Chehalis River Basin Flood Authority

Chehalis River Flood Water Storage Facilities
Appendix B:
Phase IIB Engineering Feasibility Studies Report
Draft Submitted to Chehalis River Basin Flood Authority for Review

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Executive Summary

The Chehalis River Basin Flood Authority (Flood Authority) has been conducting a phased evaluation of the feasibility of reducing flooding of the Chehalis River with flood retention structures, building off an initial high level conceptual study commissioned by the Lewis County Public Utility District (Phase I).

During Phase I of the studies, locations for two potential flood storage structures and reservoirs were identified and studied. The first site is located on the Upper Chehalis River approximately two miles upstream from Pe Ell, at approximately River Mile (RM) 106. This is the Upper Chehalis site. The second site is located on the South Fork of the Chehalis River upstream of Boistfort at approximately RM 19. This is the South Fork site. The Phase I study assumed flood storage of approximately 80,000 acre-feet (ac-ft) on the Upper Chehalis River and 20,000 ac-ft on the South Fork Chehalis River. Northwest Hydraulic Consultants (nhc) modeled the assumed amount of storage for flood water retention in the hydraulic model of the Chehalis Basin. The Phase I analysis concluded that significant flood reduction is feasible by constructing flood storage projects at these two sites. Very preliminary engineering costs were also generated in Phase I.

In Phase IIA of the feasibility studies, Shannon & Wilson, Inc. conducted a reconnaissance level geologic/geotechnical study. They concluded that no geotechnical impediments exist to the development of flood storage facilities at the identified sites. The physical characteristics of the site topography are suitable for an earthfill structure in each location. Based on Shannon & Wilson's investigations, certain adjustments were made to the initial conceptual designs for the structures in this Phase IIB engineering study.

Within the Phase IIB scope of work, two options were developed for each of the identified sites: one a flood storage only structure, and the other a multi-purpose facility that could also release water for summer flow augmentation and generate hydroelectric power. It was assumed that fish passage would be required at either type of structure, but fishery information being gathered under separate contract will be needed before the appropriate fish passage method for each site can be determined. This would be part of a future scope of work if the Flood Authority chooses to move forward with developing these projects.

Flood Storage Only Projects

The flood storage only projects each would be an earthfill structure designed with a spillway and outlet works. Spillways safely pass surplus flood water that cannot be contained by the structure. Outlet works regulate or release water impounded by the structure.

For the Upper Chehalis structure, an elevation of 650.0 will provide approximately 80,000 ac-ft of storage. When full, the structure would create a reservoir with a surface area of 1,000 acres. The structure crest is at elevation (El.) 670.0 (Mean Sea Level, MSL) allowing for 20 feet of freeboard. The height of the structure is 238 ft.

The South Fork structure crest would be at elevation 590.0 allowing 30 ft for freeboard. At the spillway elevation (El. 560.0), the reservoir would provide approximately 20,000 ac-ft of storage with a surface area of 390 acres. The South Fork Flood Storage Structure would have a maximum height of approximately 170 ft.

Multi-Purpose Projects

The multi-purpose projects each would include a spillway, intake tower, outlet works and powerhouse. For the Upper Chehalis multi-purpose project, the maximum head selected was 195 ft, which translates to an operating water surface elevation of El. 635.0. At this elevation, the storage volume would be approximately 65,000 ac-ft. With the 80,000 ac-ft required for flood storage, the maximum reservoir capacity would be 145,000 ac-ft, with a spillway crest elevation of El. 700.0. With 20 ft of freeboard the crest elevation is 720.0. The Upper Chehalis structure would have a maximum structural height of approximately 288 ft. with two turbines, one rated at 8.3 MW and one at 1.7 MW, for a total capacity of 10 MW. Annual average energy production was calculated at 39,952 MWh.

For the South Fork multi-purpose project, the maximum head selected was 130 ft, which translates to an operating water surface elevation of El. 540.0. At this elevation, the storage volume would be approximately 13,500 ac-ft. With the 20,000 ac-ft required for flood storage, the maximum reservoir capacity would be 33,500 ac-ft, with a spillway crest at El. 620.0. With 30 ft of freeboard, the crest elevation is 640.0. The South Fork structure would have a maximum structural height of approximately 200 ft. with two turbines, one rated at 1.7 MW and one at 0.3 MW, for a total capacity of 2 MW. Annual average energy production was calculated at 7,030 MWh.

