Typical Conditions, about Midway through the Flood Regulating Sluices

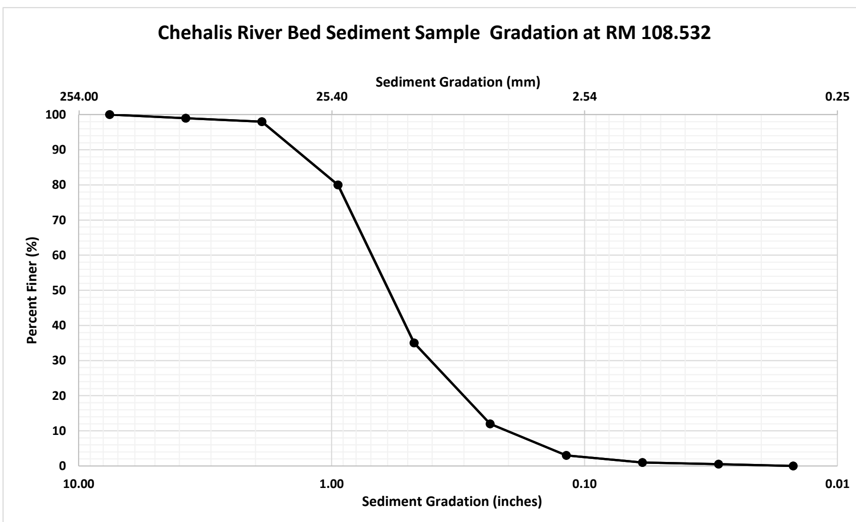


2.5.2 Sediment Transport Capacity and Performance

Sediment transport through the dam reach was evaluated using the same 1D HEC-RAS model by activating the sediment transport module available in the software. The model input parameters included a bed sediment sample gradation (Figure 2-5) and a hydrograph comprised of four years of flow data for the dam site from 1990 to 1994, based on existing hydrologic records observed at the Doty gage site and scaled to the basin area at the dam site. This period was selected for the analysis, as it comprised several larger flood events and the average annual hydrographs over these 4 years of record were fairly typical for the Chehalis River at the dam site. The sediment model calibration process is explained in detail in Appendix B (Section 2.6.2) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017). It should be noted that the model calibration was done based on visual observation and estimates of actual river bed elevation. No detailed ground penetrating radar or geophysical investigation was conducted through this scour reach in this phase of the study, and as a result we must consider the Existing Conditions Sediment model to be only roughly approximate, and only useful to compare against the With-Project Condition Sediment model which reflects the effect of flow and sediment passing through the proposed dam sluice outlets.

The particular sediment gradation samples collected from the river channel and the stability of the Meyer-Peter-Mueller (MPM) method in HEC-RAS suggested MPM would be the most appropriate. The inflow and outflow sediment loads were assumed to be in equilibrium for the purpose of these simulations, since there was no strong indication that the reach was sediment limited or, conversely, sediment oversupplied. Additional variables adjusted during the HEC-RAS model construction are not mentioned here, but were modified slightly to achieve a reasonable simulation of transport processes.

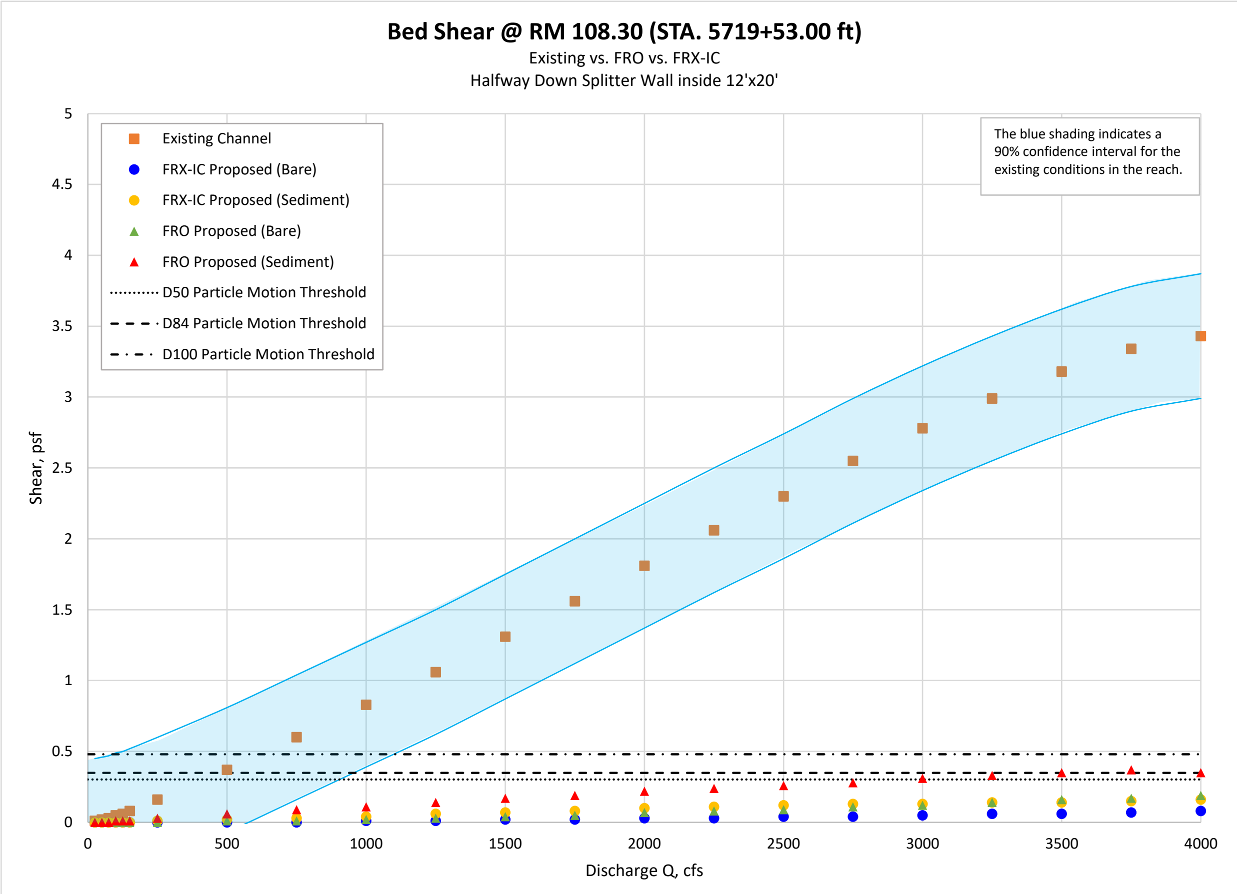
Figure 2-5
Sediment Sample Gradation near HEC-RAS Cross Section 108.532 used as Input to the Sediment Transport Modeling



Source: Dube, 2016

The primary measure of sediment transport capacity is usually the bed shear stress, which relates the hydraulic tractive force applied to the bed and to sediment particles. Bed shear stress is a function of discharge, hence with higher discharge comes greater shear stress and greater capacity for moving sediment particles. We compared bed shear stress for the existing channel, the FRO dam sluice conduits, and the FRE sluice conduits to relate the proposed dam alternatives to the natural channel reach. Bed shear stress was investigated for the FRE Dam Alternative and compared to that previously developed for the FRO and Existing Channel. A comparison of the bed shear stress between the three different models for Cross Section 108.30 is provided in below Figure 2-6. The comparisons of bed shear stress for all other cross sections are provided in Section 3.1.2 in Figure 3-15 through Figure 3-21.

Figure 2-6
Bed Shear Stress Comparison at Cross Section 108.30 about Midway through the Sluices between Existing Channel, FRO Dam Alt and FRE Dam Alt



The results of the sediment transport analysis using HEC-RAS reveals interesting and important evidence that the observed channel through the narrow scoured bedrock gorge at the proposed dam site will scour deeply and refill with sediment during flood events in which the substrate is mobilized. The results of the sediment transport analysis also show that the deep stilling basin downstream of the sluice conduits will similarly fill with sediment, and occasionally deeply scour these deposits, particularly at the sluice outlets. We compared the bed sediment elevations between the Existing natural channel (Figure 2-7), the previously evaluated FRO alternative with three sluices (Figure 2-8), and the FRE alternative (Figure 2-9) following four years of the hydrologic record from 1990 to 1994.

Figure 2-7
Bed Sediment Profile of Existing Channel following 4 years of Hydrologic Record (1990-1994)

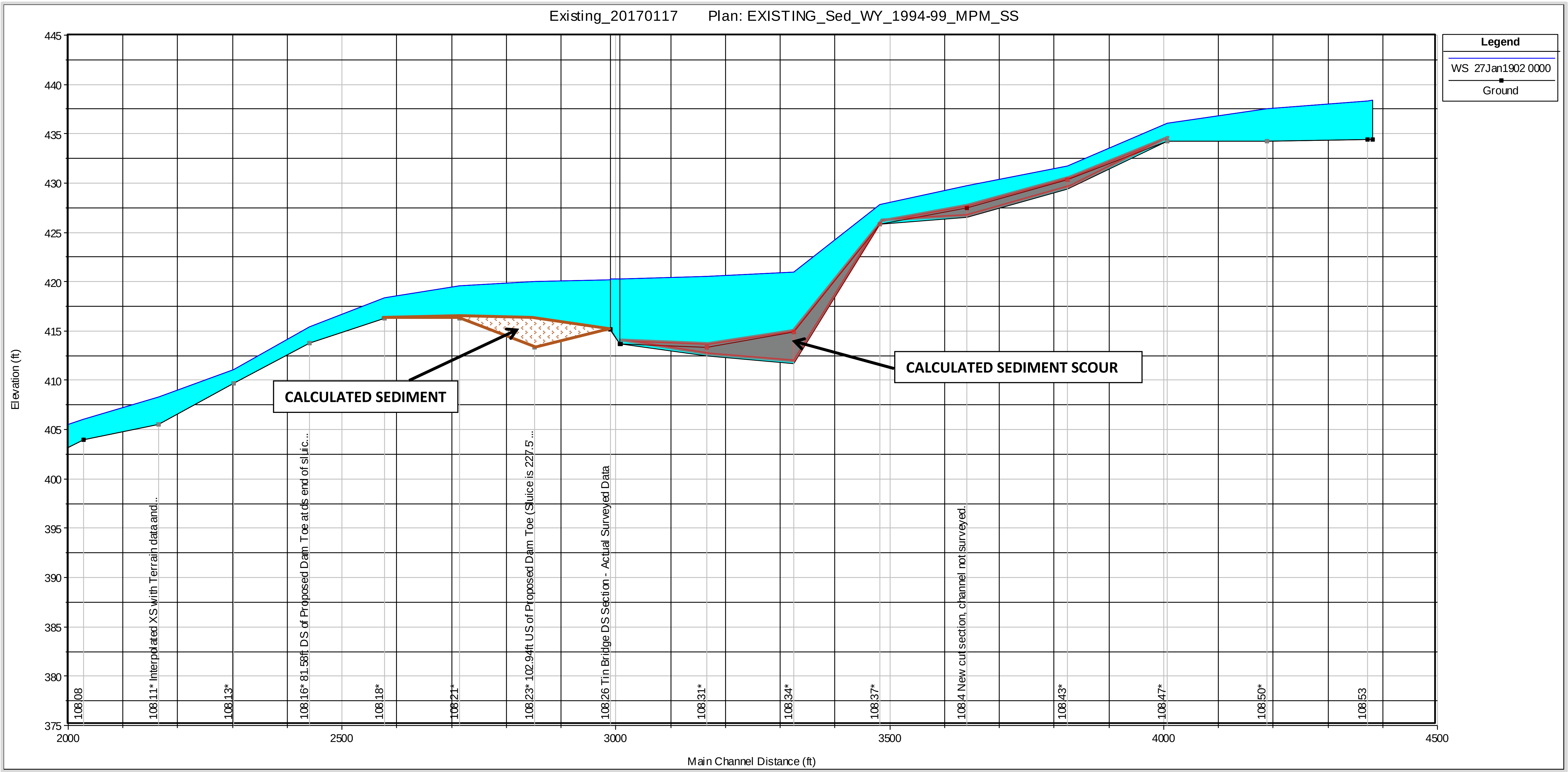


Figure 2-8

Bed Sediment Profile of the FRO Dam Alternative Following 4 Years of Hydrologic Record (1990-1994)

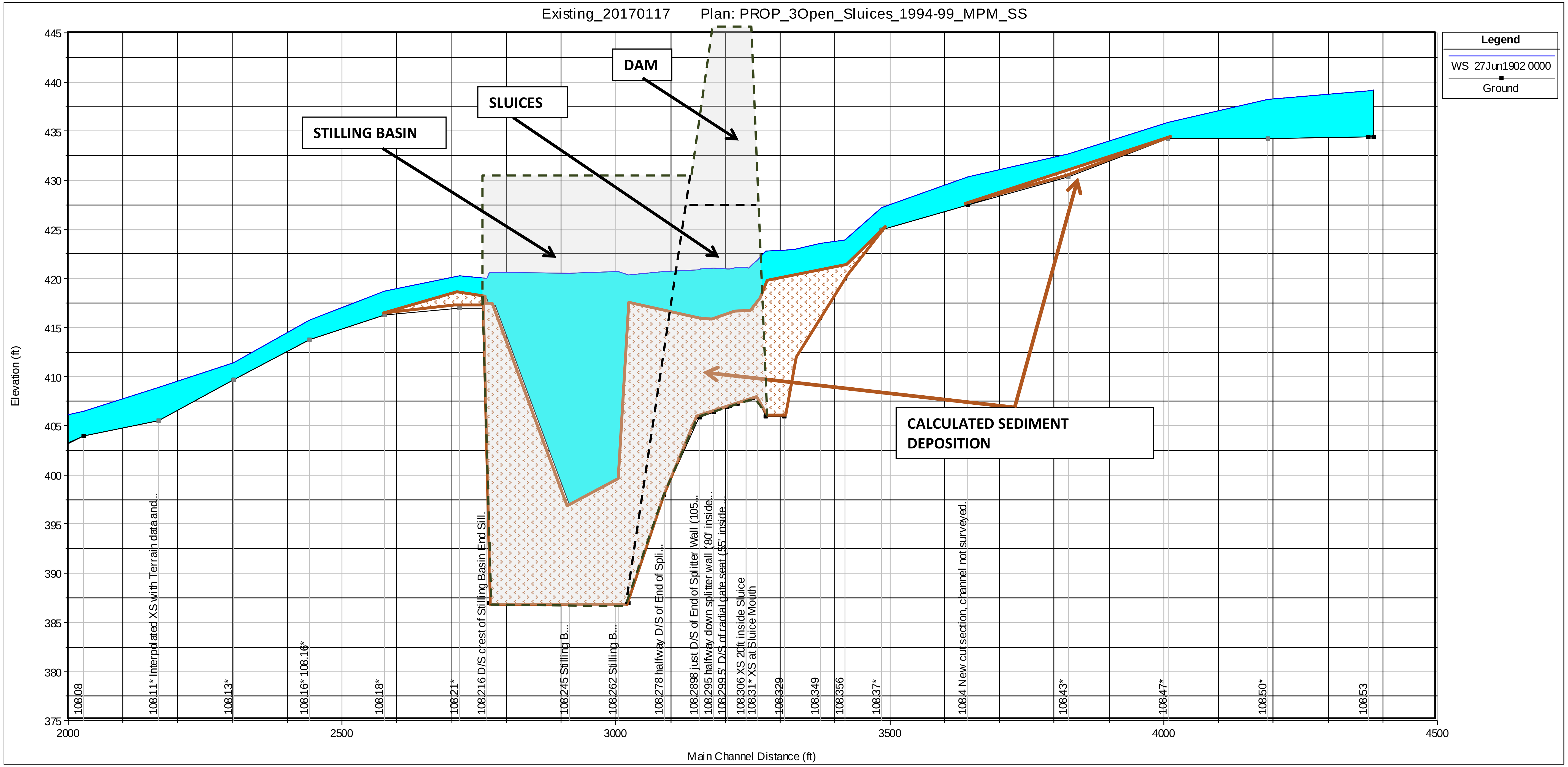
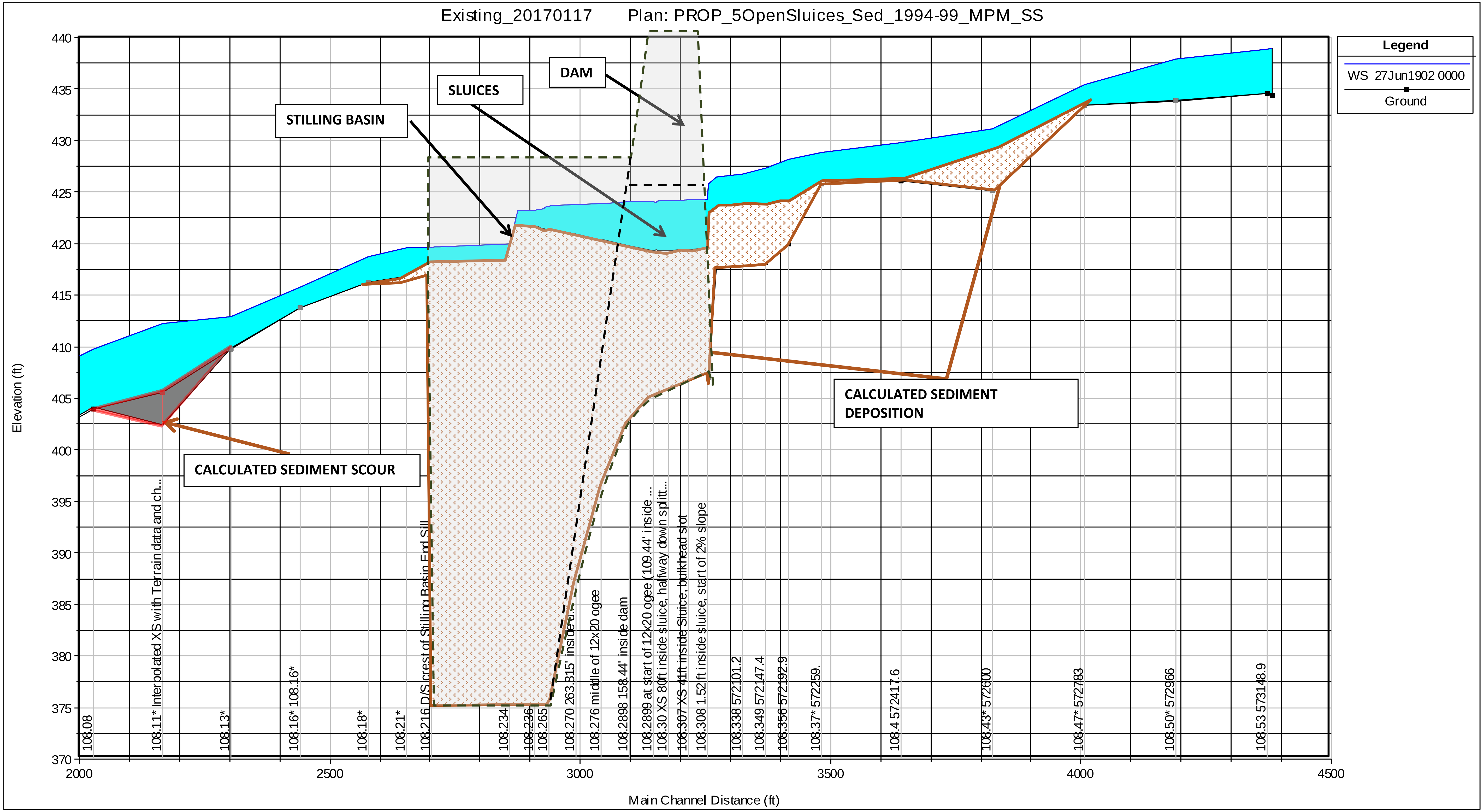


Figure 2-9
Bed Sediment Profile of the FRE Dam Alternative Following 4 Years of Hydrologic Record (1990-1994)



Through all river discharges in which the sluice gates are held fully open (i.e. no flood regulation operations), sediment will deposit throughout the sluice conduits and largely fill the stilling basin. This would represent the average condition, from a natural process and fish passage perspective. However, during a flood event in which the sluice gates would be closed or otherwise used to regulate dam discharges, any sediment that had deposited within the sluice conduits would be expected to be swept through the dam and deposit in the stilling basin or downstream in the natural channel. The action of closing the gates causes a high velocity flow jet to form immediately downstream of the gates, which would clear the sluices of deposits quickly. We evaluated both conditions numerically using the 1D HEC-RAS modeling to determine the range of expected conditions within the sluice conduits. As expected, the cleared sluices are much deeper than the existing natural channel, with commensurately lower flow velocities following the event. Bed sediment profiles following sluice gate regulation operations are provided in Figure 2-10 and Figure 2-11 below, for the FRO Dam Alternative and the FRE Dam Alternative, respectively. It should be noted that these sediment transport analyses are approximate only. More accurate and quantifiable sediment transport, deposition, scour, and performance information would be obtained from a physical scale model of the entire dam and appurtenant outlet works that will be conducted during the next phase of design.

Figure 2-10
Bed Sediment Profile for the FRO Dam Alternative Following Flood Regulation Operation

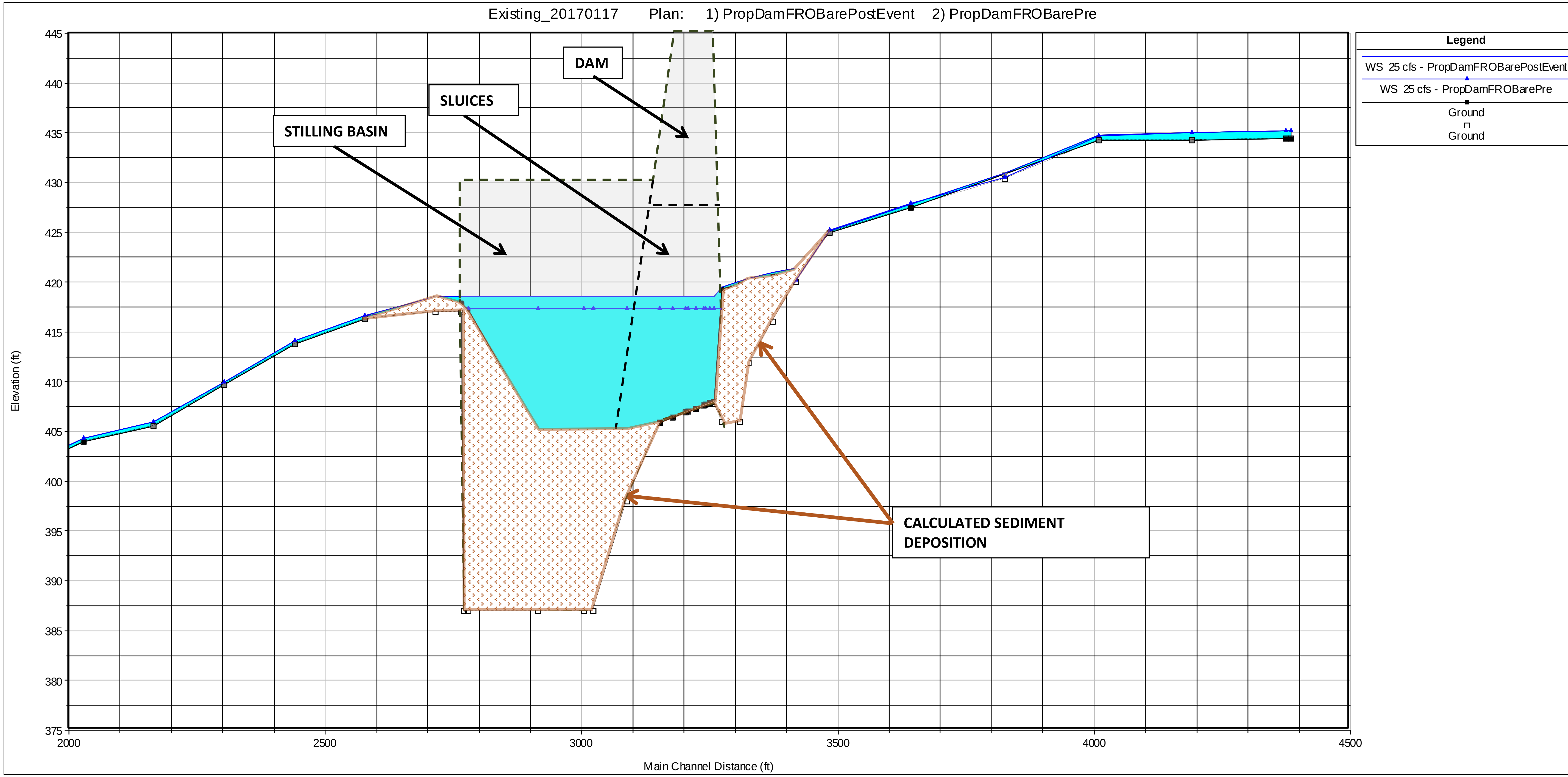
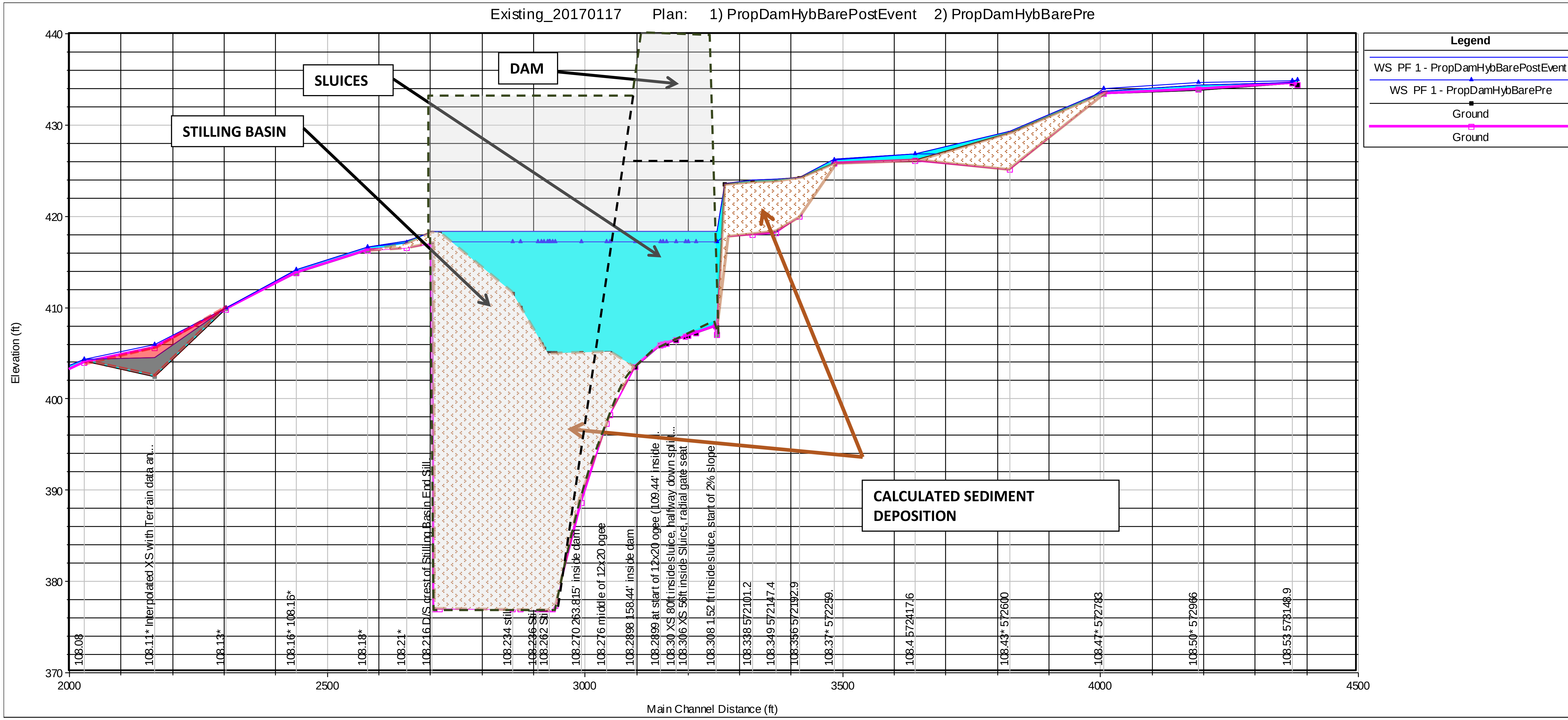


Figure 2-11

Bed Sediment Profile for the FRE Dam Alternative Following Flood Regulation Operation



2.5.3 Computational Fluid Dynamic (CFD) Modeling

A Computational Fluid Dynamic (CFD) model of the FRE geometry, with upstream boundary at the interior side of the intake trashrack and downstream boundary below the stilling basin control sill was constructed using FLOW3D software (product of Flow Science, Inc.). The CFD model mapped the bed bathymetry calculated with the HEC-RAS sediment transport model following the 4 year hydrograph discussed above (1990 – 1994). The upstream boundary was assumed to be a uniform flow boundary, which is appropriate given that the intake trashrack would tend to distribute inflows uniformly as result of the head loss induced across the width of the trashrack. The downstream boundary was assumed to be simply a flow boundary meeting the conservation of mass criteria by passing equal flow to the inflow boundary. The CFD model was run in steady state condition for 9 flows across the range of fish passage river discharges (100 cfs, 250 cfs, 500 cfs, 750 cfs, 1,000 cfs, 1,250 cfs, 1,500 cfs, 1,750 cfs, 2,000 cfs, and 2,200 cfs). Typical CFD model results are shown below for 750 cfs and 2200 cfs in Figure 2-12 through Figure 2-15, illustrating the flow velocity contours through the sluice conduits and stilling basin. The CFD modeling results for all other discharges are presented in Section (3.1.3) in Figure 3-22 through

Figure 3-39.

Figure 2-12
Isometric View of Velocity Contours for 750 cfs Discharge through Low Level Outlets

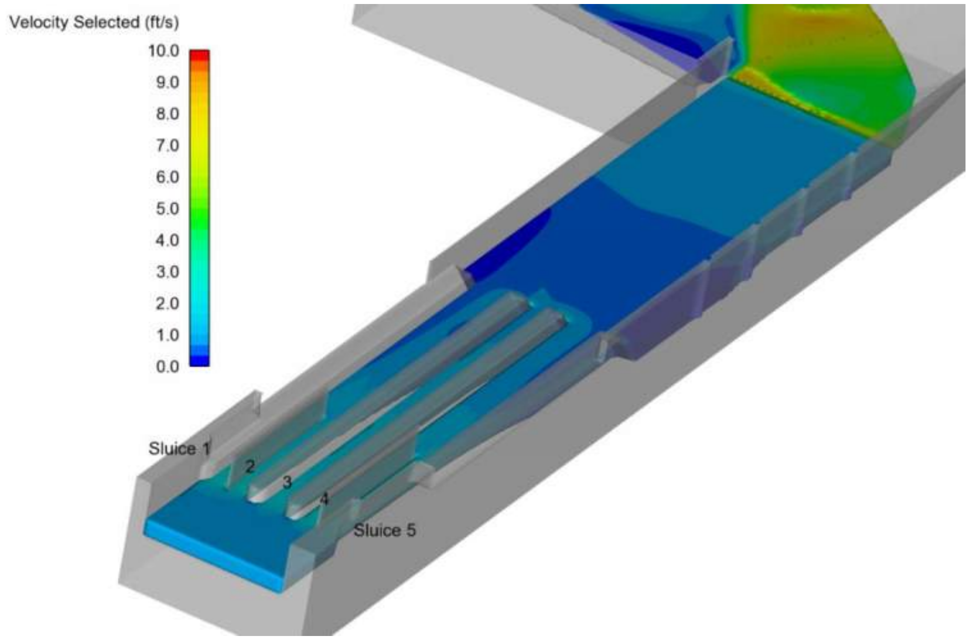


Figure 2-13
Profile View of Velocity Contours for 750 cfs Discharge through Low Level Outlets

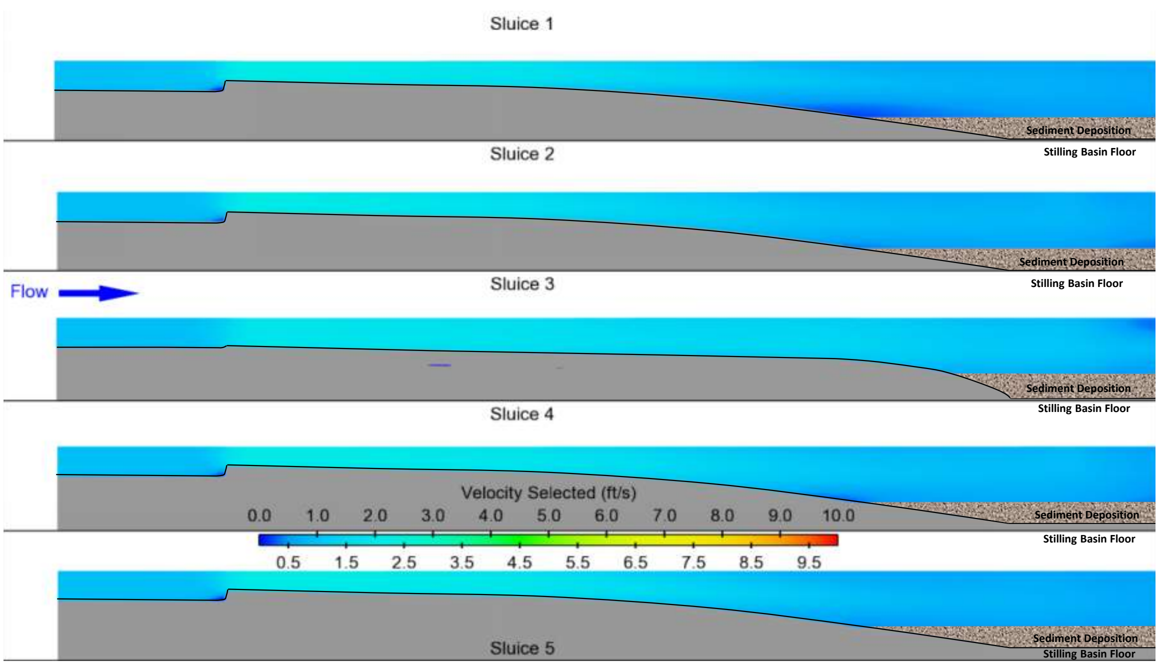


Figure 2-14
Isometric View of Velocity Contours For 2,200 cfs Discharge through Low Level Outlets

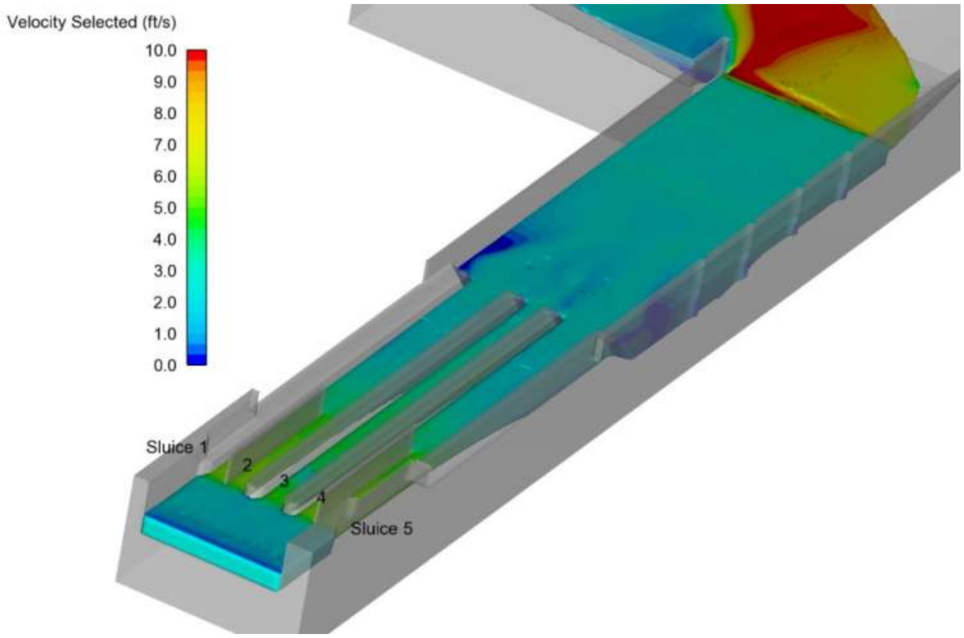
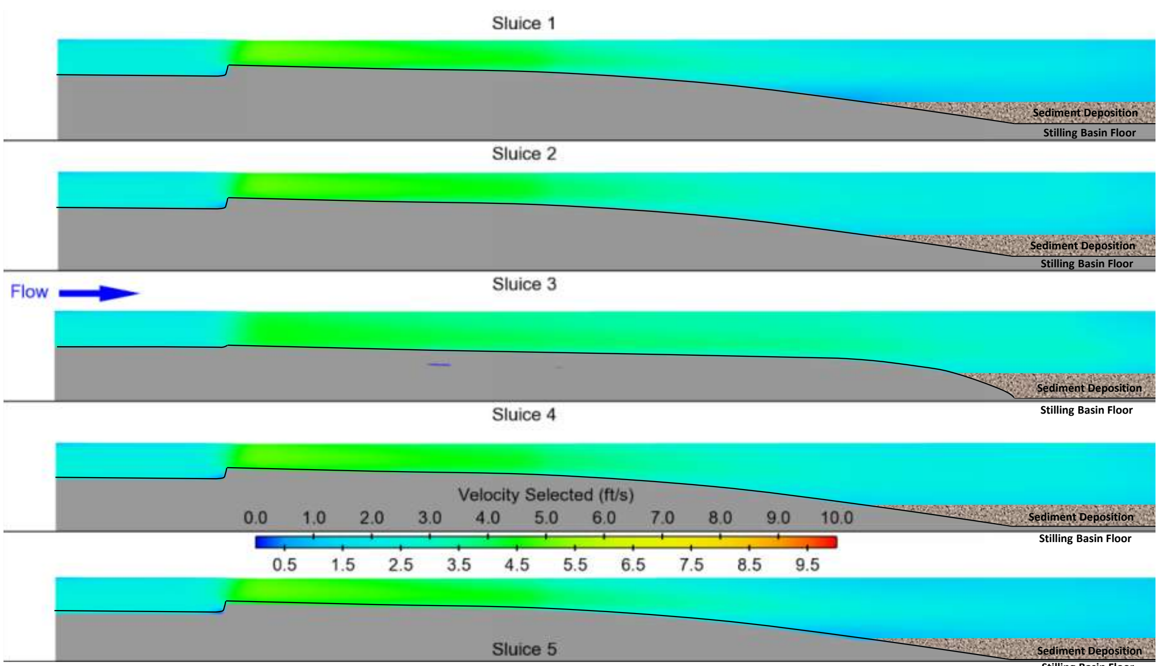


Figure 2-15
Profile View of Velocity Contours for 2,200 cfs Discharge through Low Level Outlets



2.6 Fish Passage

Similar to FRO, the FRE Dam alternative is designed to permit unimpeded fish passage upstream and downstream through the large low level sluice conduits, achieved by holding the sluice gates fully open under all flow conditions except when anticipated flood discharge is forecast to increase above the specified 38,000 cfs threshold at the Grand Mound gage. At and above this threshold, the low level flood regulating sluice gates would be closed as needed to store flood water in the reservoir. When the low level flood regulating sluice gates are closed or under operation, a fish ladder and trap and truck facility would commence operation to collect fish from the dam stilling basin and move them upstream as needed. No downstream migrant fish collection facilities are proposed for the FRE dam alternative.

The FRE-FC Dam alternative upstream migrating fish facility is the same as the FRE dam during flood regulation operation mode. However, unlike the FRE dam the sluices cannot be utilized for fish passage given the permanent reservoir. Therefore, the downstream migrating fish would be collected using a floating collector in the reservoir, then trucked downstream to be released into the river in FRE-FC dam alternative. The FRE dam alternative upstream migrating fish facility is similar to FRO and FRFA in size and configuration, as discussed in main body of the Draft Combined Dam and Fish Passage Conceptual Design Report. The remainder of this text will focus on the FRE Dam fish passage only.

The low level outlet works configuration for the FRO dam was determined by evaluating the hydraulic conditions of the flow through the sluices for various configurations. The final design of the FRO dam consists of a single large 12’ W x 20’ H sluice conduit at invert elevation of 408 ft, and a pair of 10’W x 16’ sluice conduits at invert elevation of 411 ft. The HEC-RAS clear-water simulations (no sediment transport) of the flow through the sluices for full open gate and open channel conditions showed that this configuration results in a flow velocities similar to that of the preexisting river channel conditions across the full range of fish passage discharges from 25 to 2,200 cfs. This met the Washington Department of Fish & Wildlife fish passage criteria of the flow velocity through the conduits shall not exceed the preexisting river velocity at the project location. This concept of a slightly lower, larger sluice gate and conduit was based on the Mud Mountain Dam analogous outlet works, where the lowest sluice intentionally passes the majority of bed load sediment in order to isolate erosion damage to a single outlet that can be readily repaired.

Following the FRO low level outlet work configuration design, it was decided to add a second pair of 10’W by 16’H sluice conduits at the invert elevation of 411 ft to the FRE dam alternative to reduce the flow velocities in the sluices. This effort was made to investigate the possibility of achieving 2 fps flow velocity over the range of fish passage discharges through the sluices which was initially the target criteria provided by the Washington Department of Fish & Wildlife fish passage.

The refined sluice outlet configuration for the FRE dam alternative was modeled using the HEC-RAS 1D and CFD models to examine more detailed velocity and depth characteristics, as discussed above in

Section (2.5). As expected, the addition of second pair of 10’W x 16’H in FRE alternative design reduced the flow velocities through the conduits compare to the three conduits configuration for FRO.

2.7 Construction Diversion

Construction diversion is arguably the highest risk construction component of the project, in terms of both cost and schedule. Constructing the diversion is critical-path work, as is much of the work that relies on that diversion. Since the FRE dam alternative is a phased approach combination of the FRO and FRFA, the previously designed construction diversion structure for FRO and FRFA alternatives would provide satisfactory performance for the FRE alternative as well. The construction diversion design procedure is presented in detail in the Appendix B (Section 2.8) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

2.8 Spillway Design

Spillway provides safe conveyance from reservoir to the downstream of the dam for all flood discharges up to the spillway design flood. Design guidance utilized in the design of the spillway included USACE EM 1110-2-1603, Hydraulic Design of Spillways; the USACE Hydraulic Design Criteria (HDC); and the USBUREC Design of Small Dams. Similar to FRO and FRFA spillways, the FRE alternative spillway is an uncontrolled ogee spillway. The Ogee spillway shape design procedure is presented in detail in the Appendix B (Section 2.9) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

The FRE spillway crest is set at elevation 628 ft with a width of 200 feet, and is designed to pass up to 69,800 cfs with 4.3 feet of freeboard to the top of the upstream crest parapet wall. The equivalent unit discharge at full design capacity is 349 cfs per linear foot. The design discharge capacity has been conservatively estimated using a slightly lower discharge coefficient (C_d = 3.73) than is typically found for smooth ogee designs, to ensure adequate capacity without risk of overtopping. The FRE spillway is designed with a relatively short and shallow approach channel which positions the ogee crest approximately 50 ft downstream of the dam crest. The optimal depth of approach channel was selected to provide subcritical flow condition in the channel. The 10 ft deep approach channel resulted in Froude number values less than 0.5 for the range of spill flows up to PMF. This ensures that the critical depth control condition only occurs at the spillway crest for all flows and there would not be any control shift phenomenon from the crest to the approach channel entrance section. The flow depth and velocity at the toe of spillway just before entering the energy dissipation structure are estimated using the turbulent boundary layer development method. The flow leaving the spillway chute has a depth and velocity of about 3.7 ft and 99.9 ft/s, respectively, and an equivalent energy head loss of about 11 ft. Figure 2-16 shows the FRE spillway rating curve.

The FRE-FC spillway crest is set at elevation 687 feet with a width of 200 feet, and is designed to pass up to 69,800 cfs with 5 feet of freeboard to the top of the upstream dam parapet wall. The equivalent unit discharge at full design capacity is 349 cfs per linear foot. The design discharge capacity has been conservatively estimated using a slightly lower discharge coefficient (C_d = 3.84) than is typically found for smooth ogee designs, to ensure adequate capacity without risk of overtopping. To construct the FRE-FC spillway, the FRE spillway crest will be demolished while the flip bucket structure and a significant portion of the spillway chute will remain in place. Then, the RCC construction will proceed in lifts to facilitate the construction of the FRE-FC spillway. The flow depth and velocity at the toe of spillway just before entering the energy dissipation structure are estimated using the turbulent boundary layer development method. The flow leaving the spillway chute has a depth and velocity of about 3.2 ft and 117.5 ft/s, respectively, and an equivalent energy head loss of about 22.5 ft. Figure 2-17 shows the FRE-FC spillway rating curve.

Figure 2-16
FRE Spillway Discharge Curve

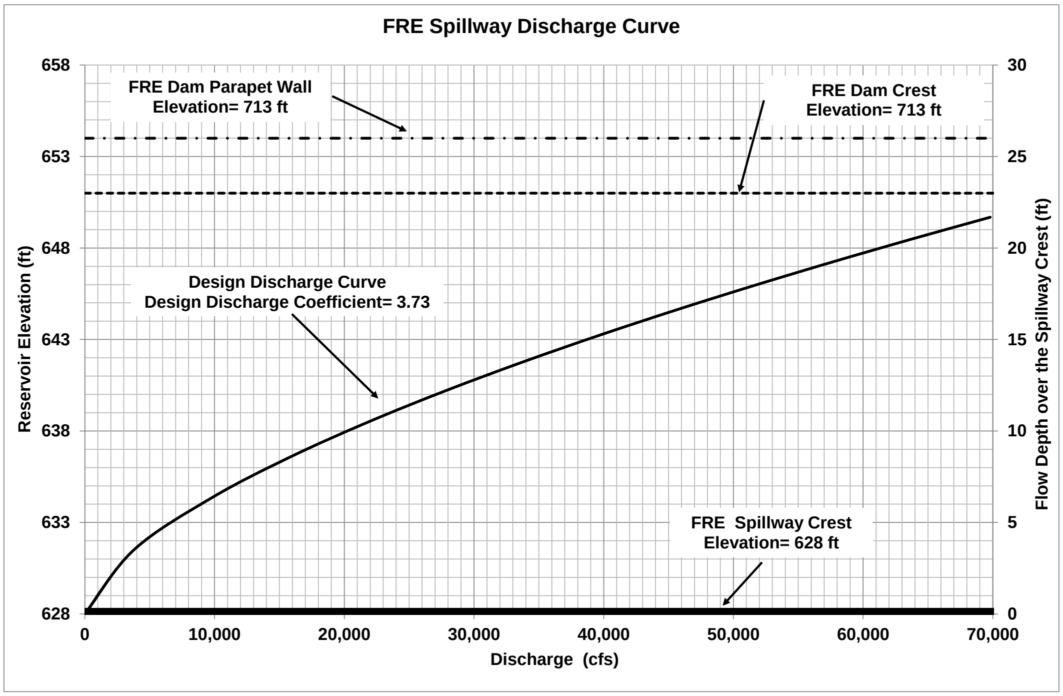
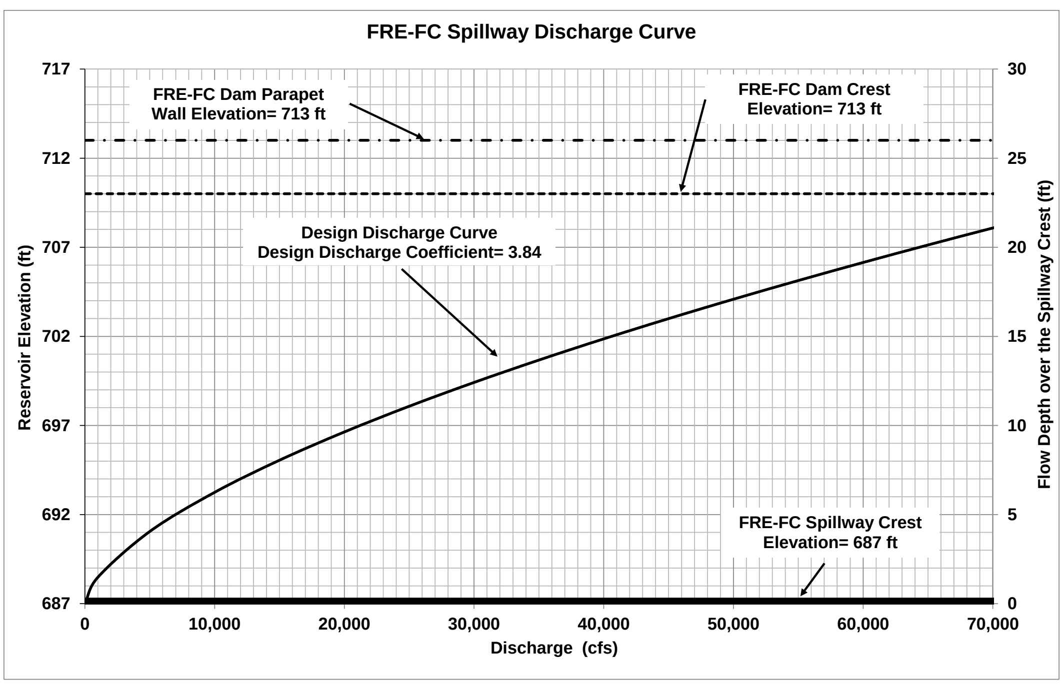


Figure 2-17
FRE-FC Spillway Discharge Curve



2.9 Flip Bucket and Plunge Pool

Flip bucket is part of the energy dissipation system which directs the incoming high velocity flow down the spillway chute away from the dam. After the flow leaves the flip bucket, extreme turbulence and consequently large quantity of air entrainment into the jet helps to dissipate its energy.

Similar to FRO and FRFA, the FRE alternative spillway is expected to be used very rarely, and for events of very short duration. Therefore, no spillway stilling basin is provided. Rather, a flip bucket and preformed impact plunge pool will be constructed to dissipate the energy of spillway flows.

Design guidance utilized in the design of the flip bucket geometry included USACE EM 1110-2-1603, Hydraulic Design of Spillways and the USACE Hydraulic Design Criteria (HDC). The FRE alternative flip bucket structure design procedure is similar to FRFA and FRO. A sample design calculation for FRFA alternative is explained in detail in Appendix B (Section 2.10) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

For the FRE dam alternative (both FRE and FRE-FC), the flip bucket design is based on the unit discharge of 349 cfs per linear foot of width at maximum spillway flow (PMF), with the bucket invert at elevation 475 ft and the lip at elevation 489.6 ft.

For the FRE dam, the flow profile down the spillway chute was evaluated using the turbulent boundary layer development method, with the result that at maximum discharge (PMF) the toe velocity is about 99.9 feet per second and depth of about 3.7 feet, yielding a minimum bucket radius of 40.4 ft.

For the FRE-FC dam, the flow profile down the spillway chute was also evaluated using the turbulent boundary layer development method, with the result that at maximum discharge (PMF) the toe velocity is about 117.5 feet per second and depth of about 3.2 feet, yielding a minimum bucket radius of 48.0 ft.

However, we have used the same 50-foot radius for both the FRE and FRE-FC flip bucket designs for simplicity. The trajectory angle of 45 degree was considered to achieve a maximum jet trajectory distance. Figure 2-18 shows the PMF water surface profile down the FRE spillway and jet trajectory leaving the flip bucket. Trajectory calculations determined an approximate impact zone of about 350 feet downstream of the bucket lip.

Figure 2-19 shows the PMF water surface profile down the FRE-FC spillway and jet trajectory leaving the flip bucket. Trajectory calculations determined an approximate impact zone about 500 feet downstream of the lip. The rockfill design below the flip bucket would be developed during the next phase of the study.

Figure 2-18
FRE Spillway and PMF Water Surface Profile

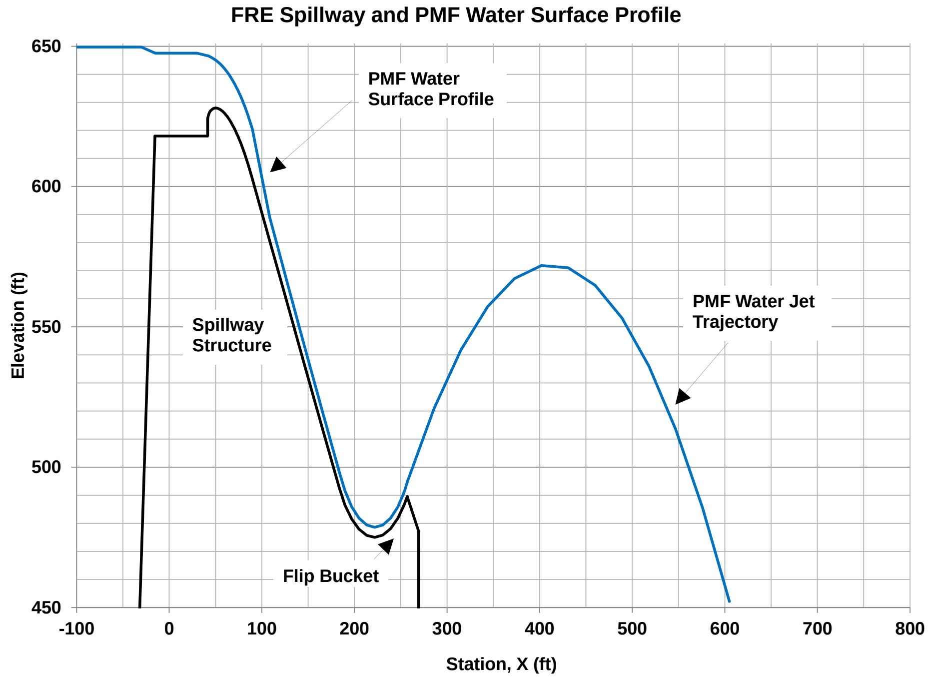
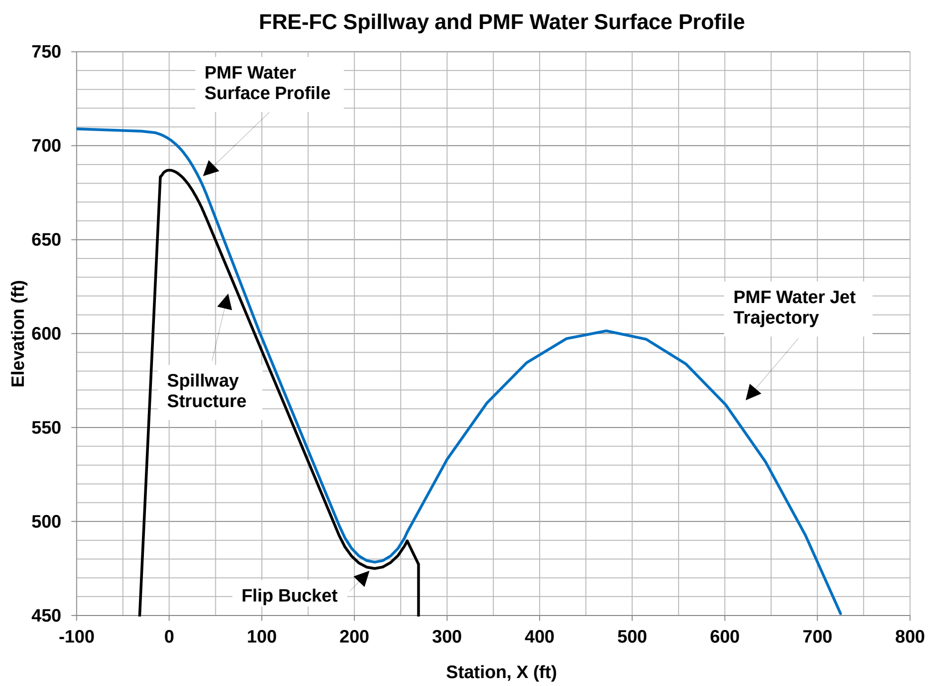


Figure 2-19
FRE-FC Spillway and PMF Water Surface Profile



2.10 Flood Regulation Outlets

Flood regulation outlets are designed to pass relatively large flows and can be gated to provide close regulation of the flow. USACE EM 1110-2-1602, Hydraulic Design of Reservoir Outlet Works, was utilized as the design guidance in the design of the outlet works. Rating curves were generated for each potential sluice size and elevation to determine the proper design that would work best if implemented. These rating curves were compared with the design discharge, and the sluice sizes were iterated to meet the discharge required for flood control outlets as well as to function as effective fish passage conduits, matching the velocities of the existing channel.

The FRE alternative design has five low-level sluice outlets, consisting of a single larger 12’ W x 20’ H sluice at invert elevation 408 ft and two pairs of 10’ W x 16’ H sluices at invert elevation 411 ft on each side of the larger sluice. A large, full height trashrack extending from the riverbed to the dam crest will exclude most large trees from the sluice conduits and provide excess open area under all reservoir elevations to pass the desired project outflows. The partial and full open gate rating curves for the single large 12’ W x 20’ H sluice gate, single and double 10’ W x 16’ H sluice gates are provided in Figure 2-20 through Figure 2-22.

For FRE dam, with all five low-level flood regulation sluice gates fully open, up to approximately 12,500 cfs can be passed through the sluices without transitioning to orifice or pressure flow in any of the sluice openings, with reservoir elevation at 426 ft. The 15,000 cfs project design outflow can be passed entirely through one pair of 10’ W x 16’ H sluices at reservoir elevations greater than about 580 ft with the gate fully open. Typical flood regulation operation would initiate closure of the larger sluice at any time the pool levels exceed about 72 feet in depth over the sluice ceiling (i.e., reservoir elevation 500 ft), to prevent excessive wear on the large sluice floor due to bed sediments entrained in high flow velocity. The higher gates (the two pairs of 10’ W x 16’ H sluices) are expected to entrain considerably less sediment, though the specific elevation details to confirm this and establish the final higher sluice gate seat elevation would have to be evaluated using a physical laboratory scale model. Following the closure of the larger 12’ W x 20’ H sluice gate, one pair of the 10’ W x 16’ H sluice gates would also initiate closure and the flood would only be regulated through one pair of the 10’ W x 16’ H ft sluices.

The smaller 10’ W x 16’ H sluice gates are designed to pass up to 3,000 cfs each with 23 feet of static head on the gate at the 75 percent open setting, while the larger 12’ W x 20’ H gate can pass the same 3,000 cfs with 13 feet of static head on the gate at the 75 percent open setting. This ensures that the full 15,000 cfs desired sluice discharge capacity is available at reservoir elevations as low as 440 ft in a fully controlled manner, which is about 188 feet below the spillway crest.

At full flood storage reservoir elevation of 628 ft, each of the smaller sluice gates at 75 percent open can pass up to about 9,500 cfs, and the larger gate can pass up to about 14,200 cfs alone. The paired design of the two smaller gates was selected to ensure that finely controlled flood regulation would be available with a single gate as needed, given that the larger gate will likely be closed. Adjustment of a single 10 ft wide gate in 6-inch typical lift increments gives just 380 cfs per increment at the maximum flood regulation reservoir elevation of 628 ft. The importance of controlling downstream flows is that required ramping rates can be achieved. Flood regulation operation would include operation of the sluices at reservoir elevations up to the spillway crest of 628 ft. At reservoir elevation above the spillway crest, sluice operation may be curtailed to avoid adverse flow conditions within the stilling basin.

For the FRE-FC dam, the low-level outlet works are identical to the FRE. The only modification to accommodate the FRE-FC dam outlet works would be extending the large trashrack in front of the outlet works to the full height of the FRE-FC dam. As described above, the low-level flood regulation sluices are designed for a controlled discharge of 15,000 cfs at any reservoir elevation within the full operating range of the project (reservoir elevation 588 ft to 687 ft). At minimum operational reservoir elevation of the project (reservoir elevation of 588 ft) each of the smaller sluice gates at 75 percent open can pass up to about 8,500 cfs, and the larger gate can pass up to about 12,800 cfs alone. At full flood storage reservoir elevation of 687 ft each of the smaller sluice gates at 75 percent open can pass up to about 10,700 cfs, and the larger gate can pass up to about 16,100 cfs alone. FRE-FC flood regulation operation would include operation of the sluices at reservoir elevations up to the spillway crest of 687 ft. At reservoir elevation above the spillway crest, sluice operation may be curtailed to avoid adverse flow conditions within the stilling basin.

Figure 2-20
FRE Alternative Single 12 ft wide by 20 ft high Sluice Gate Rating Curves

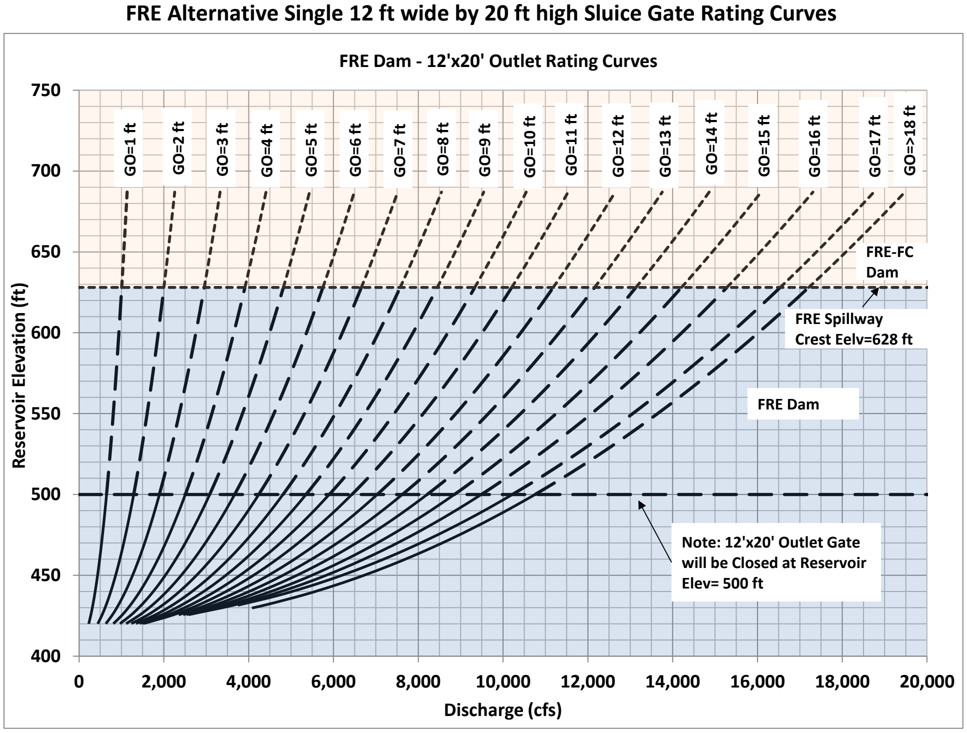


Figure 2-21

FRE Alternative Single 10 ft wide by 16 ft high Sluice Gate Rating Curves

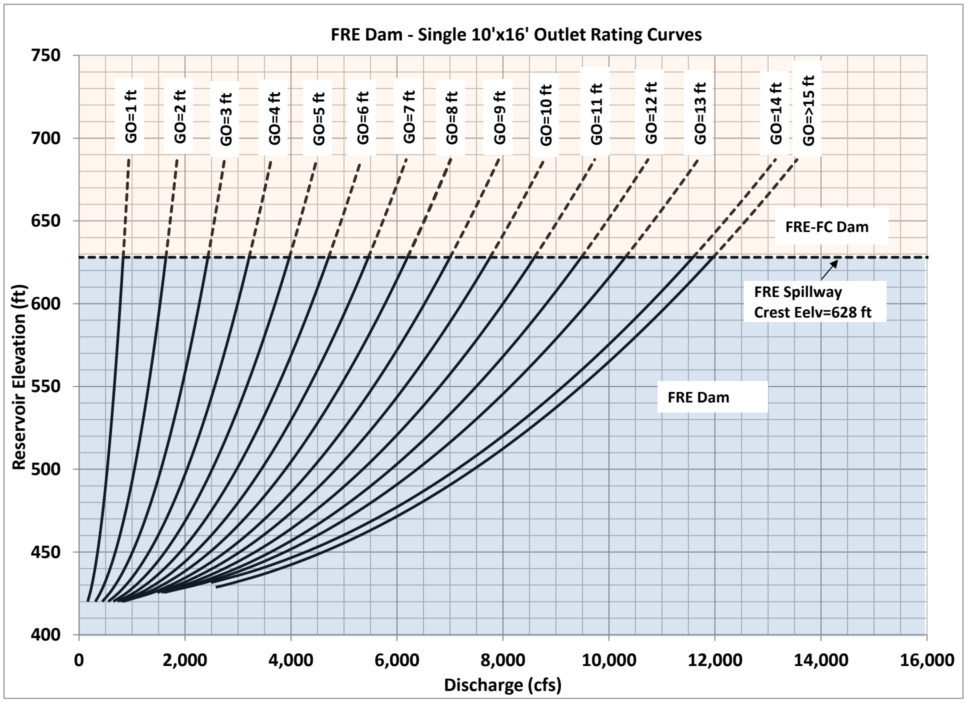
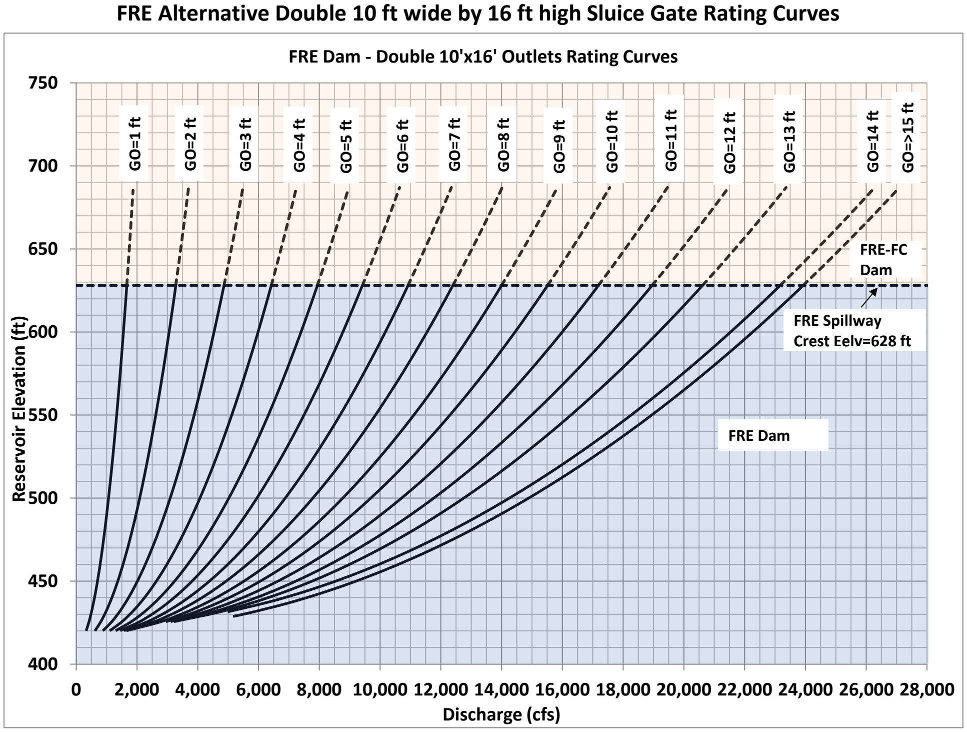


Figure 2-22

FRE Alternative Double 10 ft wide by 16 ft high Sluice Gate Rating Curves



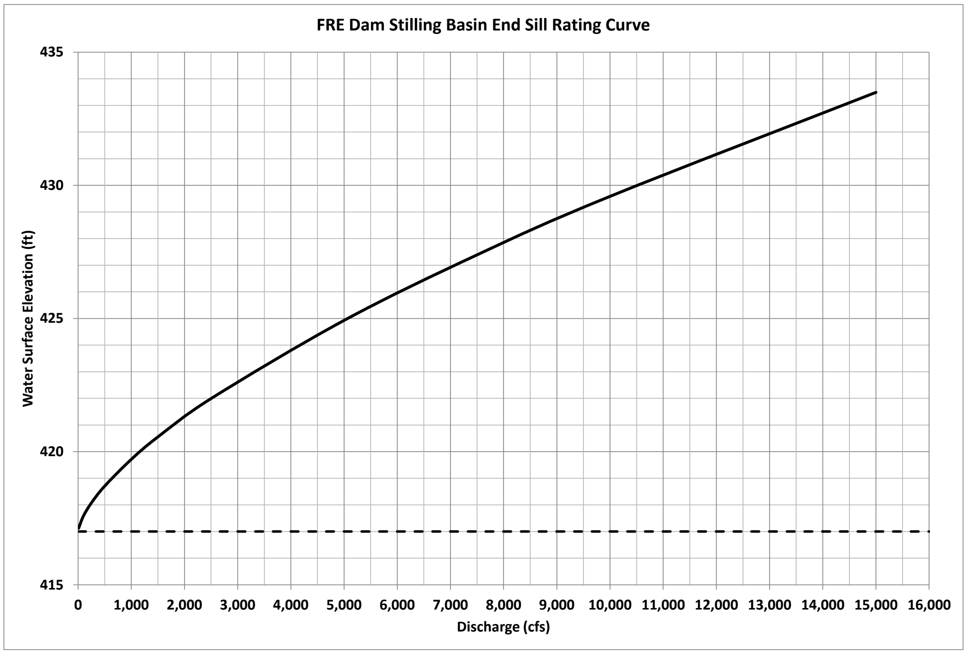
2.11 Stilling Basin

To dissipate the high energy of flowing water exiting the outlet work structure a stilling basin is required. Stilling basin produces a hydraulic jump and consequently dissipates the flow energy. Design guidance utilized in the design of the outlet works stilling basin is USACE EM 1110-2-1602, Hydraulic Design of Reservoir Outlet Works. A sample of the stilling basin design procedure is presented in detail in the Appendix B (Section 2.12) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

The stilling basin for the FRE alternative design receives flood regulation outflows from the 12' W x 20' H gate at reservoir elevations up to about 500 ft and also discharges from the two pairs of 10' W x 16' H sluice gates, up to a design discharge of 15,000 cfs at maximum reservoir elevation at the spillway crest elevation of 628 ft and 687 ft for the FRE and FRE-FC, respectively. The design for the FRE-FC stilling basin handles water under higher heads and was used to define the design dimensions, which are conservative for the outflows expected from the FRE.

Assuming one pair of 10' W x 16' H sluices is discharging 15,000 cfs under the maximum reservoir elevation of 687 ft for FRE-FC, the flow velocity entering the basin would be approximately 140 feet per second, with a Froude number of about 12.6. Following USACE guidance, a baffled stilling basin length of approximately 230 ft is obtained, assuming a 102-foot width overall. The end sill elevation was selected to be commensurate with the natural bedrock-controlled stream bed elevation of about 417 ft, and the width of 102 feet provides a water surface profile of about 430 ft at the full sluice outlet discharge of 15,000 cfs. HEC-RAS modeling of the natural downstream channel indicates that the natural water surface at the end sill location is about 422 ft at the maximum stilling basin capacity of 15,000 cfs, ensuring hydraulic control by the end sill, since submergence of the end sill is just 5 feet against a driving head of 13 ft. The downstream conjugate depth at 15,000 cfs is approximately 66 ft, yielding a basin floor elevation of 377 ft, which provides adequate energy dissipation within the basin. Currently, the endsill is considered to be a broad crest weir. However for fish passage purposes, the flow pattern through the stilling basin could favorably be altered by designing a compound endsill configuration. The endsill configuration will be refined in the next phase of study. Figure 2-23 shows the stilling basin end sill rating curve.

Figure 2-23
FRE Dam Alternative Stilling Basin End Sill Rating Curve



2.12 References

Anchor QEA, 2014. Revised Operations for Flood Retention Only Dam, Seattle, Washington.

Anchor QEAS, 2016. Chehalis Basin Strategy: Draft Operations Plan for Flood Retention Facilities. November, 2016

Dube, Kathy. 2016. email communication regarding sediment bed gradation and transport rates.

HDR, 2017. Draft Combined Dam and Fish Passage Conceptual Design. June, 2017

Henderson, F.M. 1966. Open Channel Flow. MacMillan Publishing Company, New York.

USACE, *Engineer Manual EM 1110-2-1601, Hydraulic Design of Flood Control Channels*, U.S. Army Corps of Engineers, Washington D.C., June 1994

USACE, *Engineer Manual EM 1110-2-1602, Hydraulic Design of Reservoir Outlet Works*, U.S. Army Corps of Engineers, Washington D.C., October 1980

USACE, *Engineer Manual EM 1110-2-1603, Hydraulic Design of Spillways*, U.S. Army Corps of Engineers, Washington D.C., August 1992

USACE, *Engineer Manual EM 1110-2-2006, Roller Compacted Concrete*, U.S. Army Corps of Engineers, Washington D.C., January 2000

USACE, *Engineer Manual EM 1110-2-2701, Vertical Lift Gates*, U.S. Army Corps of Engineers, Washington D.C., November 1997

USACE, *Engineer Manual EM 1110-2-2702, Design of Spillway Tainter Gates*, U.S. Army Corps of Engineers, Washington D.C., January 2000

USACE, *Engineer Manual EM 1110-2-4000, Sedimentation in Rivers and Reservoirs*, U.S. Army Corps of Engineers, Washington D.C., December 1989

USACE, *Engineer Regulation ER-1105-2-101, Risk-Based Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability, and Economics in Flood Damage Reduction Studies*, U.S. Army Corps of Engineers, Washington D.C., March 1996

USACE, *Engineer Regulation ER 1110-2-1156, Safety of Dams – Policy and Procedures*, U.S. Army Corps of Engineers, Washington D.C., March 2014

USACE, *Hydraulic Design Criteria*, U.S. Army Corps of Engineers, Washington D.C., November 1987

USBUREC, *Engineering Monograph No. 25 - Hydraulic Design of Stilling Basins and Energy Dissipators*, U.S. Department of the Interior, Bureau of Reclamation, 1994

USBUREC, *Engineering Monograph No. 41 - Air-Water Flow in Hydraulic Structures*, U.S. Department of the Interior, Bureau of Reclamation, 1980

USBUREC, *Engineering Monograph No. 42 - Cavitation in Chutes and Spillways*, U.S. Department of the Interior, Bureau of Reclamation, 1990

USBUREC, *Design of Small Dams*, U.S. Department of the Interior, Bureau of Reclamation, 1987

USBUREC, *Roller-Compacted Concrete - Design and Construction Considerations for Hydraulic Structures*, U.S. Department of the Interior, Bureau of Reclamation, 2005

USGS, 1967. *Roughness Characteristics of Natural Channels*, U.S. Geological Survey Water Supply Paper 1849. United States Government Printing Office, Washington, D.C.

WSE, 2014. Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species - Peer Review of December 2007 Peak and Hydrograph at Doty Gaging Station. Memorandum to H&H Technical Committee from Watershed Science and Engineering, dated 31 January, 2014.

WSE, 2016a. Personal communication with Larry Karpack. October, 2016.

WSE, 2016b. Upper Chehalis Basin HEC-HMS Model Development. DRAFT Memorandum to Chehalis Basin Strategy Technical Team, dated 30 June, 2016.

3 CALCULATIONS, TABLES AND FIGURES

3.1 FRE Hydraulic Characterization

3.1.1 Velocity and Depth Characterization

Figure 3-1

Flow Velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Project Site (RM 108.47)

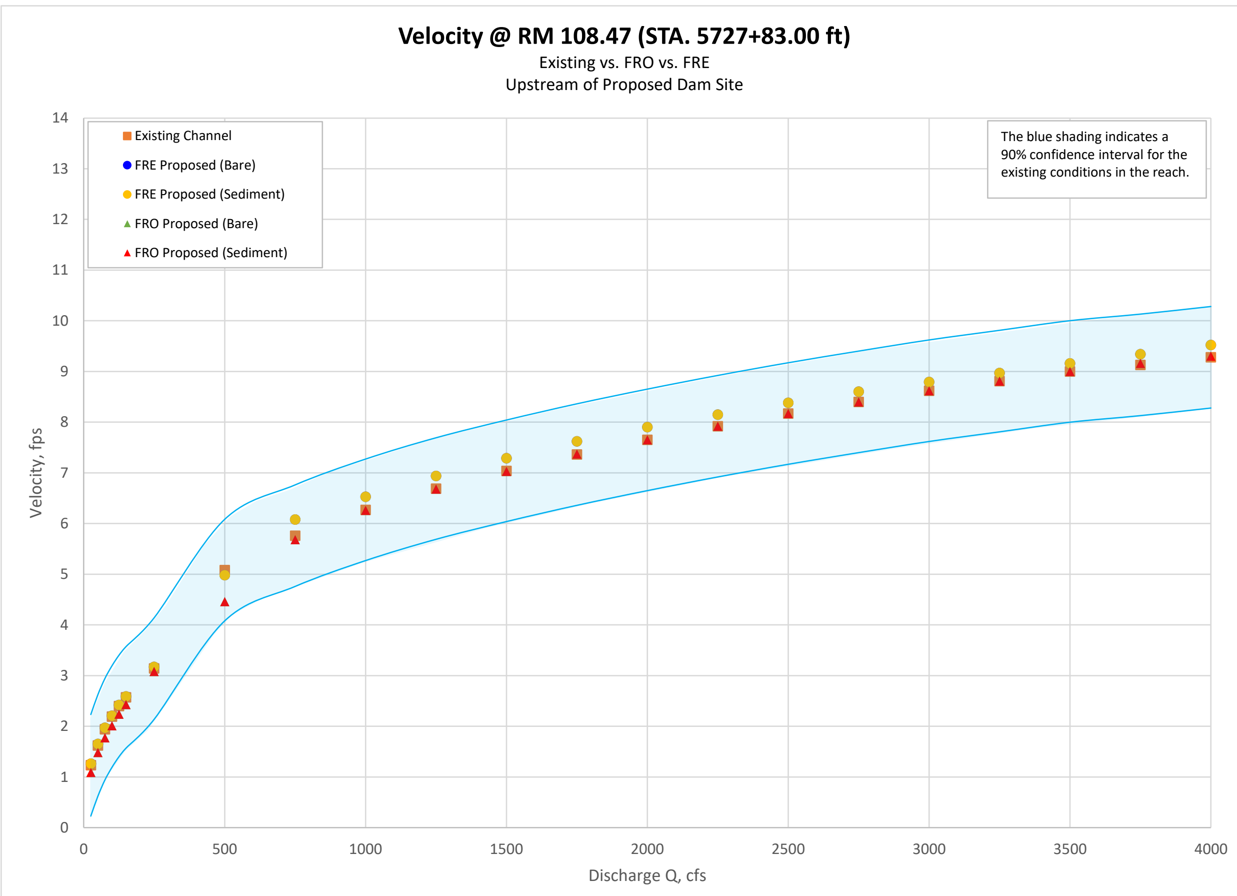


Figure 3-2

Flow Velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Project Location (RM 108.37)

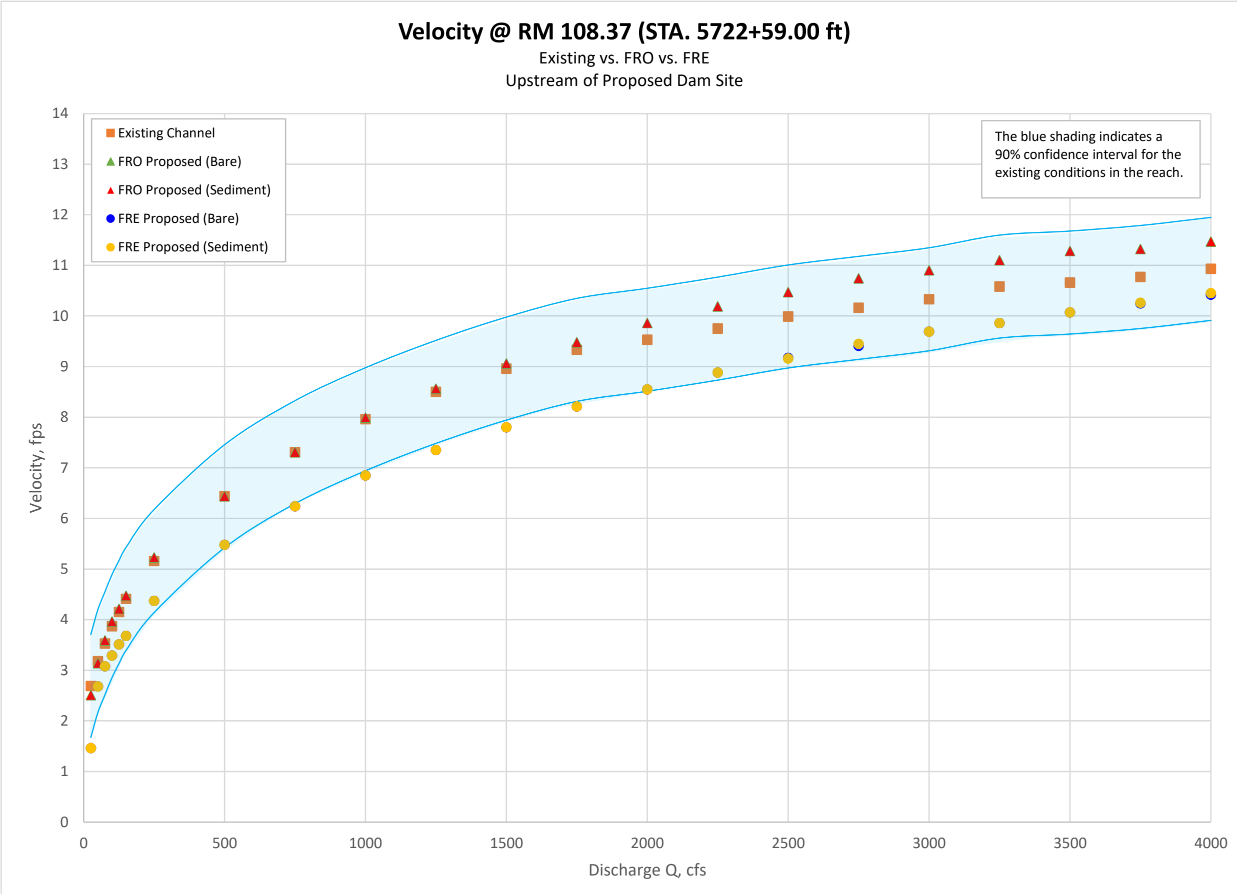


Figure 3-3

Flow Velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations at the 12'x20' Sluice Mouth (RM 108.31)

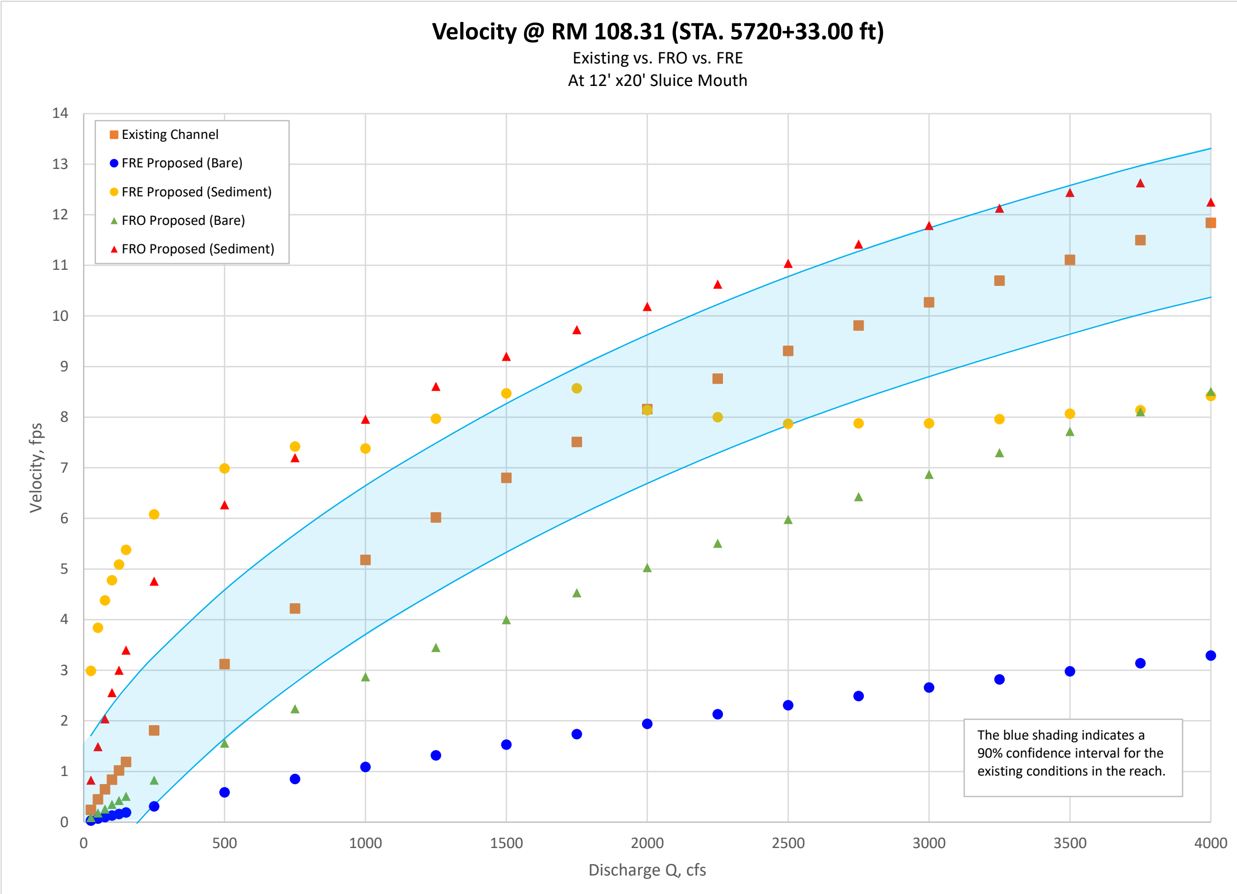


Figure 3-4

Flow Velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Inside the 12’x20’ Sluice (RM 108.30)

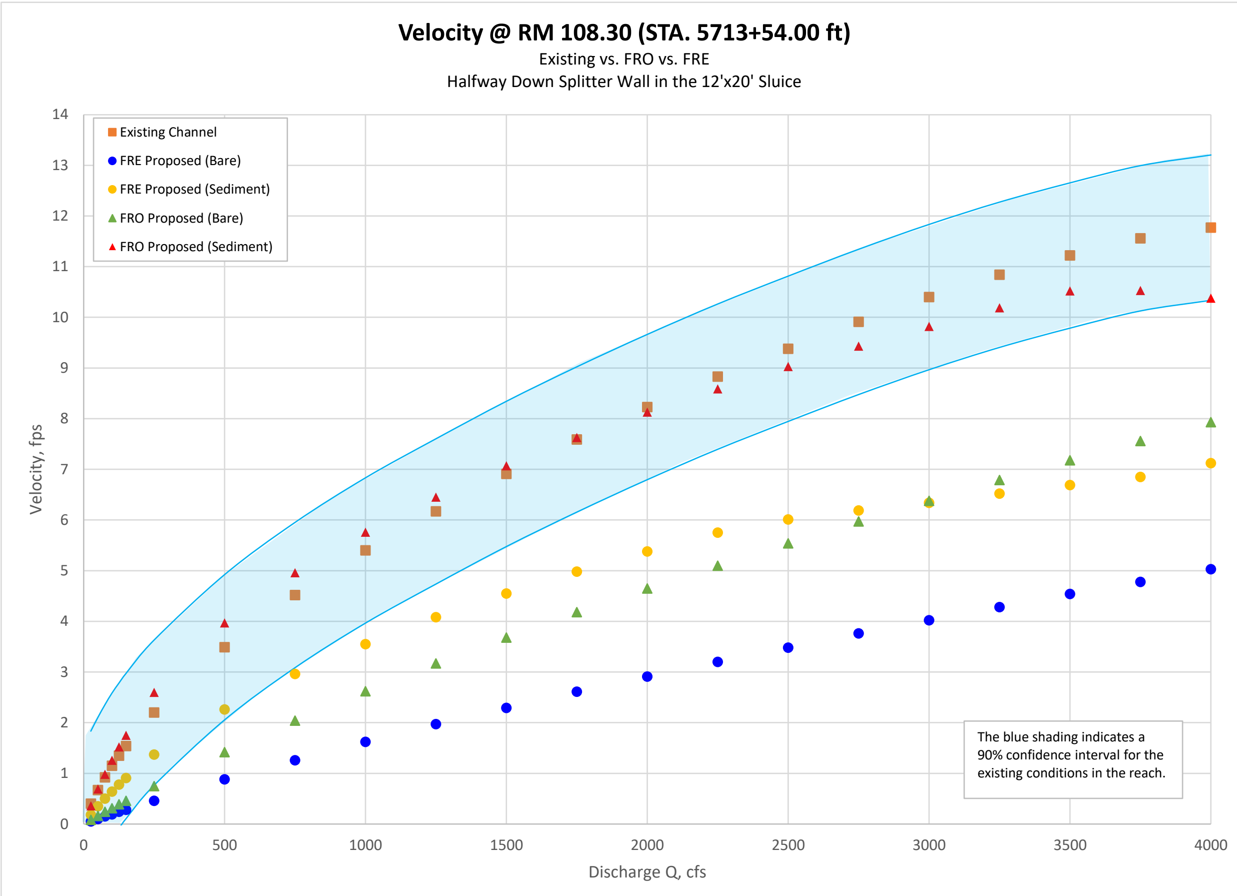


Figure 3-5

Flow Velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Downstream of the 12’x20’ Sluice (RM 108.27)

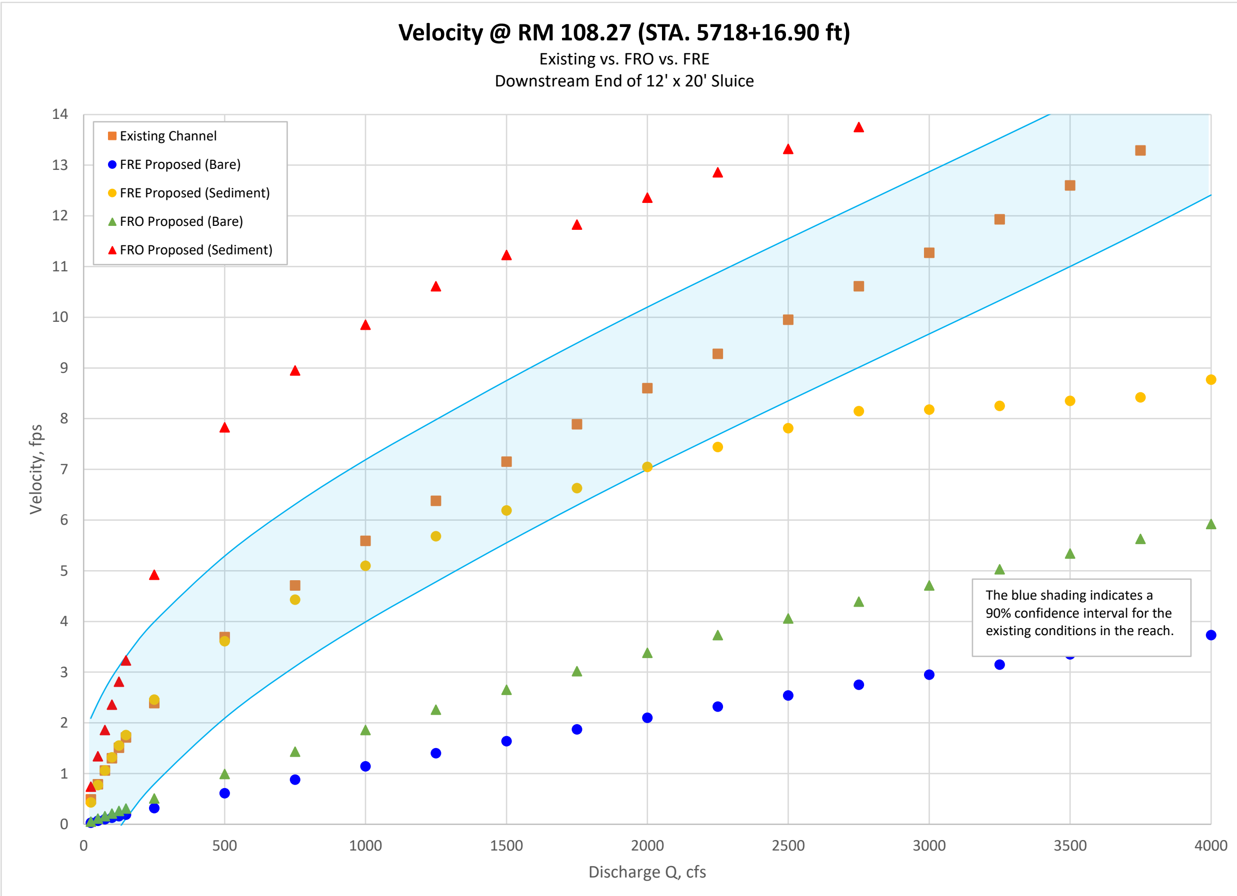


Figure 3-6

Flow velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Stilling Basin Endsill (RM 108.23)

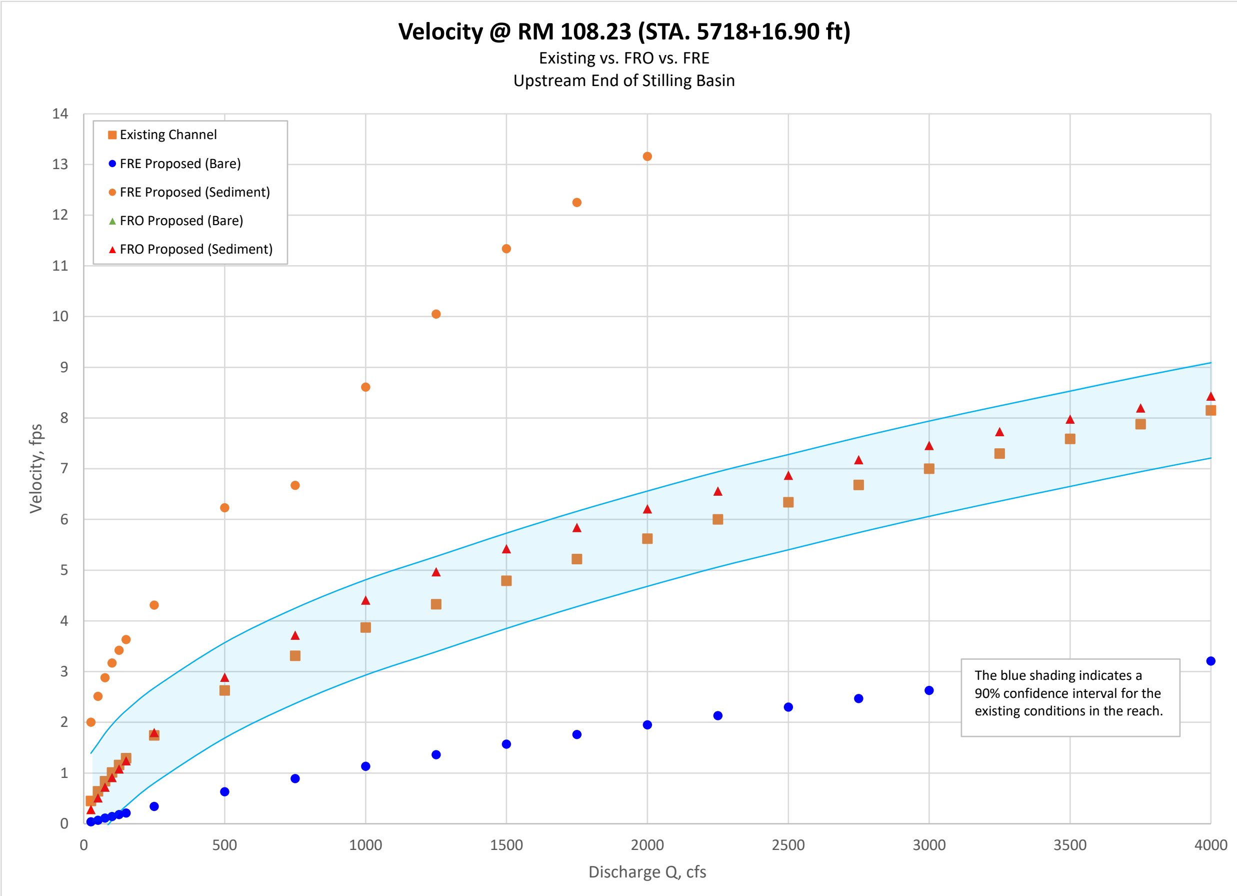


Figure 3-7

Flow Velocity Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Downstream of the Project Location (RM 108.18)

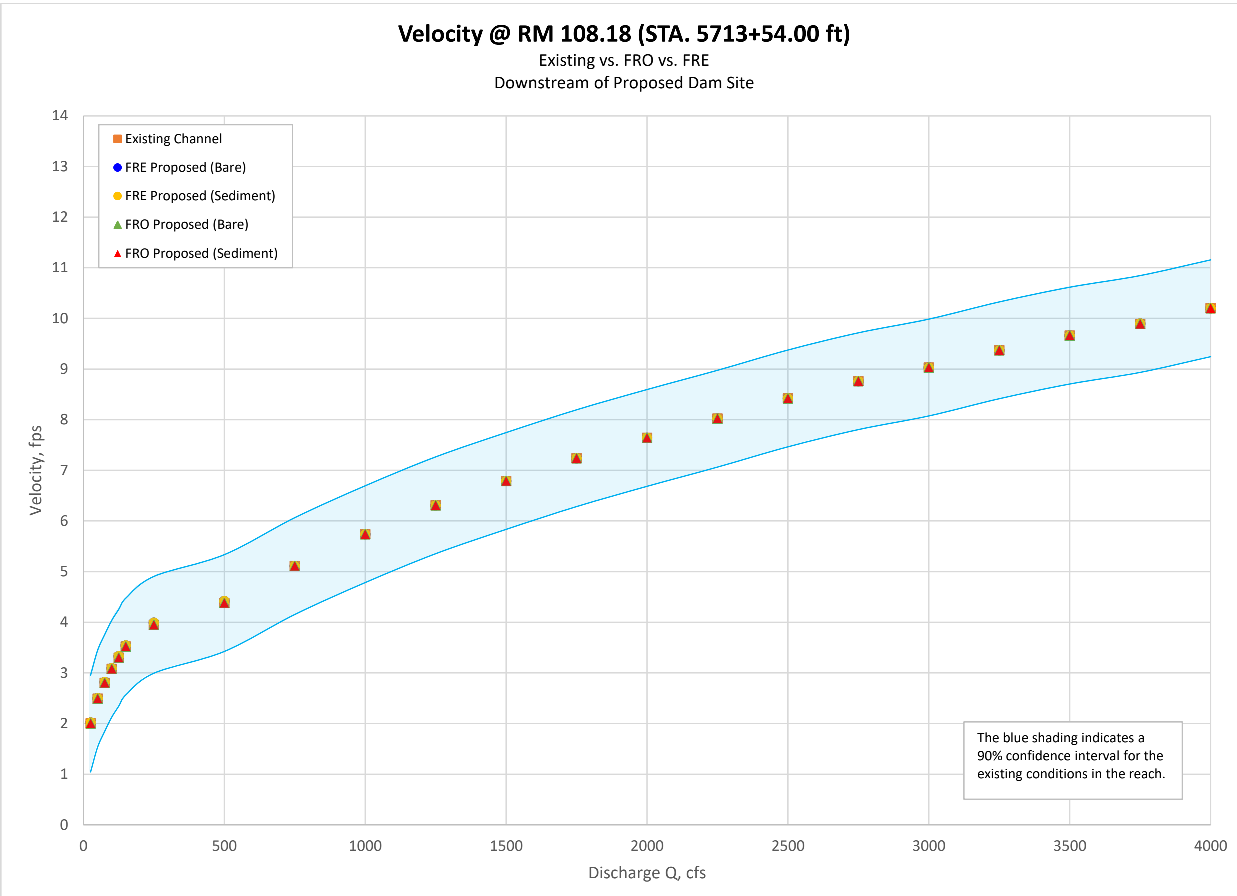


Figure 3-8
Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Project Site (RM 108.47)

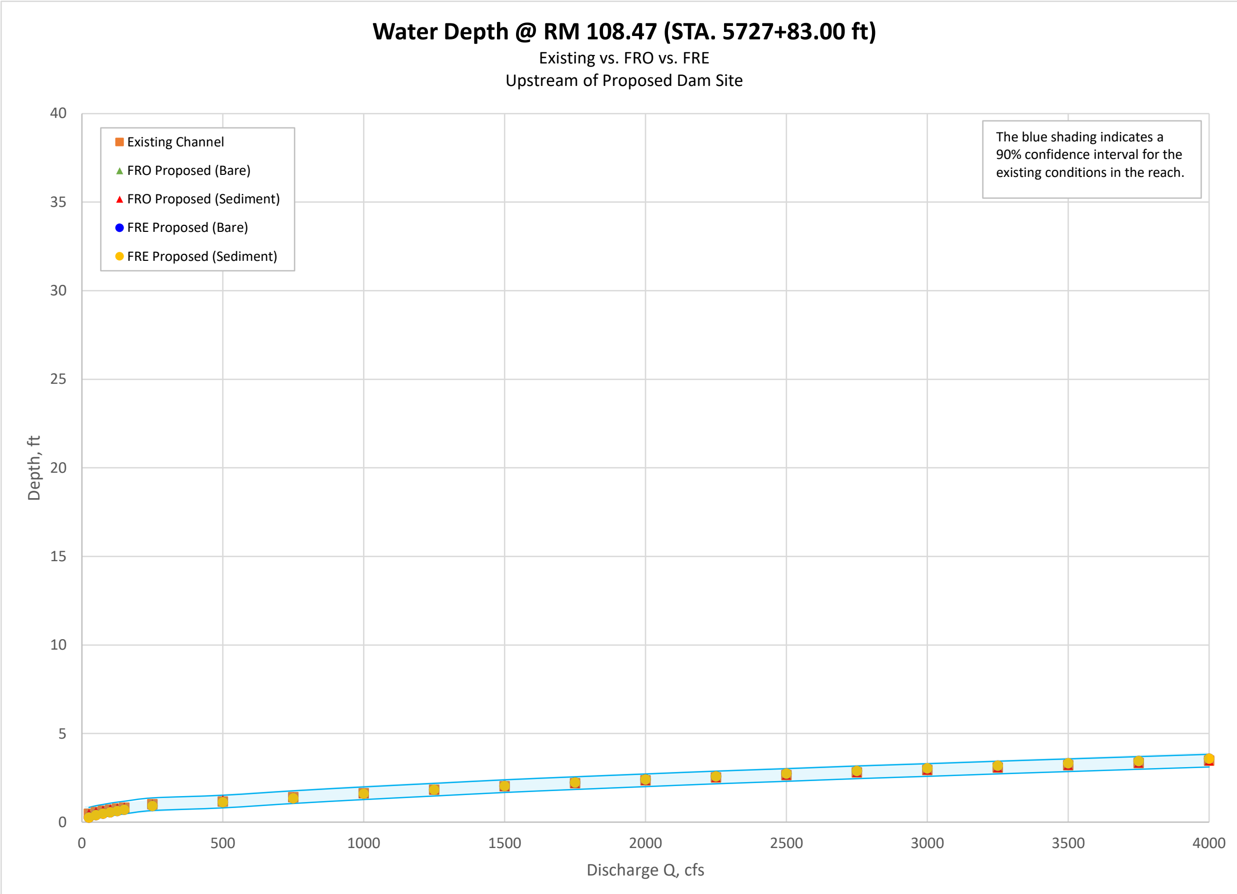


Figure 3-9

Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Project Location (RM 108.37)