Cost Estimates

The following cost estimates were developed based on the updated engineering analysis and design of the two facilities, and the costs include 30% contingencies given the level of design and need for additional work to develop fish passage alternatives.

Table ES-1
Projected Costs

	Upper Chehalis Site	South Fork Chehalis Site
Flood Storage Only Project	$165,230,000	$93,060,000
Multi-Purpose Project	$245,060,000	$148,540,000

Next Steps

Next steps for development of the Chehalis River flood storage projects would be detailed structure design studies. These would require additional and more detailed geotechnical studies, including core drilling. Results of the fisheries studies currently underway are necessary for further decision making for fish passage design concepts to be developed for the structures. Additional work anticipated to be required includes probable maximum flood studies, possible hydraulic modeling of fish passage designs, and further refinement of cost estimates.

Introduction

The Chehalis River Basin Flood Authority (Flood Authority) has been conducting a phased evaluation regarding the feasibility of reducing flooding of the Chehalis River with flood retention structures. This phase of the analysis builds off of an initial high-level conceptual study commissioned by the Lewis County Public Utility District (Phase I).

During Phase I work, locations for two potential flood storage reservoirs were identified and studied. The first site is located on the Upper Chehalis River approximately two miles upstream from Pe Ell, at approximately River Mile (RM) 106. This is referred to as the Upper Chehalis site. The second site is located on the South Fork of the Chehalis River upstream of Boistfort at approximately RM 19 (referred to as South Fork site).

The Phase I study, a high-level conceptual study, determined that flood reduction could be feasible by constructing flood storage projects at these two sites. This would include 80,000 acre-feet (ac-ft) on the Upper Chehalis River and 20,000 ac-ft on the South Fork Chehalis River. Northwest Hydraulic Consultants (nhc) analyzed the impact of the proposed storage using hydraulic modeling of the Chehalis River under 100 year flood conditions and using the 2007 flood event. They concluded that the storage would significantly reduce the flooding downstream.

In Phase IIA, Shannon & Wilson, Inc. prepared a geologic reconnaissance study and a reconnaissance level geotechnical report. Their work describes the geologic conditions at the two structure sites that affect design and construction. Although design and construction challenges exist, and further studies are needed, Shannon & Wilson "did not identify any fatal flaws that would preclude construction of the proposed structures at either the Chehalis River or South Fork sites."[1] Washington Department of Ecology reviewed Shannon & Wilson's work, and concurred in their findings in a letter dated December 1, 2009[2].

This report describes Phase IIB work by EES Consulting (EESC) in further investigating the feasibility of storage reservoirs to address flooding of the Chehalis River. While the primary purpose of the structures is to manage flooding, the structures could also be designed to augment low summer flows for fish and provide hydroelectric power generation. The work performed by EESC under the Phase IIB scope of work included study of a "run-of-the-river" flood storage only structure at both sites as well as a multi-purpose option that could provide flow augmentation during summer low flows and generate hydroelectric power. The work scope included refining reservoir storage volume requirements, preparing conceptual drawings, coordinating with geotechnical engineers from Shannon & Wilson, developing reservoir storage curves, studying project operations and estimating construction costs. This work draws upon the conceptual work conducted in Phase I, but added more detail and information to the design and cost estimation. The results of Phase IIB engineering study have been compiled and are presented in this report.

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[1] Shannon & Wilson. October 28, 2009. *Reconnaissance-Level Geotechnical Report Proposed Chehalis River and South Fork Structure Sites*. Page ii. Seattle, WA.

[2] Johnson, Douglas L. December 1, 2009. *Dam Safety review comments on Shannon & Wilson's geotechnical reports for the proposed Chehalis River and South Fork Dams*. Department of Ecology. Olympia, WA.

Structure Locations and Characteristics

The locations and types of the structures were based on topographic considerations. Lewis County provided digital mapping with 2 ft contour intervals. This mapping was studied to choose sites as far downstream as practical while allowing for sufficient abutment height for water storage.

Based on site geology information obtained in the Phase IIA geotechnical study,[3] the Upper Chehalis structure site was revised slightly from the original location studied during the Phase I work. In the Phase IIB conceptual design, the structure axis was rotated and moved approximately 1,500 ft downstream. This resulted in a slightly shorter crest length and a more desirable alignment for a tunnel through the left abutment for water diversion during construction. Vicinity and project location maps for the Upper Chehalis project are in Appendix B.