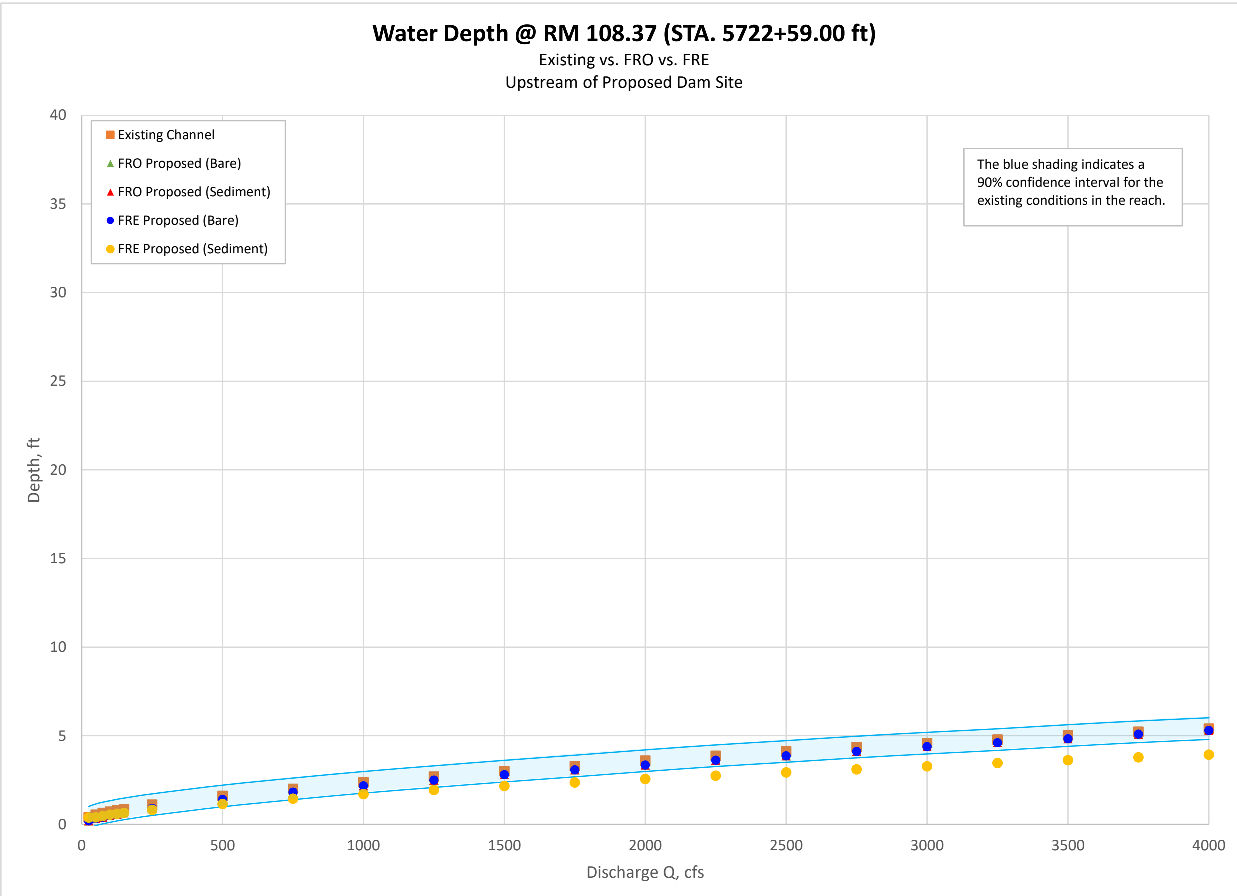


Figure 3-10
Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations at the 12'x20' Sluice Mouth (RM 108.31)

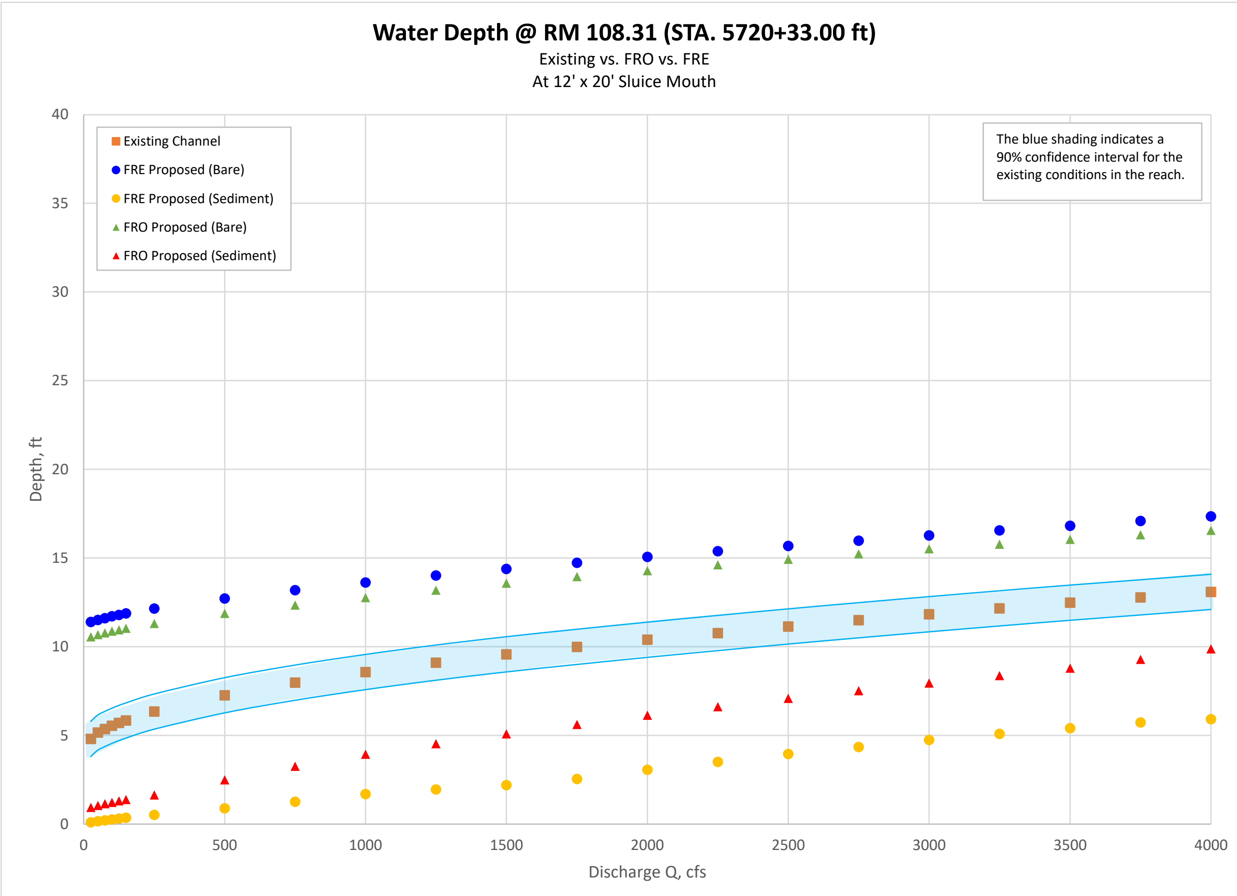


Figure 3-11
Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Inside the 12'x20' Sluice (RM 108.30)

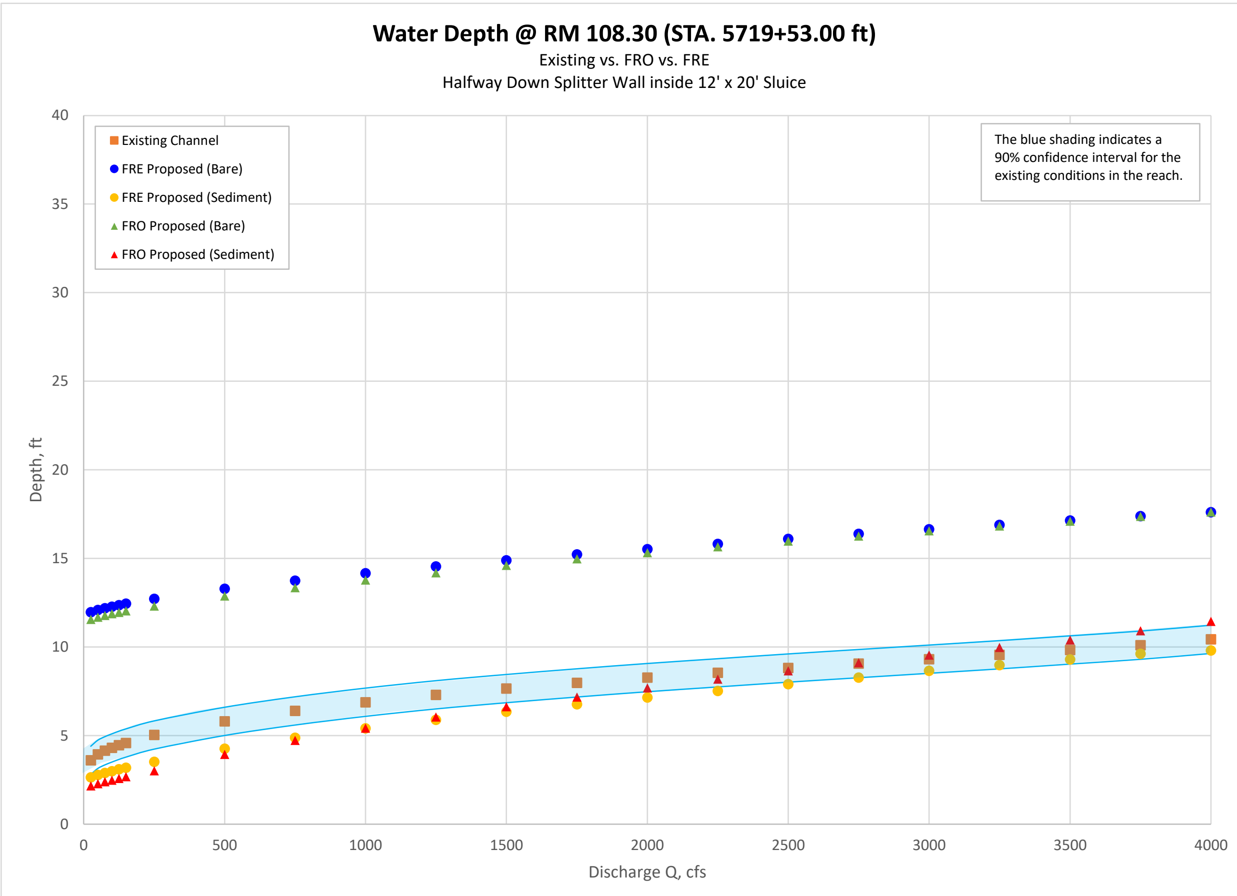


Figure 3-12
Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Downstream of the 12’x20’ Sluice (RM 108.27)

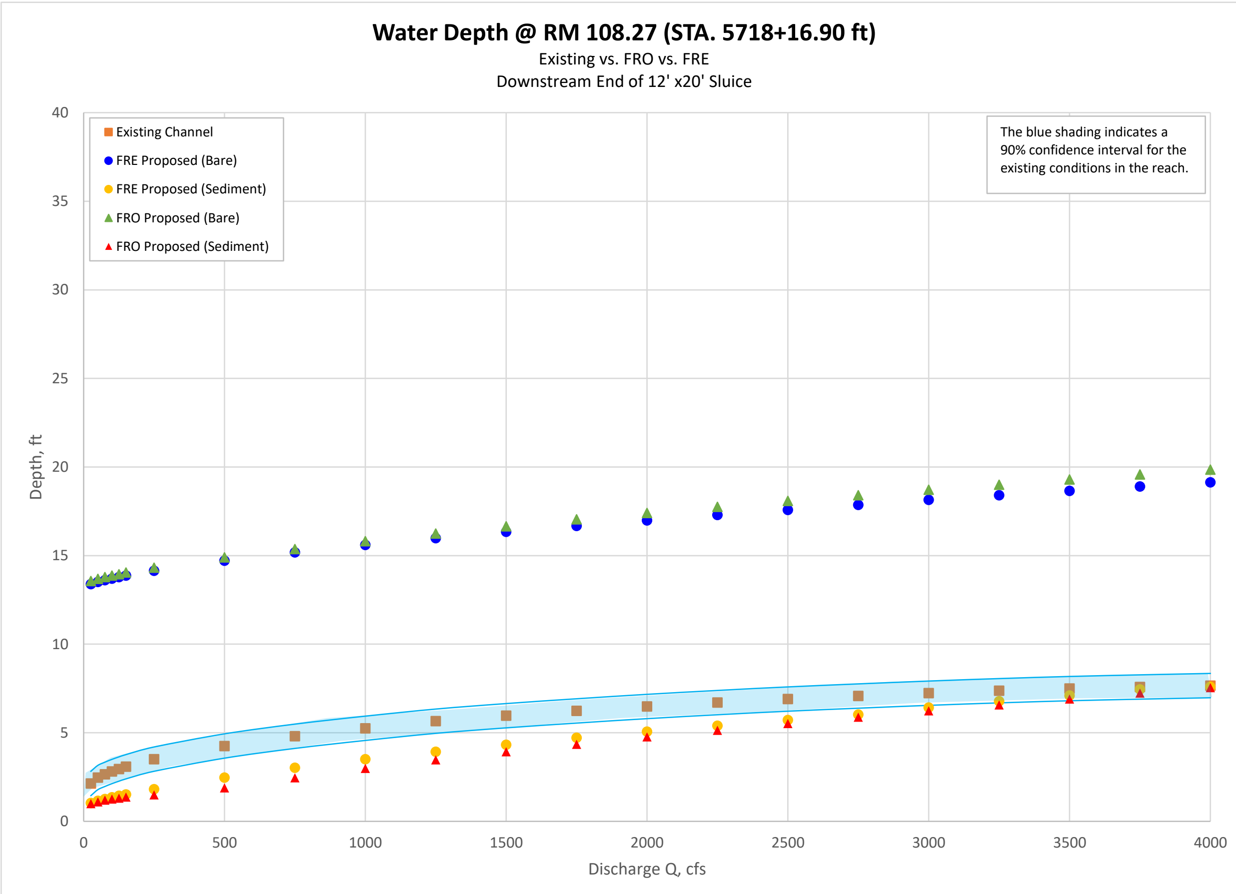


Figure 3-13
Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Stilling Basin Endsill (RM 108.23)

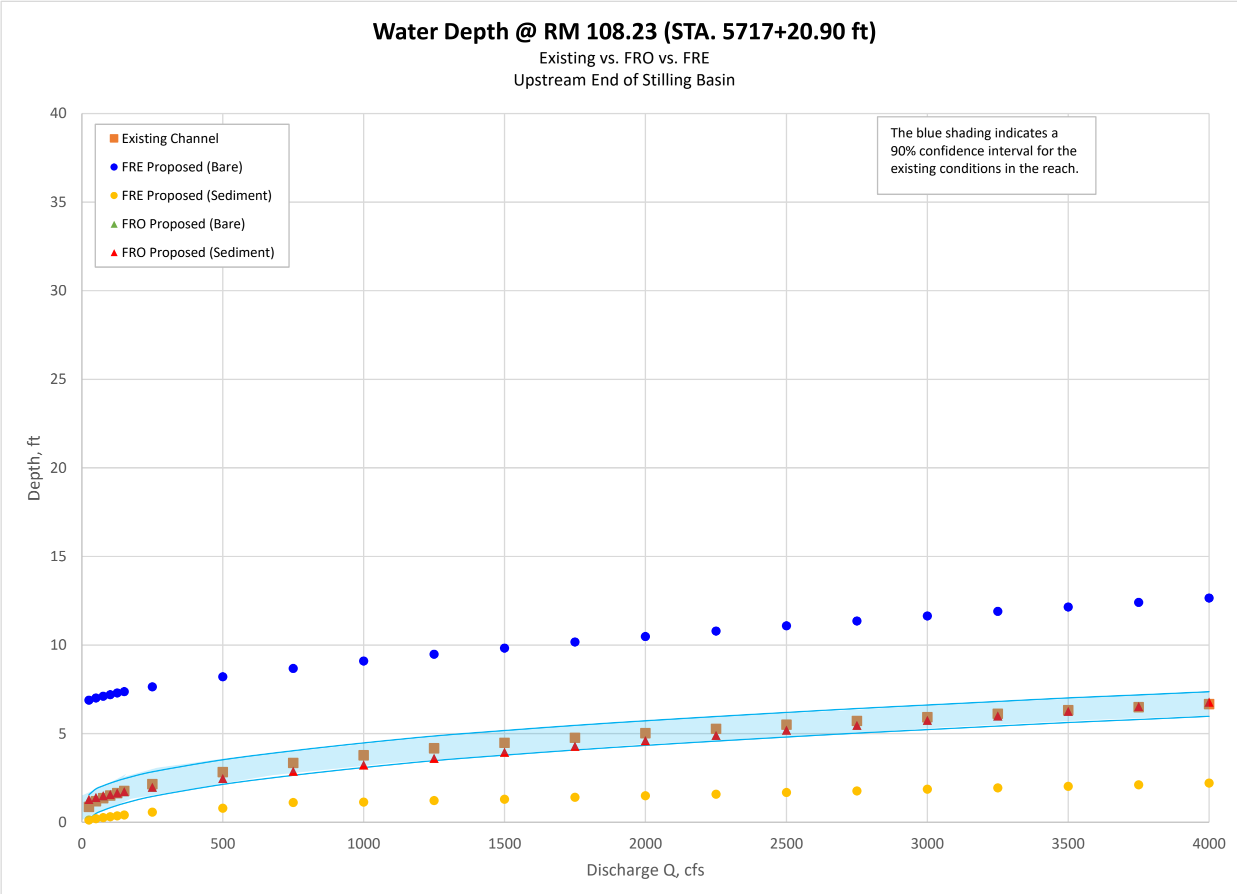
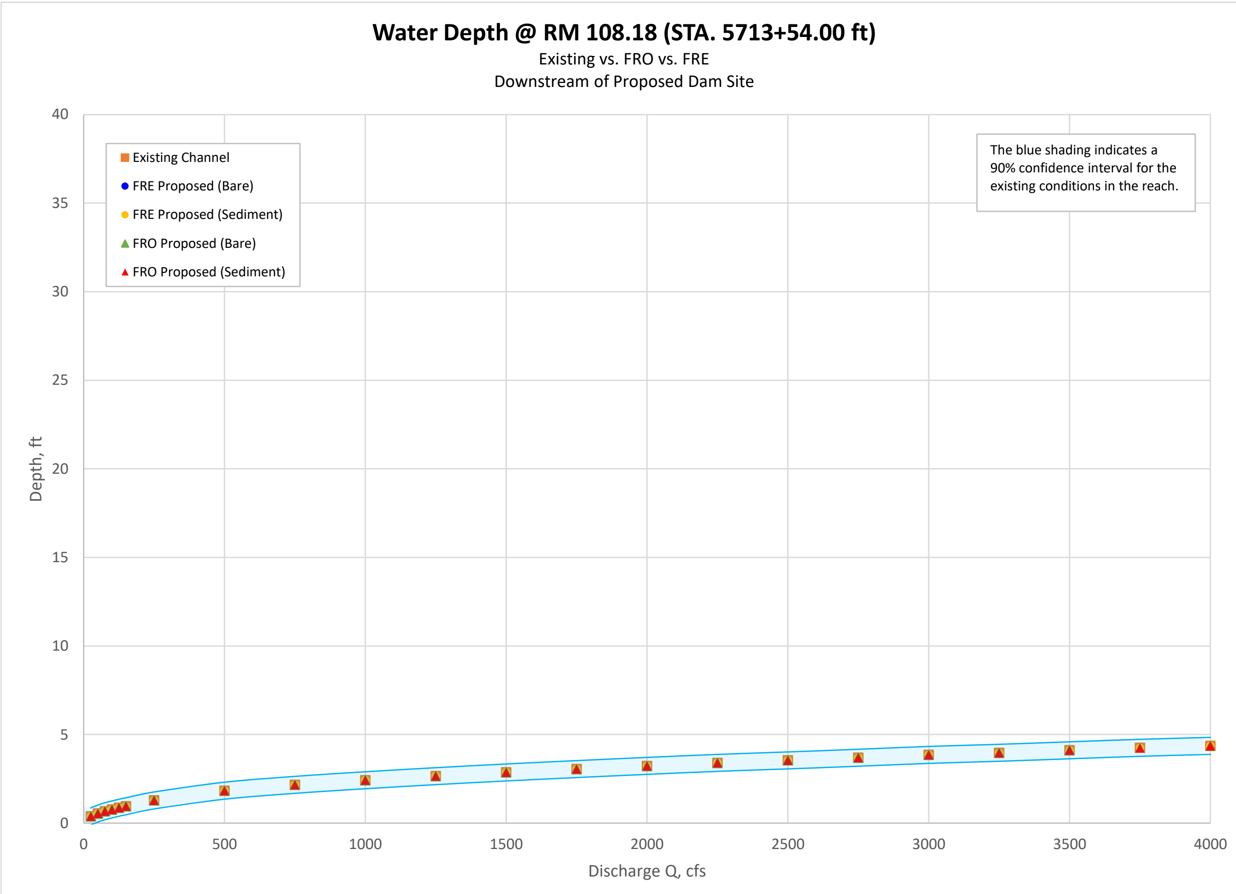


Figure 3-14

Flow Depth Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Downstream of the Project Location (RM 108.18)



3.1.2 Sediment Transport Capacity and Performance

Figure 3-15

Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Project Site (RM 108.47)

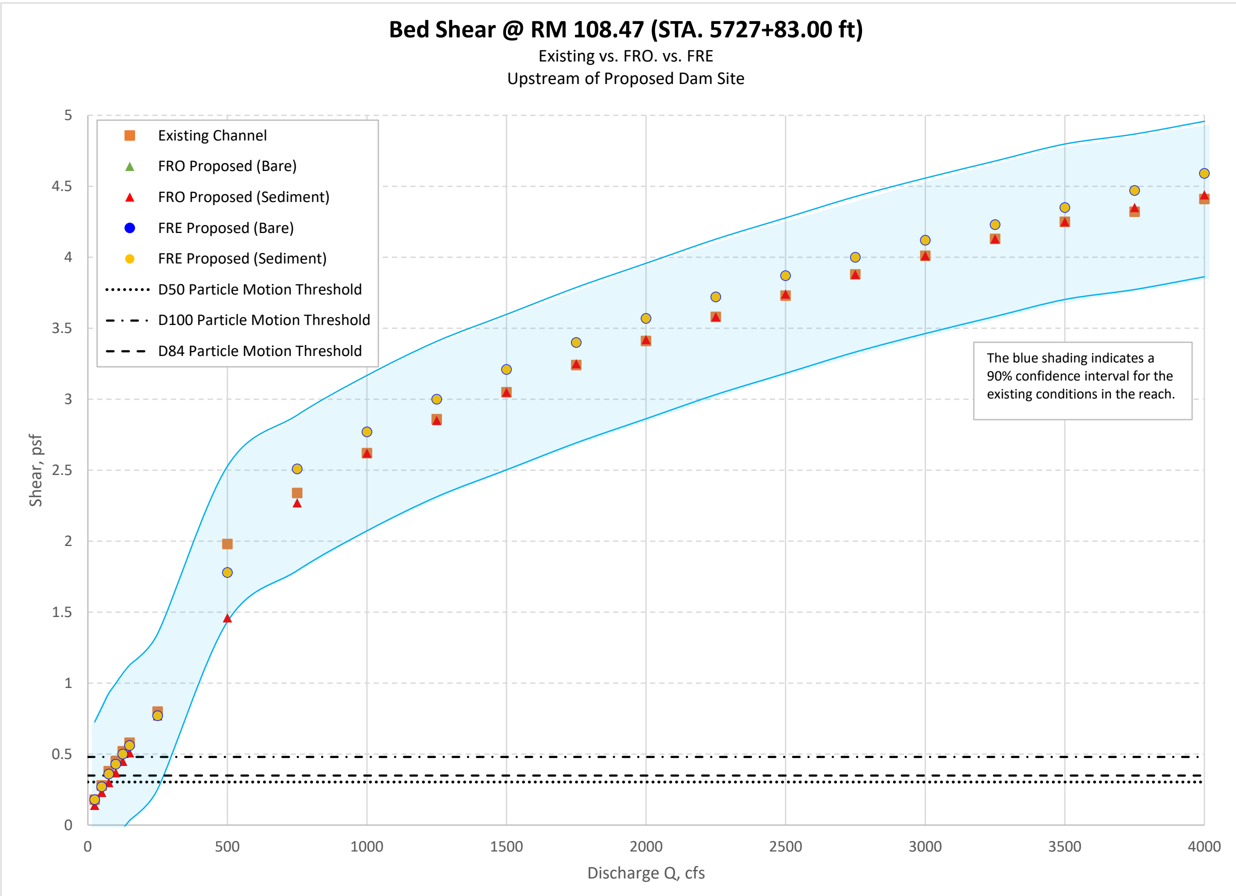


Figure 3-16

Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Project Location (RM 108.37)

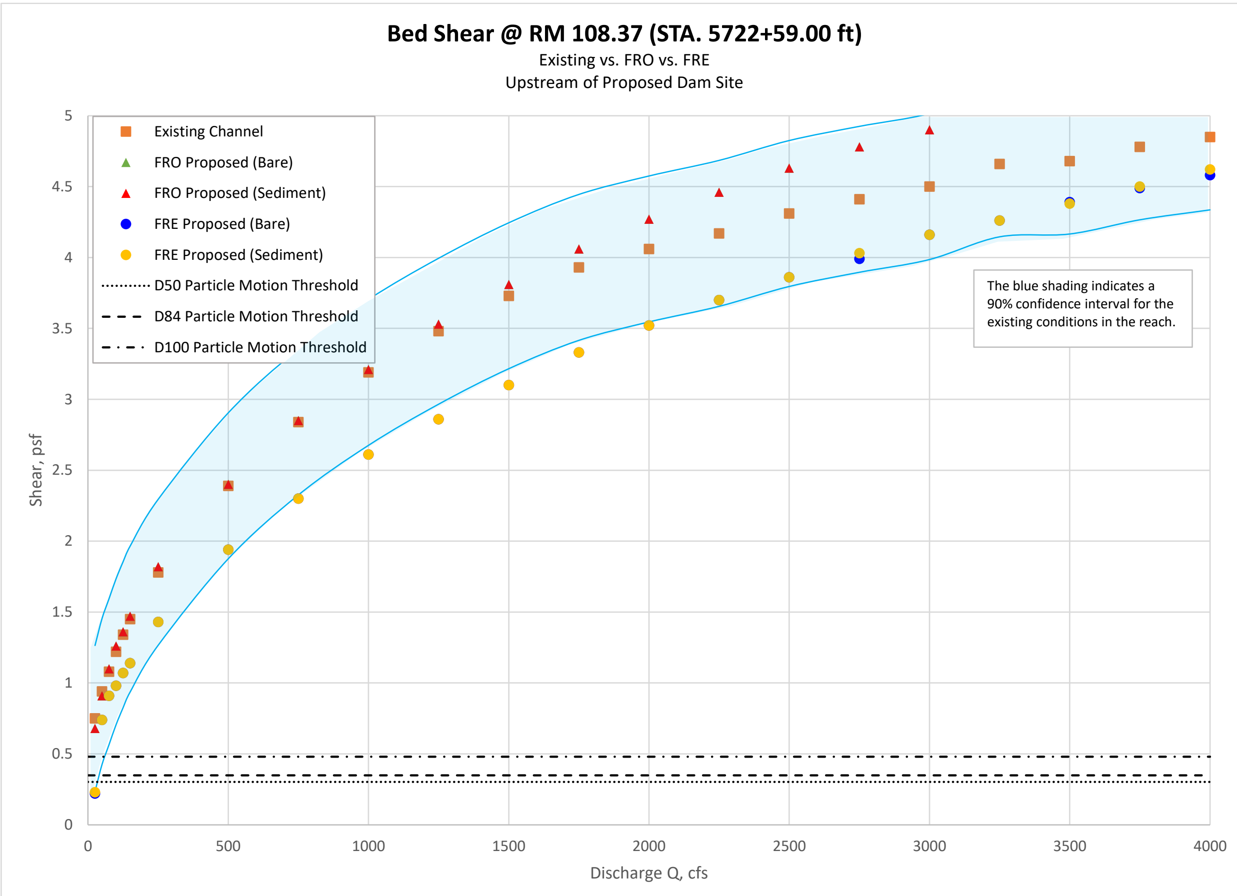


Figure 3-17

Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations at the 12'x20' Sluice Mouth (RM 108.31)

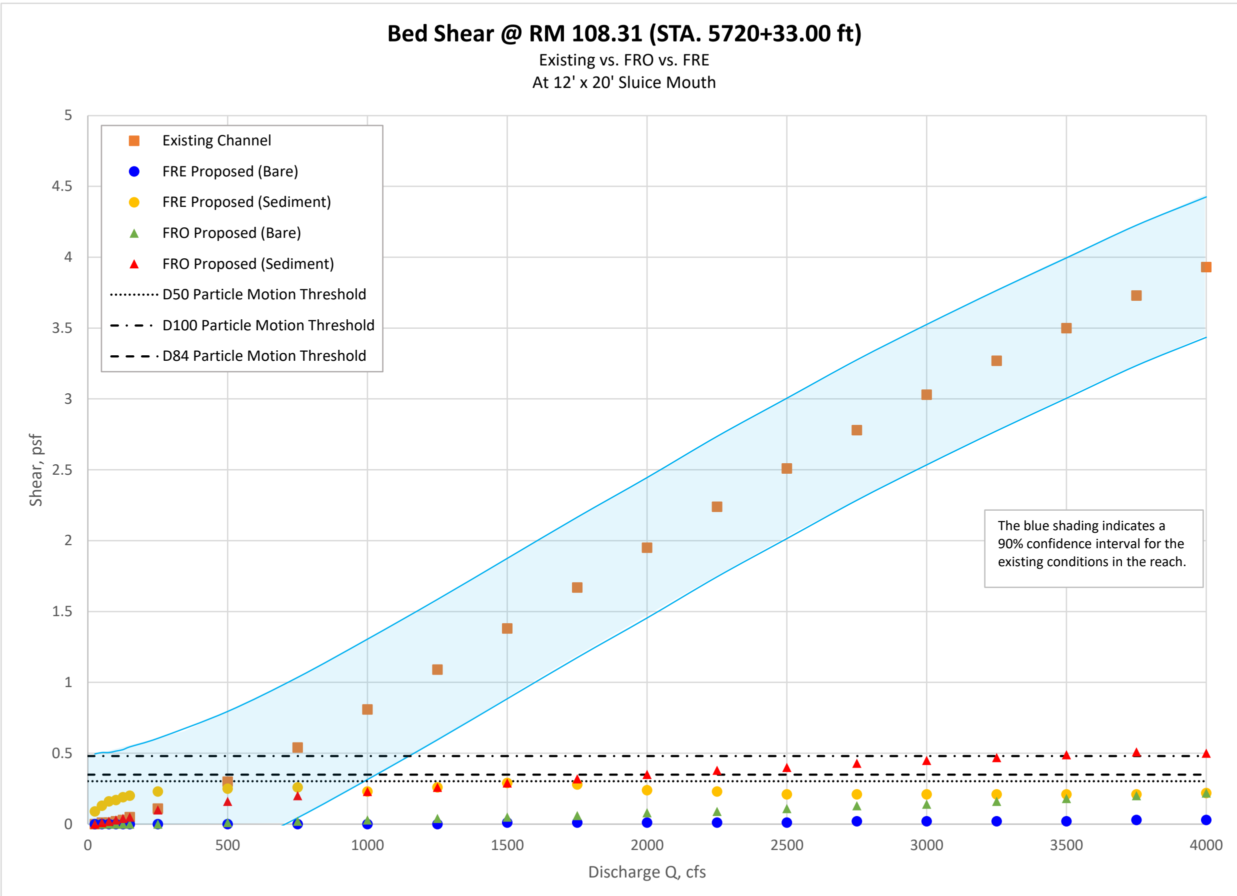


Figure 3-18
Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Inside the 12'x20' Sluice (RM 108.30)

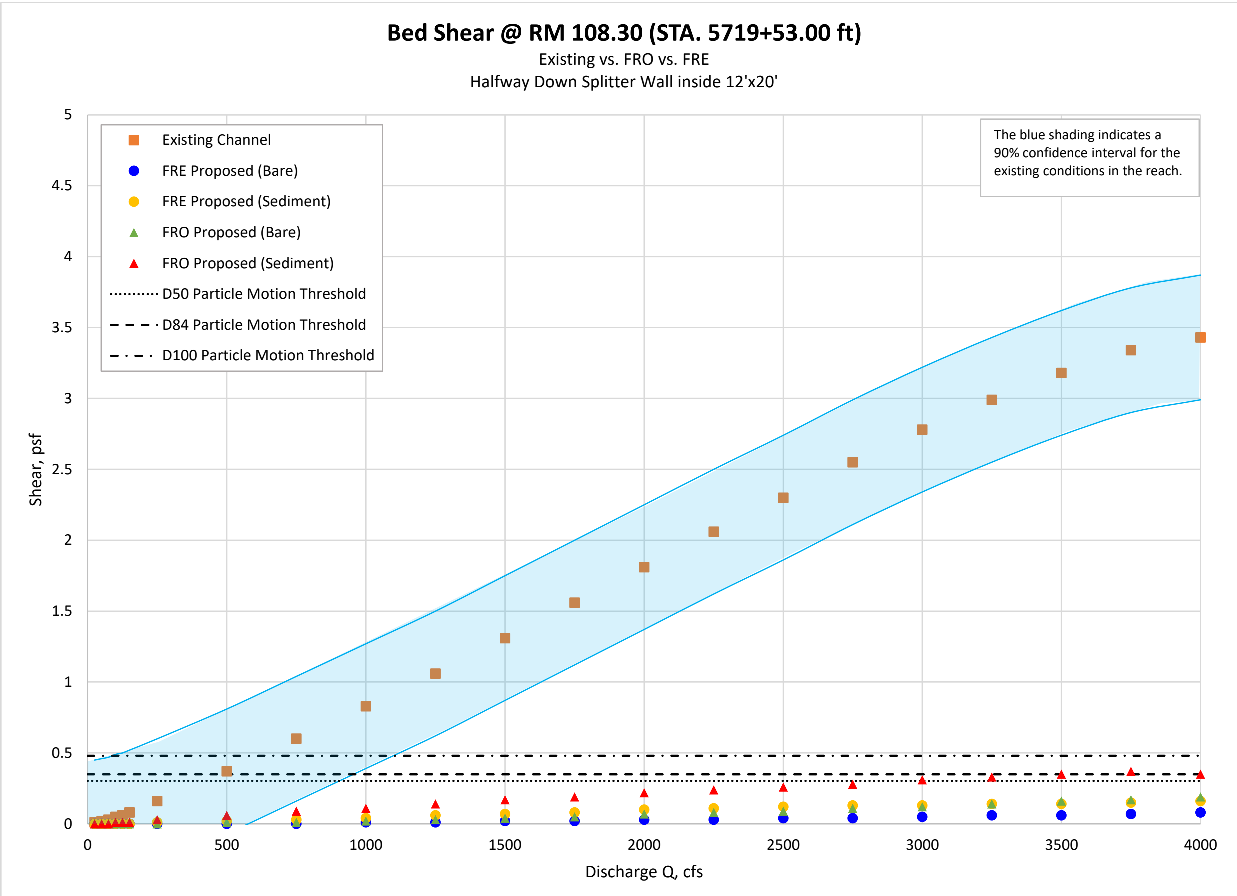


Figure 3-19
Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Downstream of the 12'x20' Sluice (RM 108.27)

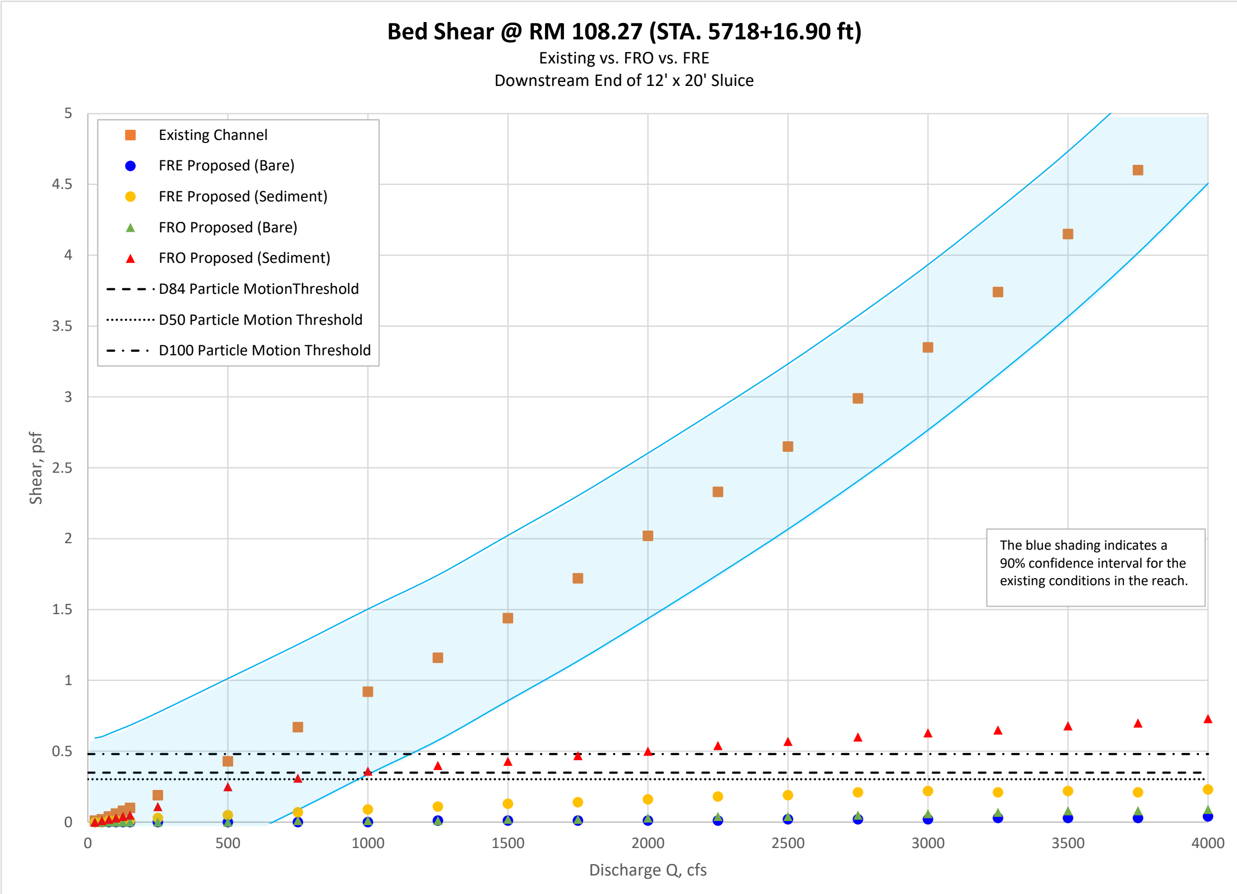


Figure 3-20

Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Upstream of the Stilling Basin Endsill (RM 108.23)

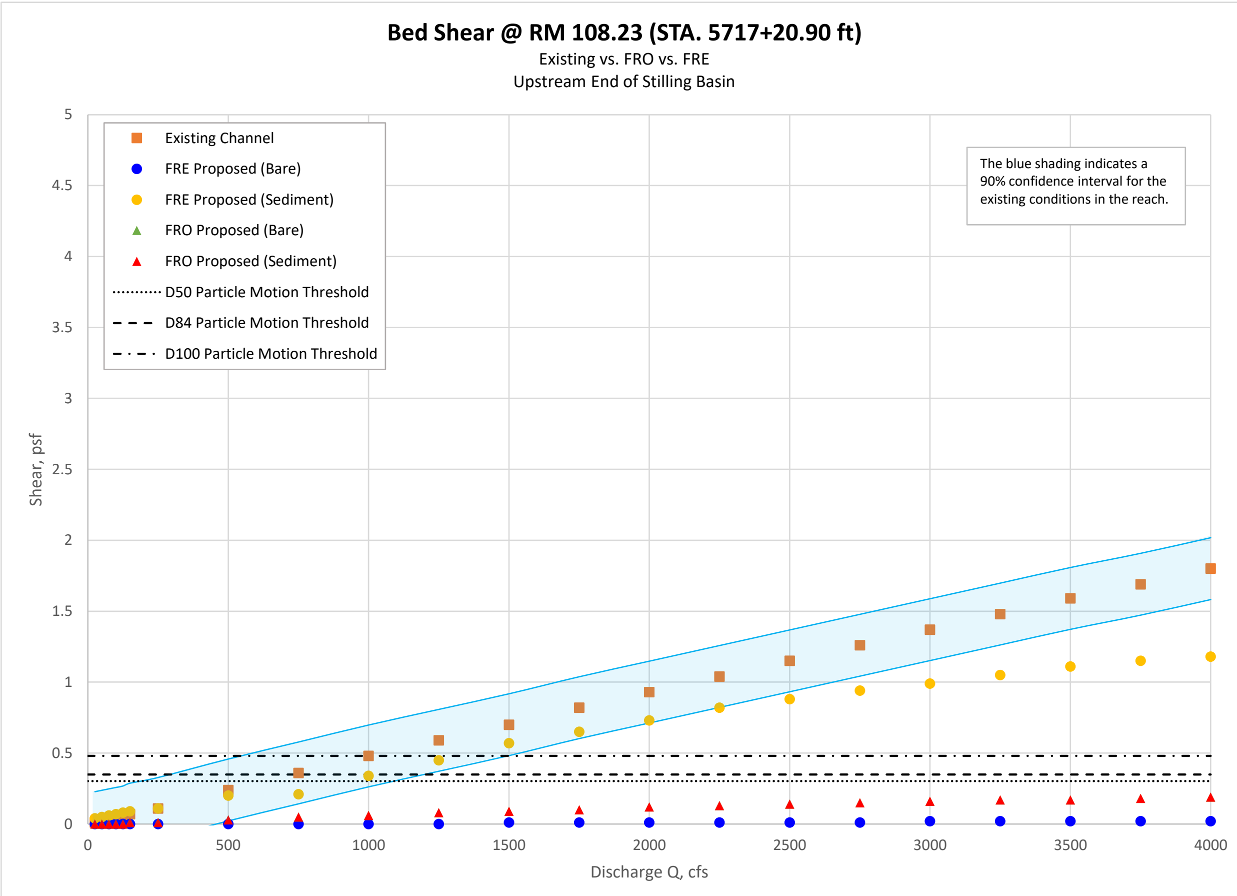
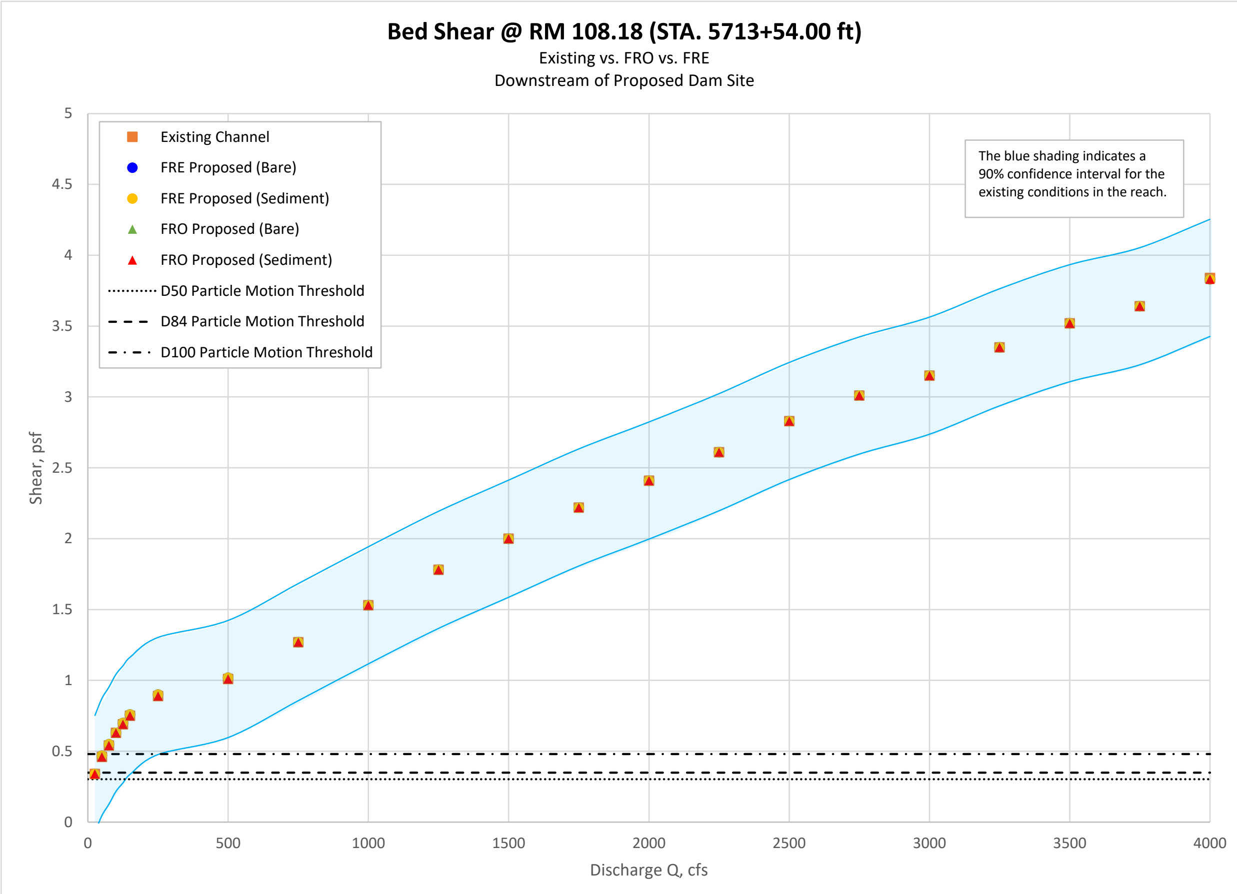


Figure 3-21
Bed Shear Stress Comparison for the Existing Condition, FRO and FRE Proposed Sluice Configurations Downstream of the Project Location (RM 108.18)



3.1.3 Computational Fluid Dynamic (CFD) Modeling

Figure 3-22
Isometric View of Velocity Contours for 100 Cfs Discharge Through Low Level Outlets

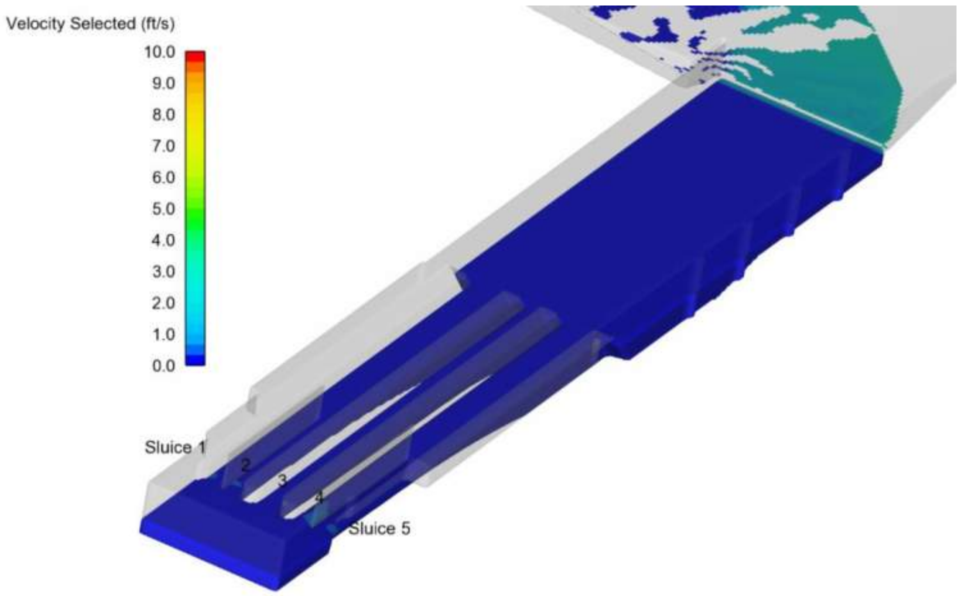


Figure 3-23

Profile View of Velocity Contours for 100 cfs Discharge Through Low Level Outlets

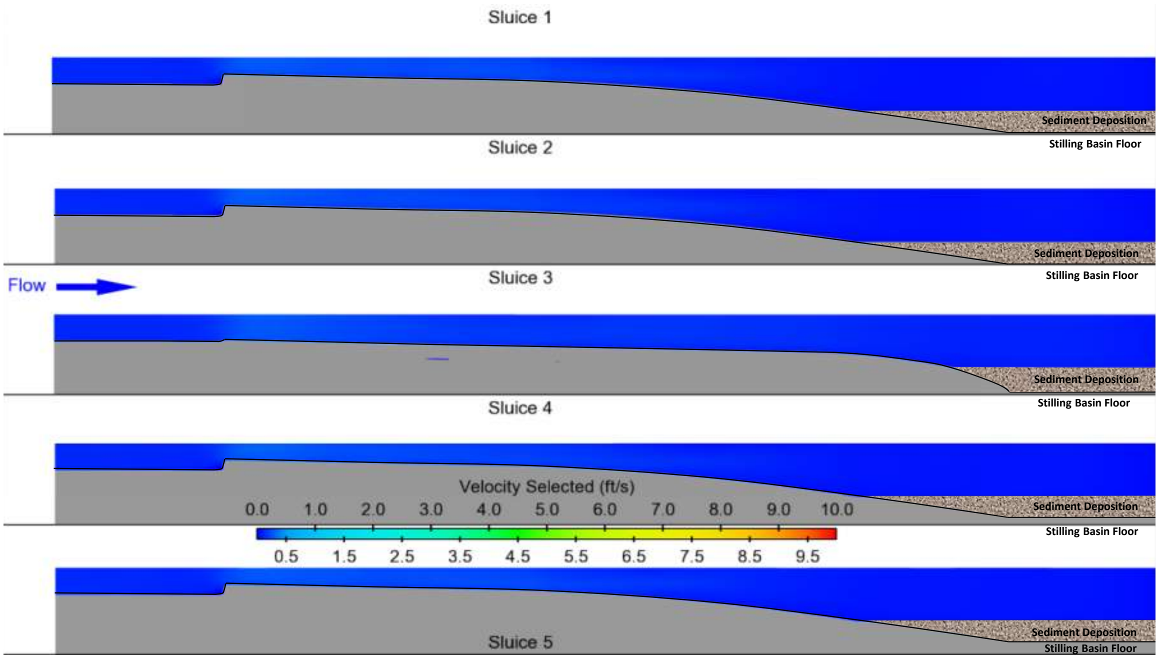


Figure 3-24

Isometric View of Velocity Contours for 250 cfs Discharge Through Low Level Outlets

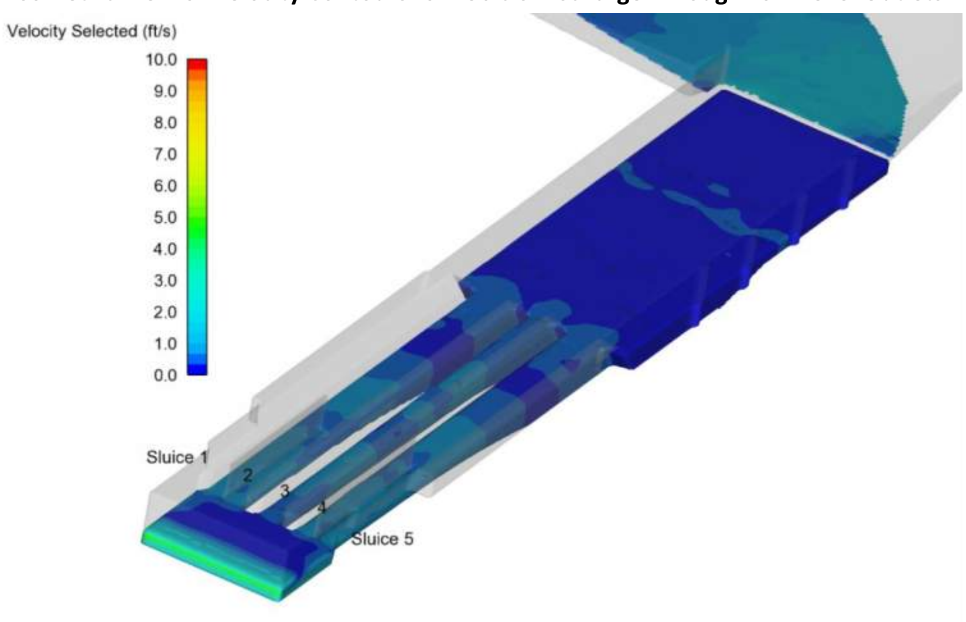


Figure 3-25

Profile View of Velocity Contours for 250 cfs Discharge Through Low Level Outlets

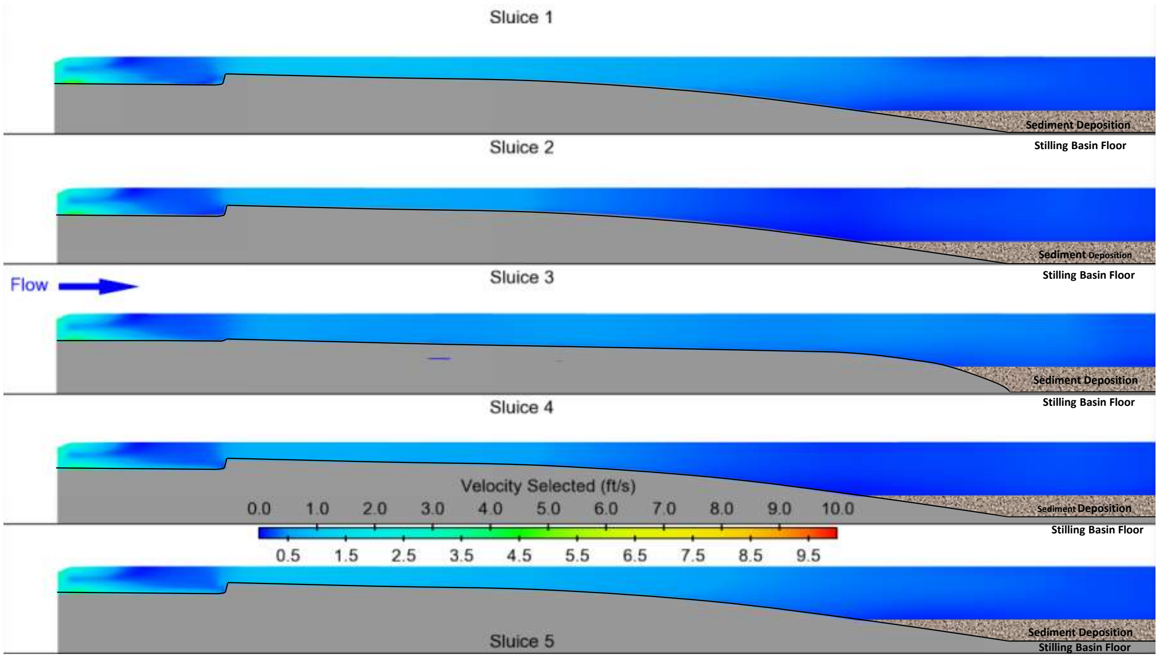


Figure 3-26
Isometric View of Velocity Contours for 500 cfs Discharge Through Low Level Outlets

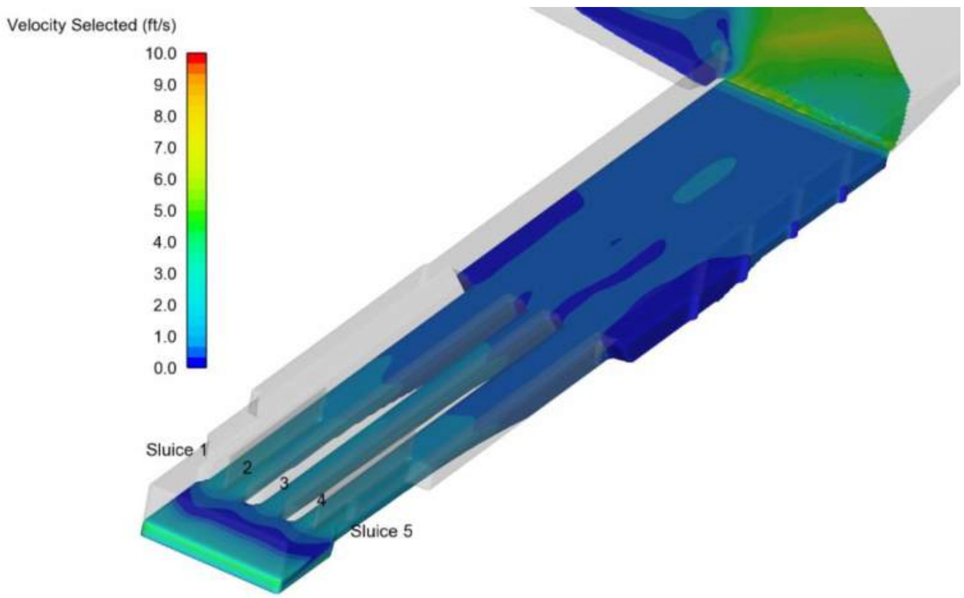


Figure 3-27
Profile View of Velocity Contours for 500 cfs Discharge Through Low Level Outlets

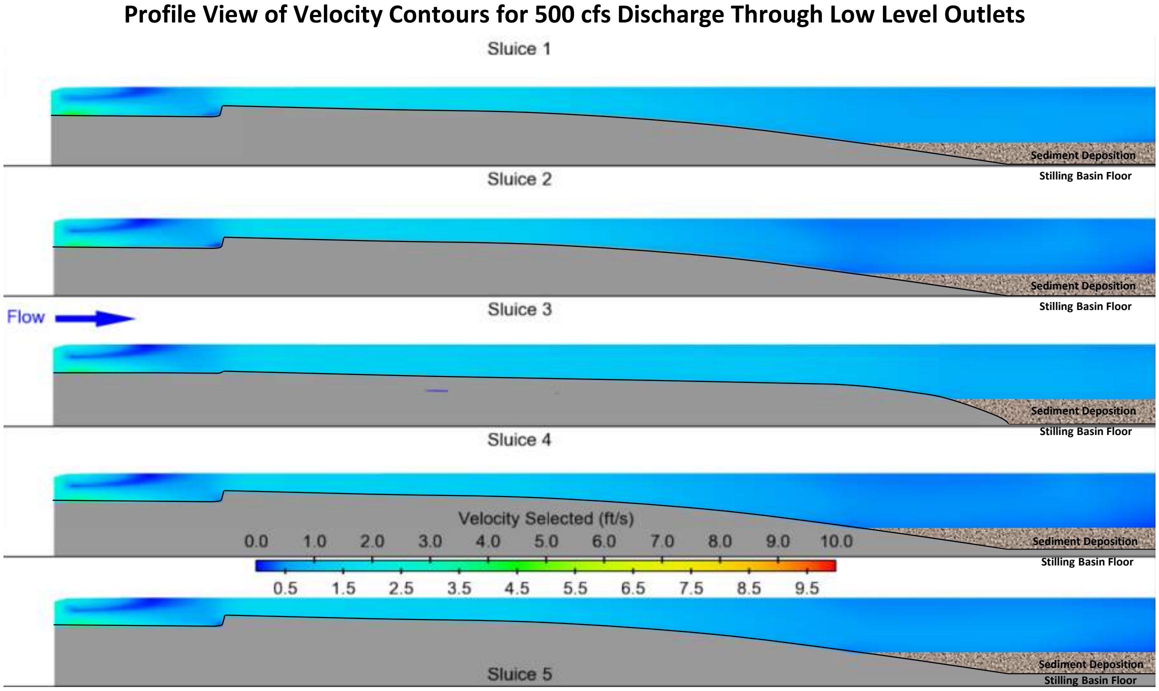


Figure 3-28
Isometric View of Velocity Contours for 1,000 cfs Discharge Through Low Level Outlets

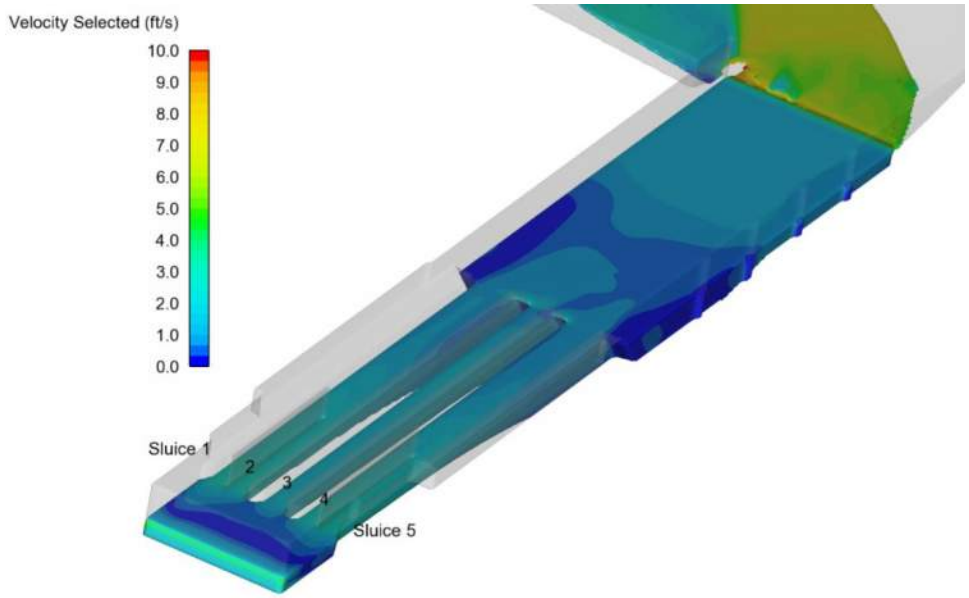


Figure 3-29
Profile View of Velocity Contours for 1,000 cfs Discharge Through Low Level Outlets

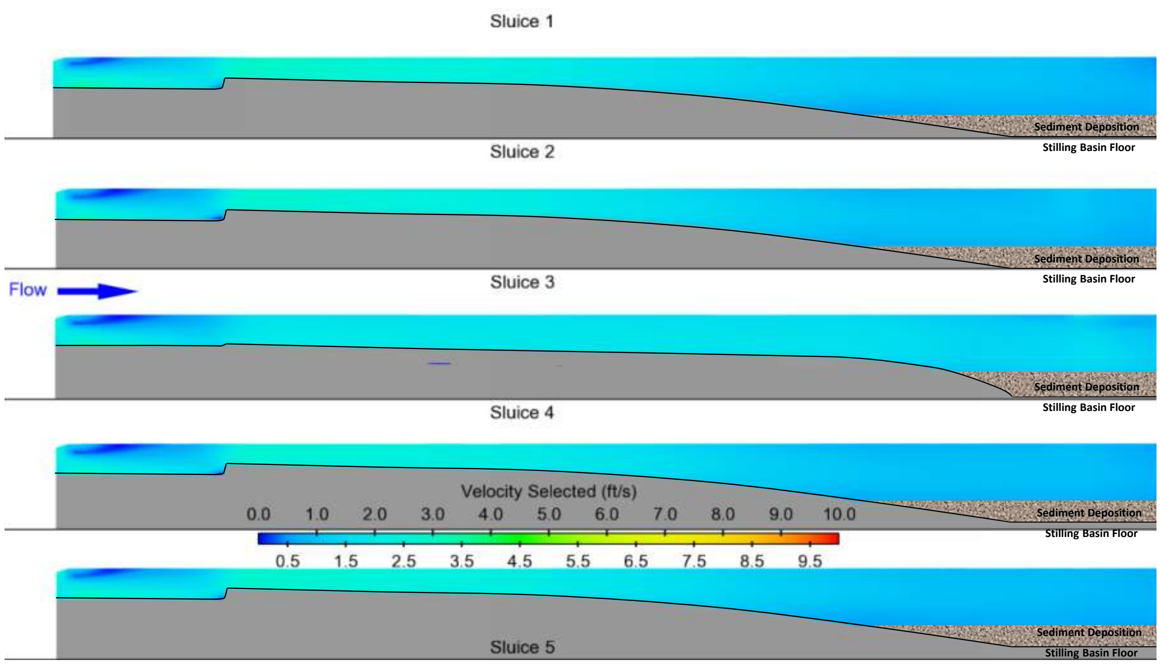


Figure 3-30
Isometric View of Velocity Contours for 1,250 cfs Discharge Through Low Level Outlets

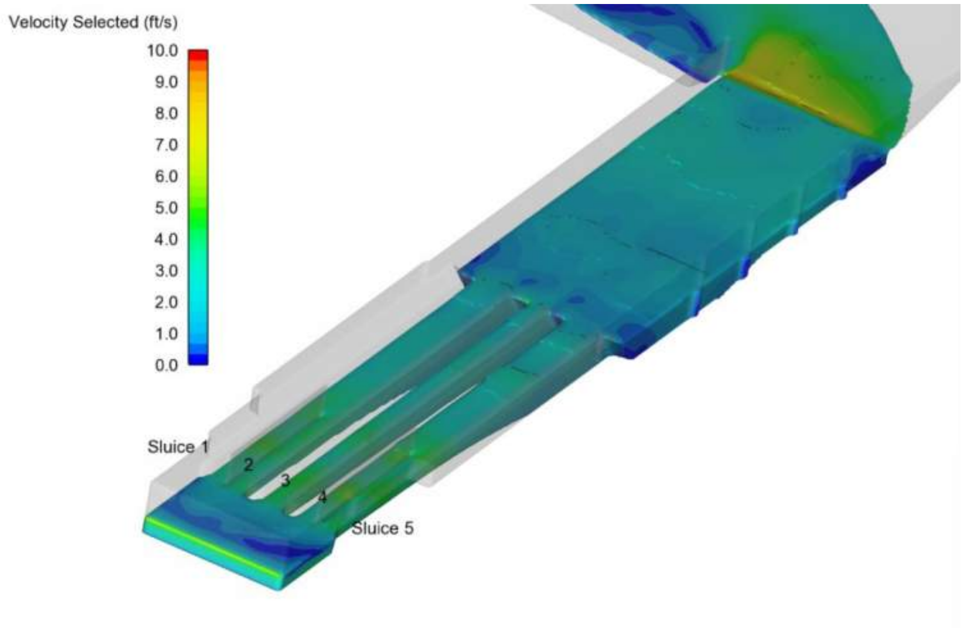


Figure 3-31
Profile View of Velocity Contours for 1,250 cfs Discharge Through Low Level Outlets

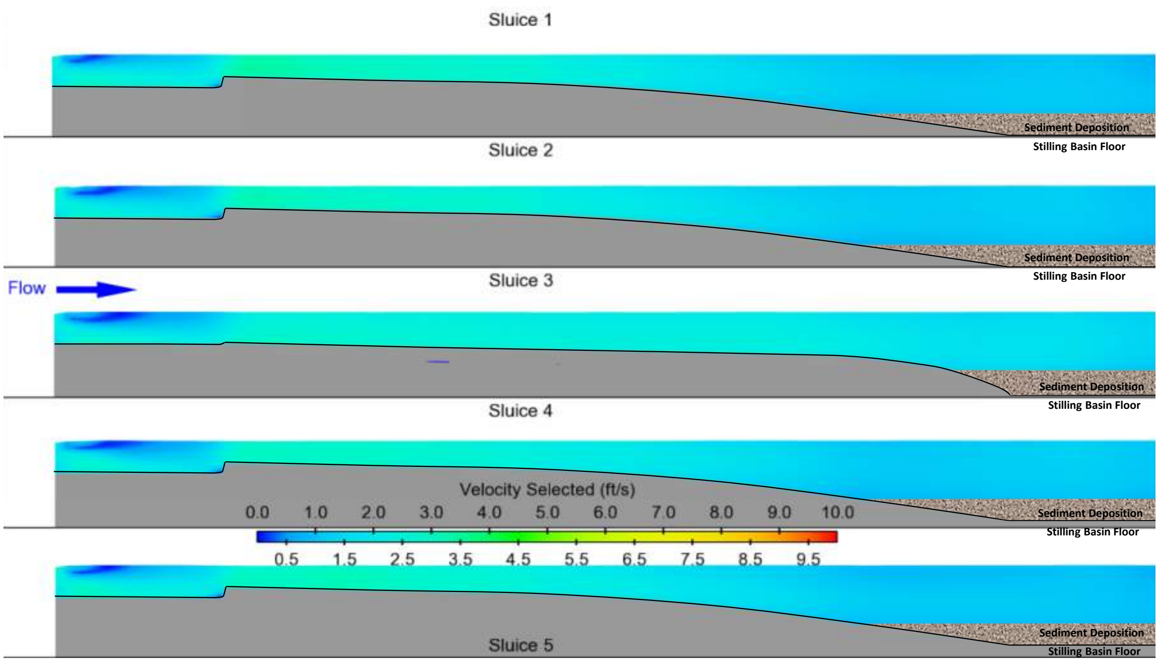


Figure 3-32
Isometric View of Velocity Contours for 1,500 cfs Discharge Through Low Level Outlets

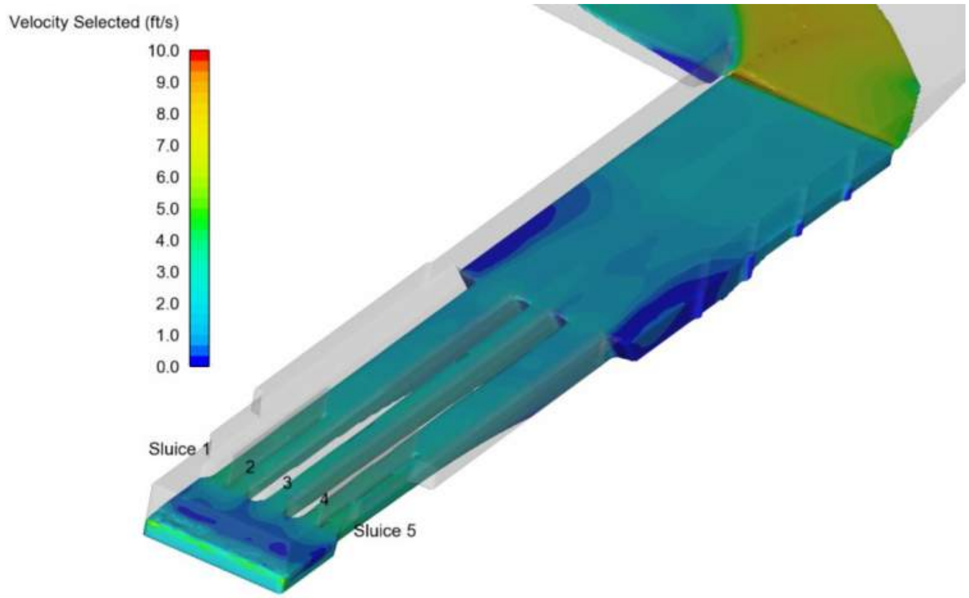


Figure 3-33
Profile View of Velocity Contours for 1,500 cfs Discharge Through Low Level Outlets

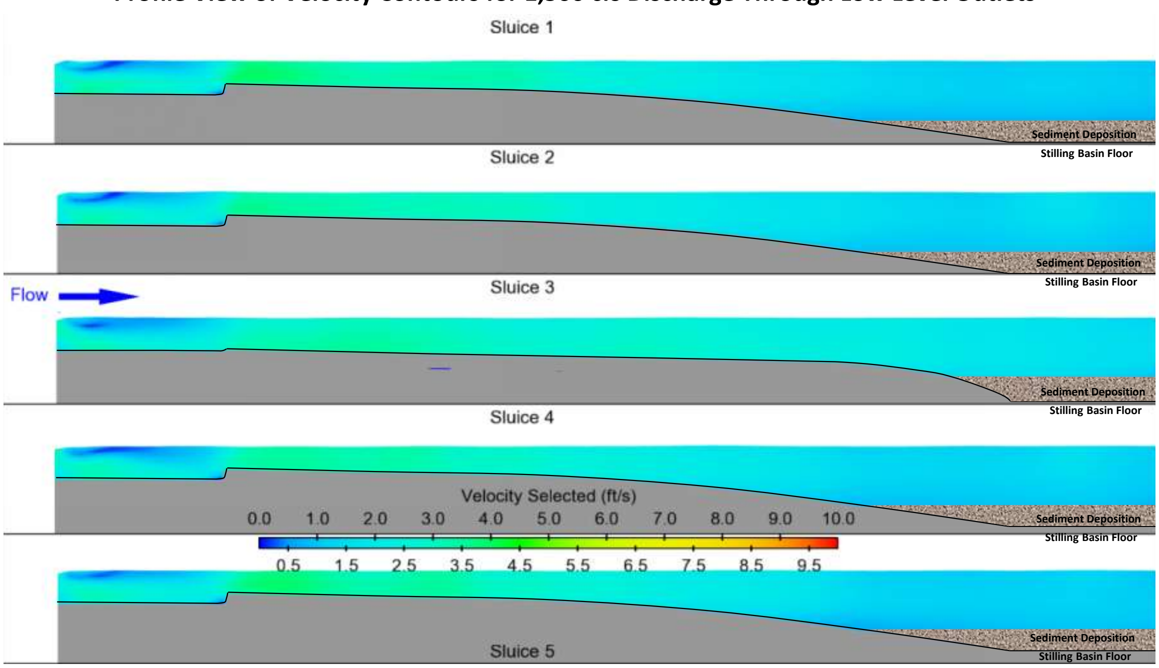


Figure 3-34
Isometric View of Velocity Contours For 1,500 cfs Discharge Through Low Level Outlets

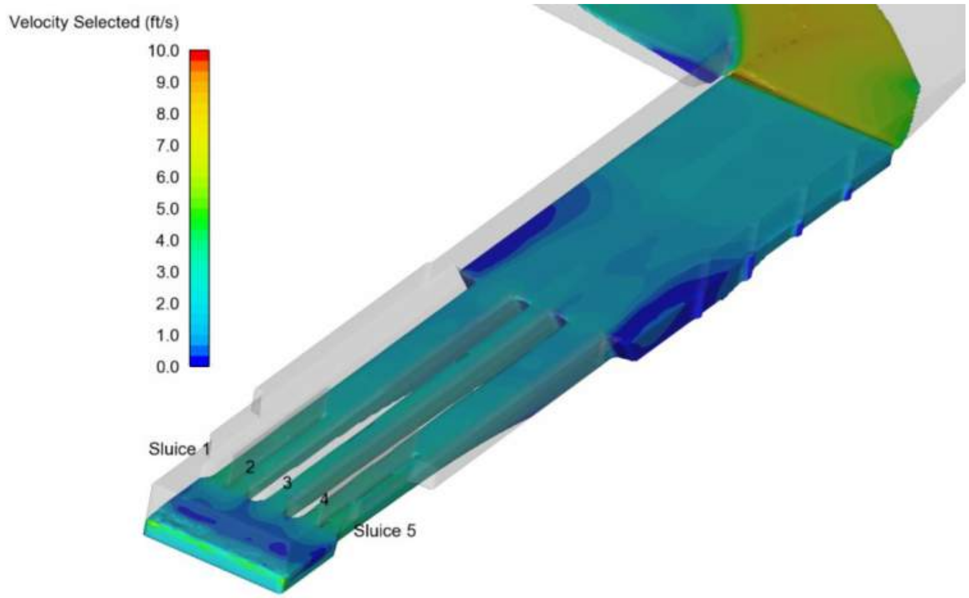


Figure 3-35
Profile View of Velocity Contours for 1,500 cfs Discharge Through Low Level Outlets

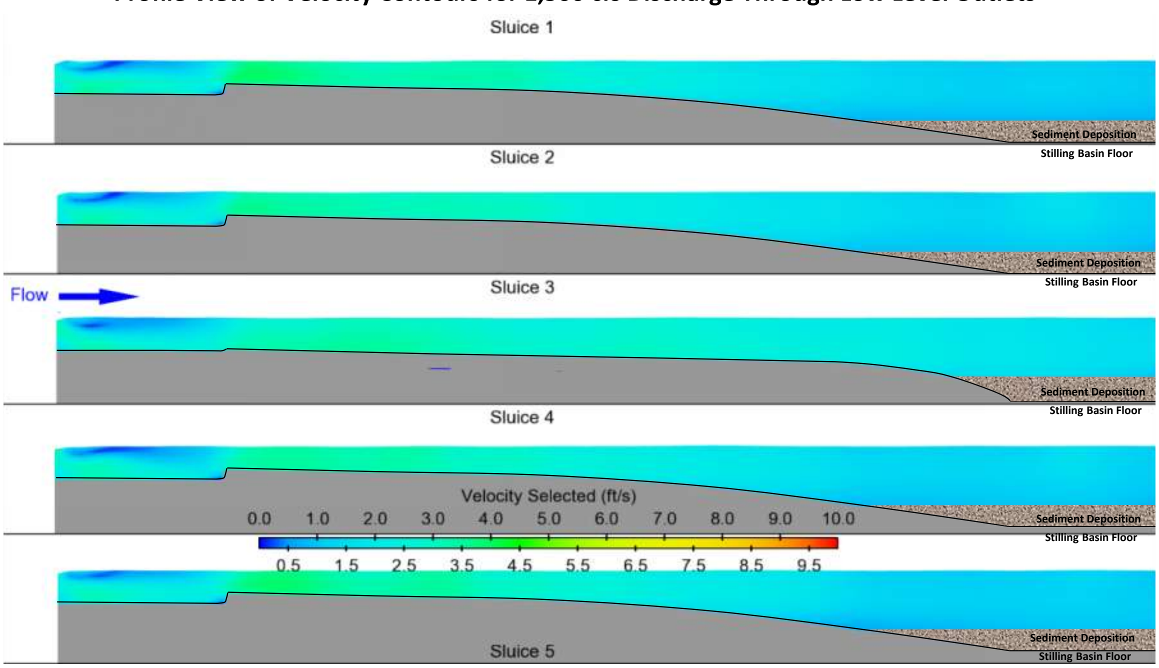


Figure 3-36
Isometric View of Velocity Contours for 1,750 cfs Discharge Through Low Level Outlets

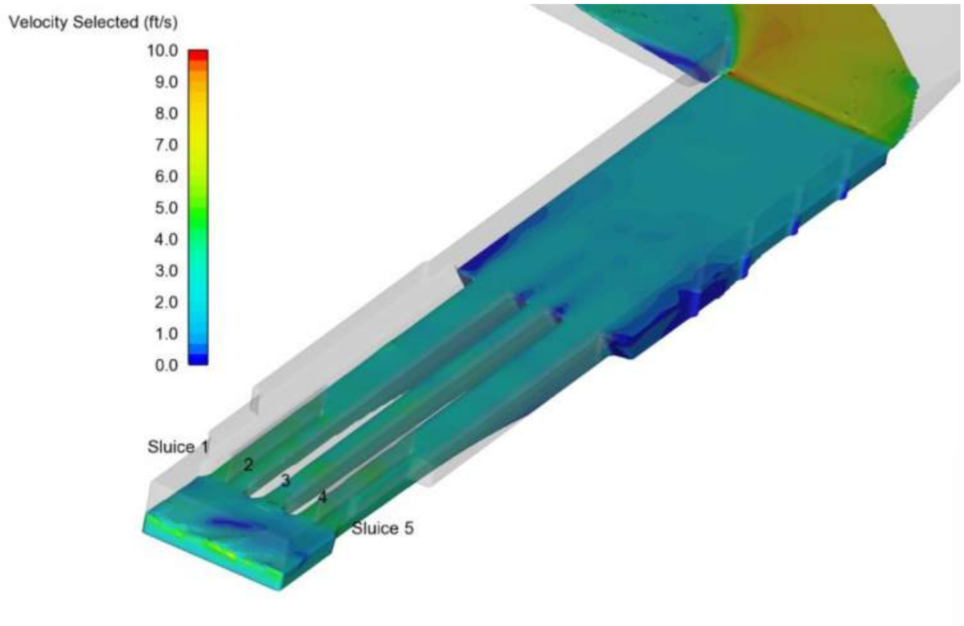


Figure 3-37
Profile View of Velocity Contours for 1,750 cfs Discharge Through Low Level Outlets

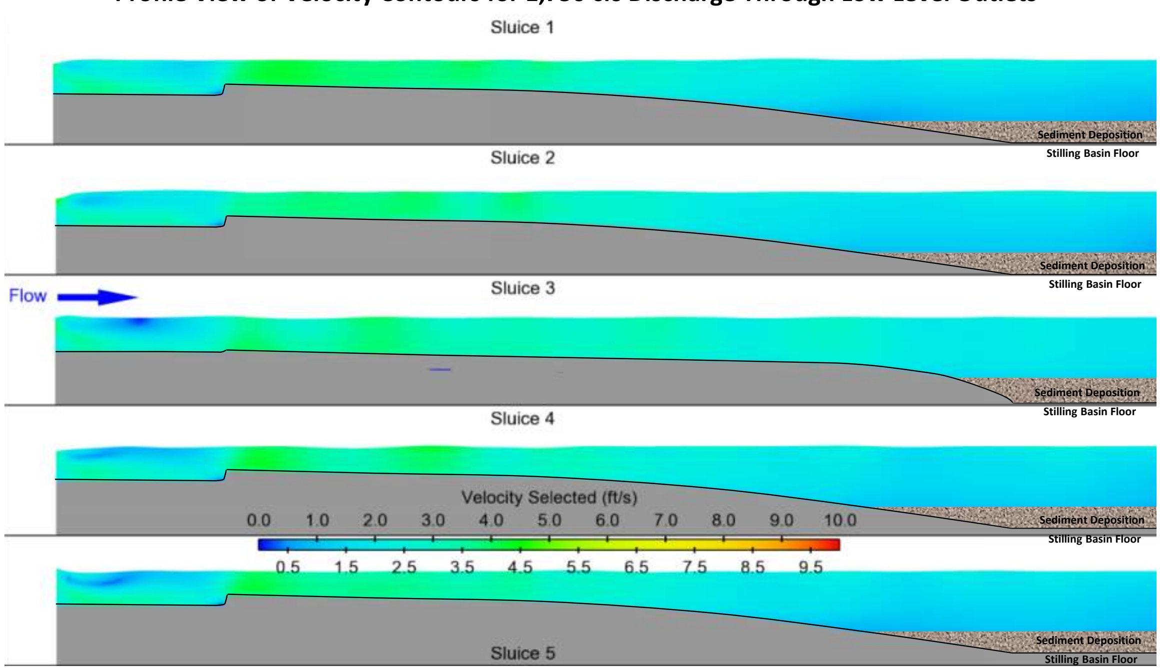


Figure 3-38

Isometric View of Velocity Contours For 2,000 cfs Discharge Through Low Level Outlets

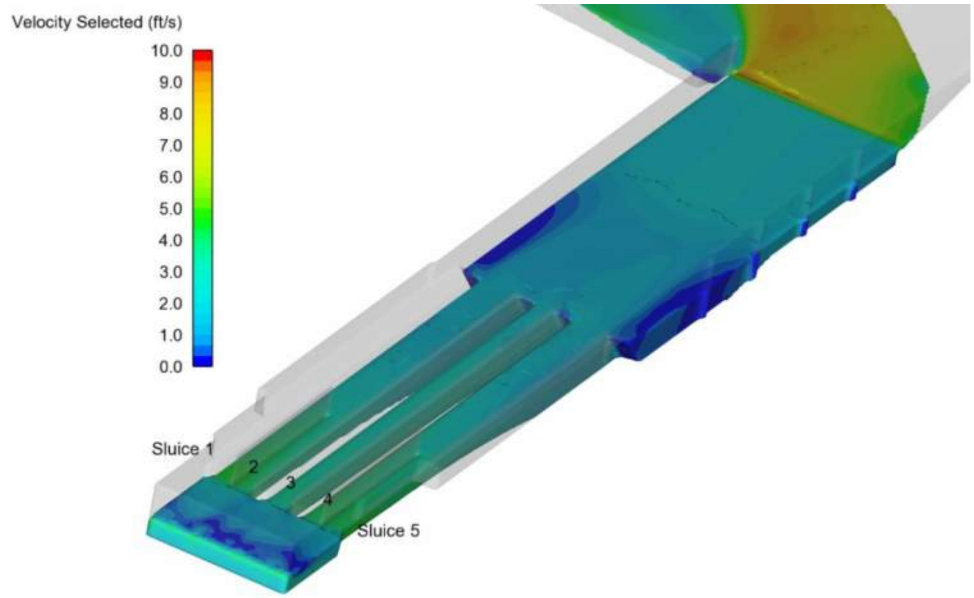
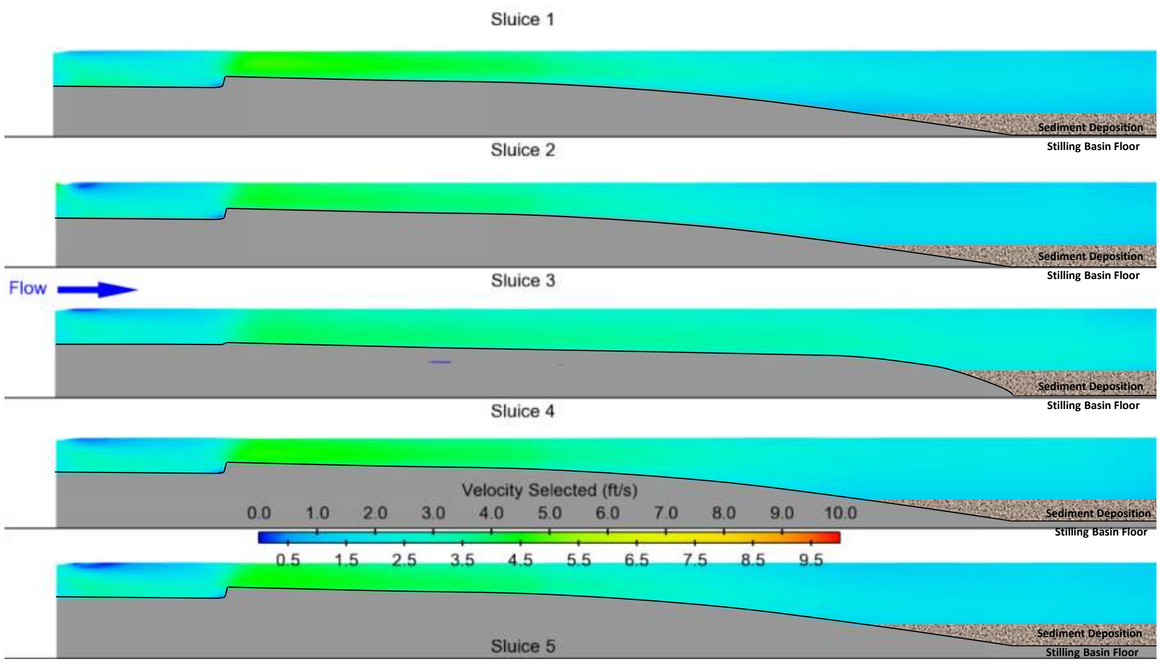


Figure 3-39

Profile View of Velocity Contours For 2,000 cfs Discharge Through Low Level Outlets



3.2 Diversion Tunnel Rating

The hydraulic design calculation of the diversion tunnel rating curve for the FRO, FRFA and FRE alternatives is identical and presented in detail in the Appendix B (Section 3.2) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

3.3 Spillway Design

The spillway design procedure and calculation for FRFA, FRO and FRE alternatives are similar. As an example, the spillway shape design calculation for FRFA dam alternatives is presented in detail in the Appendix B (Section 3.3) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017). The Ogee spillway shape of the FRE is identical to the FRO spillway shape and geometry with the addition of a short and shallow approach channel. The spillway shape and geometry for FRE-FC is identical to FRFA. The detail geometry of FRE and FRE-FC spillways are presented in Table 3-1 and Table 3-2. The spillway geometry design parameters are shown in Figure 3-40.

Table 3-1

Ogee Spillway Upstream Quadrant Profile Parameters for FRE Dam FRE (Left) and FRE-FC (Right)

R_{CL}(ft)	15.0
X_{CL} (ft)	50.0
Y_{CL}(ft)	613.0
$R_{2,3}$(ft)	6.0
$X_{2,3}$ (ft)	46.9
$Y_{2,3}$ (ft)	621.4
R_1(ft)	1.2
$X_{1,CEN}$ (ft)	42.7
$Y_{1,CEN}$ (ft)	623.9
X_1(ft)	58.5
Y_1 (ft)	623.9
X_2(ft)	58.3
Y_2(ft)	624.5
X_3(ft)	55.3
Y_3 (ft)	627.1

R_{CL}(ft)	15.0
X_{CL} (ft)	0.0
Y_{CL}(ft)	672.0
$R_{2,3}$(ft)	6.0
$X_{2,3}$ (ft)	-3.2
$Y_{2,3}$ (ft)	680.4
R_1(ft)	1.2
$X_{1,CEN}$ (ft)	-8.5
$Y_{1,CEN}$ (ft)	682.9
X_1(ft)	8.5
Y_1 (ft)	682.9
X_2(ft)	8.3
Y_2(ft)	683.5
X_3(ft)	5.3
Y_3 (ft)	686.1

Figure 3-40
USACE Hydraulic Design Criteria 111-2/1 Design of Ogee Crest Shape

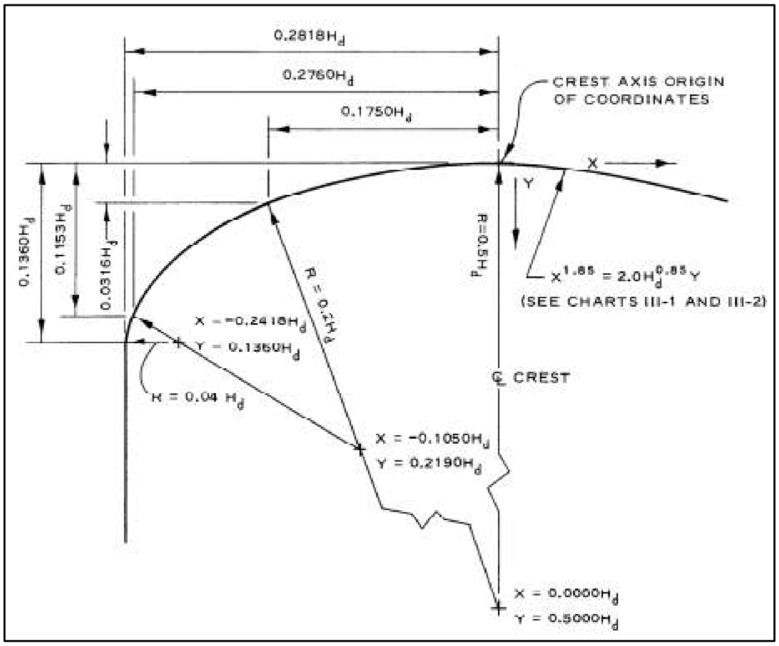


Table 3-2

Spillway Shape Downstream Quadrant for FRE (left) FRE-FC (right)

X (ft)	Y (ft)	Elevation (ft)	Slope	Location
50.0	0.0	628.0	--	
52.0	0.1	627.9	19.99	
52.9	0.2	627.8	8.71	
53.6	0.3	627.7	7.51	
54.2	0.4	627.6	6.09	
54.8	0.5	627.5	5.42	
55.3	0.6	627.4	4.94	
55.7	0.7	627.3	4.58	
56.2	0.8	627.2	4.28	
56.6	0.9	627.1	4.04	
56.9	1.0	627.0	3.84	
57.3	1.1	626.9	3.67	
57.7	1.2	626.8	3.52	
58.0	1.3	626.7	3.39	
58.3	1.4	626.6	3.27	
58.6	1.5	626.5	3.16	
58.9	1.6	626.4	3.07	
59.2	1.7	626.3	2.98	
59.5	1.8	626.2	2.90	
59.8	1.9	626.1	2.83	
60.1	2.0	626.0	2.76	
60.4	2.1	625.9	2.70	Downstream Qudrant
62.8	3.1	624.9	2.43	
64.9	4.1	623.9	2.09	
66.7	5.1	622.9	1.86	
68.4	6.1	621.9	1.70	
70.0	7.1	620.9	1.58	
71.5	8.1	619.9	1.48	
72.9	9.1	618.9	1.40	
74.2	10.1	617.9	1.33	
75.5	11.1	616.9	1.27	
76.7	12.1	615.9	1.22	
77.9	13.1	614.9	1.17	
79.0	14.1	613.9	1.13	
80.1	15.1	612.9	1.09	
81.2	16.1	611.9	1.06	
82.2	17.1	610.9	1.03	
83.2	18.1	609.9	1.00	
84.2	19.1	608.9	0.98	
85.1	20.1	607.9	0.96	
86.1	21.1	606.9	0.93	
87.0	22.1	605.9	0.91	
87.9	23.1	604.9	0.90	
88.8	24.1	603.9	0.88	
89.8	25.3	602.7	0.85	Point of Tangency
108.5	47.3	580.7	0.85	
127.2	69.3	558.7	0.85	
145.9	91.3	536.7	0.85	Spillway Chute
164.6	113.3	514.7	0.85	
183.6	25.3	492.7	0.85	

X (ft)	Y (ft)	Elevation (ft)	Slope	Location
0.0	0.0	687.0	--	
2.0	0.1	686.9	19.99	
2.9	0.2	686.8	9.09	
3.6	0.3	686.7	7.13	
4.2	0.4	686.6	6.09	
4.8	0.5	686.5	5.42	
5.3	0.6	686.4	4.94	
5.7	0.7	686.3	4.58	
6.2	0.8	686.2	4.28	
6.6	0.9	686.1	4.04	
6.9	1.0	686.0	3.84	
7.3	1.1	685.9	3.67	
7.7	1.2	685.8	3.52	
8.0	1.3	685.7	3.39	
8.3	1.4	685.6	3.27	
8.6	1.5	685.5	3.16	
8.9	1.6	685.4	3.07	
9.2	1.7	685.3	2.98	
9.5	1.8	685.2	2.90	
9.8	1.9	685.1	2.83	
10.1	2.0	685.0	2.76	
10.4	2.1	684.9	2.70	Downstream Qudrant
12.8	3.1	683.9	2.43	
14.9	4.1	682.9	2.09	
16.7	5.1	681.9	1.86	
18.4	6.1	680.9	1.70	
20.0	7.1	679.9	1.58	
21.5	8.1	678.9	1.48	
22.9	9.1	677.9	1.40	
24.2	10.1	676.9	1.33	
25.5	11.1	675.9	1.27	
26.7	12.1	674.9	1.22	
27.9	13.1	673.9	1.17	
29.0	14.1	672.9	1.13	
30.1	15.1	671.9	1.09	
31.2	16.1	670.9	1.06	
32.2	17.1	669.9	1.03	
33.2	18.1	668.9	1.00	
34.2	19.1	667.9	0.98	
35.1	20.1	666.9	0.96	
36.1	21.1	665.9	0.93	
37.0	22.1	664.9	0.91	
37.9	23.1	663.9	0.90	
38.8	24.1	662.9	0.88	
39.8	25.3	661.7	0.85	Point of Tangency
68.5	59.1	627.9	0.85	
97.3	92.9	594.1	0.85	
126.0	126.8	560.2	0.85	Spillway Chute
154.8	160.6	526.4	0.85	
183.5	194.4	492.6	0.85	

The spillway rating curve is calculated following the procedure provided in USACE Hydraulic Design Criteria Sheet 111-3/3. Table 3-3 presents the spillway rating curve calculations for FRE and FRE-FC dams.

Table 3-3
Spillway Rating Curve for FRE (Left) and FRE-FC (Right)

Q (cfs)	H_e (ft)	WSE (ft)
69800	21.7	649.7
65000	20.7	648.7
59000	19.5	647.5
53000	18.3	646.3
47000	16.9	644.9
41000	15.5	643.5
35000	14.1	642.1
29000	12.5	640.5
23000	10.8	638.8
17000	9.0	637.0
11000	6.8	634.8
5000	4.2	632.2
0	0.0	628.0

Q (cfs)	H_e (ft)	WSE (ft)
69800	21.0	708.0
65000	20.1	707.1
60000	19.1	706.1
55000	18.1	705.1
50000	17.1	704.1
45000	16.0	703.0
40000	14.9	701.9
35000	13.7	700.7
30000	12.4	699.4
25000	11.1	698.1
20000	9.6	696.6
15000	8.0	695.0
10000	6.2	693.2
5000	4.1	691.1
0	0.0	687.0

Notes: Q= discharge, H_e= effective head, WSE= water surface elevation

The 10 ft deep spillway approach channel for FRE was designed to provide satisfactory hydraulic performance for the range of flows up to PMF. The Froude number calculation presented in Table 3-4 shows that the flow is subcritical and no control transitioning will occur in the approach channel.

Table 3-4
FRE Spillway Approach Channel Flow Regime Calculation

Q (cfs)	Reservoir Elev (ft)	Depth (ft)	V (ft/s)	Fr
69800.0	649.7	31.7	11.0	0.34
63800.0	648.5	30.5	10.5	0.33
57800.0	647.3	29.3	9.9	0.32
51800.0	646.0	28.0	9.3	0.31
45800.0	644.7	26.7	8.6	0.29
39800.0	643.3	25.3	7.9	0.28
33800.0	641.8	23.8	7.1	0.26
27800.0	640.2	22.2	6.3	0.23
21800.0	638.5	20.5	5.3	0.21
15800.0	636.6	18.6	4.3	0.17
9800.0	634.4	16.4	3.0	0.13
3800.0	631.5	13.5	1.4	0.07

3.4 Flip Bucket

The flip buck design procedure and calculation for FRFA, FRO and FRE alternatives are similar. As an example, the flip bucket design calculation for FRFA dam alternatives is presented in detail in the Appendix B (Section 3.4) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017). The jet trajectory leaving the flip bucket was evaluated using the equation for trajectory of a projectile. Table 3-5 presents the water jet trajectory for FRE and FRE-FC dams.

Table 3-5
Water Jet Trajectory Leaving the Flip Buck for FRE (Left) and FRE-FC (Right)

X (ft)	Elevation (ft)
257.0	494.64
286.0	520.93
315.0	541.80
344.0	557.24
373.0	567.26
402.0	571.85
431.0	571.03
460.0	564.78
489.0	553.10
518.0	536.01
547.0	513.49
576.0	485.55
605.0	452.18

X (ft)	Elevation (ft)
257.0	494.37
300.0	533.05
343.0	563.10
386.0	584.52
429.0	597.30
472.0	601.44
515.0	596.96
558.0	583.83
601.0	562.08
644.0	531.69
687.0	492.66
725.0	450.99

3.5 Flood Regulation Outlets Rating Curves

The rating curves for flood regulating outlet works were calculated using the radial gate discharge equation when inlet control exists at the gate location. The calculation procedure is similar for FRO, FRFA, and FRE alternatives. A sample calculation for the FRFA dam alternative flood regulation outlet works rating curve is presented in the Appendix B (Section 3.5) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017).

3.6 Stilling Basin

Stilling basin is designed for the maximum design flow and head to ensure a satisfactory performance under the range of outlet works operational flow. The stilling basin floor elevation of 377 ft was selected for the final design calculation. The design calculation procedure of the stilling basin size and elevation is similar to the FRO, FRFA alternatives. A sample calculation of the FRFA dam alternative stilling basin is presented in the Appendix B (Section 3.6) of the Draft Combined Dam and Fish Passage Conceptual Design Report (HDR, 2017). Table 3-6 presents the stilling basin endsill rating curve.

Table 3-6
Stilling Basin End Sill Rating Curve

Discharge (cfs)	H (ft)	WSE (ft)
10	0.1	417.1
100	0.6	417.6
250	1.1	418.1
500	1.7	418.7
1000	2.7	419.7
1500	3.6	420.6
2500	5.0	422.0
5000	7.9	424.9
7500	10.4	427.4
10000	12.6	429.6
15000	16.5	433.5

Notes: H= water head, WSE= water surface elevation

Appendix J
Construction Cost Opinion

Chehalis Basin Strategy

Appendix J

Construction Cost Opinion for FRE Dam Alternative

Reducing Flood Damage and
Restoring Aquatic Species Habitat

Updated September 2018

Prepared for: State of Washington Recreation and Conservation Office and Chehalis Basin Work Group

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EXECUTIVE SUMMARY

Based on prior FRO and FRFA costs developed and brought current to June 2017, an opinion of probable costs (OPC) has been developed for constructing the flood retention expandable (FRE) alternative broken into an initial construction phase (FRE), and a future construction phase (FRE-FC), if desired. The following attachments summarize and provide support for the FRE cost development:

Attachment 1 – Summary of Costs and Key Information; 1 page

Attachment 2 – FRO and FRFA OPC Refinement for Comparison to the FRE ; 1 page

Attachment 3 – FRE, FRE-FC, and updated FRO and FRFA Cost Sheets; 8 pages

Attachment 4 – FRE RCC Placement Analysis Summary; 2 pages

Attachment 5 – FRE, FRE-FC, and updated FRO and FRFA RCC Unit Cost Development; 4 pages

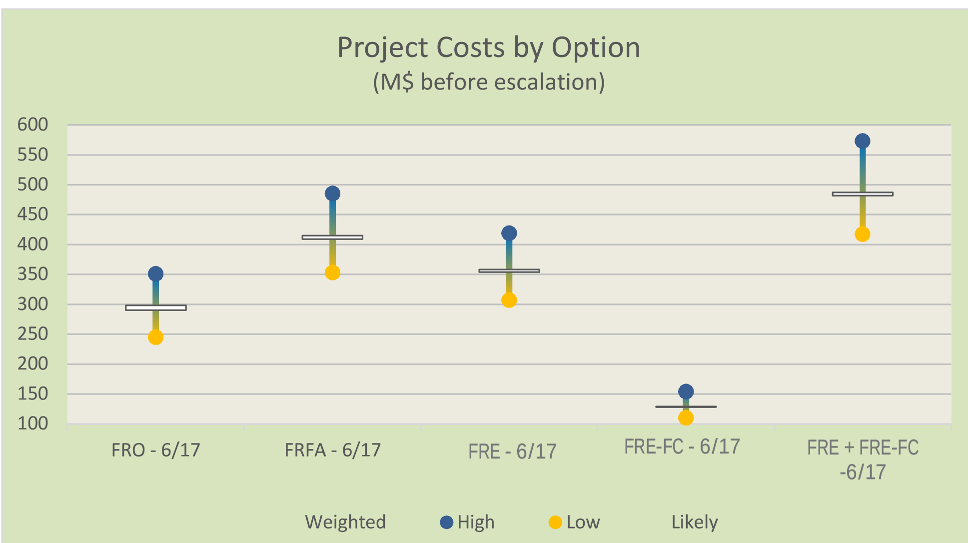
Attachment 6 – Drawing Sheets Illustrating FRE RCC Progression and Quantity Takeoff Support; 16 pages

1 SUMMARY OF COSTS AND KEY INFORMATION

Summary of costs and key information for different alternatives are provided in the following page.

Table 13-1: Concept-Level Opinion of Probable Costs: Summary of Key Information

Summary Information	FRO	FRFA	FRE	FRE-FC	FRE & FRE-FC
Costs Prior to Escalation					
Low End Project Cost[1]	245,000,000	353,000,000	307,000,000	110,000,000	417,000,000
Likely Project Cost[1]	298,000,000	415,000,000	358,000,000	129,000,000	487,000,000
High End Project Cost[1]	351,000,000	485,000,000	419,000,000	154,000,000	573,000,000
Project Cost Range from Likely	82% - 118%	85% - 117%	82% - 118%	82% - 118%	86% - 118%
Costs Applying Escalation					
Low End Project Cost[2]	311,000,000	457,000,000	390,000,000	140,000,000	530,000,000
Likely Project Cost[2]	379,000,000	537,000,000	456,000,000	164,000,000	620,000,000
High End Project Cost[2]	447,000,000	628,000,000	533,000,000	196,000,000	729,000,000
Escalation period from Jun-2017[3]	7.0 yr	7.5 yr	7.0 yr	7.0 yr	7.0 yr
Escalation to presumed midpoint of construction[4]	1-Jun-24	1-Dec-24	1-Jun-24	1-Jun-24	1-Jun-24
Select Cost Estimate Information [1]					
Driving RCC quantity	810,000 cy	1,360,000 cy	892,000 cy	467,000 cy	1,359,000 cy
RCC Unit Bid - Likely (FRO GERCC, FRFA U/S conv.)	$ 93.00	$ 99.00	$ 103.50	$ 111.00	$ 106.08
RCC Unit Bid Range	$ 76.50 - $ 109.50	$ 83.50 - $ 113.50	$ 88.00 - $ 119.00	$ 94.00 - $ 127.00	
RCC Scope - as % of Contractor Bid	38%	49%	39%	61%	45%
Notes: 1 - prior to escalation; 2 - 3.5% annual; 3 - mid 2021 presumed NTP, then to midpoint of construction; 4 - FRX-FC escalation to midpoint of FRX-IC					0%



2 FRO AND FRFA OPINION OF PROBABLE COST REFINEMENT FOR COMPARISON TO THE FRE

Opinion of probable cost of FRO and FRFA dam alternatives were refined to provide a realistic comparison with the OPC of FRE alternative. The FRO and FRFA refinement process rationale and key information are provided in the following page.