The South Fork structure is in approximately the same location as identified in Phase I, but was rotated slightly in Phase IIB for a more desirable alignment. Vicinity and project location maps for the South Fork project are presented in Appendix C.

Shannon & Wilson suggested four types of structures, three of which are earth or rock-filled. Design and construction of earthfill structures is well understood. In addition, the physical characteristics of the site topography (low rolling hills) are also suitable for an earthfill structure in each location. Shannon & Wilson reviewed but concluded that concrete structures would be neither practical nor economical given the site conditions. The appropriate type of earthfill structure is discussed in Shannon & Wilson's geotechnical report.[4]

The structures would each be designed with a spillway and outlet works. Spillways are provided to safely pass surplus flood water that cannot be contained by the structure. Outlet works regulate or release water impounded by the structure. Spillways and outlet works are common to both the flood storage only and multi-purpose structures. In addition, fish passage structures will need to be included, but additional work currently underway by Anchor QEA will be needed to better define this component.

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[3] Refer to two reports by Shannon & Wilson:
Shannon & Wilson. October 28, 2009. *Reconnaissance-Level Geotechnical Report Proposed Chehalis River and South Fork Structure Sites*. Seattle, WA.
Shannon & Wilson. October 27, 2009. *Geologic Reconnaissance Study Proposed Chehalis River and South Fork Structure Sites*. Seattle, WA.

[4] Shannon & Wilson. October 28, 2009. *Reconnaissance-Level Geotechnical Report Proposed Chehalis River and South Fork Structure Sites*. Seattle, WA.

Reservoir Storage Volume and Surface Area Curves

Based on the Phase I analysis by nhc, EESC assumed that 80,000 acre-feet (ac-ft) on the Upper Chehalis River and 20,000 ac-ft on the South Fork Chehalis River would provide the majority of flood protection available from storage.

The storage volume curve represents the relationship between water surface elevation and storage volume. The surface area curve is the relationship between water surface elevation and the reservoir surface area. These curves for the Upper Chehalis and South Fork reservoirs are shown in Figures 1 and 2. For the Upper Chehalis structure, an elevation of 650 ft will provide approximately 80,000 ac-ft of storage with a surface area of 1,000 acres. At elevation 560.0 feet, the South Fork structure would provide approximately 20,000 ac-ft of storage with a surface area of 390 acres.