Chehalis Judgment-Level Cost Opinion
FRO-FRFA June 2017 Cost Adjustments

Item #	Adjustment ($)	Estimate Refinement Rationale
FRFA Adjustments		
3.01	1,080,000	Increased the length of the diversion tunnel to consider some uncertainty related the ground conditions and handling those conditions near the downstream portal.
5.03	(6,960,000)	Adjust RCC quantity from 1,475,000 cy to 1,360,000 cy and the unit price from $96 to $99 to reflect excavation surface refined for the FRE and to increase some material components of the RCC unit price bringing the pricing to a June 2017 price level.
5.04	(500,500)	Adjust backfill quantity form full FRE QTO; 375,000 cy to 260,000 cy.
Various	12,858,750	Adjusted and reorganized dam and hydaulic structure concrete to reflect FRE and hydraulic modeling: 68,500 cy to 85,500 cy; and composite unit pricing from $537.32/cy to $580.88 Items- 5.05-5.07, 5.10, 5.17-5.18, 5.20, 6.01-6.02, 7.04-7.05.
Various	(1,563,840)	Adjusted project control gates, valves, and trashrack steel to reflect FRE and hydraulic modeling and . Items- 5.11-5.16, 5.19.
Various	1,803,333	Adjusted wing dam earthwork quantities and unit prices to better reflect the excavation surface developed for the FRE and a composite embankment unit price. Items-8.01-8.04
		keep cell
		keep cell
		keep cell
		keep cell
		keep cell
		keep cell
		keep cell
		keep cell
Subtotal	**6,717,743**	**Subtotal line-item cost adjustments**
	839,718	Design and procurement contingencies; remaining at 12.5% (unchanged)
Subtotal	7,557,461	Net cost additions to the "likely" estimate; before construction contingencies and non-contract cost factor
	35%	Construction contingency and non-contract cost factor to arrive at total adjustments before escalation (unchanged)
	2,645,111	
Total	**10,202,573**	**Total cost adjustments to likely estimate, before escalation**
	11,000,000	Rounded comparison from summary
FRO Adjustments		
2.04	4,000	Typo correction in initial quantity
3.01	1,080,000	Increased the length of the diversion tunnel to consider some uncertainty related the ground conditions and handling those conditions near the downstream portal.
5.03	(3,840,000)	Adjust RCC quantity from 870,000 10cy to 8,000 cy and the unit price from $91 to $93 to reflect excavation surface refined for the FRE and to increase some material components of the RCC unit price bringing the pricing to a June 2017 price level.
5.06	(302,500)	Adjust backfill quantity form full FRE QTO; 375,000 cy to 265,000 cy.
Various	20,374,750	Adjusted and reorganized dam and hydaulic structure concrete to reflect FRE and hydraulic modeling: 50,200 cy to 84,510 cy; and composite unit pricing from $561.33/cy to $574.53 Items- 5.05-5.07, 5.10, 5.17-5.18, 5.20, 6.01-6.02, 7.04-7.05.
Various	724,200	Adjusted project control gates, valves, and trashrack steel to reflect FRE and hydraulic modeling and . Items- 5.11-5.16, 5.19.
Subtotal	**18,040,450**	**Subtotal line-item cost adjustments**
	2,255,056	Design and procurement contingencies; remaining at 12.5% (unchanged)
Subtotal	20,295,506	Net cost additions to the "likely" estimate; before construction contingencies and non-contract cost factor
	35%	Construction contingency and non-contract cost factor to arrive at total adjustments before escalation (unchanged)
	7,103,427	
Total	**27,398,933**	**Total cost adjustments to likely estimate, before escalation**
	27,000,000	Rounded comparison from summary

3 FRE, FRE-FC, AND UPDATED FRO AND FRFA COST SHEETS

Detailed cost break down sheets for FRE, FRE-FC, and updated FRO and FRFA alternatives are provided in the following pages.

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: ***Chehalis Dam***
Alternative: ***FRE***

Pricing - contractor cost basis 1 or bid basis 2:	**2**			
Range Driver - 1 = %, 2 = Q & $, 3 = Combination:	**3**			
Default Low ⇨	**80%**	**Default High ⇨**	**120%**	

Weighting ⇨	**20% low**	**70% likely**	**10% high**	**20% low**	**70% likely**	**10% high**
$293M - Jul-16	**Low End**	**$306,543,571**		**Low End**	**$390,083,824**	
	Likely	**$358,397,146**		**Likely**	**$456,068,705**	
$454M - Jul-18	**High End**	**$419,217,088**		**High End**	**$533,463,496**	
	Weighted	**$354,108,425**		**Weighted**	**$450,611,208**	

Quantity references: "FRE - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					Range Development											
							Driven by Percent				Driven by Q & Unit $						Driven by Combo	
Work Item	**Description**	**Quantity**	**Unit**	**Unit Price [1]**	**Total $**	**Estimate Notes & Considerations (Notes prior to FRE eval grayed out)**	**Low End % (def=80%)**	**High End % (def=120%)**	**Low % Total $**	**High % Total $**	**Low End Q**	**Low End Unit $**	**Low End Total $**	**High End Q**	**High End Unit $**	**High End Total $**	**Low End Tot $**	**High End Tot $**
	Phase 1 - Site Development, Diversion Constrruction,				$0				$0	$0			info?			info?	$0	$0
0	**Mobilization**								$0	$0			info?			info?	$0	$0
	Mobilization	1	LS	$5,000,000.00	$5,000,000	**No change for FRE.** Contractor mob bid; balance of project overhead in below-the-line factors	100%	140%	$5,000,000	$7,000,000			info?			info?	$5,000,000	$7,000,000
1	**Clearing & Grubbing**				$0				$0	$0			info?			info?	$0	$0
1.01	Clearing and grubbing, stripping topsoil, reclamation of disturbed areas	30	Acre	$30,000.00	$900,000	**No change for FRE.**			$720,000	$1,080,000	25	$30,000.00	$750,000	35	$25,000.00	$875,000	$750,000	$875,000
1.02	Reservoir Clearing to 100-yr Flood Stage	362	Acre	$6,000.00	$2,170,800	**Assumed 30% FRE and 70% FRE-FC from orig FRFA of 1206 ac @ $6K/ac.** Potentially in Phase 2 or possibly Phase 3 contract			$1,736,640	$2,604,960		$5,000.00	$1,809,000		$7,500.00	$2,713,500	$1,809,000	$2,713,500
2	**Temporary Access & Staging**				$0				$0	$0			info?			info?	$0	$0
2.01	Construction Surveying & Layout	35	Acre	$10,000.00	$350,000	**No change for FRE.** Under temporary access & staging; i.e. temporary works only, predominant surveys and layout in unallocated contractor project overhead expense (already in the unit pricing)	100%	150%	$350,000	$525,000			info?			info?	$350,000	$525,000
2.02	Pioneer/Access Roads (e.g. dam site, abutments, quarry site, etc.)	3	Mile	$700,000.00	$2,100,000	**No change for FRE. Changes for final: increase access road development by adding 1 mile, from 2 to 3.** dependent upon aggregate sourcing, staging locations, contractor approach. Reference Chehalis_All_Figs_2016-10-19.pdf drawing G-3, for site, non-quarry access concepts, totaling about 10,000lf of new access, say 5000lf of upgraded access. Say 50% new and full access development, 20% construction & track access only, 30% improved existing. Consider quarry acces costs in aggregate price range.			$1,680,000	$2,520,000	2.5	$750,000.00	$1,875,000	3.5	$800,000.00	$2,800,000	$1,875,000	$2,800,000
2.03	Material Laydown Area Prep (minor excavation, grading, surfacing, drainage	20	Acre	$25,000.00	$500,000	**No change for FRE.** 1 acre at 5' avg cut to 5' average fill = 4000cy cut to fill; @ $6/cy cut to fill = $24,200/ac; 1ac surfacing at 6" & 30% surfaced = 430ton, @ 10/tn = $4.5k/ac			$400,000	$600,000	15	$30,000.00	$450,000	25		$625,000	$450,000	$625,000
2.04	Temporary construction site access security control facilities (e.g. fencing, gates, etc.)	2,200	LF	$20.00	$44,000	**No change for FRE.** 'predominant security expense in unallocated contractor project overhead expense			$35,200	$52,800			info?			info?	$35,200	$52,800
3	**Diversion & Dewatering**				$0				$0	$0			info?			info?	$0	$0
3.01	Diversion Tunnel 20 ft modified horseshoe	1,635	LF	$8,000.00	$13,080,000	**Increased length for FRE and both FRO and FRFA, from 1500. Changes for final: increase length of tunnel to better reflect final drawing alignment.** increase high end for variability in linnig limits, portaling, tunnel plug adit construction, vent construction, etc.	90%	125%	$11,772,000	$16,350,000			info?			info?	$11,772,000	$16,350,000
3.02	Conventional Concrete Non-Reinforced Mass Concrete (100' plug following construction)	1,200	CY	$600.00	$720,000	**No change for FRE.** low end 30'plug but include mechanical.			$576,000	$864,000			info?		$650.00	$780,000	$576,000	$780,000
3.03	Coffer Dams (2) - Fill cells u/s and d/s + toe slopes	14,000	CY	$40.00	$560,000	**No change for FRE.** check Q's with new crest heights, say 8,000 cy RCC @ 70 + 6,000 cy Rockfill @ 15. = 650KHigh end if pushed to 480 and rockfill - say 45kcy = $675K.			$448,000	$672,000			info?			info?	$448,000	$672,000
3.04	Foundation Excavation - seepage key (assume 20'wide x 150' long x 4' deep	450	CY	$8.00	$3,600	**No change for FRE.** Cofferdam key allowance		300%	$2,880	$10,800			info?			info?	$2,880	$10,800
3.05	Foundation Dewatering - assume several dewatering pump systems operating selectively 24/7 over 12 month foundation construction exposure	360	Day	$2,800.00	$1,008,000	**No change for FRE. Changes for final: increase foundation exposure from 6 to 12 months.** 2nd contract may add unwaterring and time for dewatering for RCC foundation		150%	$806,400	$1,512,000			info?			info?	$806,400	$1,512,000
3.06	Coffer Dams - Other assume 25' high x 150 top length, 35' base length, cell construction (e.g. sheet pile, steel, other fabricated metal items)	7,000	SF	$30	$210,000	**No change for FRE.** may include isolation of portal structures, tailwater structures, peripheral dewatering stages			$168,000	$252,000			info?			info?	$168,000	$252,000
3.07	Coffer Dams - Risk contingency for overtopping	1	LS	$1,000,000.00	$1,000,000	**No change for FRE.** contemplates partial or threshold-bound contractor responsibility, risk apportioned cost of event recovery, rework, delay			$800,000	$1,200,000			info?			info?	$800,000	$1,200,000
4	**Lands and Easements**				$0				$0	$0			info?			info?	$0	$0
4.01	Reservoir Extents Fee Title	1,200	Acre	$4,400	$5,280,000	**No change for FRE.** Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$5,280,000	$5,280,000			info?			info?	$5,280,000	$5,280,000
4.02	Reservoir Extents/Flood Easement	110	Acre	$4,400	$484,000	**No change for FRE.** Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$484,000	$484,000			info?			info?	$484,000	$484,000
4.03	Reservoir orphaned access roadway reconnection allowance (to WeyCo?)	5	Mile	$1,000,000	$5,000,000	**No change for FRE.** Unit price potentially higher for permanent versus constuction roads. Line item also perhaps better considered under non-contract cost factor.		110%	$4,000,000	$5,500,000			info?			info?	$4,000,000	$5,500,000
	Phase 2 - Main Dam																$0	$0
5	**Main Dam Structure**				$0				$0	$0			info?			info?	$0	$0
5.01	Excavation - Foundation General	710,000	CY	$6.50	$4,615,000	**No change for FRE - pending Q verification. Changes for final: revised quantities.** Reference FRFA S-1 annotated from Chehalis_All_Figs_2016-10-19.pdf, also this worksheet FRFA Exc Guess tab.			$3,692,000	$5,538,000		$5.50	$3,905,000		$7.50	$5,325,000	$3,905,000	$5,325,000
5.02	Excavation - Foundation Rock	210,000	CY	$27.00	$5,670,000	**No change for FRE - pending Q verification. Changes for final: revised quantities.** Reference FRFA S-1 annotated from Chehalis_All_Figs_2016-10-19.pdf, also this worksheet FRFA Exc Guess tab. Some rock will be structural exc in fresh rock, most will be foundation footprint, getting to good rock below the rock contact; i.e potentially a high degree ripable.			$4,536,000	$6,804,000		$25.00	$5,250,000		$30.00	$6,300,000	$5,250,000	$6,300,000
5.03	Roller Compacted Concrete - Composite Scope	892,000	CY	$103.50	$92,322,000	**Revised RCC Q (1,475k to 892k) for FRE that fully preps FRE-FC foundation. Revised unit pricing ($96 to $103.50) to reflect slightly higher aggregate and cementitous materials to reflect Jun 2017 pricing, increased fixed costs for delivery adjustments, slower productivity, increased formwork. Changes for final: revised quantities. Expanded RCC unit cost development work breakdown, revisited unit pricing, and increased unit pricing to reflect upstream conventional face and downstream GERCC.** RCC unit pricing includes aggregate, cement-fly ash, lift bedding, abutment bedding, dam joints, and **2.5' upstream conventional face and downstream GERCC.** Conventional concrete spillway face - included elsewhere.			$73,857,600	$110,786,400		$88.00	$78,496,000		$119.00	$106,148,000	$78,496,000	$106,148,000
5.04	Fill - Foundation Backfill	127,000	CY	$5.50	$698,500	**Adjusted Q's for full upstream groin fill (112kcy) plus 5' RCC apron cover downstream (15kcy); Pending Q verification. Changes for final: revised quantities.**			$558,800	$838,200			info?			info?	$558,800	$838,200
5.05	Conventional Concrete Reinforced (miscellaneous)	0	CY	$850.00	$0	**Item not used in FRE estimate. Q was 750cy @ $850.** Refine quantities along with all structures next phase.			$0	$0			info?			info?	$0	$0
5.06	Outlet works encasement: sluicing conduits, river outlet works conduits, gate chamber, vent and gallery passages	60,000	CY	$450.00	$27,000,000	**Prior item mixed dam items integral with RCC composite unit price, and OW massive encasement. FRE estimate considers this item now fully the OW and sluiceway enasement and gate chamber. Q was 15,000cy @ $400. Consider the quantities as drawn to represent the high side anticipating optimization from 70,000cy down to 60,000cy. This 10kcy Q difference would need to be replaced with RCC; approx 10,000cy @ $100/cy / 1.36Mcy = $0.75/cy RCC, which has not been accounted for in the estimate. Ref "FRE - Annotated Dwgs Supporting OPC.pdf" FRE S-6-S-7 sheets.** Refine quantities along with all structures next phase.			$21,600,000	$32,400,000	55,000		$24,750,000	70,000		$31,500,000	$24,750,000	$31,500,000
5.07	Concrete - Dam Crest Slab & Parapet and unlisted dam concrete structures	5,400	CY	$750.00	$4,050,000	**Prior item included "Dam and Crest Spillway". For FRE, item has been changed to reflect the dam crest, and parapet walls plus 4,000cy of dam conventional concrete not yet itemized (adit entrances, spillway end walls, diversion plug conversion to operating chamber, etc.) Item was 6500cy @ $750. Changes for final: None. Consider this item only as upper spillway.** No facing should be included if flip bucket chute face is elsewhere. Leave in for ogee, spillway approach walls, piers.	70%	110%	$2,835,000	$4,455,000			info?			info?	$2,835,000	$4,455,000

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: ***Chehalis Dam***
Alternative: ***FRE***

Weighting ⇨	20% low	70% likely	10% high	20% low	70% likely	10% high
$293M - Jul-16	**Low End**	**$306,543,571**		**Low End**	**$390,083,824**	
	Likely	**$358,397,146**		**Likely**	**$456,068,705**	
$454M - Jul-18	**High End**	**$419,217,088**		**High End**	**$533,463,496**	
	Weighted	**$354,108,425**		**Weighted**	**$450,611,208**	

Range Driver - 1 = %, 2 = Q & $, 3 = Combination:	**3**		
Default Low ⇨	**80%**	**Default High ⇨**	**120%**

Pricing - contractor cost basis 1 or bid basis 2: **2**

Quantity references: "FRE - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					Range Development: Driven by Percent				Driven by Q & Unit $						Driven by Combo	
Work Item	**Description**	**Quantity**	**Unit**	**Unit Price [1]**	**Total $**	**Estimate Notes & Considerations (Notes prior to FRE eval grayed out)**	**Low End % (def=80%)**	**High End % (def=120%)**	**Low % Total $**	**High % Total $**	**Low End Q**	**Low End Unit $**	**Low End Total $**	**High End Q**	**High End Unit $**	**High End Total $**	**Low End Tot $**	**High End Tot $**
5.08	Foundation Treatment - Grout Curtain Drilling	50,000	LF	$45.00	$2,250,000	**FRE is 1780' of foundation contact. No change to Q or unit pricing.** revisited pricing; 1700lf @ 10', plus 50% secondary, plus 25% tertiary @ 80' deep = 298 holes @ 90' = 26,820lf; if consolidation grouting - add 220,000 sf @ 400sf/ hole @ 20' deep = 11,000lf = 37,820 lf. If double curtain plus 25% extra = 383 holes @ 90' = 34,470lf, plus 11k consolidation grouting = 45,470lf. Use 50k lf. Depth: 300' at 35'+300' at 85'+500' at 140' +			$1,800,000	$2,700,000			info?			info?	$1,800,000	$2,700,000
5.09	Foundation Treatment - Grout Curtain Cement	35,000	Sack	$40.00	$1,400,000	**FRE is 1780' of foundation contact. No change to Q or unit pricing.** **Changes for final: revised quantity, increased unit price.** Assume 0.7 bag per lf			$1,120,000	$1,680,000			info?			info?	$1,120,000	$1,680,000
5.1	Flood Regulating Conduit Control Structures - Reinforced Concrete	0	CY	$800.00	$0	**Now in item 5.06. Was 5800cy @ $850.** Assume 2' thick around perimeter of sluices & air shafts. Refine quantities along with all structures next phase; include inside and downstream of dam; include control building on crest or at downstream, depending on final concept drawings			$0	$0			info?			info?	$0	$0
5.11	Flood Regulating Conduit Control Gates - Fab and Construct	320,000	LB	$15.00	$4,800,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 120,000# @ $15.00.** Assume 2 @ 30 tons.			$3,840,000	$5,760,000			info?			info?	$3,840,000	$5,760,000
5.12	Emergency, flood regulating, & WQ bulkhead gates	976,000	LB	$10.00	$9,760,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 300,000# @ $15.00.** Assume 2 @ 25 tons, and 2 @ 50 tons			$7,808,000	$11,712,000			info?			info?	$7,808,000	$11,712,000
5.13	Hoists, cylinders, machinery	300,000	LB	$15.00	$4,500,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 200,000# @ $15.00.**			$3,600,000	$5,400,000			info?			info?	$3,600,000	$5,400,000
5.14	Reservoir drain valve in tunnel plug (assume 4x4' knife valve)	1	Each	$200,000.00	$200,000	**No change for FRE.**	50%	100%	$100,000	$200,000			info?			info?	$100,000	$200,000
5.15	WQ Regulating Outlets w/ hollow cone valves (4 - 4'dia)	0	Each	$375,000.00	$0	**FRE does not furnish or install the WQ outlet valves. Item was 4 each at $375k.**			$0	$0			info?			info?	$0	$0
5.16	WQ Regulating Outlet w/ hollow cone valves (1 - 7'dia)	0	Each	$100,000.00	$0	**FRE does not furnish or install the WQ outlet valves. Item was 1 each at 1,100k.**			$0	$0			info?			info?	$0	$0
5.17	WQ Intake Tower / concrete sidewall & decking - Conventional Concrete Reinforced	5,800	CY	$850.00	$4,930,000	**Items 5.17 and 5.18 prior, totaled 14,000cy (2800 @ $750 and 11,200 @ $400). All intake concrete is now in this item; ref "FRE - Annotated Dwgs Supporting OPC.pdf" FRE S-6-S-7 sheets.**			$3,944,000	$5,916,000			info?			info?	$3,944,000	$5,916,000
5.18	Unused	0	CY	$400.00	$0	**Now in item 5.17. Was 11,200cy @ $400.** **Refine quantities along with all structures next phase.**	100%		$0	$0			info?			info?	$0	$0
5.19	Trashrack steel framing	1,769,040	LB	$6.50	$11,498,760	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 1,360,000# @ $6.50.** Assume 300 ft high, 10 members 3' dia x 4.5'deep, steel column			$9,199,008	$13,798,512			info?			info?	$9,199,008	$13,798,512
5.2	unused	0	CY	$850.00	$0	**Now in item 5.17. Was 2000cy @ $850.**			$0	$0			info?			info?	$0	$0
6	**Spillway**				$0				$0	$0			info?			info?	$0	$0
6.01	Flip Bucket Conventional Concrete - surface	5,800	CY	$650.00	$3,770,000	**Adjust based on 5' minimum structure overlying RCC block to elev 470. Q prior was 7800cy at $700.**			$3,016,000	$4,524,000			info?			info?	$3,016,000	$4,524,000
6.02	Conventional Concrete - spillway approach, ogee, chute slab, and training walls	8,700	CY	$850.00	$7,395,000	**Line item prior contemplated the foundation block beneath the Ogee. Use item now for spillway training walls, chute slab, approach and ogee. Q was 9,750cy at $225. RCC foundation is now in RCC item.** unit price - accomodates higher RCC placement and utilization of some mass conventional concrete	90%	110%	$6,655,500	$8,134,500			info?			info?	$6,655,500	$8,134,500
7	**Sluice Stilling Basin**				$0				$0	$0			info?			info?	$0	$0
7.01	Excavation - Foundation General	20,000	CY	$8.00	$160,000	Refine all excavation and backfill quantities next phase			$128,000	$192,000			info?			info?	$128,000	$192,000
7.02	Excavation - Foundation Rock	10,000	CY	$30.00	$300,000				$240,000	$360,000			info?			info?	$240,000	$360,000
7.03	Fill - Foundation Backfill	18,000	CY	$9.00	$162,000				$129,600	$194,400			info?			info?	$129,600	$194,400
7.04	Conventional Concrete Reinforced	8,600	CY	$750.00	$6,450,000	**Reference "FRE - Annotated Dwgs Supporting OPC.pdf", sheets FRE S-06, S07. Was 4900 @ $8700 and item 7.04 2000cy at $400.**			$5,160,000	$7,740,000			info?			info?	$5,160,000	$7,740,000
7.05	Conventional Concrete Non-Reinforced	1,600	CY	$400.00	$640,000		70%		$448,000	$768,000			info?			info?	$448,000	$768,000
8	**Wing Dam Structure**				$0				$0	$0			info?			info?	$0	$0
8.01	Excavation - Foundation General	0	CY	$6.50	$0	**Not in FRE; was 33,333 cy**			$0	$0			info?			info?	$0	$0
8.02	Excavation Cutoff Trench - Foundation Rock (assume trench 30 ft wide x 20 ft deep)	0	CY	$30.00	$0	**Not in FRE; was 13,333 cy**			$0	$0			info?			info?	$0	$0
8.03	Fill - Wingdam Embankment	0	CY	$15.00	$0	**Not in FRE; was 120,000 cy**	90%		$0	$0			info?			info?	$0	$0
8.04	Fill - Wingdam Riprap Facing (assume 5' blanket U/S and D/S)	0	CY	$65.00	$0	**Not in FRE; was 8,000 cy**			$0	$0			info?			info?	$0	$0
	Composite & Unlisted Work																	
55	Fish passage structure - costs not included	1	ls	$0	$0	Costs independently assessed in report			$0	$0			info?			info?	$0	$0
56	Unlisted Work	1	ls	$5,000,000	$5,000,000	**No change for FRE.**	85%	115%	$4,250,000	$5,750,000			info?			info?	$4,250,000	$5,750,000
57					$0				$0	$0			info?			info?	$0	$0
58					$0				$0	$0			info?			info?	$0	$0
59					$0				$0	$0			info?			info?	$0	$0
60					$0				$0	$0			info?			info?	$0	$0
61					$0				$0	$0			info?			info?	$0	$0
62					$0				$0	$0			info?			info?	$0	$0
63					$0				$0	$0			info?			info?	$0	$0
64					$0				$0	$0			info?			info?	$0	$0
65					$0				$0	$0			info?			info?	$0	$0
					$0				$0	$0			info?			info?	$0	$0
Subtotal without mobilization & general expense					**$235,981,660**		**$192,776,628**	**$282,158,572**	**$192,776,628**	**$282,158,572**			**$117,285,000**			**$157,066,500**	**$201,839,388**	**$276,027,712**
Mobilization & project indirect expense			0%		$0	unallocated project indirect or jobsite overhead assumed in unit pricing												
Contractor Cost					**$235,981,660**	Note 1: Unit prices as noted in header, either reflect a bid price basis (no factor application of corporate OH & profit), or a contractor cost basis requiring a corporate OH & profit to get to a bid total												
Contractor Margin - corporate overhead & profit			~~0%~~	Bid Basis	$0	Note 2: NA - not applicable to project; NE - not evident in estimate; NI - noted but not itemized in estimate												
Contractor Bid - before design/procurement contingencies					**$235,981,660**													
Contract Contingencies - design and procurement contingencies			12.5%		$29,497,708	⇦ RCC estimate dominance, work breakdown thoroughness, and work understanding support a design contingency lower than typical (i.e. 20%) at this early design level												
Contract Cost - contractor bid with design & procurement contingencies					**$265,479,368**													
Construction Contingency: post-award change & dispute factor			10%		$26,547,937													
Non-Contract Costs: PM, planning, design, CM ...			25%		$66,369,842	⇦ permitting, site characterization, CM during construction,etc.												
Total Project Cost - before escalation					**$358,397,146**	**Compares to $293M low bound, and $454M high bound July 2016**												
Escalation - annual %; from; to		3.5%	1-Jun-17	1-Jun-24	$97,671,559	⇦ **Presume NTP - mid 2021, say 6 years construction = 4 years + 1/2 of 6 years = 7.0 years. Was early 2019, 7 years construction, 2.5 + 3.75 = 6.25**												
Total Project Cost - including escalation				**7.0 yr**	**$456,068,705**	**<< 193% above total w/o mobilization**												

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: Chehalis Dam
Alternative: FRE-FC

Weighting ⇨	20% low	70% likely	10% high	20% low	70% likely	10% high
$293M - Jul-16	Low End	$110,099,910		Low End	$140,104,697	
	Likely	$128,809,987		Likely	$163,913,704	
$454M - Jul-18	High End	$154,389,521		High End	$196,464,257	
	Weighted	$127,625,925		Weighted	$162,406,958	

Range Driver - 1 = %, 2 = Q & $, 3 = Combination:	3		
Default Low ⇨	80%	Default High ⇨	120%

Pricing - contractor cost basis 1 or bid basis 2:	2

Quantity references: "FRE - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					Range Development											
							Driven by Percent				Driven by Q & Unit $						Driven by Combo	
Work Item	Description	Quantity	Unit	Unit Price [1]	Total $	Estimate Notes & Considerations (Notes prior to FRE eval grayed out)	Low End % (def=80%)	High End % (def=120%)	Low % Total $	High % Total $	Low End Q	Low End Unit $	Low End Total $	High End Q	High End Unit $	High End Total $	Low End Tot $	High End Tot $
	Phase 1 - Site Development, Diversion Constrruction,				$0				$0	$0			info?			info?	$0	$0
0	**Mobilization**								$0	$0			info?			info?	$0	$0
	Mobilization	1	LS	$5,000,000.00	$5,000,000	No change for FRE-FC. Contractor mob bid; balance of project overhead in below-the-line factors	100%	140%	$5,000,000	$7,000,000			info?			info?	$5,000,000	$7,000,000
1	**Clearing & Grubbing**				$0				$0	$0			info?			info?	$0	$0
1.01	Clearing and grubbing, stripping topsoil, reclamation of disturbed areas	15	Acre	$8,000.00	$120,000	Was 30 ac in FRE and $30k /ac. Presumably all clearing would be completed in FRE; but unspecified return growth would need to be recleared for FRE-FC.			$96,000	$144,000			info?			info?	$96,000	$144,000
1.02	Reservoir Clearing to 100-yr Flood Stage	844	Acre	$6,000.00	$5,065,200	Assumed 30% FRE and 70% FRE-FC from orig FRFA of 1206 ac @ $6K/ac. Potentially in Phase 2 or possibly Phase 3 contract			$4,052,160	$6,078,240		$5,000.00	$4,221,000		$7,500.00	$6,331,500	$4,221,000	$6,331,500
2	**Temporary Access & Staging**				$0				$0	$0			info?			info?	$0	$0
2.01	Construction Surveying & Layout	0	Acre	$10,000.00	$0	Fully assigned to FRE, assume FRE-FC survey and layout in general expense (project indirect costs). Under temporary access & staging; i.e. temporary works only, predominant surveys and layout in unallocated contractor project overhead expense (already in the unit pricing)	100%	150%	$0	$0			info?			info?	$0	$0
2.02	Restore FRE and left-side access. Pioneer/Access Roads (e.g. dam site, abutments, quarry site, etc.)	1.0	LS	$400,000.00	$400,000	All access constructed under FRE. Consider $350k restore and maintain under FRE-FC. Was 3 mi @ $700k. Changes for final: increase access road development by adding 1 mile, from 2 to 3. dependent upon aggregate sourcing, staging locations, contractor approach. Reference Chehalis_All_Figs_2016-10-19.pdf drawing G-3, for site, non-quarry access concepts, totaling about 10,000lf of new access, say 5000lf of upgraded access. Say 50% new and full access development, 20% construction & track access only, 30% improved existing. Consider quarry acces costs in aggregate price range.			$320,000	$480,000			info?	3.5	$800,000.00	$2,800,000	$320,000	$2,800,000
2.03	Material Laydown Area Prep (minor excavation, grading, surfacing, drainage	20	Acre	$5,000.00	$100,000	All staging constructed under FRE. Consider $100k restore and maintain under FRE-FC. Was 20 ac @ $25k. . 1 acre at 5' avg cut to 5' average fill = 4000cy cut to fill; @ $6/cy cut to fill = $24,200/ac; 1ac surfacing at 6" & 30% surfaced = 430ton, @ 10/tn = $4.5k/ac			$80,000	$120,000		$30,000.00	$600,000			info?	$600,000	$120,000
2.04	Temporary construction site access security control facilities (e.g. fencing, gates, etc.)	2,200	LF	$20.00	$44,000	No change for FRE-FC. 'predominant security expense in unallocated contractor project overhead expense			$35,200	$52,800			info?			info?	$35,200	$52,800
3	**Diversion & Dewatering**				$0				$0	$0			info?			info?	$0	$0
3.01	Diversion Tunnel 20 ft modified horseshoe	0	LF	$8,000.00	$0	No diversion tunnel or low-level drawdown gate changes in FRE-FC. Changes for final: increase length of tunnel to better reflect final drawing alignment. increase high end for variability in linnig limits, portaling, tunnel plug adit construction, vent construction, etc.	90%	125%	$0	$0			info?			info?	$0	$0
3.02	Conventional Concrete Non-Reinforced Mass Concrete (100' plug following construction)	0	CY	$600.00	$0	No costs for FRE-FC. low end 30'plug but include mechanical.			$0	$0			info?			info?	$0	$0
3.03	Coffer Dams (2) - Fill cells u/s and d/s + toe slopes	0	CY	$40.00	$0	No costs for FRE-FC. check Q's with new crest heights, say 8,000 cy RCC @ 70 + 6,000 cy Rockfill @ 15. = 650KHigh end if pushed to 480 and rockfill - say 45kcy = $675K.			$0	$0			info?			info?	$0	$0
3.04	Foundation Excavation - seepage key (assume 20'wide x 150' long x 4' deep	0	CY	$8.00	$0	No costs for FRE-FC. Cofferdam key allowance		300%	$0	$0			info?			info?	$0	$0
3.05	Foundation Dewatering - assume several dewatering pump systems operating selectively 24/7 over 12 month foundation construction exposure	0	Day	$2,800.00	$0	No costs for FRE-FC. Changes for final: increase foundation exposure from 6 to 12 months. 2nd contract may add unwaterring and time for dewatering for RCC foundation		150%	$0	$0			info?			info?	$0	$0
3.06	Coffer Dams - Other assume 25' high x 150 top length, 35' base length, cell construction (e.g. sheet pile, steel, other fabricated metal items)	0	SF	$30	$0	No costs for FRE-FC. may include isolation of portal structures, tailwater structures, peripheral dewatering stages			$0	$0			info?			info?	$0	$0
3.07	All project Care-of-Water Coffer Dams - Risk contingency for overtopping	1	LS	$400,000	$400,000	Full allowance for FRE-FC dewater and diversion considerations, including risk. contemplates partial or threshold-bound contractor responsibility, risk apportioned cost of event recovery, rework, delay			$320,000	$480,000			info?			info?	$320,000	$480,000
4	**Lands and Easements**				$0				$0	$0			info?			info?	$0	$0
4.01	Reservoir Extents Fee Title	0	Acre	$4,400	$0	Presumed fully settled in FRE. Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$0	$0			info?			info?	$0	$0
4.02	Reservoir Extents/Flood Easement	0	Acre	$4,400	$0	Presumed fully settled in FRE. Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$0	$0			info?			info?	$0	$0
4.03	Reservoir orphaned access roadway reconnection allowance (to WeyCo?)	0	Mile	$1,000,000	$0	Presumed fully settled in FRE. Unit price potentially higher for permanent versus constuction roads. Line item also perhaps better considered under non-contract cost factor.		110%	$0	$0			info?			info?	$0	$0
	Phase 2 - Main Dam																$0	$0
5	**Main Dam Structure**				$0				$0	$0			info?			info?	$0	$0
5.01	Excavation - Foundation General	15,000	CY	$15	$225,000	Wing excavation in item 8.01. Excavation for FRE-FC dam includes temporary backfill of downstream groin. Changes for final: revised quantities. Reference FRFA S-1 annotated from Chehalis_All_Figs_2016-10-19.pdf, also this worksheet FRFA Exc Guess tab.			$180,000	$270,000		$5.50	$82,500		$7.50	$112,500	$82,500	$112,500
5.02	Excavation - Foundation Rock	0	CY	$27	$0	No costs for FRE-FC. Changes for final: revised quantities. Reference FRFA S-1 annotated from Chehalis_All_Figs_2016-10-19.pdf, also this worksheet FRFA Exc Guess tab. Some rock will be structural exc in fresh rock, most will be foundation footprint, getting to good rock below the rock contact; i.e potentially a high degree ripable.			$0	$0		$25.00	$0		$30.00	$0	$0	$0
5.03	Roller Compacted Concrete - Composite Scope	467,000	CY	$111	$51,837,000	RCC quantity from RCC Dam Q-s & Placement Plan - R09.xls; composite unit price development from Con-Sked-$ Support - FRE Chehalis - R01.xls. Changes for final: revised quantities. Expanded RCC unit cost development work breakdown, revisited unit pricing, and increased unit pricing to reflect upstream conventional face and downstream GERCC. RCC unit pricing includes aggregate, cement-fly ash, lift bedding, abutment bedding, dam joints, and 2.5' upstream conventional face and downstream			$41,469,600	$62,204,400		$94.00	$43,898,000		$127.00	$59,309,000	$43,898,000	$59,309,000
5.04	Fill - Foundation Backfill	126,000	CY	$6	$693,000	includes backfull of upper abutments and downstream groin after FRE-FC construction; Reference "FRE - Annotated Dwgs Supporting OPC.pdf"; Pending Q verification. Changes for final: revised quantities.			$554,400	$831,600			info?			info?	$554,400	$831,600
5.05	Conventional Concrete Reinforced (miscellaneous)	0	CY	$850	$0	Item not used in FRE estimate. Q was 750cy @ $850. Refine quantities along with all structures next phase.			$0	$0			info?			info?	$0	$0
5.06	Outlet works encasement: sluicing conduits, river outlet works conduits, gate chamber, vent and gallery passages	0	CY	$450	$0	No costs for FRE-FC. Refine quantities along with all structures next phase.			$0	$0			info?			info?	$0	$0
5.07	Concrete - Dam Crest Slab & Parapet and unlisted dam concrete structures	2,460	CY	$750	$1,845,000	FRE-FC crest and parapet walls plus 1000cy unlisted. Changes for final: None. Consider this item only as upper spillway. No facing should be included if flip bucket chute face is elsewhere. Leave in for ogee, spillway approach walls, piers.	70%	110%	$1,291,500	$2,029,500			info?			info?	$1,291,500	$2,029,500

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: ***Chehalis Dam***
Alternative: ***FRE-FC***

Pricing - contractor cost basis 1 or bid basis 2: **2**

Range Driver - 1 = %, 2 = Q & $, 3 = Combination:	**3**		
Default Low ⇨	**80%**	**Default High ⇨**	**120%**

Weighting ⇨	**20% low**	**70% likely**	**10% high**	**20% low**	**70% likely**	**10% high**
$293M - Jul-16	**Low End**	**$110,099,910**		**Low End**	**$140,104,697**	
	Likely	**$128,809,987**		**Likely**	**$163,913,704**	
$454M - Jul-18	**High End**	**$154,389,521**		**High End**	**$196,464,257**	
	Weighted	**$127,625,925**		**Weighted**	**$162,406,958**	

Quantity references: "FRE - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					**Range Development**											
							Driven by Percent				**Driven by Q & Unit $**						**Driven by Combo**	
Work Item	**Description**	**Quantity**	**Unit**	**Unit Price [1]**	**Total $**	**Estimate Notes & Considerations** (Notes prior to FRE eval grayed out)	**Low End % (def=80%)**	**High End % (def=120%)**	**Low % Total $**	**High % Total $**	**Low End Q**	**Low End Unit $**	**Low End Total $**	**High End Q**	**High End Unit $**	**High End Total $**	**Low End Tot $**	**High End Tot $**
5.08	Foundation Treatment - Grout Curtain Drilling	1	LS	$350,000	$350,000	**FRE grout limits are very near adequate for FRE-FC. Add upper left abutment lump sum grouting allowance.** revisited pricing; 1700lf @ 10', plus 50% secondary, plus 25% tertiary @ 80' deep = 298 holes @ 90' = 26,820lf; if consolidation grouting - add 220,000 sf @ 400sf/ hole @ 20' deep = 11,000lf = 37,820 lf. If double curtain plus 25% extra = 383 holes @ 90' = 34,470lf, plus 11k consolidation grouting = 45,470lf. Use 50k lf. Depth: 300' at 35'+300'			$280,000	$420,000			info?			info?	$280,000	$420,000
5.09	Foundation Treatment - Grout Curtain Cement	0	Sack	$40	$0	**In 5.08 allowance. Changes for final: revised quantity, increased unit price.** Assume 0.7 bag per lf			$0	$0			info?			info?	$0	$0
5.1	Flood Regulating Conduit Control Structures - Reinforced Concrete	0	CY	$800	$0	**No costs for FRE-FC.** Assume 2' thick around perimeter of sluices & air shafts. Refine quantities along with all structures next phase; include inside and downstream of dam; include control building on crest or at downstream, depending on final concept drawings			$0	$0			info?			info?	$0	$0
5.11	Flood Regulating Conduit Control Gates - Fab and Construct	0	LB	$15	$0	**No costs for FRE-FC.** Assume 2 @ 30 tons.			$0	$0			info?			info?	$0	$0
5.12	Emergency, flood regulating, & WQ bulkhead gates	0	LB	$10	$0	**No costs for FRE-FC.** Assume 2 @ 25 tons, and 2 @ 50 tons			$0	$0			info?			info?	$0	$0
5.13	Hoists, cylinders, machinery	0	LB	$15	$0	**No costs for FRE-FC.**			$0	$0			info?			info?	$0	$0
5.14	Reservoir drain valve in tunnel plug (assume 4x4' knife valve)	0	Each	$200,000	$0	**No costs for FRE-FC.**	50%	100%	$0	$0			info?			info?	$0	$0
5.15	WQ Regulating Outlets w/ hollow cone valves (4 - 4'dia)	4	Each	$450,000	$1,800,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Increase for to accommodate removing bulkheads and installing in the existing config**			$1,440,000	$2,160,000			info?			info?	$1,440,000	$2,160,000
5.16	WQ Regulating Outlet w/ hollow cone valves (1 - 7'dia)	1	Each	$1,250,000	$1,250,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls".**			$1,000,000	$1,500,000			info?			info?	$1,000,000	$1,500,000
5.17	WQ Intake Tower / concrete sidewall & decking - Conventional Concrete Reinforced	1,350	CY	$1,000	$1,350,000	**Reference "RCC FRE-FC Section - FRE Draft" sheet of "FRE - Annotated Dwgs Supporting OPC.pdf".**			$1,080,000	$1,620,000			info?			info?	$1,080,000	$1,620,000
5.18	unused	0	CY	$400	$0	**Now in item 5.17.**	100%		$0	$0			info?			info?	$0	$0
5.19	Trashrack steel framing	294,840	LB	$7	$1,916,460	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls".** Assume 300 ft high, 10 members 3' dia x 4.5'deep, steel column			$1,533,168	$2,299,752			info?			info?	$1,533,168	$2,299,752
5.2	unused	0	CY	$850	$0	**Now in item 5.17.**			$0	$0			info?			info?	$0	$0
6	**Spillway**				$0				$0	$0			info?			info?	$0	$0
6.01	Flip Bucket Conventional Concrete - surface	0	CY	$650	$0	**No costs for FRE-FC.**			$0	$0			info?			info?	$0	$0
6.02	Conventional Concrete - spillway approach, ogee, chute slab, and training walls	3,600	CY	$850	$3,060,000	**No costs for FRE-FC.** unit price - accomodates higher RCC placement and utilization of some mass conventional concrete	90%	110%	$2,754,000	$3,366,000			info?			info?	$2,754,000	$3,366,000
7	**Sluice Stilling Basin**				$0				$0	$0			info?			info?	$0	$0
7.01	Excavation - Foundation General	0	CY	$8	$0	**No costs for FRE-FC.**			$0	$0			info?			info?	$0	$0
7.02	Excavation - Foundation Rock	0	CY	$30	$0	**No costs for FRE-FC.**			$0	$0			info?			info?	$0	$0
7.03	Fill - Foundation Backfill	0	CY	$9	$0	**No costs for FRE-FC.**			$0	$0			info?			info?	$0	$0
7.04	Conventional Concrete Reinforced	0	CY	$800	$0	**No costs for FRE-FC.**			$0	$0			info?			info?	$0	$0
7.05	Conventional Concrete Non-Reinforced	0	CY	$400	$0	**No costs for FRE-FC.**	70%		$0	$0			info?			info?	$0	$0
8	**Wing Dam Structure**				$0				$0	$0			info?			info?	$0	$0
8.01	Excavation - Foundation General (assume footprint 270' @ widest x 10 ft deep)	70,000	CY	$10	$700,000	**Consider as all excavation and unclassified, all should be ripable rock at the worst; was 33,333 cy**			$560,000	$840,000			info?			info?	$560,000	$840,000
8.02	Excavation Cutoff Trench - Foundation Rock (assume trench 30 ft wide x 20 ft deep)	0	CY	$30	$0	**Included in item 8.01; was 13,333 cy**			$0	$0			info?			info?	$0	$0
8.03	Fill - Wingdam Embankment	176,000	CY	$20	$3,520,000	**Composite fill unit price and quantity; pending more detailed QTO; increased unit price to accommodate zones; was 120,000 cy @ $15.**	90%		$3,168,000	$4,224,000			info?			info?	$3,168,000	$4,224,000
8.04	Fill - Wingdam Riprap Facing (assume 5' blanket U/S and D/S)	8,000	CY	$65	$520,000				$416,000	$624,000			info?			info?	$416,000	$624,000
	Composite & Unlisted Work																	
55	Fish passage structure - costs not included	1	ls	$0	$0	Costs independently assessed in report			$0	$0			info?			info?	$0	$0
56	Unlisted Work	1	ls	$3,000,000	$3,000,000		85%	115%	$2,550,000	$3,450,000			info?			info?	$2,550,000	$3,450,000
57	**Added for FRE Alternative - FRE-FC specific**				$0				$0	$0			info?			info?	$0	$0
58	FRE-FC - Add Concrete demo	4,350	cy	$50	$217,500	**Reference "RCC FRE-FC Section - FRE Draft" sheet of "FRE - Annotated Dwgs Supporting OPC.pdf".**			$174,000	$261,000			info?			info?	$174,000	$261,000
59	FRE-FC - Add Existing FRE d/s face surface prep; anchor allowance	250,000	sf	$4	$1,000,000	**Downstream and vert form sf of FRE x 1.25 (adj for sloping portion) - 260'x200' (full spillway slope built to FRE-FC limits) = 236k * 1.25 - 52k = 243k; use 250k sf**			$800,000	$1,200,000			info?			info?	$800,000	$1,200,000
60	FRE-FC - Include wing dam seepage mitigation allowance	1	ls	$400,000	$400,000	**assume 400' x 20' = 8000sf, or 750cy @ 2.5';**			$320,000	$480,000			info?			info?	$320,000	$480,000
61					$0				$0	$0			info?			info?	$0	$0
62					$0				$0	$0			info?			info?	$0	$0
63					$0				$0	$0			info?			info?	$0	$0
64					$0				$0	$0			info?			info?	$0	$0
65					$0				$0	$0			info?			info?	$0	$0
					$0				$0	$0			info?			info?	$0	$0
Subtotal without mobilization & general expense					**$84,813,160**		**$69,474,028**	**$102,135,292**	**$69,474,028**	**$102,135,292**			**$48,801,500**			**$68,553,000**	**$72,493,768**	**$101,655,652**
Mobilization & project indirect expense			0%		$0	unallocated project indirect or jobsite overhead assumed in unit pricing												
Contractor Cost					**$84,813,160**	Note 1: Unit prices as noted in header, either reflect a bid price basis (no factor application of corporate OH & profit), or a contractor cost basis requiring a corporate OH & profit to get to a bid total												
Contractor Margin - corporate overhead & profit			~~0%~~	Bid Basis	$0	Note 2: NA - not applicable to project; NE - not evident in estimate; NI - noted but not itemized in estimate												
Contractor Bid - before design/procurement contingencies					**$84,813,160**													
Contract Contingencies - design and procurement contingencies			12.5%		$10,601,645	⇦ RCC estimate dominance, work breakdown thoroughness, and work understanding support a design contingency lower than typical (i.e. 20%) at this early design level												
Contract Cost - contracator bid with design & procurement contingencies					**$95,414,805**													
Construction Contingency: post-award change & dispute factor			10%		$9,541,481													
Non-Contract Costs: PM, planning, design, CM ...			25%		$23,853,701	⇦ permitting, site characterization, CM during construction,etc.												
Total Project Cost - before escalation					**$128,809,987**	**Compares to $293M low bound, and $454M high bound July 2016**												
Escalation - annual %; from; to		3.5%	1-Jun-17	1-Jun-24	$35,103,718	**⇦ Presume NTP - mid 2021, say 6 years construction = 4 years + 1/2 of 6 years = 7.0 years. Was early 2019, 7 years construction, 2.5 + 3.75 = 6.25**												
Total Project Cost - including escalation				**7.0 yr**	**$163,913,704**	**<< 193% above total w/o mobilization**												

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: **_Chehalis Dam_**
Alternative: **_FRO_** **_Comparison for FRE Evaluation_**

Pricing - contractor cost basis 1 or bid basis 2: **2**

Range Driver - 1 = %, 2 = Q & $, 3 = Combination: **3**
Default Low ⇨ **80%** **Default High ⇨** **120%**

	Weighting ⇨	20% low	75% likely	5% high	20% low	75% likely	5% high
$201M - Jul-16	Low End		$244,615,783		Low End		$311,279,274
	Likely		$298,050,587		Likely		$379,276,305
$319M - Jul-18	High End		$351,140,680		High End		$446,834,684
	Weighted		$290,018,131		Weighted		$369,054,818

Quantity references: "FRX - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					Range Development											
							Driven by Percent				Driven by Q & Unit $						Driven by Combo	
Work Item	Description	Quantity	Unit	Unit Price [1]	Total $	Estimate Notes & Considerations (Notes prior to FRX eval grayed out)	Low End % (def=80%)	High End % (def=120%)	Low % Total $	High % Total $	Low End Q	Low End Unit $	Low End Total $	High End Q	High End Unit $	High End Total $	Low End Tot $	High End Tot $
	Phase 1 - Site Development, Diversion Constrruction,				$0				$0	$0			info?			info?	$0	$0
0	**Mobilization**								$0	$0			info?			info?	$0	$0
	Mobilization	1	LS	$3,500,000.00	$3,500,000	Contractor mob bid; balance of project overhead in below-the-line factors	100%	140%	$3,500,000	$4,900,000			info?			info?	$3,500,000	$4,900,000
1	**Clearing & Grubbing**				$0				$0	$0			info?			info?	$0	$0
1.01	Clearing and grubbing, stripping topsoil, reclamation of disturbed areas	25	Acre	$30,000.00	$750,000				$600,000	$900,000	18	$30,000.00	$540,000	25	$25,000.00	$625,000	$540,000	$625,000
1.02	Reservoir Clearing to 100-yr Flood Stage	756	Acre	$6,000.00	$4,536,000	Potentially in Phase 2 or possibly Phase 3 contract			$3,628,800	$5,443,200		$5,000.00	$3,780,000		$7,500.00	$5,670,000	$3,780,000	$5,670,000
2	**Temporary Access & Staging**				$0				$0	$0			info?			info?	$0	$0
2.01	Construction Surveying & Layout	25	Acre	$10,000.00	$250,000	Under temporary access & staging; i.e. temporary works only, predominant surveys and layout in unallocated contractor project overhead expense (already in the unit pricing)	100%	150%	$250,000	$375,000			info?			info?	$250,000	$375,000
2.02	Pioneer/Access Roads (e.g. dam site, abutments, quarry site, etc.)	2.0	Mile	$700,000.00	$1,400,000	**Changes for final: increase access road development by adding 0.5 mile from 1.5 to 2 miles.** dependent upon aggregate sourcing, staging locations, contractor approach. Reference G-4_ETZ_21Sept2016 - JCA markups 01.pdf for site, non-quarry access concepts, totaling about 13,500lf. Say 50% new and full access development, 20% construction & track access only, 30% improved existing. Consider quarry acces costs in aggregate price range.			$1,120,000	$1,680,000	1.5	$750,000.00	$1,125,000	2.25	$800,000.00	$1,800,000	$1,125,000	$1,800,000
2.03	Material Laydown Area Prep (minor excavation, grading, surfacing, drainage	18	Acre	$25,000.00	$450,000	1 acre at 5' avg cut to 5' average fill = 4000cy cut to fill; @ $6/cy cut to fill = $24,200/ac; 1ac surfacing at 6" & 30% surfaced = 430ton, @ 10/tn = $4.5k/ac			$360,000	$540,000	13	$30,000.00	$390,000	22		$550,000	$390,000	$550,000
2.04	Temporary construction site access security control facilities (e.g. fencing, gates, etc.)	2,200	LF	$20.00	$44,000	predominant security expense in unallocated contractor project overhead expense			$35,200	$52,800			info?			info?	$35,200	$52,800
3	**Diversion & Dewatering**				$0				$0	$0			info?			info?	$0	$0
3.01	Diversion Tunnel 20 ft modified horseshoe	1,635	LF	$8,000.00	$13,080,000	**Increased length for FRE and both FRO and FRFA, from 1500. Changes for final: increase length of tunnel to better reflect final drawing alignment.** increase high end for variability in linnig limits, portaling, tunnel plug adit construction, vent construction, etc.	90%	125%	$11,772,000	$16,350,000			info?			info?	$11,772,000	$16,350,000
3.02	Conventional Concrete Non-Reinforced Mass Concrete (100' plug following construction)	1,200	CY	$600.00	$720,000	low end 30'plug but include mechanical.			$576,000	$864,000		$450.00	$540,000		$650.00	$780,000	$540,000	$780,000
3.03	Coffer Dams (2) - Fill cells u/s and d/s + toe slopes	14,000	CY	$40.00	$560,000	check Q's with new crest heights, say 8,000 cy RCC @ 70 + 6,000 cy Rockfill @ 15. = 650KHigh end if pushed to 480 and rockfill - say 45kcy = $675K.			$448,000	$672,000			info?			info?	$448,000	$672,000
3.04	Foundation Excavation - seepage key (assume 20'wide x 150' long x 4' deep	450	CY	$8.00	$3,600	Cofferdam key allowance		300%	$2,880	$10,800			info?			info?	$2,880	$10,800
3.05	Foundation Dewatering - assume several dewatering pump systems operating selectively 24/7 over 6 month foundation construction period	270	Day	$2,800.00	$756,000	**Changes for final: increase foundation exposure from 6 to 9 months.** 2nd contract may add unwaterring and time for dewatering for RCC foundation		150%	$604,800	$1,134,000			info?			info?	$604,800	$1,134,000
3.06	Coffer Dams - Other assume 25' high x 150 top length, 35' base length, cell construction (e.g. sheet pile, steel, other fabricated metal items)	7,000	SF	$30	$210,000	may include isolation of portal structures, tailwater structures, peripheral dewatering stages			$168,000	$252,000			info?			info?	$168,000	$252,000
3.07	Coffer Dams - Risk contingency for overtopping	1	LS	$750,000.00	$750,000	contemplates partial or threshold-bound contractor responsibility, risk apportioned cost of event recovery, rework, delay			$600,000	$900,000			info?			info?	$600,000	$900,000
4	**Lands and Easements**				$0				$0	$0			info?			info?	$0	$0
4.01	Reservoir Extents Fee Title	750	Acre	$4,400	$3,300,000	Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$3,300,000	$3,300,000			info?			info?	$3,300,000	$3,300,000
4.02	Reservoir Extents/Flood Easement	55	Acre	$4,400	$242,000	Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$242,000	$242,000			info?			info?	$242,000	$242,000
4.03	Reservoir orphaned access roadway reconnection allowance (to WeyCo?)	4.5	Mile	$1,000,000	$4,500,000	Unit price potentially higher for permanent versus constuction roads. Line item also perhaps better considered under non-contract cost factor.		110%	$3,600,000	$4,950,000			info?			info?	$3,600,000	$4,950,000
	Phase 2 - Main Dam																$0	$0
5	**Main Dam Structure**				$0				$0	$0			info?			info?	$0	$0
5.01	Excavation - Foundation General	460,000	CY	$6.50	$2,990,000			110%	$2,392,000	$3,289,000		$5.50	$2,530,000		$7.50	$3,450,000	$2,530,000	$3,450,000
5.02	Excavation - Foundation Rock	110,000	CY	$25.00	$2,750,000	Some rock will be structural exc in fresh rock, most will be foundation footprint, getting to good rock below the rock contact; i.e potentially a high degree ripable.		110%	$2,200,000	$3,025,000		$25.00	$2,750,000		$30.00	$3,300,000	$2,750,000	$3,300,000
5.03	Roller Compacted Concrete - Composite Scope	810,000	CY	$93.00	$75,330,000	**Updated RCC quantity to FRE foundation & max section. Increased RCC unit price to bring to Jun 2017 cost basis, including high and low range. Changes for final: revised quantity to reflect QTO after CDR drawings, adjusted unit prices to reflect only GERCC; expanded RCC unit cost development composite workbreakdown, and revisited RCC unit pricing.** RCC unit pricing includes aggregate, cemen-fly ash, lift bedding, abutment bedding, dam joints, and full GERCC for both upstream and downstream			$60,264,000	$90,396,000		$76.50	$61,965,000		$109.50	$88,695,000	$61,965,000	$88,695,000
5.04	Fill - Foundation Backfill	260,000	CY	$5.50	$1,430,000	**Revised backfill Q from full FRE QTO. Changes for final: none.**			$1,144,000	$1,716,000			info?			info?	$1,144,000	$1,716,000
5.05	Conventional Concrete Reinforced (miscellaneous)	0	CY	$850.00	$0	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** Refine quantities along with all structures next phase.			$0	$0			info?			info?	$0	$0
5.06	Outlet works encasement: sluicing conduits, river outlet works conduits, gate chamber, vent and gallery passages	50,000	CY	$450.00	$22,500,000	**Reference same item in FRE - OPC and "FRE - Annotated Dwgs Supporting OPC.pdf" FRE S-6-S-7 sheets. Similarly use the high end quantity for both FRO and FRFA at 58,000cy and reduced to 50,000cy for each for optimization for the likely cases. Q was 15,000cy @ $400.** Refine quantities along with all structures next phase.			$18,000,000	$27,000,000	45,000	$400.00	$18,000,000	58,000	$450.00	$26,100,000	$18,000,000	$26,100,000
5.07	Concrete - Dam Crest Slab & Parapet and unlisted dam concrete structures	5,400	CY	$750.00	$4,050,000	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures. Changes for final: None. Consider this item only as upper spillway. Use a lower low end considering potential for less spillway quantity for FRO.** No facing should be included if flip bucket chute face is elsewhere. Leave in for ogee, spillway approach walls, piers.	60%	110%	$2,430,000	$4,455,000			info?			info?	$2,430,000	$4,455,000
5.08	Foundation Treatment - Grout Curtain Drilling	23,000	LF	$45.00	$1,035,000	**Changes for final: adjust quantity from 22,500 to 23,000lf, and slight increase to cement for grouting.** revisited pricing; 1200lf @ 10', plus 50% secondary, plus 25% tertiary @ 70' deep = 14,700lf; plus say 170,000 sf @ 400sf/ hole @ 20' deep = 8,500lf = 23,200 lf;	70%	110%	$724,500	$1,138,500			info?			info?	$724,500	$1,138,500
5.09	Foundation Treatment - Grout Curtain Cement	16,000	Sack	$40.00	$640,000	**Changes for final: increase sacks to 0.7 sack per lf. Lower range considered for both drilling and cement for grouting operations based on limited exposure of structure under stored water service conditions.**	70%	110%	$448,000	$704,000			info?			info?	$448,000	$704,000
5.1	Flood Regulating Conduit Control Structures - Reinforced Concrete	0	CY	$800.00	$0	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** Assume 2' thick around perimeter of sluices & air shafts. Refine quantities along with all structures next phase; include inside and downstream of dam; include control building on crest or at downstream, depending on final concept drawings			$0	$0			info?			info?	$0	$0
5.11	Flood Regulating Conduit Control Gates - Fab and Construct	200,000	LB	$15.00	$3,000,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 200,000# @ $15.00.** Assume 2 @ 30 tons, 1 @ 40 tons			$2,400,000	$3,600,000			info?			info?	$2,400,000	$3,600,000
5.12	Emergency & sluice dewatering bulkhead gates	780,000	LB	$10.00	$7,800,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 570,000# @ $15.00.** Assume 2 @ 25 tons, 1 @ 35 tons and 4 @ 50 tons			$6,240,000	$9,360,000			info?			info?	$6,240,000	$9,360,000
5.13	Hoists, cylinders, machinery	300,000	LB	$15.00	$4,500,000				$3,600,000	$5,400,000			info?			info?	$3,600,000	$5,400,000
5.14	Reservoir drain valve in tunnel plug (assume 4x4' knife valve)	1	Each	$200,000.00	$200,000		50%	100%	$100,000	$200,000			info?			info?	$100,000	$200,000
5.15	Unused	0	Each	$0.00	$0				$0	$0			info?			info?	$0	$0

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: ***Chehalis Dam***
Alternative: ***FRO*** ***Comparison for FRE Evaluation***

Weighting ⇨	20% low	75% likely	5% high	20% low	75% likely	5% high
$201M - Jul-16	**Low End**	**$244,615,783**		**Low End**	**$311,279,274**	
	Likely	**$298,050,587**		**Likely**	**$379,276,305**	
$319M - Jul-18	**High End**	**$351,140,680**		**High End**	**$446,834,684**	
	Weighted	**$290,018,131**		**Weighted**	**$369,054,818**	

Range Driver - 1 = %, 2 = Q & $, 3 = Combination:		**3**	
Default Low ⇦	**80%**	**Default High ⇨**	**120%**

Pricing - contractor cost basis 1 or bid basis 2: **2**

Quantity references: "FRX - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					Range Development: Driven by Percent				Driven by Q & Unit $						Driven by Combo	
Work Item	**Description**	**Quantity**	**Unit**	**Unit Price [1]**	**Total $**	**Estimate Notes & Considerations** (Notes prior to FRX eval grayed out)	**Low End % (def=80%)**	**High End % (def=120%)**	**Low % Total $**	**High % Total $**	**Low End Q**	**Low End Unit $**	**Low End Total $**	**High End Q**	**High End Unit $**	**High End Total $**	**Low End Tot $**	**High End Tot $**
5.16	Unused	0	Each	$0.00	$0				$0	$0			info?			info?	$0	$0
5.17	WQ Intake Tower / concrete sidewall & decking - Conventional Concrete Reinforced	5,650	CY	$850.00	$4,802,500	**Reference note in this cell FRE - OPC tab, and "FRE - Annotated Dwgs Supporting OPC.pdf", sheets FRE S-6, S7.**			$3,842,000	$5,763,000			info?			info?	$3,842,000	$5,763,000
5.18	Unused	0	CY	$0.00	$0				$0	$0			info?			info?	$0	$0
5.19	Trashrack steel framing	1,360,800	LB	$6.50	$8,845,200	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 1,134,000# @ $6.50.** Assumes 250 ft high, 10 members 3' dia x 4.5'deep, steel columns.			$7,076,160	$10,614,240			info?			info?	$7,076,160	$10,614,240
5.2	Unused	0	CY	$850.00	$0	**Item moved to 5.17 to be consistent with other alts.**			$0	$0			info?			info?	$0	$0
6	**Spillway**				$0				$0	$0			info?			info?	$0	$0
6.01	Flip Bucket Conventional Concrete - surface	5,800	CY	$650.00	$3,770,000	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.**			$3,016,000	$4,524,000			info?			info?	$3,016,000	$4,524,000
6.02	Conventional Concrete - spillway approach, ogee, chute slab, and training walls	7,460	CY	$850.00	$6,341,000	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** Unit price - accomodates higher RCC placement and utilization of some mass conventional concrete. Lower range due to strong potential for this volume to be less for FRO	75%	100%	$4,755,750	$6,341,000			info?			info?	$4,755,750	$6,341,000
7	**Sluice Stilling Basin**				$0				$0	$0			info?			info?	$0	$0
7.01	Excavation - Foundation General	20,000	CY	$8.00	$160,000				$128,000	$192,000			info?			info?	$128,000	$192,000
7.02	Excavation - Foundation Rock	10,000	CY	$30.00	$300,000				$240,000	$360,000			info?			info?	$240,000	$360,000
7.03	Fill - Foundation Backfill	18,000	CY	$9.00	$162,000				$129,600	$194,400			info?			info?	$129,600	$194,400
7.04	Conventional Concrete Reinforced	8,600	CY	$750.00	$6,450,000	**Reference "FRE - Annotated Dwgs Supporting OPC.pdf", sheets FRE S-06, S07. Was 4900 @ $8700 and item 7.04 2000cy at $400.**			$5,160,000	$7,740,000			info?			info?	$5,160,000	$7,740,000
7.05	Conventional Concrete Non-Reinforced	1,600	CY	$400.00	$640,000	Refine quantities after drawings are complete; must schedule after dam is up; include control building on crest;			$512,000	$768,000			info?			info?	$512,000	$768,000
8	**Wing Dam Structure**				$0				$0	$0			info?			info?	$0	$0
8.01	Unused	0	ls	$0.00	$0				$0	$0			info?			info?	$0	$0
8.02	Unused	0	ls	$0.00	$0				$0	$0			info?			info?	$0	$0
8.03	Unused	0	ls	$0.00	$0				$0	$0			info?			info?	$0	$0
8.04	Unused	0	ls	$0.00	$0				$0	$0			info?			info?	$0	$0
	Composite & Unlisted Work																	
55	Fish passage structure - costs not included	1	ls	$0	$0	Costs independently assessed in report			$0	$0			info?			info?	$0	$0
56	Unlisted Work	1	ls	$3,500,000	$3,500,000		85%	115%	$2,975,000	$4,025,000			info?			info?	$2,975,000	$4,025,000
57					$0				$0	$0			info?			info?	$0	$0
58					$0				$0	$0			info?			info?	$0	$0
59					$0				$0	$0			info?			info?	$0	$0
60					$0				$0	$0			info?			info?	$0	$0
61					$0				$0	$0			info?			info?	$0	$0
62					$0				$0	$0			info?			info?	$0	$0
63					$0				$0	$0			info?			info?	$0	$0
64					$0				$0	$0			info?			info?	$0	$0
65					$0				$0	$0			info?			info?	$0	$0
					$0				$0	$0			info?			info?	$0	$0
Subtotal without mobilization & general expense					**$196,247,300**				**$158,584,690**	**$233,370,940**			**$91,620,000**			**$130,970,000**	**$161,063,890**	**$231,203,740**
Mobilization & project indirect expense			0%		$0	unallocated project indirect or jobsite overhead assumed in unit pricing												
Contractor Cost					**$196,247,300**	Note 1: Unit prices as noted in header, either reflect a bid price basis (no factor application of corporate OH & profit), or a contractor cost basis requiring a corporate OH & profit to get to a bid total												
Contractor Margin - corporate overhead & profit			~~0%~~	Bid Basis	$0	Note 2: NA - not applicable to project; NE - not evident in estimate; NI - noted but not itemized in estimate												
Contractor Bid - before design/procurement contingencies					**$196,247,300**													
Contract Contingencies - design and procurement contingencies			12.5%		$24,530,913	⇦ RCC estimate dominance, work breakdown thoroughness, and work understanding support a design contingency lower than typical (i.e. 20%) at this early design level												
Contract Cost - contractor bid with design & procurement contingencies					**$220,778,213**													
Construction Contingency: post-award change & dispute factor			10%		$22,077,821													
Non-Contract Costs: PM, planning, design, CM ...			25%		$55,194,553	⇦ permitting, site characterization, CM during construction,etc.												
Total Project Cost - before escalation					**$298,050,587**	**Compares to $201M low bound, and $319M high bound July 2016**												
Escalation - annual %; from; to		3.5%	1-Jun-17	1-Jun-24	$81,225,718	**⇦ Presume NTP - mid 2021, say 6 years construction = 4.0 years + 3 years = 7.0 years**												
Total Project Cost - including escalation				**7.0 yr**	**$379,276,305**	**<< 193% above total w/o mobilization**												

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: **_Chehalis Dam_**
Alternative: **_FRFA_** **_Comparison for FRE Evaluation_**

Weighting ⇨	20% low	70% likely	10% high	20% low	70% likely	10% high
$293M - Jul-16	Low End	$352,951,969		Low End	$457,019,556	
	Likely	$414,642,686		Likely	$536,899,728	
$454M - Jul-18	High End	$484,932,003		High End	$627,913,791	
	Weighted	$409,333,474		Weighted	$530,025,100	

Range Driver - 1 = %, 2 = Q & $, 3 = Combination:	3		
Default Low ⇨	80%	Default High ⇨	120%

Pricing - contractor cost basis 1 or bid basis 2: 2

Quantity references: "FRE - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

Work Item	Description	Base or Likely Cost Case: Quantity	Unit	Unit Price [1]	Total $	Estimate Notes & Considerations (Notes prior to FRE eval grayed out)	Range Development — Driven by Percent: Low End % (def=80%)	High End % (def=120%)	Low % Total $	High % Total $	Driven by Q & Unit $: Low End Q	Low End Unit $	Low End Total $	High End Q	High End Unit $	High End Total $	Driven by Combo: Low End Tot $	High End Tot $
	Phase 1 - Site Development, Diversion Constrruction,				$0				$0	$0			info?			info?	$0	$0
0	**Mobilization**								$0	$0			info?			info?	$0	$0
	Mobilization	1	LS	$5,000,000.00	$5,000,000	Contractor mob bid; balance of project overhead in below-the-line factors	100%	140%	$5,000,000	$7,000,000			info?			info?	$5,000,000	$7,000,000
1	**Clearing & Grubbing**				$0				$0	$0			info?			info?	$0	$0
1.01	Clearing and grubbing, stripping topsoil, reclamation of disturbed areas	30	Acre	$30,000.00	$900,000				$720,000	$1,080,000	25	$30,000.00	$750,000	35	$25,000.00	$875,000	$750,000	$875,000
1.02	Reservoir Clearing to 100-yr Flood Stage	1,206	Acre	$6,000.00	$7,236,000	Potentially in Phase 2 or possibly Phase 3 contract			$5,788,800	$8,683,200		$5,000.00	$6,030,000		$7,500.00	$9,045,000	$6,030,000	$9,045,000
2	**Temporary Access & Staging**				$0				$0	$0			info?			info?	$0	$0
2.01	Construction Surveying & Layout	35	Acre	$10,000.00	$350,000	Under temporary access & staging; i.e. temporary works only, predominant surveys and layout in unallocated contractor project overhead expense (already in the unit pricing)	100%	150%	$350,000	$525,000			info?			info?	$350,000	$525,000
2.02	Pioneer/Access Roads (e.g. dam site, abutments, quarry site, etc.)	3	Mile	$700,000.00	$2,100,000	**Changes for final: increase access road development by adding 1 mile, from 2 to 3.** dependent upon aggregate sourcing, staging locations, contractor approach. Reference Chehalis_All_Figs_2016-10-19.pdf drawing G-3, for site, non-quarry access concepts, totaling about 10,000lf of new access, say 5000lf of upgraded access. Say 50% new and full access development, 20% construction & track access only, 30% improved existing. Consider quarry acces costs in aggregate price range.			$1,680,000	$2,520,000	2.5	$750,000.00	$1,875,000	3.5	$800,000.00	$2,800,000	$1,875,000	$2,800,000
2.03	Material Laydown Area Prep (minor excavation, grading, surfacing, drainage	20	Acre	$25,000.00	$500,000	1 acre at 5' avg cut to 5' average fill = 4000cy cut to fill; @ $6/cy cut to fill = $24,200/ac; 1ac surfacing at 6" & 30% surfaced = 430ton, @ 10/tn = $4.5k/ac			$400,000	$600,000	15	$30,000.00	$450,000	25		$625,000	$450,000	$625,000
2.04	Temporary construction site access security control facilities (e.g. fencing, gates, etc.)	2,200	LF	$20.00	$44,000	predominant security expense in unallocated contractor project overhead expense			$35,200	$52,800			info?			info?	$35,200	$52,800
3	**Diversion & Dewatering**				$0				$0	$0			info?			info?	$0	$0
3.01	Diversion Tunnel 20 ft modified horseshoe	1,635	LF	$8,000.00	$13,080,000	**Increased length for FRE and both FRO and FRFA, from 1500. Changes for final: increase length of tunnel to better reflect final drawing alignment.** increase high end for variability in linnig limits, portaling, tunnel plug adit construction, vent construction, etc.	90%	125%	$11,772,000	$16,350,000			info?			info?	$11,772,000	$16,350,000
3.02	Conventional Concrete Non-Reinforced Mass Concrete (100' plug following construction)	1,200	CY	$600.00	$720,000	low end 30'plug but include mechanical.			$576,000	$864,000			info?		$650.00	$780,000	$576,000	$780,000
3.03	Coffer Dams (2) - Fill cells u/s and d/s + toe slopes	14,000	CY	$40.00	$560,000	check Q's with new crest heights, say 8,000 cy RCC @ 70 + 6,000 cy Rockfill @ 15. = 650KHigh end if pushed to 480 and rockfill - say 45kcy = $675K.			$448,000	$672,000			info?			info?	$448,000	$672,000
3.04	Foundation Excavation - seepage key (assume 20'wide x 150' long x 4' deep	450	CY	$8.00	$3,600	Cofferdam key allowance		300%	$2,880	$10,800			info?			info?	$2,880	$10,800
3.05	Foundation Dewatering - assume several dewatering pump systems operating selectively 24/7 over 12 month foundation construction exposure	360	Day	$2,800.00	$1,008,000	**Changes for final: increase foundation exposure from 6 to 12 months.** 2nd contract may add unwaterring and time for dewatering for RCC foundation		150%	$806,400	$1,512,000			info?			info?	$806,400	$1,512,000
3.06	Coffer Dams - Other assume 25' high x 150 top length, 35' base length, cell construction (e.g. sheet pile, steel, other fabricated metal items)	7,000	SF	$30.00	$210,000	may include isolation of portal structures, tailwater structures, peripheral dewatering stages			$168,000	$252,000			info?			info?	$168,000	$252,000
3.07	Coffer Dams - Risk contingency for overtopping	1	LS	$1,000,000.00	$1,000,000	contemplates partial or threshold-bound contractor responsibility, risk apportioned cost of event recovery, rework, delay			$800,000	$1,200,000			info?			info?	$800,000	$1,200,000
4	**Lands and Easements**				$0				$0	$0			info?			info?	$0	$0
4.01	Reservoir Extents Fee Title	1,200	Acre	$4,400.00	$5,280,000	Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$5,280,000	$5,280,000			info?			info?	$5,280,000	$5,280,000
4.02	Reservoir Extents/Flood Easement	110	Acre	$4,400.00	$484,000	Best to be considered in non-contract costs. Perhaps cost conservatively overlaps with non-contract cost factor below.	100%	100%	$484,000	$484,000			info?			info?	$484,000	$484,000
4.03	Reservoir orphaned access roadway reconnection allowance (to WeyCo?)	5	Mile	$1,000,000.00	$5,000,000	Unit price potentially higher for permanent versus constuction roads. Line item also perhaps better considered under non-contract cost factor.		110%	$4,000,000	$5,500,000			info?			info?	$4,000,000	$5,500,000
	Phase 2 - Main Dam																$0	$0
5	**Main Dam Structure**				$0				$0	$0			info?			info?	$0	$0
5.01	Excavation - Foundation General	710,000	CY	$6.50	$4,615,000	**Changes for final: revised quantities.** Reference FRFA S-1 annotated from Chehalis_All_Figs_2016-10-19.pdf, also this worksheet FRFA Exc Guess tab.			$3,692,000	$5,538,000		$5.50	$3,905,000		$7.50	$5,325,000	$3,905,000	$5,325,000
5.02	Excavation - Foundation Rock	210,000	CY	$27.00	$5,670,000	**Changes for final: revised quantities.** Reference FRFA S-1 annotated from Chehalis_All_Figs_2016-10-19.pdf, also this worksheet FRFA Exc Guess tab. Some rock will be structural exc in fresh rock, most will be foundation footprint, getting to good rock below the rock contact; i.e potentially a high degree ripable.			$4,536,000	$6,804,000		$25.00	$5,250,000		$30.00	$6,300,000	$5,250,000	$6,300,000
5.03	Roller Compacted Concrete - Composite Scope	1,360,000	CY	$99.00	$134,640,000	**Updated RCC quantity to FRE foundation & max section. Increased RCC unit price to bring to Jun 2017 cost basis, including high and low range. Changes for final: revised quantities. Expanded RCC unit cost development work breakdown, revisited unit pricing, and increased unit pricing to reflect upstream conventional face and downstream GERCC.** RCC unit pricing includes aggregate, cement-fly ash, lift bedding, abutment bedding, dam joints, and **2.5' upstream conventional face and downstream GERCC.** Conventional concrete spillway face - included elsewhere.			$107,712,000	$161,568,000		$83.50	$113,560,000		$113.50	$154,360,000	$113,560,000	$154,360,000
5.04	Fill - Foundation Backfill	284,000	CY	$5.50	$1,562,000	**Revised backfill Q from full FRE QTO. Changes for final: revised quantities.**			$1,249,600	$1,874,400			info?			info?	$1,249,600	$1,874,400
5.05	Conventional Concrete Reinforced (miscellaneous)	0	CY	$850.00	$0	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** Refine quantities along with all structures next phase.			$0	$0			info?			info?	$0	$0
5.06	Outlet works encasement: sluicing conduits, river outlet works conduits, gate chamber, vent and gallery passages	50,000	CY	$450.00	$22,500,000	**Reference same item in FRE and "FRE - Annotated Dwgs Supporting OPC.pdf" FRE S-6-S-7 sheets. Similarly use the high end quantity for both FRO and FRFA at 58,000cy and reduced to 50,000cy for each for optimization for the likely cases. Q was 15,000cy @ $400.** Refine quantities along with all structures next phase.			$18,000,000	$27,000,000	45,000		$20,250,000	58,000	$450.00	$26,100,000	$20,250,000	$26,100,000
5.07	Concrete - Dam Crest Slab & Parapet and unlisted dam concrete structures	5,400	CY	$750.00	$4,050,000	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures. Changes for final: None. Consider this item only as upper spillway.** No facing should be included if flip bucket chute face is elsewhere. Leave in for		120%	$3,240,000	$4,860,000			info?			info?	$3,240,000	$4,860,000
5.08	Foundation Treatment - Grout Curtain Drilling	50,000	LF	$45.00	$2,250,000	revisited pricing; 1700lf @ 10', plus 50% secondary, plus 25% tertiary @ 80' deep = 298 holes @ 90' = 26,820lf; if consolidation grouting - add 220,000 sf @ 400sf/ hole @ 20' deep = 11,000lf = 37,820 lf. If double curtain plus 25% extra = 383 holes @ 90' = 34,470lf, plus 11k consolidation grouting = 45,470lf. Use 50k lf. Depth: 300' at 35'+300' at 85'+500' at 140' + 200' at 130' + 400' at 55' = 154,000 / 1700' = 90'.			$1,800,000	$2,700,000			info?			info?	$1,800,000	$2,700,000
5.09	Foundation Treatment - Grout Curtain Cement	35,000	Sack	$40.00	$1,400,000	**Changes for final: revised quantity, increased unit price.** Assume 0.7 bag per lf			$1,120,000	$1,680,000			info?			info?	$1,120,000	$1,680,000
5.1	Flood Regulating Conduit Control Structures - Reinforced Concrete	0	CY	$800.00	$0	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** Assume 2' thick around perimeter of sluices & air shafts. Refine quantities along with all structures next phase; include inside and downstream of dam; include control building on crest or at downstream, depending on final concept drawings			$0	$0			info?			info?	$0	$0
5.11	Flood Regulating Conduit Control Gates - Fab and Construct	120,000	LB	$15.00	$1,800,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 120,000# @ $15.00.** Assume 2 @ 30 tons.			$1,440,000	$2,160,000			info?			info?	$1,440,000	$2,160,000
5.12	Emergency & sluice dewatering bulkhead gates	440,000	LB	$10.00	$4,400,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 300,000# @ $15.00.** Assume 2 @ 25 tons, and 2 @ 50 tons			$3,520,000	$5,280,000			info?			info?	$3,520,000	$5,280,000
5.13	Hoists, cylinders, machinery	200,000	LB	$15.00	$3,000,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 200,000# @ $15.00.**			$2,400,000	$3,600,000			info?			info?	$2,400,000	$3,600,000

HDR

Judgment-Level Cost Opinion
Pricing/Work Breakdown Summary

Project: ***Chehalis Dam***
Alternative: ***FRFA*** ***Comparison for FRE Evaluation***

Weighting ⇨	20% low	70% likely	10% high	20% low	70% likely	10% high
$293M - Jul-16	**Low End**	**$352,951,969**		**Low End**	**$457,019,556**	
	Likely	**$414,642,686**		**Likely**	**$536,899,728**	
$454M - Jul-18	**High End**	**$484,932,003**		**High End**	**$627,913,791**	
	Weighted	**$409,333,474**		**Weighted**	**$530,025,100**	

Pricing - contractor cost basis 1 or bid basis 2:	**2**			
Range Driver - 1 = %, 2 = Q & $, 3 = Combination:			**3**	
Default Low ⇨	**80%**	**Default High ⇨**	**120%**	

Quantity references: "FRE - Annotated Dwgs Supporting OPC.pdf" (concrete & misc);"RCC Dam Q-s & Placement Plan - R09.xls" (RCC);"2017_Chehalis_Construction_Costs_DRAFT_06082017.xls" (mechanical and steel); and this sheets notes and considerations

		Base or Likely Cost Case					Range Development: Driven by Percent				Driven by Q & Unit $						Driven by Combo	
Work Item	**Description**	**Quantity**	**Unit**	**Unit Price [1]**	**Total $**	**Estimate Notes & Considerations** *(Notes prior to FRE eval grayed out)*	**Low End % (def=80%)**	**High End % (def=120%)**	**Low % Total $**	**High % Total $**	**Low End Q**	**Low End Unit $**	**Low End Total $**	**High End Q**	**High End Unit $**	**High End Total $**	**Low End Tot $**	**High End Tot $**
5.14	Reservoir drain valve in tunnel plug (assume 4x4' knife valve)	1	Each	$200,000.00	$200,000		50%	100%	$100,000	$200,000			info?			info?	$100,000	$200,000
5.15	WQ Regulating Outlets w/ hollow cone valves (4 - 4'dia)	4	Each	$450,000.00	$1,800,000	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 4ea @ $375,000.**			$1,440,000	$2,160,000			info?			info?	$1,440,000	$2,160,000
5.16	WQ Regulating Outlet w/ hollow cone valves (1 - 7'dia)	1	Each	$1,100,000.00	$1,100,000				$880,000	$1,320,000			info?			info?	$880,000	$1,320,000
5.17	WQ Intake Tower / concrete sidewall & decking - Conventional Concrete Reinforced	5,400	CY	$900.00	$4,860,000	**Items 5.17 and 5.18 prior, totaled 14,000cy (2800 @ $750 and 11,200 @ $400). All intake concrete is now in this item; ref "FRE - Annotated Dwgs Supporting OPC.pdf" FRE S-6-S-7 sheets.**			$3,888,000	$5,832,000			info?			info?	$3,888,000	$5,832,000
5.18	unused	0	CY	$400.00	$0	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** Refine quantities along with all structures next phase.	100%		$0	$0			info?			info?	$0	$0
5.19	Trashrack steel framing	1,088,640	LB	$6.50	$7,076,160	**Adjust to "2017_Chehalis_Construction_Costs_DRAFT_06082017.xls". Item was 1,360,000# @ $6.50.** Assume 300 ft high, 10 members 3' dia x 4.5'deep, steel column			$5,660,928	$8,491,392			info?			info?	$5,660,928	$8,491,392
5.2	unused	0	CY	$850.00	$0	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.**			$0	$0			info?			info?	$0	$0
6	**Spillway**				$0				$0	$0			info?			info?	$0	$0
6.01	Flip Bucket Conventional Concrete - surface	5,800	CY	$650.00	$3,770,000	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.**			$3,016,000	$4,524,000			info?			info?	$3,016,000	$4,524,000
6.02	Conventional Concrete - spillway approach, ogee, chute slab, and training walls	8,700	CY	$850.00	$7,395,000	**Reference note in this cell FRE - OPC tab, adjusting FRO and FRFA to better reflect anticipated structures.** unit price - accomodates higher RCC placement and utilization of some mass conventional concrete	85%		$6,285,750	$8,874,000			info?			info?	$6,285,750	$8,874,000
7	**Sluice Stilling Basin**				$0				$0	$0			info?			info?	$0	$0
7.01	Excavation - Foundation General	20,000	CY	$8.00	$160,000	Refine all excavation and backfill quantities next phase			$128,000	$192,000			info?			info?	$128,000	$192,000
7.02	Excavation - Foundation Rock	10,000	CY	$30.00	$300,000				$240,000	$360,000			info?			info?	$240,000	$360,000
7.03	Fill - Foundation Backfill	18,000	CY	$9.00	$162,000				$129,600	$194,400			info?			info?	$129,600	$194,400
7.04	Conventional Concrete Reinforced	8,600	CY	$750.00	$6,450,000	**Reference "FRE - Annotated Dwgs Supporting OPC.pdf", sheets FRE S-06, S07. Was 4900 @ $8700 and item 7.04 2000cy at $400.**			$5,160,000	$7,740,000			info?			info?	$5,160,000	$7,740,000
7.05	Conventional Concrete Non-Reinforced	1,600	CY	$400.00	$640,000				$512,000	$768,000			info?			info?	$512,000	$768,000
8	**Wing Dam Structure**				$0				$0	$0			info?			info?	$0	$0
8.01	Excavation - Foundation General (assume footprint 270' @ widest x 10 ft deep)	70,000	CY	$10.00	$700,000	**Consider as all excavation and unclassified, all should be ripable rock at the worst; was 33,333 cy**			$560,000	$840,000			info?			info?	$560,000	$840,000
8.02	Excavation Cutoff Trench - Foundation Rock (assume trench 30 ft wide x 20 ft deep)	0	CY	$30.00	$0	**Included in item 8.01; was 13,333 cy**			$0	$0			info?			info?	$0	$0
8.03	Fill - Wingdam Embankment	176,000	CY	$20.00	$3,520,000	**Composite fill unit price and quantity; pending more detailed QTO; increased unit price to accommodate riprap item being included; was 120,000 cy @ $15.**	90%		$3,168,000	$4,224,000			info?			info?	$3,168,000	$4,224,000
8.04	Fill - Wingdam Riprap Facing (assume 5' blanket U/S and D/S)	8,000	CY	$65.00	$520,000				$416,000	$624,000			info?			info?	$416,000	$624,000
	Composite & Unlisted Work																	
55	Fish passage structure - costs not included	1	ls	$0	$0	Costs independently assessed in report			$0	$0			info?			info?	$0	$0
56	Unlisted Work	1	ls	$5,000,000	$5,000,000		85%	115%	$4,250,000	$5,750,000			info?			info?	$4,250,000	$5,750,000
57					$0				$0	$0			info?			info?	$0	$0
58					$0				$0	$0			info?			info?	$0	$0
59					$0				$0	$0			info?			info?	$0	$0
60					$0				$0	$0			info?			info?	$0	$0
61					$0				$0	$0			info?			info?	$0	$0
62					$0				$0	$0			info?			info?	$0	$0
63					$0				$0	$0			info?			info?	$0	$0
64					$0				$0	$0			info?			info?	$0	$0
65					$0				$0	$0			info?			info?	$0	$0
					$0				$0	$0			info?			info?	$0	$0
Subtotal without mobilization & general expense					**$273,015,760**		**$222,855,158**	**$327,743,992**	**$222,855,158**	**$327,743,992**			**$152,070,000**			**$206,210,000**	**$232,396,358**	**$319,296,792**
Mobilization & project indirect expense			0%		$0	unallocated project indirect or jobsite overhead assumed in unit pricing												
Contractor Cost					**$273,015,760**	Note 1: Unit prices as noted in header, either reflect a bid price basis (no factor application of corporate OH & profit), or a contractor cost basis requiring a corporate OH & profit to get to a bid total												
Contractor Margin - corporate overhead & profit			~~0%~~	Bid Basis	$0	Note 2: NA - not applicable to project; NE - not evident in estimate; NI - noted but not itemized in estimate												
Contractor Bid - before design/procurement contingencies					**$273,015,760**													
Contract Contingencies - design and procurement contingencies			12.5%		$34,126,970	⇦ RCC estimate dominance, work breakdown thoroughness, and work understanding support a design contingency lower than typical (i.e. 20%) at this early design level												
Contract Cost - contracator bid with design & procurement contingencies					**$307,142,730**													
Construction Contingency: post-award change & dispute factor			10%		$30,714,273													
Non-Contract Costs: PM, planning, design, CM ...			25%		$76,785,683	⇦ permitting, site characterization, CM during construction,etc.												
Total Project Cost - before escalation					**$414,642,686**	**Compares to $293M low bound, and $454M high bound July 2016**												
Escalation - annual %; from; to		3.5%	1-Jun-17	1-Dec-24	$122,257,043	⇦ Presume NTP - mid 2021, say 7 years construction = 4.0 + 3.5 years = 7.5 years												
Total Project Cost - including escalation				**7.5 yr**	**$536,899,728**	**<< 197% above total w/o mobilization**												

4 FRE RCC PLACEMENT ANALYSIS SUMMARY

RCC placement analysis for FRE and FRE-FC alternatives are provided in the following pages.

Chehalis Dam
Concept-Level RCC Placement Analysis

Flood Retention Expandable (FRE) RCC Quantity & Placement Summary

The Flood Retention Expandable project **(FRE)** has an initial construction phase **(FRE)** and a potential future construction phase **(FRE-FC).** Phase I or PHI should be read as **(FRE)** and Phase II or PHII should be read as **(FRE-FC)**.

FRE Quantities by Phase & Sequence

	Starting Elev	No. of Lifts	Ending Elev	Lift Volume	Avg Lift Volume	Starting Forms to RCC ratio	Ending Forms to RCC ratio	Likley Prod Control	Vert Adv per Day	Days in Sequence	Weeks at 5.5 dy/wk (adj for weather)	Months @ 19dy/mo
Phase I												
PHI - 1 Full	395	23	418	38,855	1,689	0.2 : 1	0.2 : 1	foundation & learning curve	2	12.0	2.2	0.6
PHI - 1 Left	418	13	431	41,697	3,207	0.2 : 1	0.2 : 1	foundation & learning curve	3	5.0	0.9	0.3
PHI - 2a Right	420	11	431	5,551	505	0.2 : 1	0.2 : 1	foundation & learning curve	3	4.0	0.7	0.2
PHI - 2b Right	431	40	471	42,338	1,058	0.2 : 1	0.3 : 1	foundation & small lift size	4	10.0	1.8	0.5
PHI - 3 Left	431	40	471	148,556	3,714	0.2 : 1	0.3 : 1	mix & deliver RCC	3	14.0	2.5	0.7
PHI - 4 Full	471	30	501	152,828	5,094	0.3 : 1	0.4 : 1	mix & deliver RCC	1.5	20.0	3.6	1.1
PHI - 5 Full	501	115	616	444,475	3,865	0.4 : 1	1.9 : 1	mix & deliver RCC; length & facing	1.5	77.0	14.0	4.1
PHI - 6 Right	616	36	651	20,149	560	1.9 : 1	3.2 : 1	length & facing; constricted geometry	3	12.0	2.2	0.6
PHI - 7 Left	616	36	651	18,492	514	1.9 : 1	3.2 : 1	length & facing; RCC delivery, constricted geometry	3	12.0	2.2	0.6
Phase I Subtotals		344		912,941	2,654					166.0	31.0	9.0
Delivery resets								4 each @ 2 shifts = 4 days		4.0	0.7	0.2
Vertical form transitions								2 each @ 4 shifts = 4 days		4.0	0.7	0.2
Phase I Totals										**174.0**	**32.5**	**9.4**
									2.0 ft/dy	**5,247 cy/dy**	**28,130 cy/wk**	**96,904 cy/mo**
Phase II												
PHII - 1a Right	431	40	471	11,458	286	0.5 : 1	0.5 : 1	learning curve; constricted geometry & delivery	3	14.0	2.5	0.7
PHII - 1b Right	471	30	501	18,955	632	0.5 : 1	0.5 : 1	learning curve; constricted geometry & delivery	4	8.0	1.5	0.4
PHII - 2 Right	501	115	616	92,865	808	0.5 : 1	0.5 : 1	mix & delivery, constricted geometry	4	29.0	5.3	1.5
PHII - 3 Left	431	185	616	147,505	797	0.5 : 1	0.5 : 1	mix & delivery, constricted geometry	4	47.0	8.5	2.5
PHII - 4 Full	616	35	651	94,565	2,702	0.5 : 1	0.5 : 1	mix & delivery, length & facing	4	9.0	1.6	0.5
PHII - 5 Full	651	30	681	75,846	2,528	0.5 : 1	2.2 : 1	mix & delivery, length & facing	3	10.0	1.8	0.5
PHII - 6 Right	681	30	710	17,857	595	2.2 : 1	4.7 : 1	length & facing; RCC delivery, constricted geometry	3	10.0	1.8	0.5
PHII - 7 Left	681	30	710	17,414	580	2.2 : 1	4.7 : 1	length & facing; RCC delivery, constricted geometry	3	10.0	1.8	0.5
Phase II Subtotals		495		476,465	963					137.0	25.0	8.0
Delivery resets								5 each @ 2 shifts; say 5 days		5.0	0.9	0.3
Vertical form transitions								2 each @ 4 shifts = 4 days		4.0	0.7	0.2
Phase II Totals										**146.0**	**26.6**	**8.5**
									3.4 ft/dy	**3,263 cy/dy**	**17,888 cy/wk**	**56,229 cy/mo**

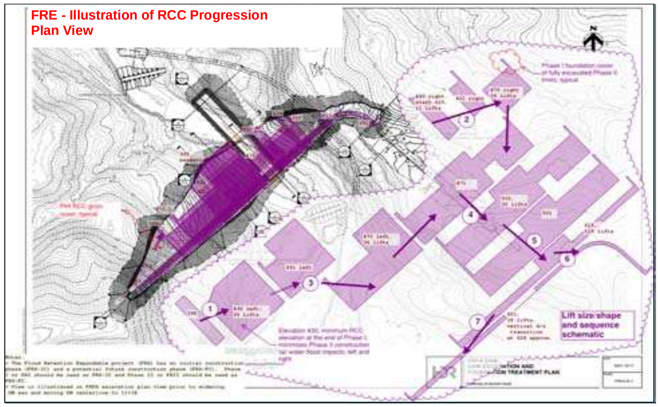
FRE Quantities by Vertical Section

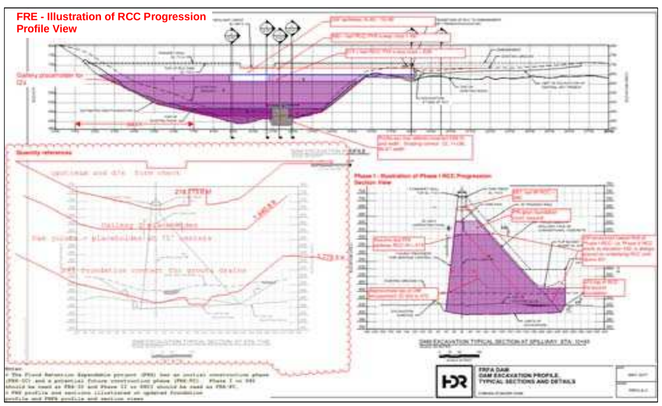
Row Labels	Min of Elev	Max of Elev	Max of Top of Lift #	Max of PHI non-overflow lift width	Max of PHII full non-overflow elev width	Max of PHI lift width in spillway	Min of Left Abut Contact	Max of Rt Abut Contact	Sum of PHI - Lift Volume - cy	Max of PHI - Lift Volume - cy	Sum of PHI - U/S Facing Element - cy	Max of PHI - U/S Facing Element - cy	Sum of PHI - D/S Facing Element - cy	Max of PHI - D/S Facing Element - cy	Sum of PHII - Lift Volume - cy	Max of PHII - Lift Volume - cy	Sum of PHII - U/S Facing Element - cy2	Max of PHII - U/S Facing Element - cy	Sum of PHII - D/S Facing Element - cy	Max of PHII - D/S Facing Element - cy2	Max of PHI Form sf : cy RCC	Max of PHII Form sf : cy RCC
1 - below 431	395	430	35	299	299	307	7+80	12+66	86,103	4,213	727	37	874	44	0	0	0	0	0	0	0.2 : 1	0.0 : 1
2 - 431 thru 470	431	470	75	209	265	303	6+06	13+74	190,894	5,378	2,040	63	2,443	76	25,367	910	0	0	1,131	41	0.3 : 1	0.5 : 1
3 - 470 thru 615	471	615	220	171	227	227	2+83	15+43	597,303	5,231	13,641	117	13,641	117	245,416	2,163	0	0	10,946	96	1.3 : 1	0.5 : 1
4 - 616 thru 651	616	651	256	33	89	0	2+16	18+19	38,641	1,556	4,054	130	4,539	140	97,889	3,324	667	19	4,674	148	3.2 : 1	0.8 : 1
5 - 652 thru 680	652	680	285	0	55	0	1+82	18+17	0	0	0	0	224	10	72,523	3,269	4,342	151	4,342	151		2.1 : 1
6 - 681 thru 710	681	710	315	0	28	0	1+50	18+14	0	0	0	0	122	5	35,271	1,462	4,018	135	4,018	135		4.7 : 1
Grand Total	**395**	**710**	**315**	**299**	**299**	**307**	**1+50**	**18+19**	**912,941**	**5,378**	**20,462**	**130**	**21,844**	**140**	**476,465**	**3,324**	**9,027**	**151**	**25,112**	**151**	**3.2 : 1**	**4.7 : 1**

FRE RCC Quantity & Placement Summary

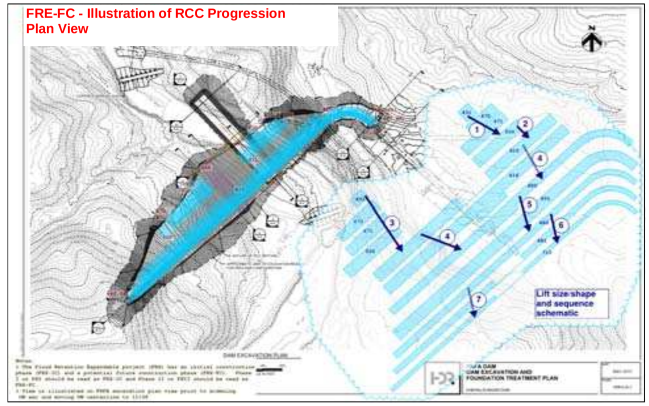
The Flood Retention Expandable project **(FRE)** has an initial construction phase **(FRE)** and a potential future construction phase **(FRE-FC).** Phase I or PHI should be read as **(FRE)** and Phase II or PHII should be read as **(FRE-FC)**.

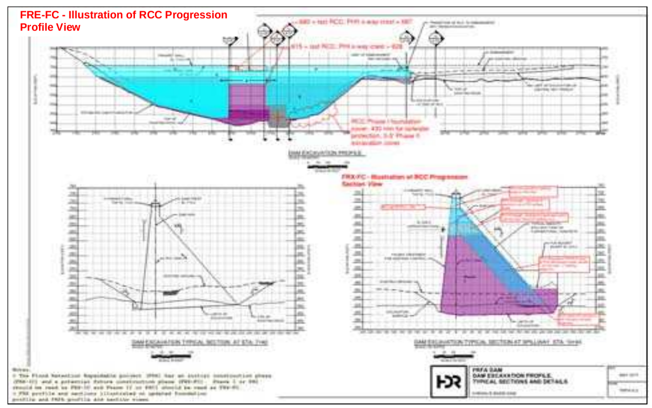
FRE *RCC Lift Shape & Sequence Illustration*





FRE-FC *RCC Lift Shape & Sequence Illustration*

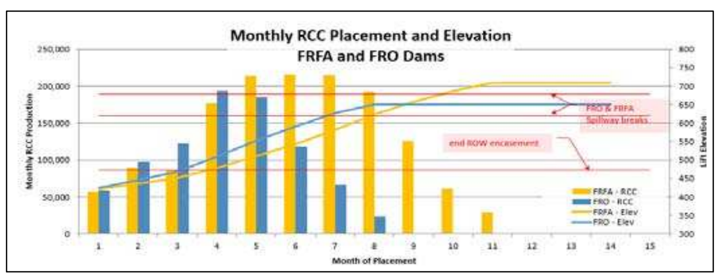




*RCC **FRE** Estimate Basis*

- > PHI upstream CIP face; downstream GERCC
- > PHII upstream CIP face; downstream GERCC
- > PHI & II abutment contact - GERCC
- > PHI fully excavates for PHII and covers exposed groin with 4' min RCC
- > PHI places all PHII RCC thru elev 430 to exceed tailwater for PHII
- > PHI fully backfills the U/S groin and 3-5' of fill over RCC groin
- > PHII removes fill in RCC groin, and backfills d/s to orig grade
- > PHII removes approach, ogee, and crest parapets
- > PHII preps the PHI downstream and interface surfaces
- > PHII has a upper right abutment treatment allowance in lieu of grouting
- > PHI fully completes the PHII sluice and river OW below 651
- > PHI fully constructs the chute and flip bucket below 620
- > PHI OW encasement top is elev. 500 u/s & 470 d/s
- > PHI flip bucket foundation block is RCC up to 470

Reference from FRO and FRFA RCC Production Assessment



5 FRE, FRE-FC, AND UPDATED FRO AND FRFA RCC UNIT COST DEVELOPMENT

Unit cost development for FRE, FRE-FC, updated FRO and FRFA alternatives are presented in the following pages.

Chehalis Dam - Constructability, Schedule and Cost Support
FRE RCC - Jugdment Level Cost Breakdown

The Flood Retention Expandable project **(FRE)** has an initial construction phase **(FRE)** and a potential future construction phase **(FRE-FC).** Phase I or PHI should be read as **(FRE)** and Phase II or PHII should be read as **(FRE-FC)**.

FRE

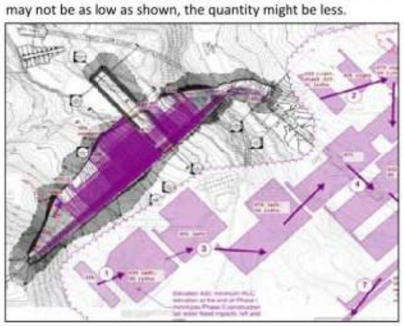
Driving RCC Quantity — *892,000 cy* *(Driven off of " FRE Lift Chart" tab of "RCC Dam Q-s & Placement Plan - R09.xls"; and drawings as noted in "FRE-Annotated Dwgs Supporting OPC.pdf")*

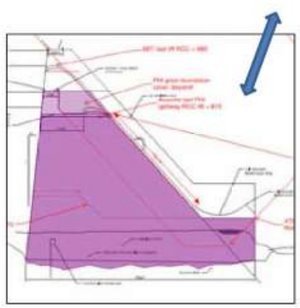
RCC Unit Cost Development by Component

Cost Component	Qty Determination	Ref Qty	Priced Qty	Unit	Low	Likely	High	Likely Total	RCC Unit Contribution
Aggregate	3,550 #/cy w/1.05%		1,662,465	ton	12.25	14.75	17.75	$ 24,521,359	$ 27.49 /cy
Cement & FA	285 #/cy w/1.03%		130,923	ton	115.00	135.00	145.00	$ 17,674,646	$ 19.81 /cy
Other materials	RCC		892,000	cy	0.75	1.00	1.25	$ 892,000	$ 1.00 /cy
RCC test section	ls		1	ls	125,000	250,000	300,000	$ 250,000	$ 0.28 /cy
RCC plant & delivery mob-setup-demob	ls		1	ls	400,000	450,000	600,000	$ 450,000	$ 0.50 /cy
Mix	RCC		892,000	cy	5.50	6.00	6.50	$ 5,352,000	$ 6.00 /cy
Mix Cooling	240,000 cy @ 5-10 def F cooling		240,000	cy	2.50	3.50	4.50	$ 840,000	$ 0.94 /cy
Deliver	RCC (4 months @ 60kcy / mo = 240k cy)		892,000	cy	4.50	5.50	6.00	$ 4,906,000	$ 5.50 /cy
Place	RCC		892,000	cy	4.50	5.00	5.50	$ 4,460,000	$ 5.00 /cy
Dam Joints	75 ft on center		321,120	sf	2.75	3.00	3.50	$ 963,360	$ 1.08 /cy
Bedding	12.5% of RCC @ 1/2in		4,646	cy	275.00	300.00	325.00	$ 1,393,750	$ 1.56 /cy
Facing & S-way block forming - slope + vert	full u/s & d/s from "FRX - Lift Chart"		457,000	sf	4.00	5.00	6.00	$ 2,285,000	$ 2.56 /cy
Facing options:									
Base - GERCC (all faces)	0.75 gal/sf of all faces	42,315 cy	1,695	cy	650.00	700.00	800.00	$ 1,186,397	$ 1.33 /cy
Option 1 - u/s conventional	2.5 ft thick - on all formwork	221,000 sf	20,463	cy	250.00	290.00	320.00	$ 5,934,259	$ 6.65 /cy
Option 1 - d/s GERCC face	0.75 gal/sf of d/s and other formwork	236,000 sf	875	cy	650.00	700.00	800.00	$ 612,669	$ 0.69 /cy
Option 2 - Facing (u/s & d/s conventional)	2.5 ft thick - on all formwork		42,315	cy	250.00	290.00	320.00	$ 12,271,296	$ 13.76 /cy
GERCC - abutment contact	0.75 gal/sf of abut surface x 150%	19,056 cy	1,780	cy	650.00	700.00	800.00	$ 1,246,106	$ 1.40 /cy
Gallery	1,480' + 2 adits @ 50'+ 1 @ 180'		1,720	lf	800.00	900.00	1100.00	$ 1,548,000	$ 1.74 /cy
Other drain features	RCC		892,000	cy	0.50	0.75	1.25	$ 669,000	$ 0.75 /cy
Total with Base Facing (GERCC all faces)	343,000 sf abutment contact x 1.5' thick				$ 58,218,812	$ 68,637,617	$ 78,806,451		
					$ 65.27 /cy	$ 76.95 /cy	$ 88.35 /cy		$ 76.95 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 72,800,000**	**$ 85,800,000**	**$ 98,500,000**		
Total RCC - inclusive bid					**$81.61 /cy**	**$96.19 /cy**	**$110.43 /cy**		
Cementitious materials - bid			on 127,110 tn		**$148.06 /tn**	**$173.81 /tn**	**$186.69 /tn**		
Aggregate materials - bid			on 1,583,300 tn		**$16.08 /tn**	**$19.36 /tn**	**$23.30 /tn**		
Facing elements - form & place - bid			on 892,000 cy		**$3.28 /cy**	**$3.89 /cy**	**$4.59 /cy**		
Mix - Deliver - Place - Other - bid			on 892,000 cy		**$28.69 /cy**	**$33.17 /cy**	**$37.88 /cy**		
RCC - w/out cementitious - bid			on 892,000 cy		**$60.52 /cy**	**$71.42 /cy**	**$83.82 /cy**	Use Option 1) u/s conventional & d/s GERCC, as basis for estimate	
Check					**$72,800,000**	**$85,800,000**	**$98,500,000**		
Total with full conventional facings (Option 2)					$ 67,695,862	$ 79,722,516	$ 90,991,310		
					$75.89 /cy	$89.38 /cy	$102.01 /cy		$89.38 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 84,600,000**	**$ 99,700,000**	**$ 113,700,000**		
Contractor Bid Unit Prices					**$94.84 /cy**	**$111.77 /cy**	**$127.47 /cy**		
Contractor Bid Unit Prices (Option 1)					**$88.01 /cy**	**$103.70 /cy**	**$118.69 /cy**		
			Compares to Current FRO @		**$76.30 /cy**	**$93.09 /cy**	**$109.63 /cy**		
			Compares to Current FRFA @		**$83.53 /cy**	**$98.84 /cy**	**$113.54 /cy**		

Cost Development Qualifications

1) Cost judgment contemplates 2017 costs
2) The unit costs and cost ranges reflect industry experience and judgment, not developed estimates
3) The quantities reflect rough estimates of preliminary drawings, and anticipated design details
4) The low and high ranges intend to reflect design development and choices that might affect both the quantity and nature of the work, within the context of the given dam size. For example, while the low cement and pozzolan price may not be as low as shown, the quantity might be less.





Quantity Development - supporting parameters and numbers

Quantity Development Check Not Used in Hybrid Quick Cost. Reference drawing pdf's referenced in table note.

	Max	NA	NA
Approx crest length	1,650		
Crest width			
Crest elev			
U/S work point elev			
Foundation elev			
U/S slope	0.1		
D/S slope	0.85		
Joint spacing	75		
Approx vertical profile sf	335,537		
Structure H	311	0	0
H of D/S chimney	23.5	#DIV/0!	#DIV/0!
Elev of D/S chimney break	686.5	#DIV/0!	#DIV/0!
Base width	295.5	0.0	0.0
Area - max	46,178 sf	#DIV/0!	#DIV/0!
Volume / lf of dam	1,710 cy	#DIV/0!	#DIV/0!
U/S face vertical length	312.6	0	0
U/S face length as % of H	100.5%	#DIV/0!	#DIV/0!
D/S face length	401	#DIV/0!	#DIV/0!
D/S face length as % of H	128.9%	#DIV/0!	#DIV/0!
full joint sf / cy of dam	0.36 sf/cy	#DIV/0!	#DIV/0!
Approx RCC Check	890 lf	46,178 full sf	1,530,000 cy

Chehalis Dam - Constructability, Schedule and Cost Support
FRE-FC RCC - Judgment Level Cost Breakdown

The Flood Retention Expandable project **(FRE)** has an initial construction phase **(FRE)** and a potential future construction phase **(FRE-FC)**. Phase I or PHI should be read as **(FRE)** and Phase II or PHII should be read as **(FRE-FC)**.

FRE-FC

Driving RCC Quantity **467,000 cy** *(Driven off of " FRE Lift Chart" tab of "RCC Dam Q-s & Placement Plan - R09.xls"; and drawings as noted in " FRE-Annotated Dwgs Supporting OPC.pdf")*

RCC Unit Cost Development by Component

Cost Component	Qty Determination	Ref Qty	Priced Qty	Unit	Low	Likely	High	Likely Total	RCC Unit Contribution
Aggregate	3,550 #/cy w/1.05%		870,371	ton	12.25	14.75	17.75	$ 12,837,976	$ 27.49 /cy
Cement & FA	285 #/cy w/1.03%		68,544	ton	115.00	135.00	145.00	$ 9,253,430	$ 19.81 /cy
Other materials	RCC		467,000	cy	0.75	1.00	1.25	$ 467,000	$ 1.00 /cy
RCC test section	ls		1	ls	100,000	200,000	275,000	$ 200,000	$ 0.43 /cy
RCC plant & delivery mob-setup-demob	ls		1	ls	300,000	350,000	450,000	$ 350,000	$ 0.75 /cy
Mix	RCC		467,000	cy	5.50	6.00	6.50	$ 2,802,000	$ 6.00 /cy
Mix Cooling	300,000 cy @ 5-10 def F cooling		300,000	cy	3.00	4.00	5.00	$ 1,200,000	$ 2.57 /cy
Deliver	RCC		467,000	cy	5.50	6.50	7.00	$ 3,035,500	$ 6.50 /cy
Place	RCC		467,000	cy	5.00	6.00	6.50	$ 2,802,000	$ 6.00 /cy
Dam Joints	75 ft on center		168,120	sf	2.75	3.00	3.50	$ 504,360	$ 1.08 /cy
Bedding	12.5% of RCC @ 1/2in		2,432	cy	275.00	300.00	325.00	$ 729,688	$ 1.56 /cy
Facing & S-way block forming - slope + vert	full u/s & d/s from "FRX - Lift Chart"		368,500	sf	3.75	4.50	5.50	$ 1,658,250	$ 3.55 /cy
Facing options:									
Base - GERCC (all faces)	0.75 gal/sf of all faces	34,120 cy	1,367	cy	650.00	700.00	800.00	$ 956,646	$ 2.05 /cy
Option 1 - u/s conventional	2.5 ft thick - on all formwork	97,500 sf	9,028	cy	250.00	290.00	320.00	$ 2,618,056	$ 5.61 /cy
Option 1 - d/s GERCC face	0.75 gal/sf of d/s and other formwork	271,000 sf	1,005	cy	650.00	700.00	800.00	$ 703,531	$ 1.51 /cy
Option 2 - Facing (u/s & d/s conventional)	2.5 ft thick - on all formwork		34,120	cy	250.00	290.00	320.00	$ 9,894,907	$ 21.19 /cy
GERCC - abutment contact	0.75 gal/sf of abut surface x 150%	261 cy	1,780	cy	650.00	700.00	800.00	$ 1,246,106	$ 2.67 /cy
Gallery	Lump sum modification of PHI		1	ls	150,000	300,000	350,000	$ 300,000	$ 0.64 /cy
Other drain features	RCC		467,000	cy	0.50	0.75	1.25	$ 350,250	$ 0.75 /cy
Total with Base Facing (GERCC all faces)					$ 32,608,847	$ 38,693,205	$ 44,393,554		
					$ 69.83 /cy	$ 82.85 /cy	$ 95.06 /cy		$ 82.85 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 40,800,000**	**$ 48,400,000**	**$ 55,500,000**		
Total RCC - inclusive bid					**$87.37 /cy**	**$103.64 /cy**	**$118.84 /cy**		
Cementitious materials - bid			on 66,548 tn		**$148.06 /tn**	**$173.81 /tn**	**$186.69 /tn**		
Aggregate materials - bid			on 828,925 tn		**$16.08 /tn**	**$19.36 /tn**	**$23.30 /tn**		
Facing elements - form & place - bid			on 467,000 cy		**$4.86 /cy**	**$5.60 /cy**	**$6.68 /cy**		
Mix - Deliver - Place - Other - bid			on 467,000 cy		**$32.87 /cy**	**$38.91 /cy**	**$44.21 /cy**		
RCC - w/out cementitious - bid			on 467,000 cy		**$66.27 /cy**	**$78.87 /cy**	**$92.24 /cy**		
Check					**$40,800,000**	**$48,400,000**	**$55,500,000**		
Total with full conventional facings (Option 2)					$ 40,250,625	$ 47,631,467	$ 54,218,763		
					$86.19 /cy	$101.99 /cy	$116.10 /cy		$101.99 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 50,300,000**	**$ 59,500,000**	**$ 67,800,000**		
Contractor Bid Unit Prices					**$107.71 /cy**	**$127.41 /cy**	**$145.18 /cy**		
Contractor Bid Unit Prices (Option 1)					**$92.69 /cy**	**$109.90 /cy**	**$125.78 /cy**		
			Compares to Current FRC		**$76.30 /cy**	**$93.09 /cy**	**$109.63 /cy**		
			Compares to Current FRF		**$83.53 /cy**	**$98.84 /cy**	**$113.54 /cy**		

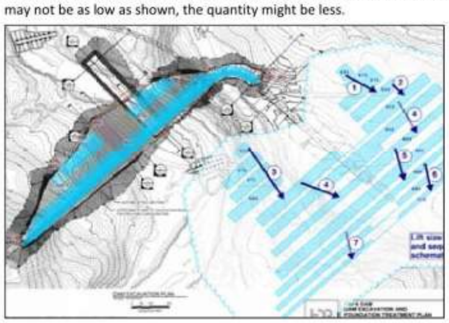
assume more aggressive cooling for Ph II to ensure monolith behavior and lower risk of poor existing adhesion

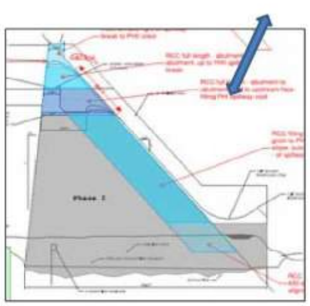
4700 sf abutment contact x 1.5' thick

Use Option 1) u/s conventional & d/s GERCC, as basis for estimate

Cost Development Qualifications

1) Cost judgement contemplates 2017 costs
2) The unit costs and cost ranges reflect industry experience and judgment, not developed estimates
3) The quantities reflect rough estimates of preliminary drawings, and anticipated design details
4) The low and high ranges intend to reflect design development and choices that might affect both the quantity and nature of the work, within the context of the given dam size. For example, while the low cement and pozzolan price may not be as low as shown, the quantity might be less.





Quantity Development - supporting parameters and numbers

	Max	NA	NA
Approx crest length	[illegible]		
Crest width			
Crest elev			
U/S work point elev			
Foundation elev			
U/S slope	0.1		
D/S slope	0.85		
Joint spacing	75		
Approx vertical profile sf	335,537		
Structure H	311	0	0
H of D/S chimney	23.5	#DIV/0!	#DIV/0!
Elev of D/S chimney break	686.5	#DIV/0!	#DIV/0!
Base width	295.5	0.0	0.0
Area - max	46,178 sf	#DIV/0!	#DIV/0!
Volume / lf of dam	1,710 cy	#DIV/0!	#DIV/0!
U/S face vertical length	312.6	0	0
U/S face length as % of H	100.5%	#DIV/0!	#DIV/0!
D/S face length	401	#DIV/0!	#DIV/0!
D/S face length as % of H	128.9%	#DIV/0!	#DIV/0!
full joint sf / cy of dam	0.36 sf/cy	#DIV/0!	#DIV/0!
Approx RCC Check	890 lf	46,178 full sf	1,530,000 cy

Quantity Development Check Not Used in Hybrid Quick Cost. Reference drawing pdf's referenced in table note.

Con-Sked-$ Support - FRE Chehalis - R01; FRE-FC RCC Quick Cost

Chehalis Dam - Constructability, Schedule and Cost Support

FRO RCC - Judgment Level Cost Breakdown

FRO Refreshed for FRE Eval

Driving RCC Quantity **810,000 cy** *(driven off of lift chart; RCC Dam Q-s & Placement Plan - R09.xls, Tab RCC - Lift Chart - 3D; dwgs - Chehalis_All_Figs_2016-10-19.pdf, updated by foundation profile generated for Hybrid)*

RCC Unit Cost Development by Component

Cost Component	Qty Determination	Ref Qty	Priced Qty	Unit	Low	Likely	High	Likely Total	RCC Unit Contribution
Aggregate	3,550 #/cy w/1.05%		1,509,638	ton	12.25	14.75	17.75	$ 22,267,153	$ 27.49 /cy
Cement & FA	285 #/cy w/1.03%		118,888	ton	115.00	135.00	145.00	$ 16,049,846	$ 19.81 /cy
Other materials	RCC		810,000	cy	0.00	0.50	1.25	$ 405,000	$ 0.50 /cy
RCC test section	ls		1	ls	125,000	250,000	300,000	$ 250,000	$ 0.31 /cy
RCC plant & delivery mob-setup-demob	ls		1	ls	200,000	350,000	450,000	$ 350,000	$ 0.43 /cy
Mix	RCC		810,000	cy	5.50	6.00	6.50	$ 4,860,000	$ 6.00 /cy
Mix Cooling	200,000 cy @ 5-10 def F cooling		200,000	cy	0.00	3.00	5.00	$ 600,000	$ 0.74 /cy
Deliver	RCC		810,000	cy	4.00	4.50	5.50	$ 3,645,000	$ 4.50 /cy
Place	RCC		810,000	cy	4.00	4.50	5.50	$ 3,645,000	$ 4.50 /cy
Dam Joints	75 ft on center		291,600	sf	3.00	3.50	4.00	$ 1,020,600	$ 1.26 /cy
Bedding	12.5% of RCC @ 1/2in		4,219	cy	275.00	300.00	325.00	$ 1,265,625	$ 1.56 /cy
Facing forming (slope u/s, vert d/s)	full u/s & d/s from "RCC - Lift Chart"		447,442	sf	3.00	3.75	5.00	$ 1,677,908	$ 2.07 /cy
Facing options:									
Base - GERCC (all faces)	0.75 gal/sf of all faces	41,430 cy	1,659	cy	450.00	700.00	800.00	$ 1,161,584	$ 1.43 /cy
Option 1 - u/s conventional (@1/2 facing)	2.5 ft thick - on 1/2 formwork		20,715	cy	250.00	290.00	320.00	$ 6,007,323	$ 7.42 /cy
Option 1 - d/s GERCC face	0.75 gal/sf of 1/2 formwork		830	cy	650.00	700.00	800.00	$ 580,792	$ 0.72 /cy
Option 2 - Facing (u/s & d/s conventional)	2.5 ft thick - on all formwork		41,430	cy	250.00	290.00	320.00	$ 12,014,646	$ 14.83 /cy
GERCC - abutment contact	0.75 gal/sf of projected abut x 150%	13,778 cy	1,380	cy	650.00	700.00	800.00	$ 965,732	$ 1.19 /cy
Gallery	1330' + 2 adits @ 100'		1,530	lf	500.00	1000.00	1200.00	$ 1,530,000	$ 1.89 /cy
Other drain features	RCC		810,000	cy	0.25	0.75	1.25	$ 607,500	$ 0.75 /cy
Total with Base Facing (GERCC all faces)					$ 49,413,416	$ 60,300,948	$ 71,026,711		
					$ 61.00 /cy	$ 74.45 /cy	$ 87.69 /cy		$ 74.45 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 61,800,000**	**$ 75,400,000**	**$ 88,800,000**		
Total RCC - inclusive bid					**$76.30 /cy**	**$93.09 /cy**	**$109.63 /cy**		
Cementitious materials - bid			on 115,425 tn		**$148.06 /tn**	**$173.81 /tn**	**$186.69 /tn**		
Aggregate materials - bid			on 1,437,750 tn		**$16.08 /tn**	**$19.36 /tn**	**$23.30 /tn**		
Facing elements - form & place - bid			on 810,000 cy		**$2.58 /cy**	**$3.51 /cy**	**$4.40 /cy**		
Mix - Deliver - Place - Other - bid			on 810,000 cy		**$24.08 /cy**	**$30.45 /cy**	**$37.27 /cy**		
RCC - w/out cementitious - bid			on 810,000 cy		**$55.20 /cy**	**$68.32 /cy**	**$83.03 /cy**		
Check					**$61,800,000**	**$75,400,000**	**$88,800,000**		
Total with full conventional facings (Option 2)					$ 59,024,138	$ 71,154,010	$ 82,956,728		
					$72.87 /cy	$87.84 /cy	$102.42 /cy		$87.84 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 73,800,000**	**$ 88,900,000**	**$ 103,700,000**		
Contractor Bid Unit Prices					**$91.11 /cy**	**$109.75 /cy**	**$128.02 /cy**		
Contractor Bid Unit Prices (Option 1)					**$83.93 /cy**	**$101.43 /cy**	**$118.81 /cy**		

For FRO, no planned or long-term storage; low range - 1) no cooling, 2) no admixture or other material, 3) reduced GERCC application or utilization, 4) potentially reduced gallery and drain features.

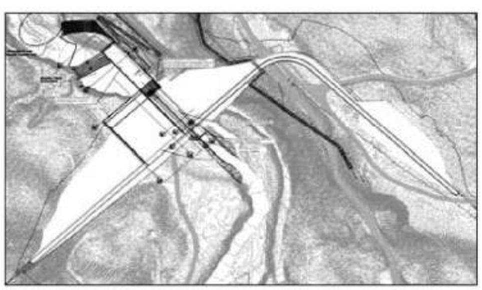
8-9 month window, potentially more flexibility to avoid hot weather; say 2 months @ 100kcy / mo = 200k cy

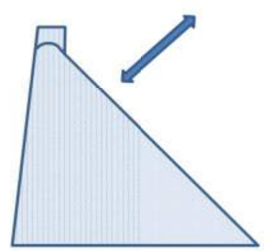
248,000 sf abutment contact x 1.5' thick

Use Base - all faces GERCC, as basis for estimate; FRO facing and water retention not as critical as with FRFA

Cost Development Qualifications

1) Cost judgement contemplates 2017 costs
2) The unit costs and cost ranges reflect industry experience and judgment, not developed estimates
3) The quantities reflect rough estimates of preliminary drawings, and anticipated design details
4) The low and high ranges intend to reflect design development and choices that might affect both the quantity and nature of the work, within the context of the given dam size. For example, while the low cement and pozzolan price may not be as low as shown, the quantity might be less.





Quantity Development - supporting parameters and numbers

Quantity Development Check Not Used in FRO/FRFA update. Reference drawing pdf's referenced in table note.

	Max	NA	NA
Approx crest length	1,400		
Crest width			
Crest elev			
U/S work point elev			
Foundation elev			
U/S slope	0.1		
D/S slope	0.85		
Joint spacing	75		
Approx vertical profile sf	238,215		
Structure H	252	0	0
H of D/S chimney	23.5	#DIV/0!	#DIV/0!
Elev of D/S chimney break	627.5	#DIV/0!	#DIV/0!
Base width	239.4	0.0	0.0
Area - max	30,400 sf	#DIV/0!	#DIV/0!
Volume / lf of dam	1,126 cy	#DIV/0!	#DIV/0!
U/S face vertical length	253.3	0	0
U/S face length as % of H	100.5%	#DIV/0!	#DIV/0!
D/S face length	323	#DIV/0!	#DIV/0!
D/S face length as % of H	128.3%	#DIV/0!	#DIV/0!
full joint sf / cy of dam	0.36 sf/cy	#DIV/0!	#DIV/0!
Approx RCC Check	775 lf	30,400 full sf	880,000 cy

Chehalis Dam - Constructability, Schedule and Cost Support **FRFA Refreshed for FRE Eval**

FRFA RCC - Jugdment Level Cost Breakdown

Driving RCC Quantity **1,360,000 cy** *(driven off of lift chart; RCC Dam Q-s & Placement Plan - R09.xls, Tab RCC - Lift Chart - 3D; dwgs - Chehalis_All_Figs_2016-10-19.pdf, updated by foundation profile generated for Hybrid)*

RCC Unit Cost Development by Component

Cost Component	Qty Determination	Ref Qty	Priced Qty	Unit	Low	Likely	High	Likely Total	RCC Unit Contribution
Aggregate	3,550 #/cy w/1.05%		2,534,700	ton	12.25	14.75	17.75	$ 37,386,825	$ 27.49 /cy
Cement & FA	285 #/cy w/1.03%		199,614	ton	115.00	135.00	145.00	$ 26,947,890	$ 19.81 /cy
Other materials	RCC		1,360,000	cy	0.75	1.00	1.25	$ 1,360,000	$ 1.00 /cy
RCC test section	ls		1	ls	125,000	250,000	300,000	$ 250,000	$ 0.18 /cy
RCC plant & delivery mob-setup-demob	ls		1	ls	300,000	400,000	500,000	$ 400,000	$ 0.29 /cy
Mix	RCC		1,360,000	cy	5.00	5.50	6.00	$ 7,480,000	$ 5.50 /cy
Mix Cooling	390,000 cy @ 5-10 def F cooling		390,000	cy	2.50	3.50	4.50	$ 1,365,000	$ 1.00 /cy
Deliver	RCC		1,360,000	cy	4.00	5.00	5.50	$ 6,800,000	$ 5.00 /cy
Place	RCC		1,360,000	cy	4.00	4.50	5.00	$ 6,120,000	$ 4.50 /cy
Dam Joints	75 ft on center		489,600	sf	2.75	3.00	3.50	$ 1,468,800	$ 1.08 /cy
Bedding	12.5% of RCC @ 1/2in		7,083	cy	275.00	300.00	325.00	$ 2,125,000	$ 1.56 /cy
Facing forming (slope u/s, vert d/s)	full u/s & d/s from "RCC - Lift Chart"		642,884	sf	3.00	3.75	5.00	$ 2,410,815	$ 1.77 /cy
Facing options:									
Base - GERCC (all faces)	0.75 gal/sf of all faces	59,526 cy	2,384	cy	650.00	700.00	800.00	$ 1,668,962	$ 1.23 /cy
Option 1 - u/s conventional (@1/2 facing)	2.5 ft thick - on 1/2 formwork		29,763	cy	250.00	290.00	320.00	$ 8,631,313	$ 6.35 /cy
Option 1 - d/s GERCC face	0.75 gal/sf of 1/2 formwork		1,192	cy	650.00	700.00	800.00	$ 834,481	$ 0.61 /cy
Option 2 - Facing (u/s & d/s conventional)	2.5 ft thick - on all formwork		59,526	cy	250.00	290.00	320.00	$ 17,262,626	$ 12.69 /cy
GERCC - abutment contact	0.75 gal/sf of projected abut x 150%	17,778 cy	1,780	cy	650.00	700.00	800.00	$ 1,246,106	$ 0.92 /cy
Gallery	1,600' + 2 adits @ 50'+ 1 @ 180'		1,880	lf	800.00	900.00	1100.00	$ 1,692,000	$ 1.24 /cy
Other drain features	RCC		1,360,000	cy	0.50	0.75	1.25	$ 1,020,000	$ 0.75 /cy
Total with Base Facing (GERCC all faces)					$ 84,219,502	$ 99,741,397	$ 114,959,564		
					$ 61.93 /cy	$ 73.34 /cy	$ 84.53 /cy		$ 73.34 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 105,300,000**	**$ 124,700,000**	**$ 143,700,000**		
Total RCC - inclusive bid					**$77.43 /cy**	**$91.69 /cy**	**$105.66 /cy**		
Cementitious materials - bid			on 193,800 tn		**$148.06 /tn**	**$173.81 /tn**	**$186.69 /tn**		
Aggregate materials - bid			on 2,414,000 tn		**$16.08 /tn**	**$19.36 /tn**	**$23.30 /tn**		
Facing elements - form & place - bid			on 1,360,000 cy		**$2.56 /cy**	**$3.00 /cy**	**$3.77 /cy**		
Mix - Deliver - Place - Other - bid			on 1,360,000 cy		**$25.23 /cy**	**$29.56 /cy**	**$33.94 /cy**		
RCC - w/out cementitious - bid			on 1,360,000 cy		**$56.33 /cy**	**$66.92 /cy**	**$79.06 /cy**		
Check					**$105,300,000**	**$124,700,000**	**$143,700,000**		
Total with full conventional facings (Option 2)					$ 97,551,326	$ 115,335,062	$ 132,100,594		
					$71.73 /cy	$84.81 /cy	$97.13 /cy		$84.81 /cy
with contractor unallocated indirect expense (15%) and overhead & profit 15%)			25%		**$ 121,900,000**	**$ 144,200,000**	**$ 165,100,000**		
Contractor Bid Unit Prices					**$89.63 /cy**	**$106.03 /cy**	**$121.40 /cy**		
Contractor Bid Unit Prices (Option 1)					**$83.53 /cy**	**$98.84 /cy**	**$113.54 /cy**		
					81.11	96.25	110.76		

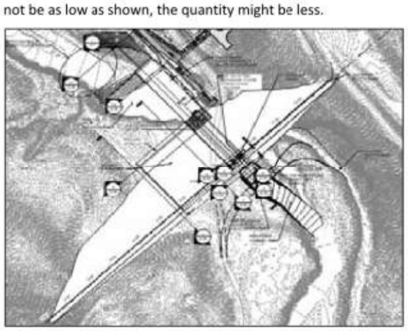
3 months @ 130kcy / mo = 390k cy

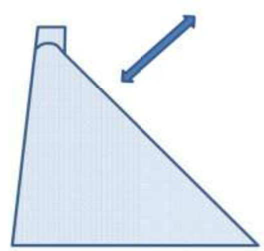
320,000 sf abutment contact x 1.5' thick

Use Option 1) u/s conventional & d/s GERCC, as basis for estimate

Cost Development Qualifications

1) Cost judgement contemplates 2017 costs
2) The unit costs and cost ranges reflect industry experience and judgment, not developed estimates
3) The quantities reflect rough estimates of preliminary drawings, and anticipated design details
4) The low and high ranges intend to reflect design development and choices that might affect both the quantity and nature of the work, within the context of the given dam size. For example, while the low cement and pozzolan price may not be as low as shown, the quantity might be less.





Quantity Development - supporting parameters and numbers

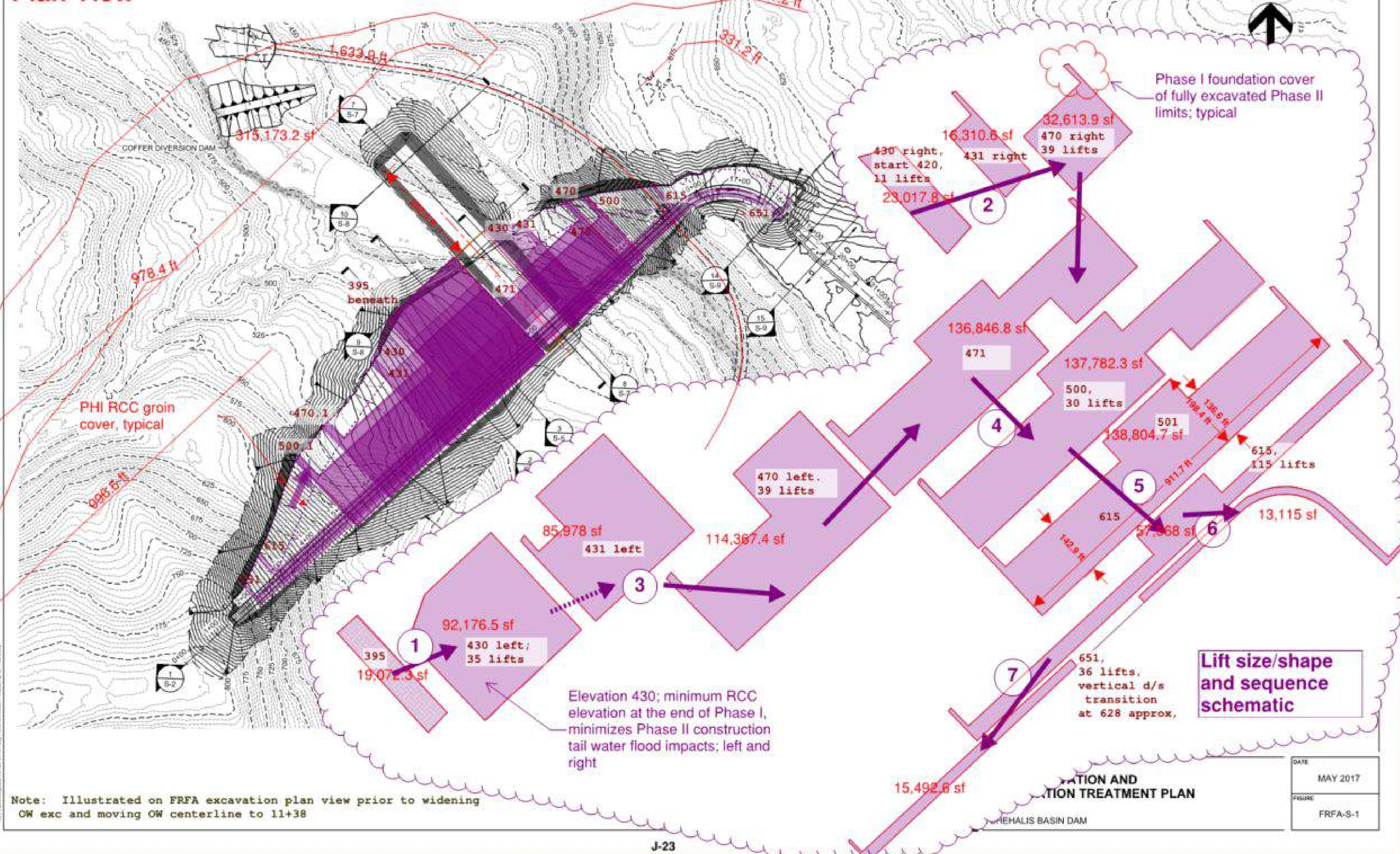
Quantity Development Check Not Used in FRO/FRFA update. Reference drawing pdf's referenced in table note.

	Max	NA	NA
Approx crest length	1,650		
Crest width			
Crest elev			
U/S work point elev			
Foundation elev			
U/S slope	0.1		
D/S slope	0.85		
Joint spacing	75		
Approx vertical profile sf	335,537		
Structure H	311	0	0
H of D/S chimney	23.5	#DIV/0!	#DIV/0!
Elev of D/S chimney break	686.5	#DIV/0!	#DIV/0!
Base width	295.5	0.0	0.0
Area - max	46,178 sf	#DIV/0!	#DIV/0!
Volume / lf of dam	1,710 cy	#DIV/0!	#DIV/0!
U/S face vertical length	312.6	0	0
U/S face length as % of H	100.5%	#DIV/0!	#DIV/0!
D/S face length	401	#DIV/0!	#DIV/0!
D/S face length as % of H	128.9%	#DIV/0!	#DIV/0!
full joint sf / cy of dam	0.36 sf/cy	#DIV/0!	#DIV/0!
Approx RCC Check	890 lf	46,178 full sf	1,530,000 cy

6 DRAWING SHEET ILLUSTRATING FRE RCC PROGRESSION AND QUANTITY TAKEOFF SUPPORT

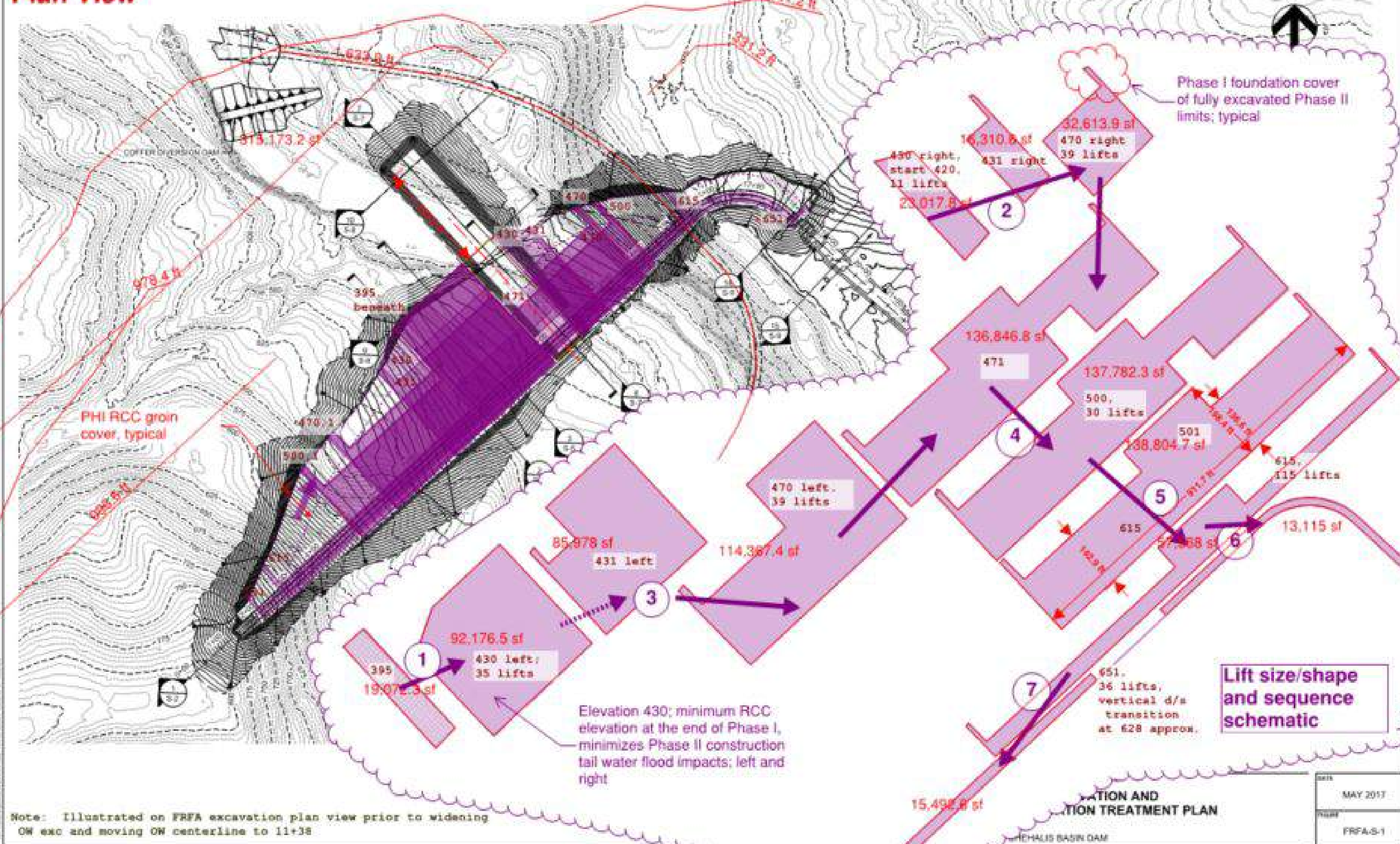
RCC placement progression and quantity takeoff analysis FRE dam alternative are illustrated on the drawing sheets presented in the following pages.

Phase I - Illustration of Phase I RCC Progression
Plan View



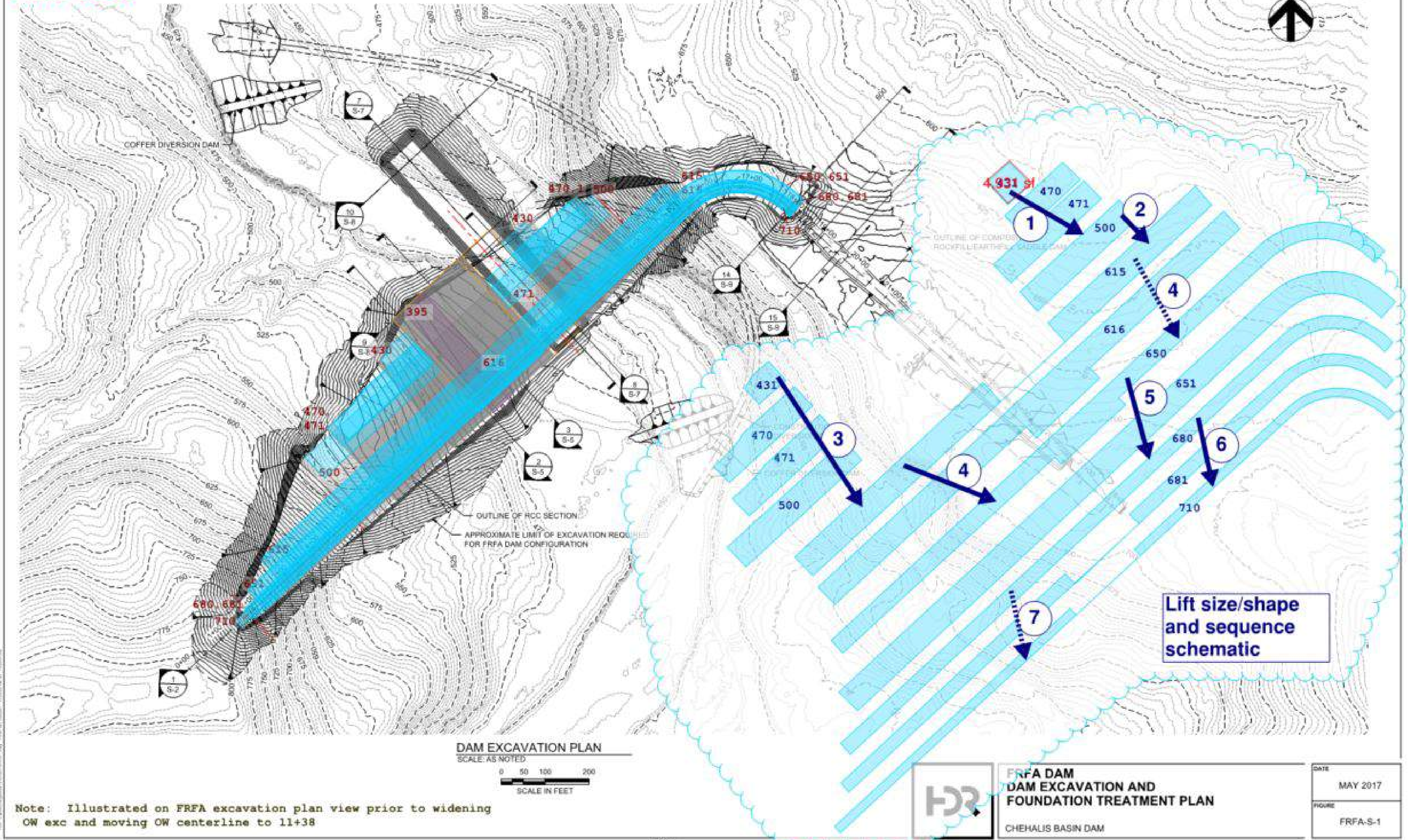
Note: Illustrated on FRFA excavation plan view prior to widening OW exc and moving OW centerline to 11+38

Phase I - Illustration of Phase I RCC Progression
Plan View

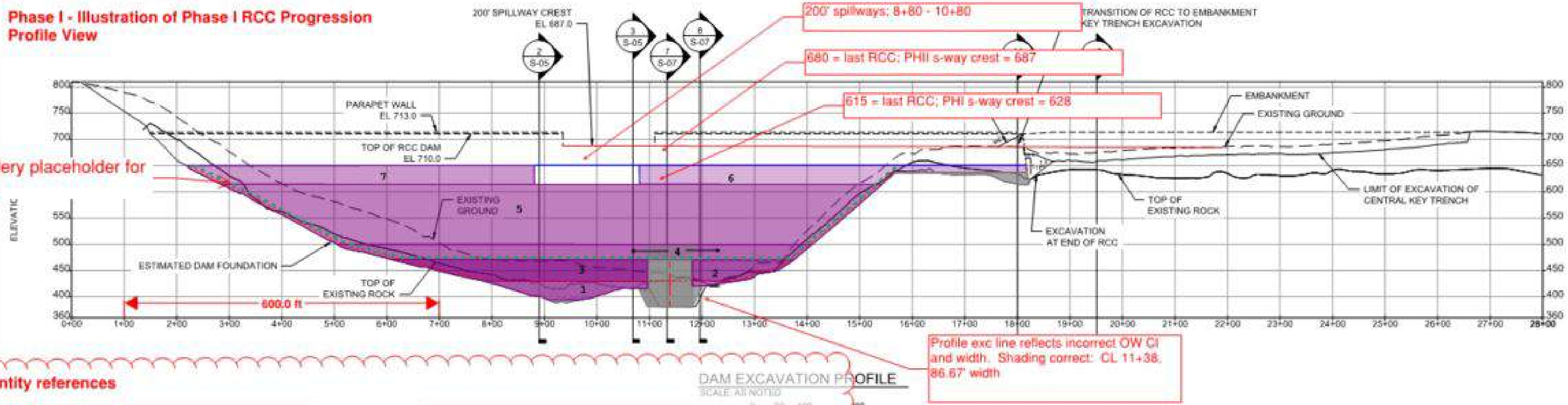


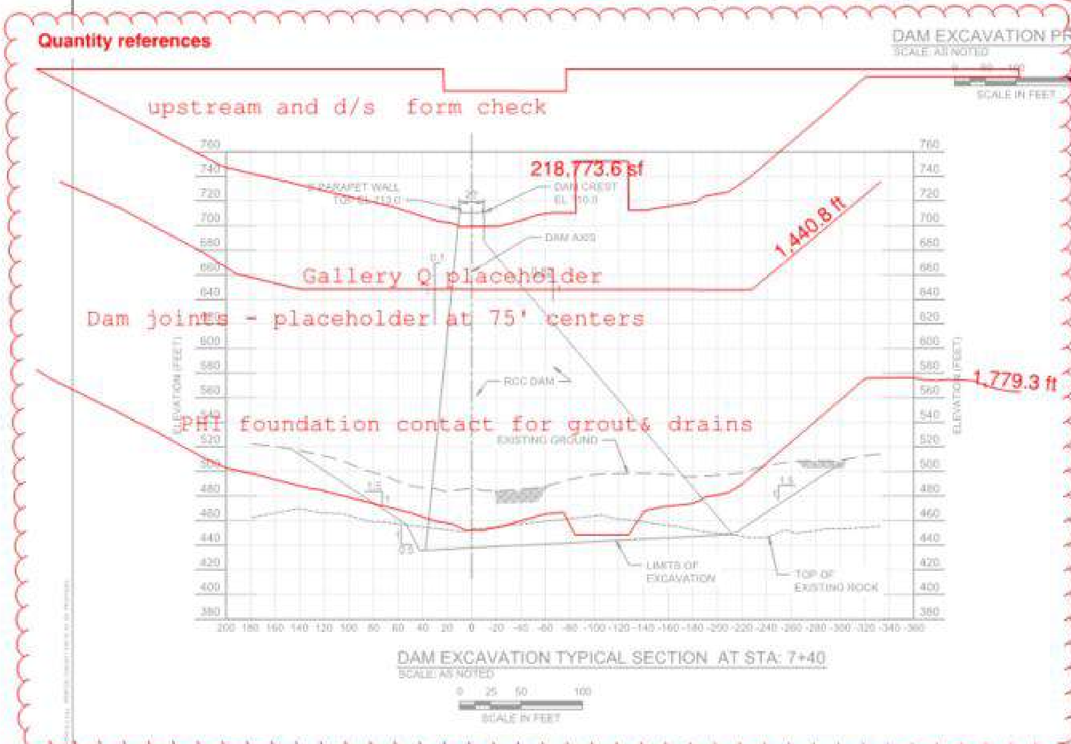
Note: Illustrated on FRFA excavation plan view prior to widening OW exc and moving OW centerline to 11+38

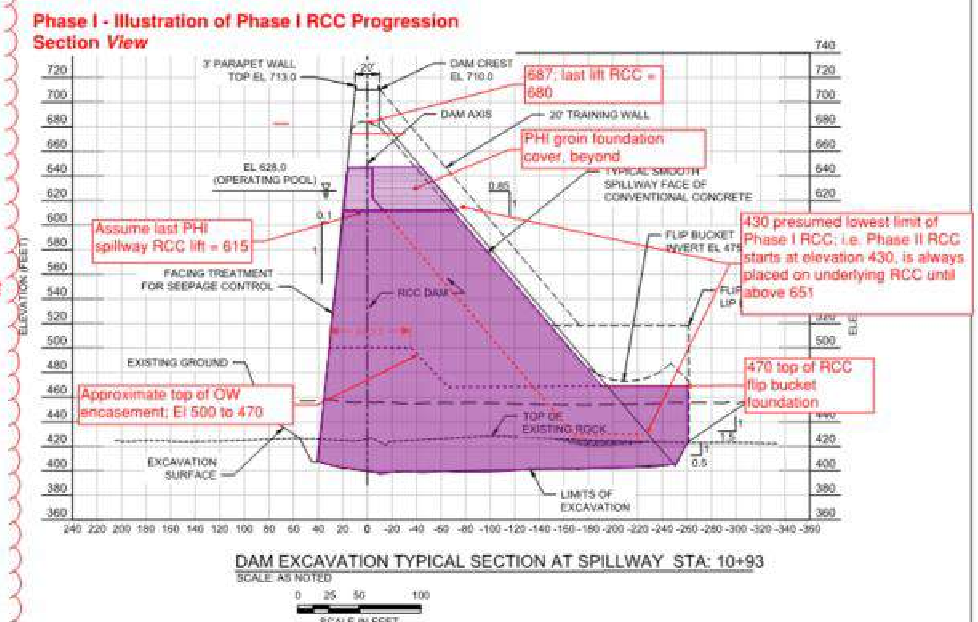
Phase II - Illustration of Phase II RCC Progression
Plan View



Note: Illustrated on FRFA excavation plan view prior to widening OW exc and moving OW centerline to 11+38







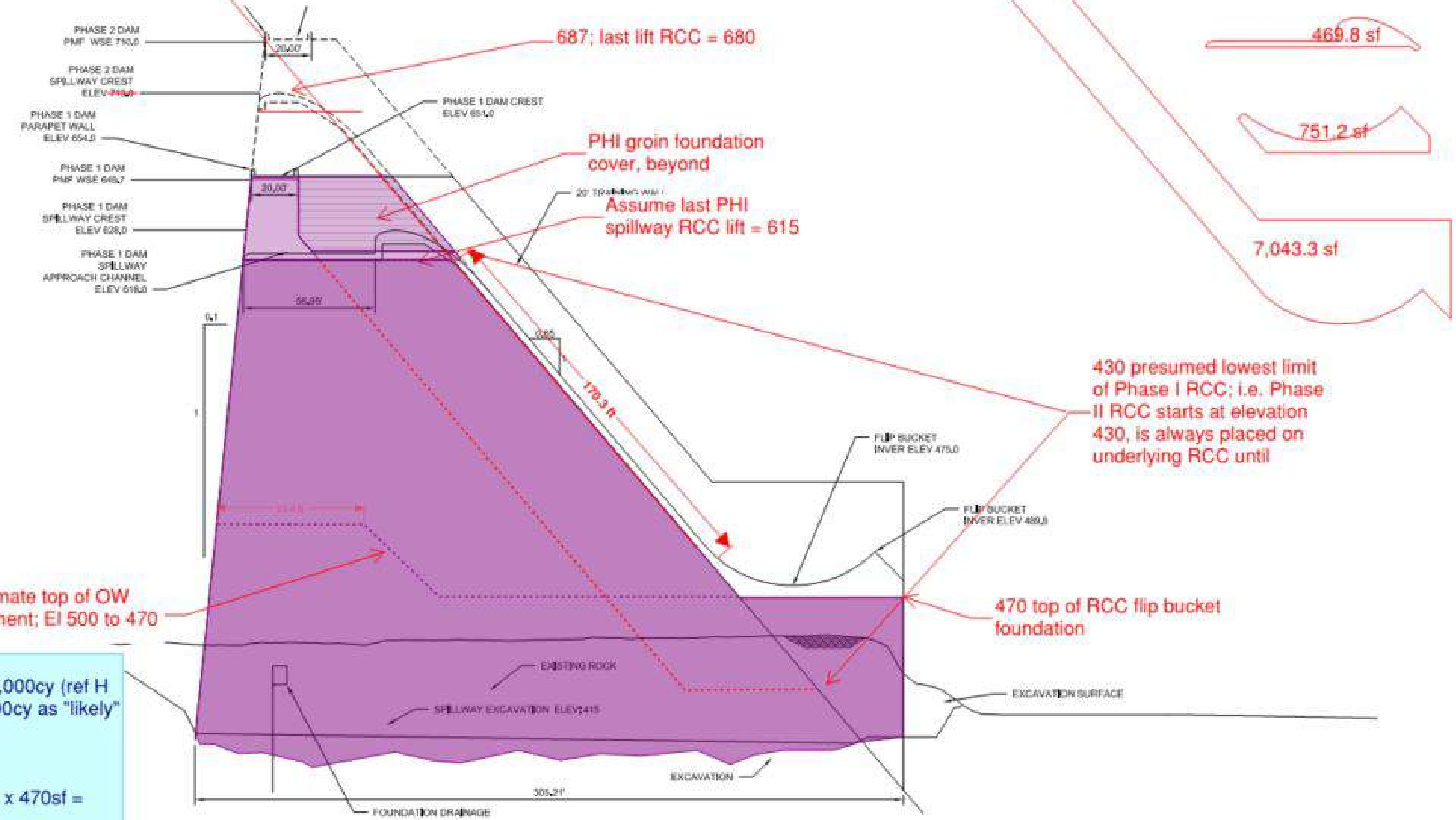
Note: Hybrid profile and sections illustrated on updated foundation profile and FRFA profile and section views

HDR

FRFA DAM
DAM EXCAVATION PROFILE, TYPICAL SECTIONS AND DETAILS
CHEHALIS BASIN DAM

DATE	MAY 2017
FIGURE	FRFA-S-2

Phase I - Illustration of Phase I RCC Progression
Section *View*



PHI Concrete Structure Quantities
1) Outlet encasement: 7400sf x 300' = 82kcy; 70,000cy (ref H S-6-7 QTO; with potential to optimize); use 60,000cy as "likely" case
2) Flip: 751sf x 210' = 5,800cy
3) PHI sloped face = 210' x 3' x 170' = 4,000cy
4) PHI approach, and ogee to sloped face = 210' x 470sf = 3,650cy
5) Crest: (20'x1' +(3.5' +3.5')x1') x (18+10-2+20 - 200') = 1,400cy
6) Stilling basin: 120% x (95' x 40' - 85' x 36') x 250' = 8,200cy; 8600cy ref H S-6,7; plus add 2' leveling = 1600cy
7) Intake and trashrack: 100% x (95' x 40' - 85' x 38') x 260' = 5,500cy. See H S-06-07, use 5800cy.
8) Spillway training walls: 7043sf x 2' x 2each = 1,050cy
9) Other - not otherwise identified: 4,000cy
Total all structures (without Fish Passage) = 105,900cy: use as max; 95,900cy as likely; and 80,000 cy as low range. adjusting in item 1).

arly draft hybrid section views

HDR

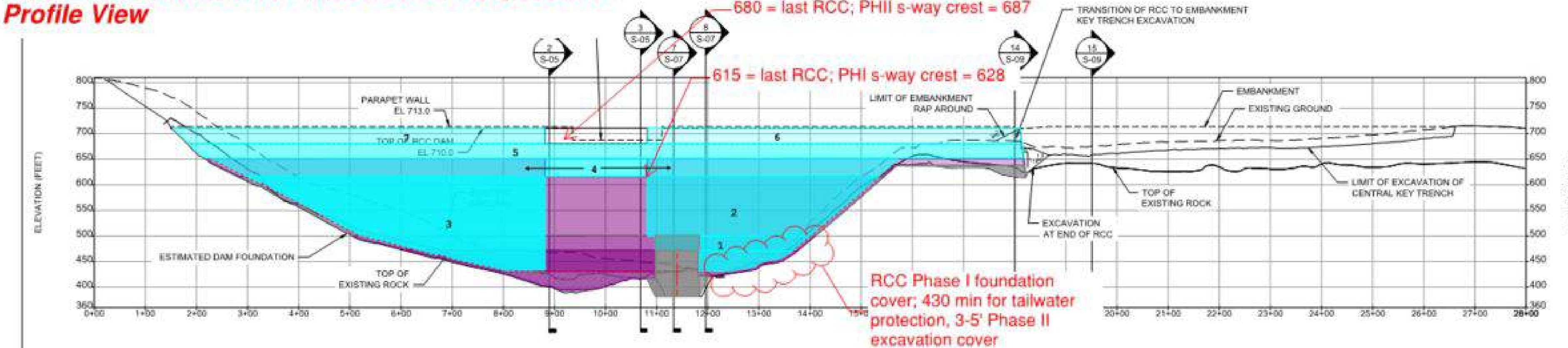
HYB DAM
SPILLWAY SECTION

CHEHALIS BASIN DAM

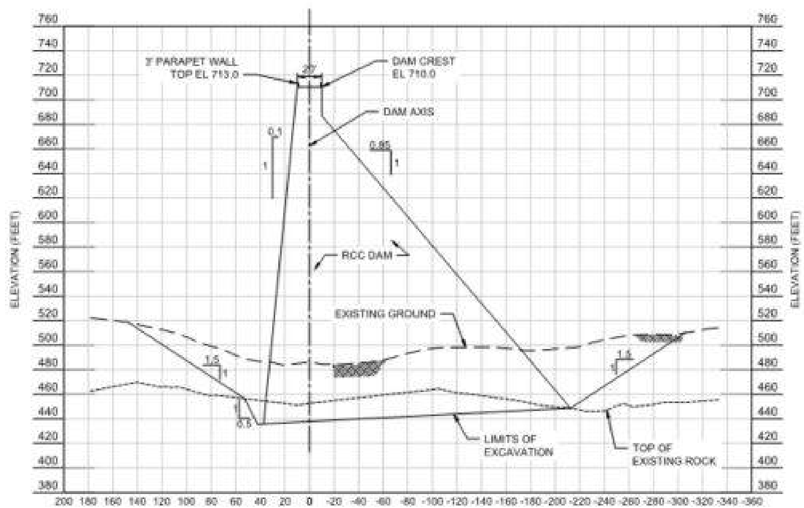
DATE
MAY 2017

FIGURE
X_HYB_Spillway_Section_Struct

Phase II - Illustration of Phase II RCC Progression
Profile View

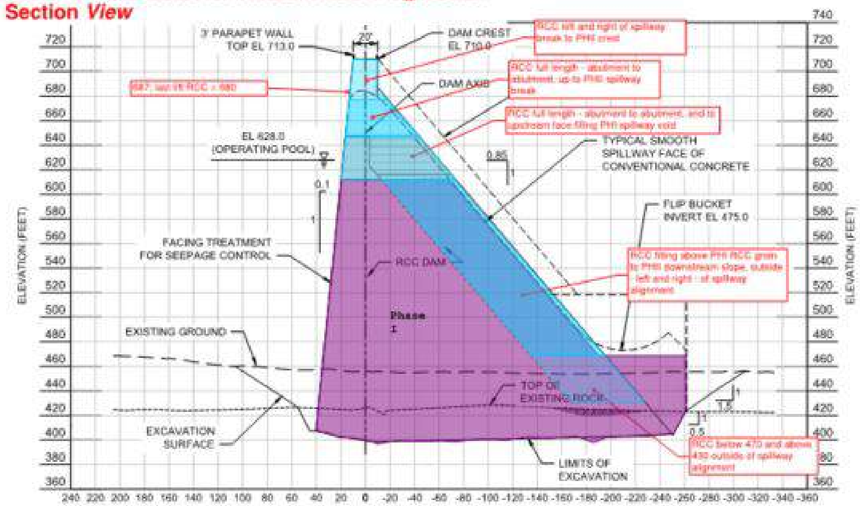


DAM EXCAVATION PROFILE
SCALE: AS NOTED
SCALE IN FEET



DAM EXCAVATION TYPICAL SECTION AT STA: 7+40
SCALE: AS NOTED
SCALE IN FEET

Phase II - Illustration of Phase II RCC Progression
Section View



DAM EXCAVATION TYPICAL SECTION AT SPILLWAY STA: 10+93
SCALE: AS NOTED
SCALE IN FEET

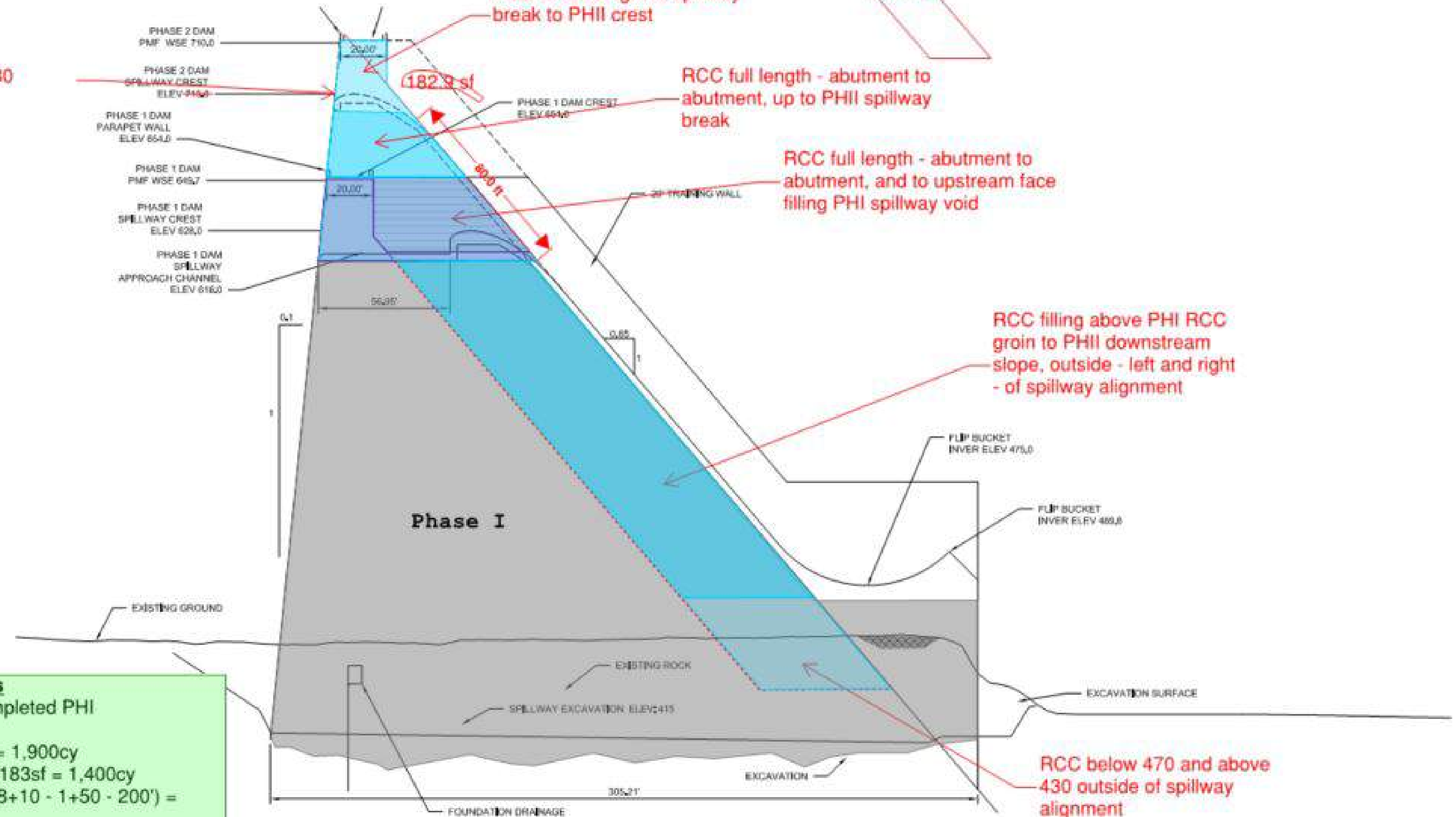
Note: Hybrid profile and sections illustrated on updated foundation profile and FRFA profile and section views

HDR

FRFA DAM
DAM EXCAVATION PROFILE, TYPICAL SECTIONS AND DETAILS
CHEHALIS BASIN DAM

DATE	MAY 2017
FIGURE	FRFA-S-2

Phase II - Illustration of Phase II RCC Progression
Section *View*



PHII Concrete Structure Quantities

1) Outlet encasement: 0 cy; fully completed PHI
2) Flip: 0 cy; fully completed PHI
3) PHII sloped face = 210' x 3' x 80' = 1,900cy
4) PHII ogee to sloped face = 210' x 183sf = 1,400cy
5) Crest: (20'x1' +(3.5' +3.5')x1') x (18+10 - 1+50 - 200') = 1,460cy
6) Stilling basin: 0 cy; fully completed PHI
7) Intake and trashrack: ~~100% x (95' x 40' - 85' x 38') x 60' = 5,500cy + 1000cy in features = 2,300cy.~~v 1650cy from H S6-7
8) Spillway training walls: 1416sf x 2' x 2each = 300cy
9) Other - not otherwise identified: 1,000cy
10) Demo Phase I - assume 1/2 crest and approach and ogee = 3650cy, totaling 4350cy

Total all structures (without Fish Passage) = 8,360cy: use as likely

Note: Hybrid sections illustrated on early draft hybrid section views

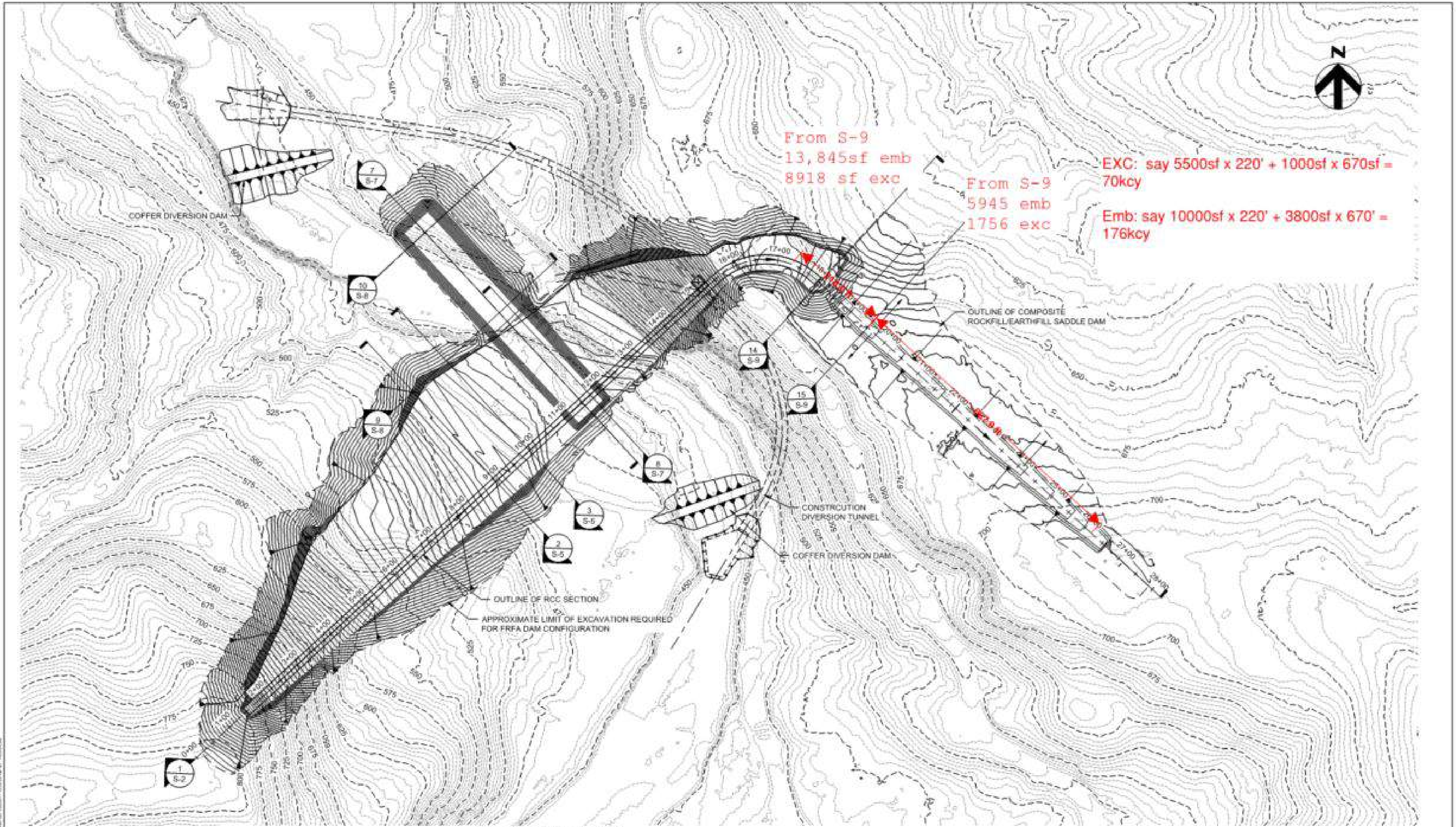
HDR

HYB DAM
SPILLWAY SECTION

CHEHALIS BASIN DAM

DATE
MAY 2017

FIGURE
X_HYB_Spillway_Section_Struct



DAM EXCAVATION PLAN

SCALE: AS NOTED

0 50 100 200

SCALE IN FEET

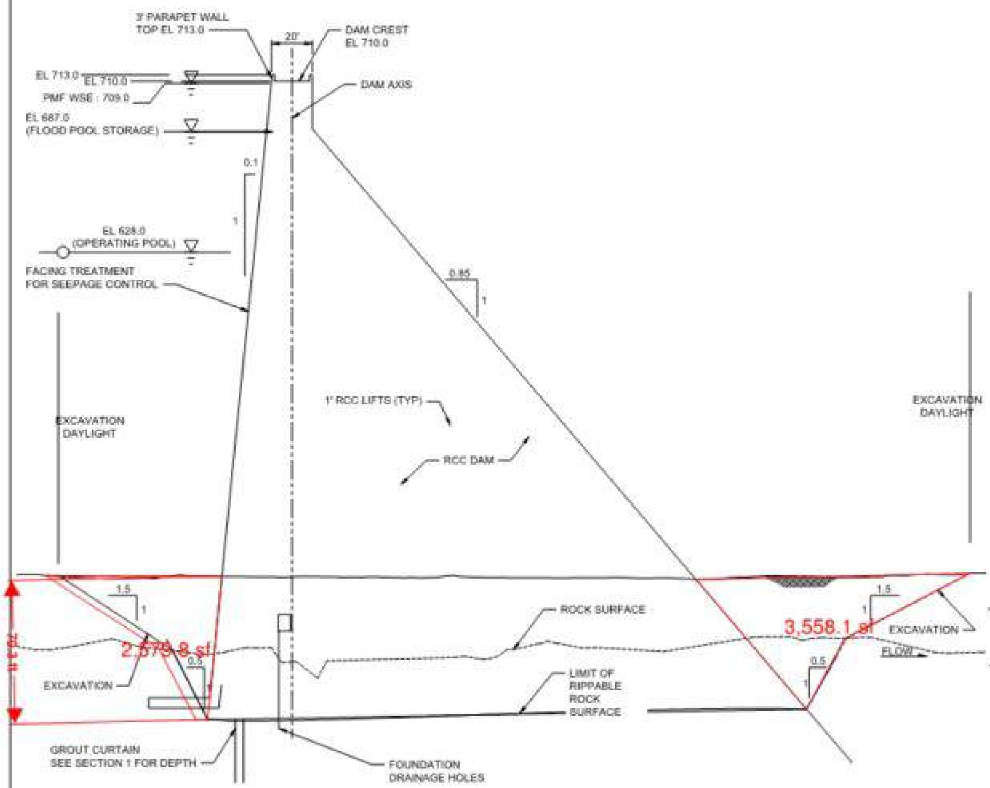
HDR

FRFA DAM
DAM EXCAVATION AND FOUNDATION TREATMENT PLAN

CHEHALIS BASIN DAM

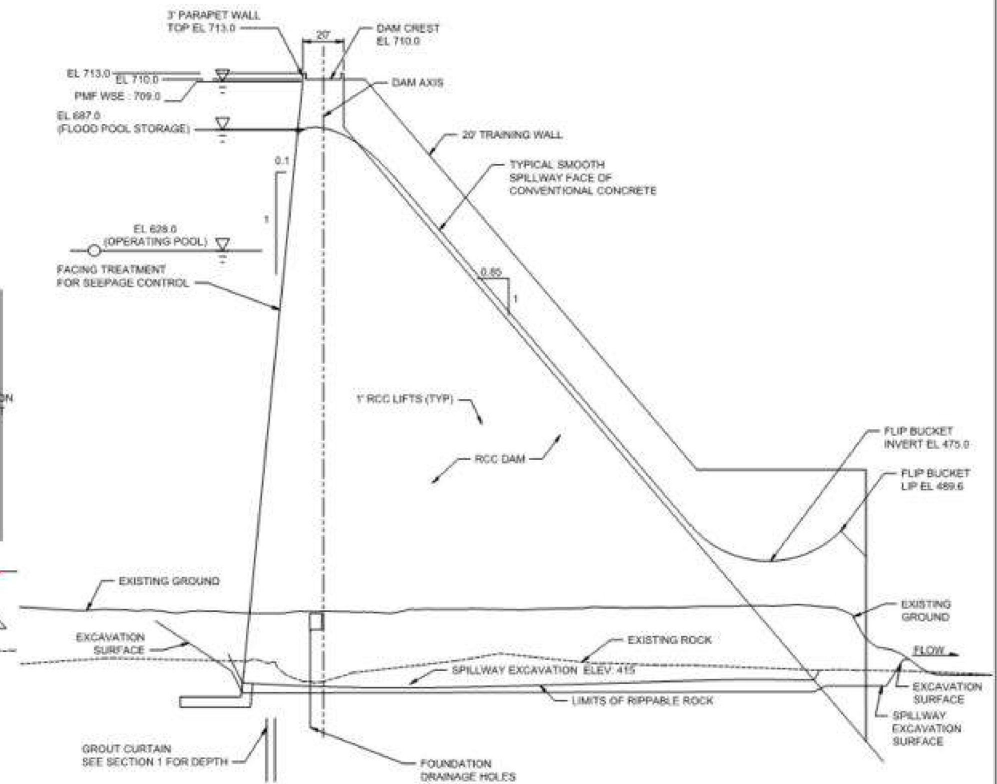
DATE: MAY 2017

FIGURE: FRFA-S-1



EL 413±

SECTION 2 S-03
SCALE: AS NOTED
0 15 30 60
SCALE IN FEET



SECTION 3 S-03
SCALE: AS NOTED
0 15 30 60
SCALE IN FEET

Backfill - PHI
2580sf x (990'+330'-150')
upstream = 112kcy; 350sf x
(978'+341' - 150') = 15kcy of
5' cover over PHI RCC

PHII - exc 15k PHI backfill + wing.
PHII Backfill -
2580sf x 150' = 14kcy upstream; + 2580sf x
978'+341') = 126kcy downstream full groin
backfill after 5' cover over is removed

FRO Backfill
(2574sf x (997+331) + 3558sf x (978+541))/27 = 327kcy
say 80% for cross section reduction from section area =
260k cy
FRFA Backfill - say add 2*2574*125' = +24,000cy; totaling
284k cy

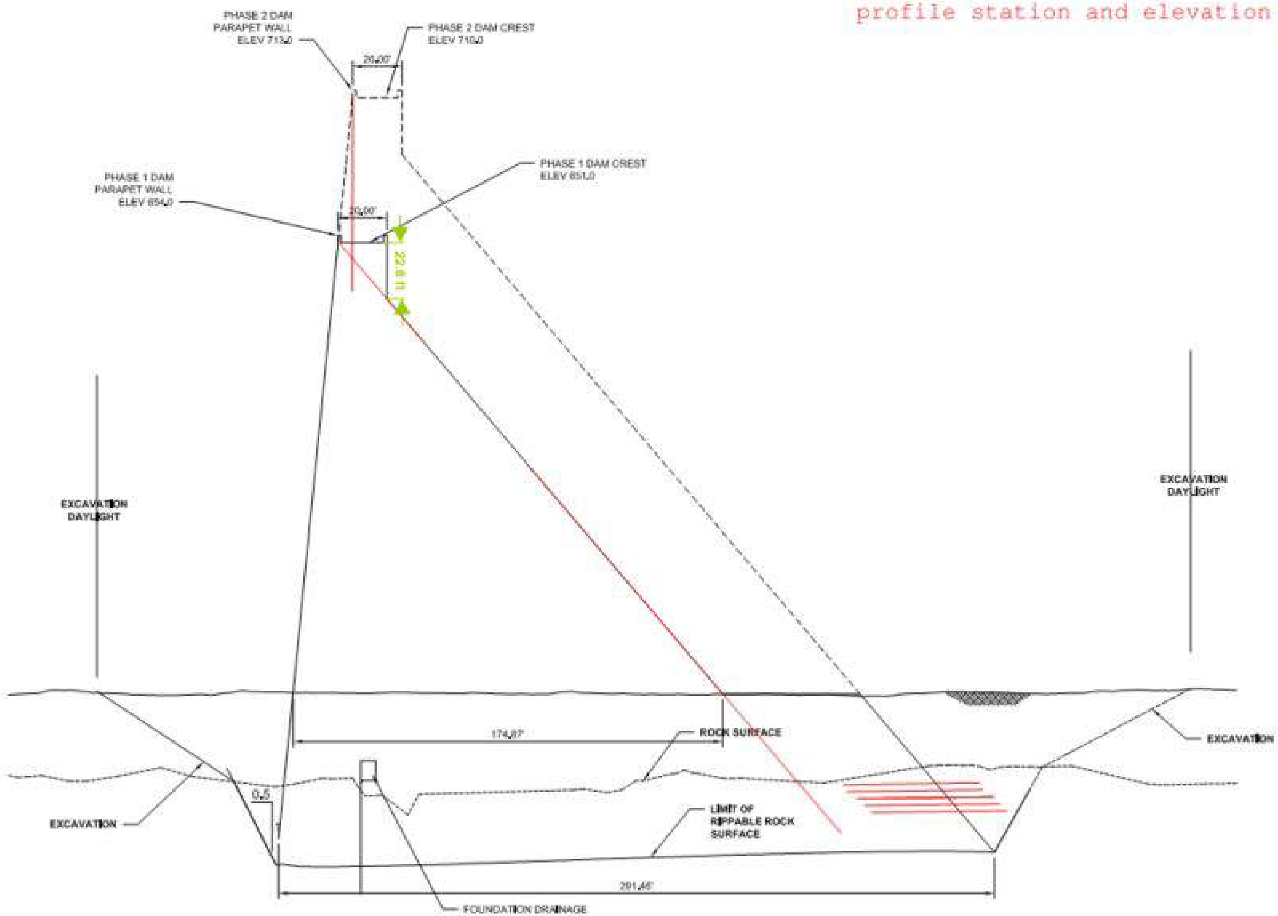
FRFA DAM
SPILLWAY AND TYPICAL DAM
SECTIONS 2 & 3

CHEHALIS BASIN DAM

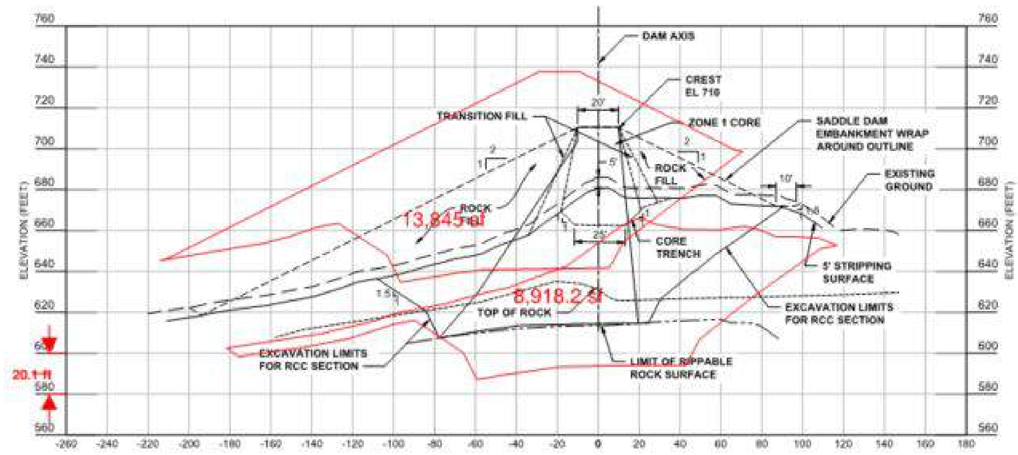
DATE MAY 2017

FIGURE FRFA-S-5

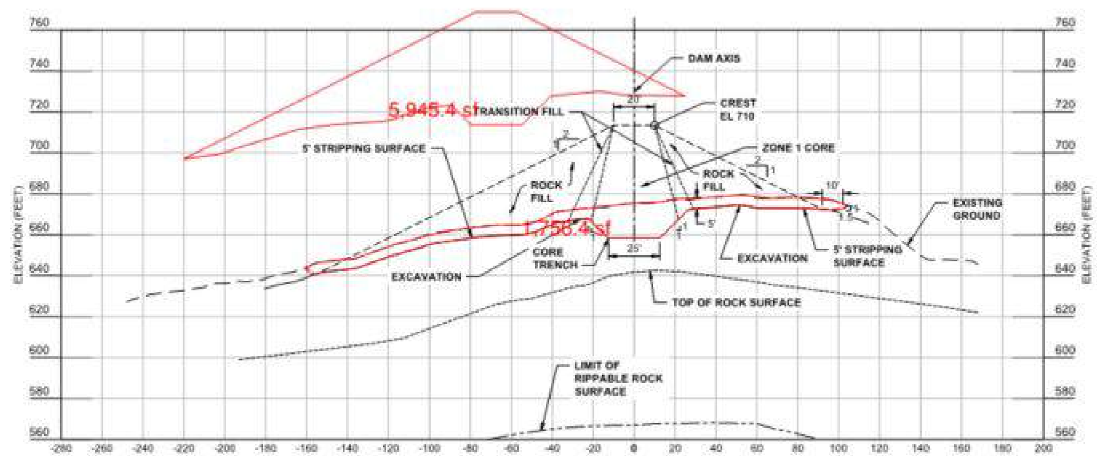
From 20-May Sections and initial Hybrid
profile station and elevation determination



HDR	HYB DAM NON-OVERFLOW DAM SECTION CHEHALIS BASIN DAM	DATE MAY 2017 FIGURE X_HYB_Sp[illegible]way_Section_Struct



SECTION
SCALE: AS NOTED
14
S-01



SECTION
SCALE: AS NOTED
15
S-01

0 15 30 60
SCALE IN FEET

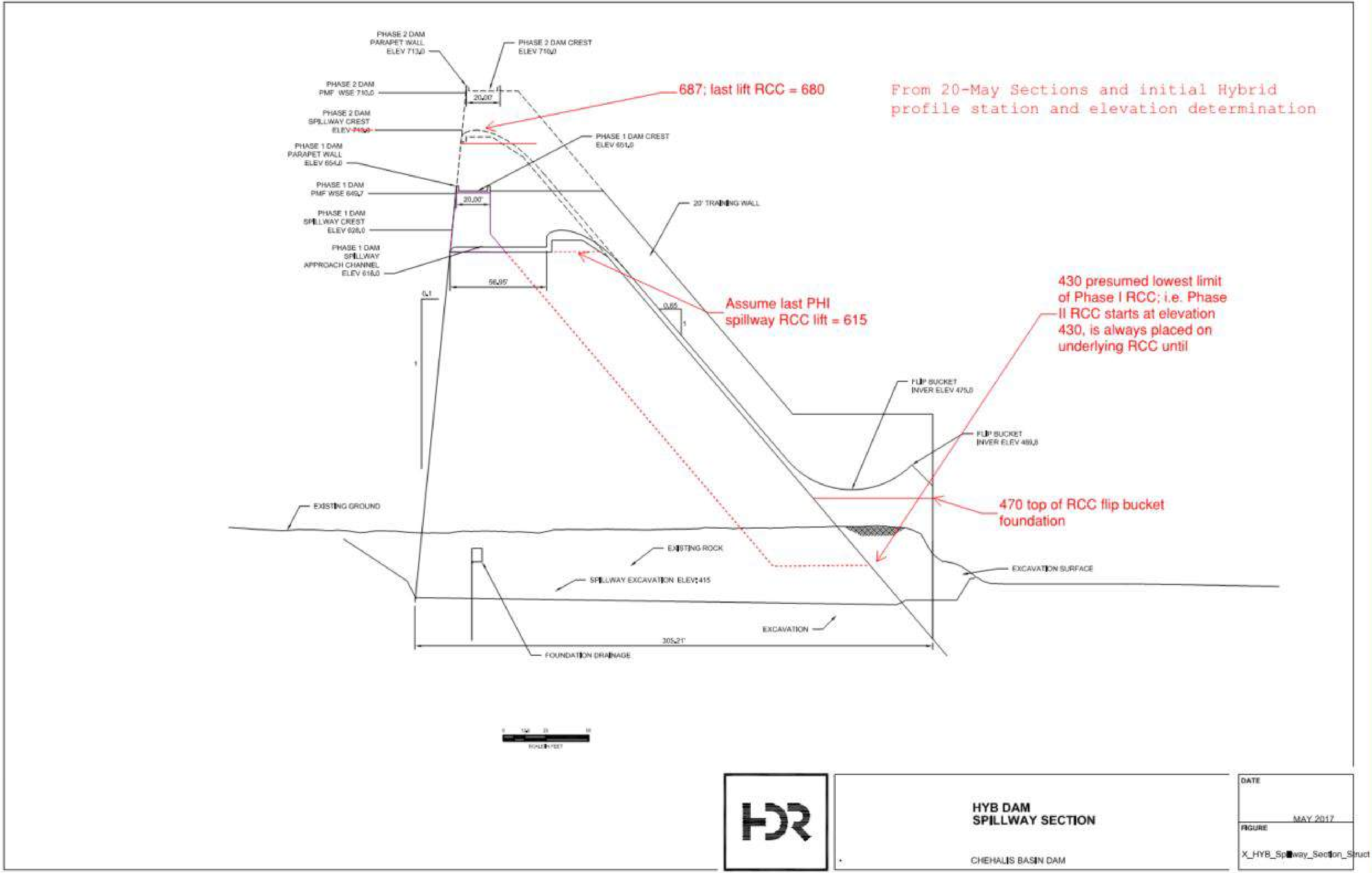
HDR

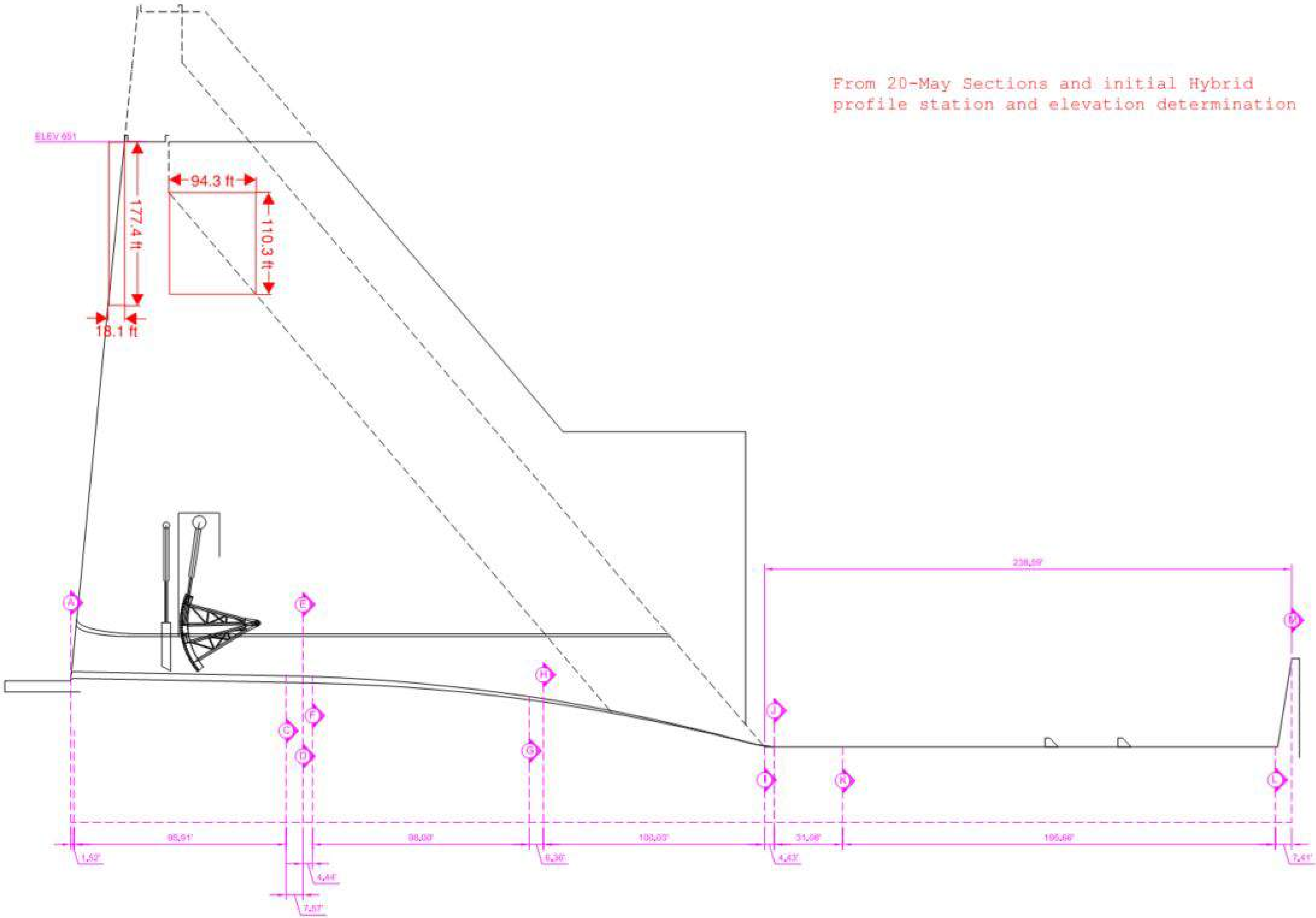
FRFA DAM
RIGHT ABUTMENT
EMBANKMENT DAM TYPICAL SECTIONS

CHEHALIS BASIN DAM

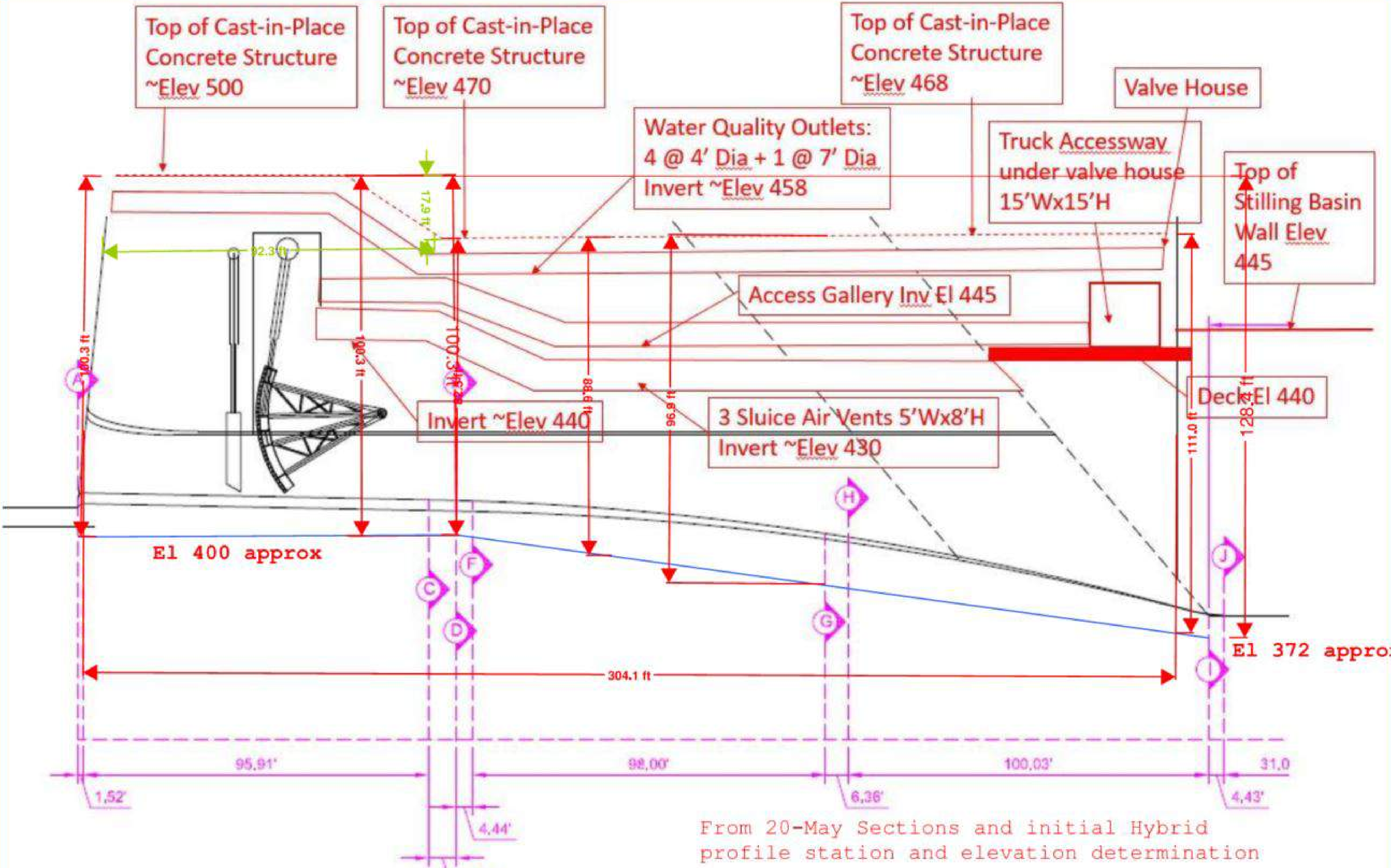
DATE
MAY 2017

FIGURE
FRFA-S-9

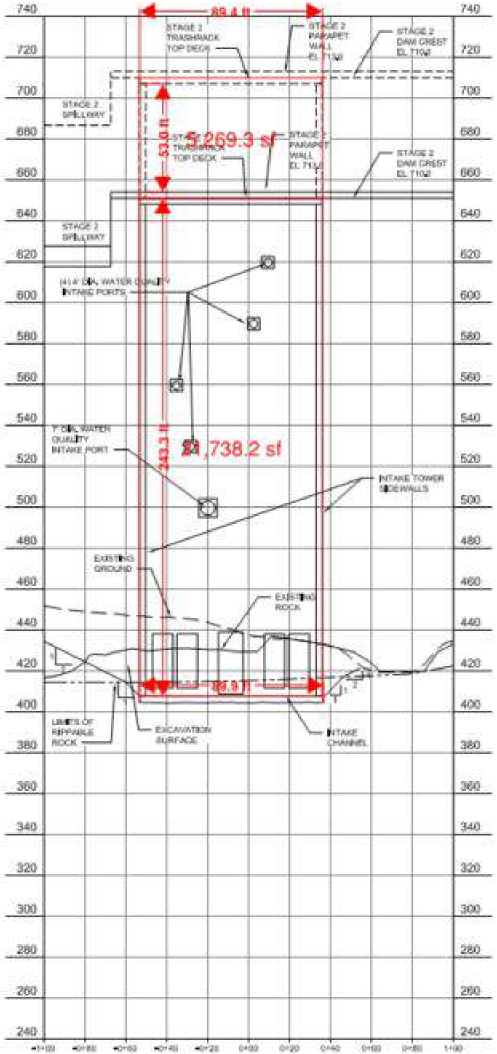

PHASE 2 DAM PARAPET WALL ELEV 713.0
PHASE 2 DAM CREST ELEV 710.0
PHASE 2 DAM PMF WSE 710.0
20.00'
687; last lift RCC = 680
From 20-May Sections and initial Hybrid profile station and elevation determination
PHASE 2 DAM SPILLWAY CREST
PHASE 1 DAM CREST ELEV 651.0
PHASE 1 DAM PARAPET WALL ELEV 654.0
PHASE 1 DAM PMF WSE 649.7
20.00'
20' TRAINING WALL
PHASE 1 DAM SPILLWAY CREST ELEV 628.0
PHASE 1 DAM SPILLWAY APPROACH CHANNEL ELEV 618.0
56.95'
Assume last PHI spillway RCC lift = 615
430 presumed lowest limit of Phase I RCC; i.e. Phase II RCC starts at elevation 430, is always placed on underlying RCC until
0.85
FLIP BUCKET INVER ELEV 475.0
FLIP BUCKET INVER ELEV 489.8
470 top of RCC flip bucket foundation
EXISTING GROUND
EXISTING ROCK
SPILLWAY EXCAVATION ELEV. 415
EXCAVATION SURFACE
EXCAVATION
305.21'
FOUNDATION DRAINAGE
SCALE IN FEET
HDR
HYB DAM
SPILLWAY SECTION
CHEHALIS BASIN DAM
DATE
MAY 2017
FIGURE
X_HYB_Spillway_Section_Struct



From 20-May Sections and initial Hybrid profile station and elevation determination

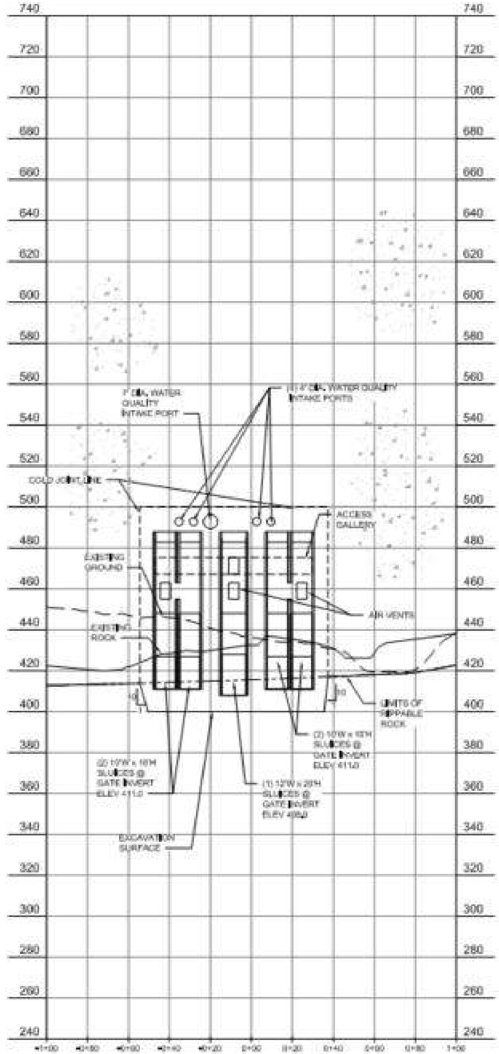


Top of Cast-in-Place Concrete Structure ~Elev 500
Top of Cast-in-Place Concrete Structure ~Elev 470
Top of Cast-in-Place Concrete Structure ~Elev 468
Valve House
Water Quality Outlets: 4 @ 4' Dia + 1 @ 7' Dia Invert ~Elev 458
Truck Accessway under valve house 15'Wx15'H
Top of Stilling Basin Wall Elev 445
Access Gallery Inv El 445
Deck El 440
Invert ~Elev 440
3 Sluice Air Vents 5'Wx8'H Invert ~Elev 430
17.9 ft
92.3 ft
100.3 ft
100.3 ft
100.3 ft
88.6 ft
96.9 ft
111.0 ft
128.1 ft
304.1 ft
El 400 approx
El 372 approx
95.91'
98.00'
100.03'
31.0
1.52'
6.36'
4.43'
4.44'
7.57'
From 20-May Sections and initial Hybrid profile station and elevation determination



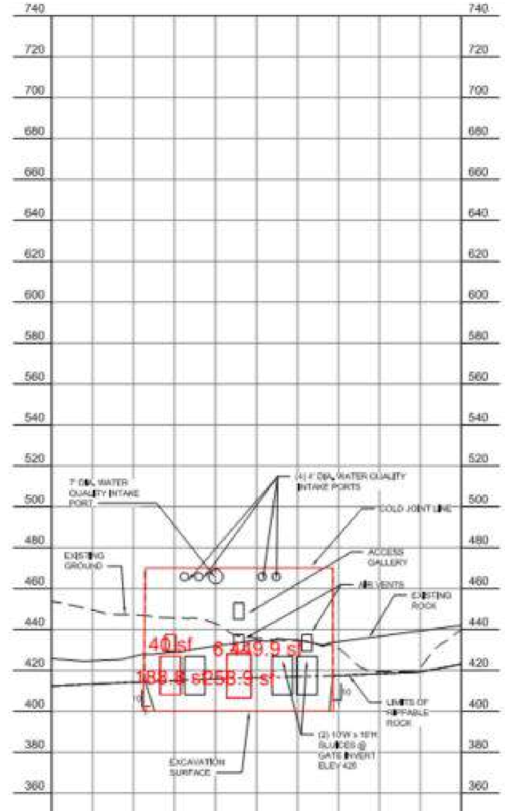
SECTION

SCALE: 1" = 30'



SECTION

SCALE: 1" = 30'



Encasement Q - ish:
conc area = 6450 - 4(189)
-259-38-4(12.5) = 5346sf; x 300' = 59,400cy;
+75' x 90' x 30' at upstream 470-500 elev = 7500cy;
66,900cy less 10% for other blockouts = 60,000cy; plus
d/s dropping wedge @ 90x25*200/2 = 8,000cy;
say total = 68,000cy

SECTION

SCALE: 1" = 30'

HDR

HYBRID DAM
INTAKE TOWER
SECTIONS 4, 5, & 6 & DETAILS

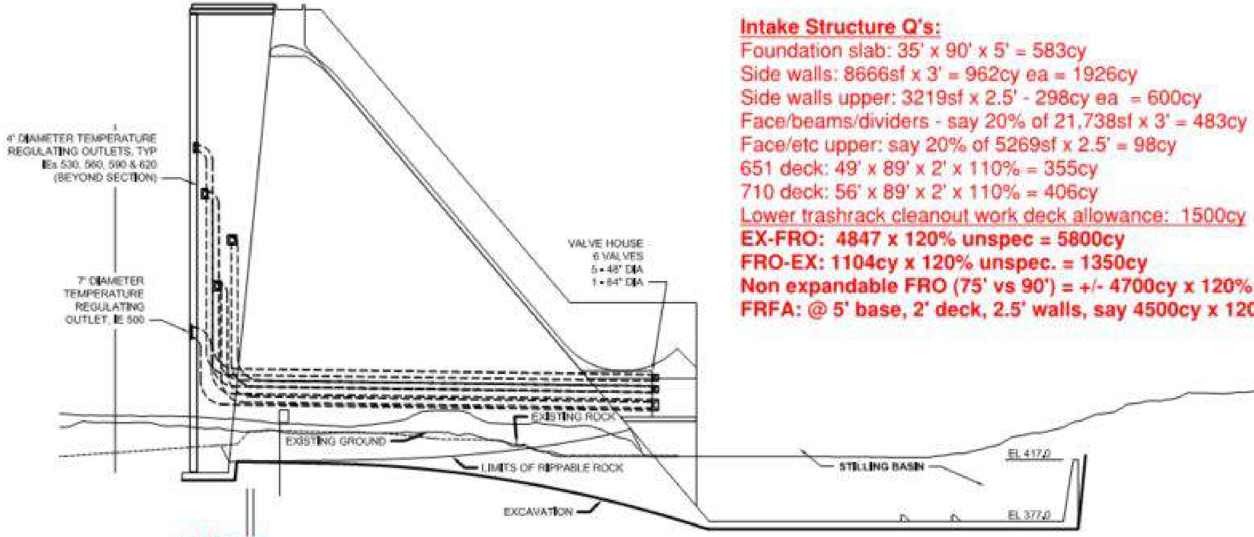
CHEHALIS BASIN DAM

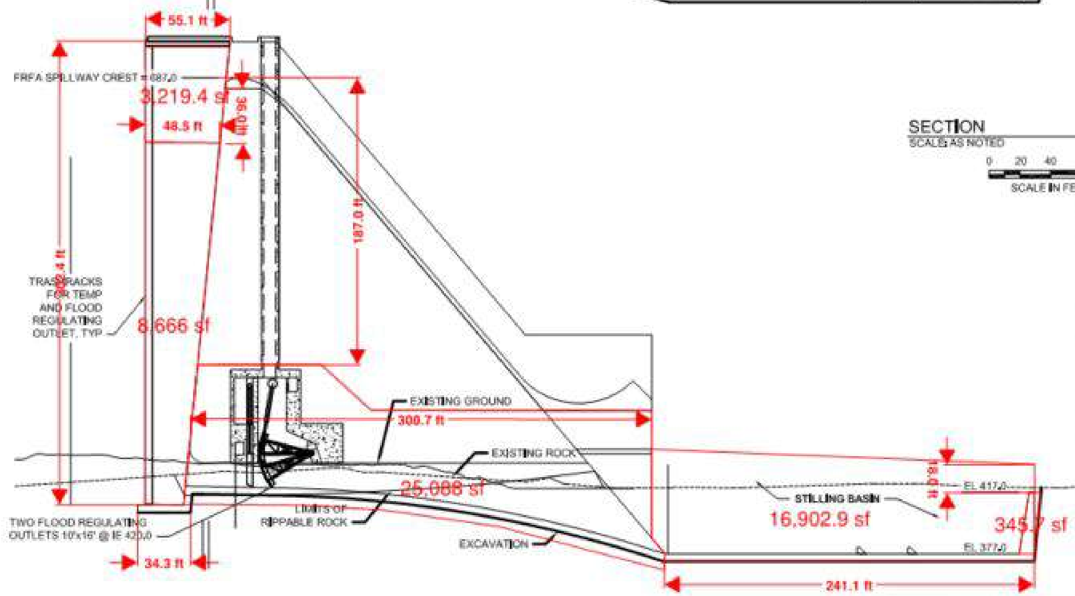
DATE: June 2017

FIGURE: HYBRID-S-6

Intake Structure Q's:

Foundation slab: 35' x 90' x 5' = 583cy
Side walls: 8666sf x 3' = 962cy ea = 1926cy
Side walls upper: 3219sf x 2.5' - 298cy ea = 600cy
Face/beams/dividers - say 20% of 21,738sf x 3' = 483cy
Face/etc upper: say 20% of 5269sf x 2.5' = 98cy
651 deck: 49' x 89' x 2' x 110% = 355cy
710 deck: 56' x 89' x 2' x 110% = 406cy
Lower trashrack cleanout work deck allowance: 1500cy
EX-FRO: 4847 x 120% unspec = 5800cy
FRO-EX: 1104cy x 120% unspec. = 1350cy
Non expandable FRO (75' vs 90') = +/- 4700cy x 120% unspec. = 5650cy
FRFA: @ 5' base, 2' deck, 2.5' walls, say 4500cy x 120% unspec = 5400cy





SECTION
SCALE AS NOTED
7 / S-08
0 20 40 80
SCALE IN FEET

Stilling Basin Q's (say same for all 4 alts):

Foundation slab: 241' x 90' x 3.5' = 2811cy
Side walls: 16,903sfsf x 2.5' = 962cy ea = 3130cy
Sill - 346sf x 90' = 1153cy
Dissipation blocks & fish passage integ. = say 1500cy
Total Stilling Basin: 8600 cy
Presume stilling basin leveling at 2' = 1600cy

Encasement Q's - Version 2:

Expandable: 25088sf x 90' x 85% full = 71,000cy
compares to 68K from S-6; Use 70K cy

FRO - assume 75/90 reduction o3 83% = 58000cy
FRFA - assume same as FRO = 58000cy

HDR	**HYBRID DAM** **FLOOD CONTROL AND FISH PASSAGE** **SLUICES LONGITUDINAL SECTIONS 7 & 8** CHEHALIS BASIN DAM	DATE: June 2017 FIGURE: HYBRID-S-7

Excavation surfaces - profile station and elevation capture for illustration support only