Figure 1
Upper Chehalis Reservoir Surface Area and Storage Volume Curves

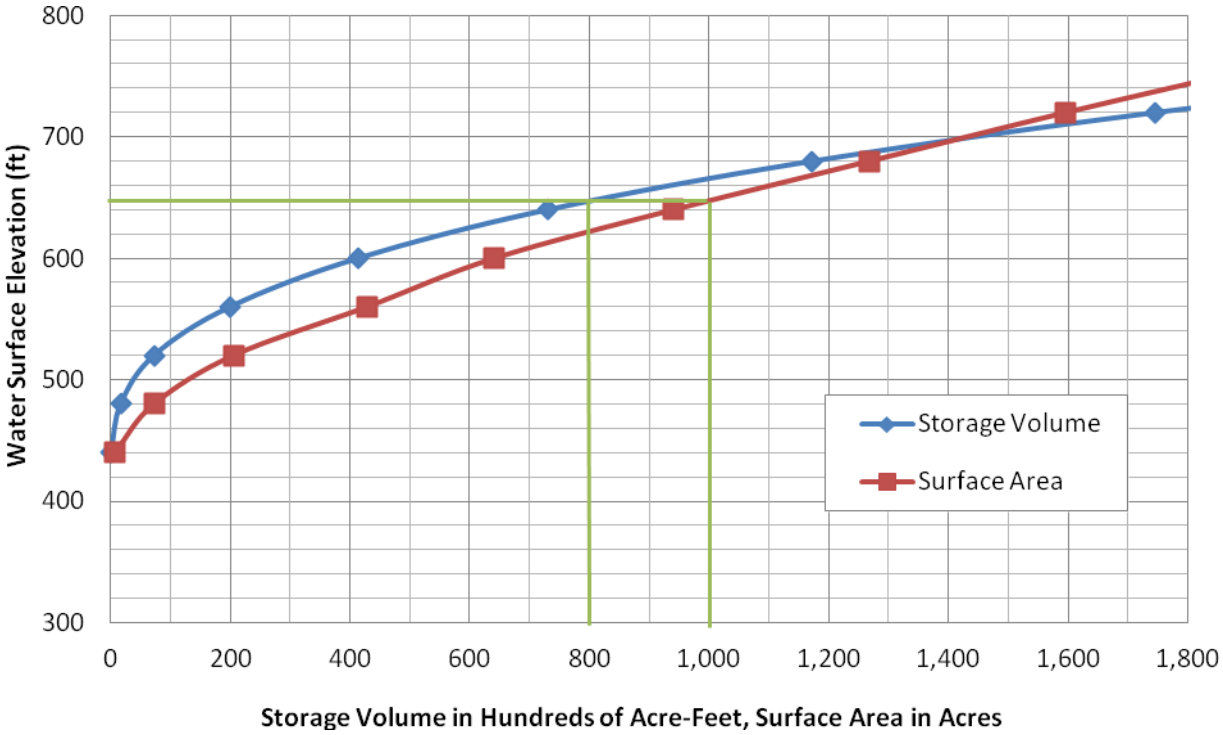
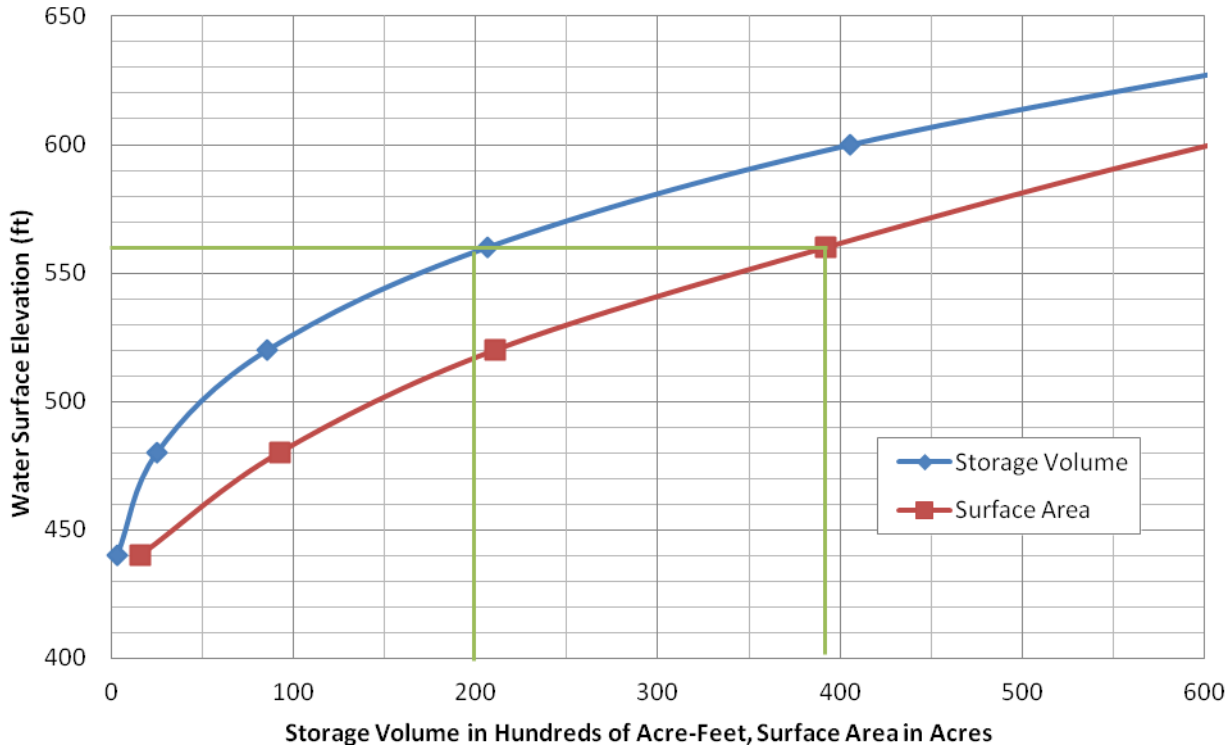


Figure 2
South Fork Chehalis Reservoir Surface Area and Storage Volume Curves



The above curves were developed using digital mapping that included contour intervals. Areas inside of the contour lines were measured and plotted. Volumes between contours were calculated by the average-end-area method using a contour interval of 40 ft.

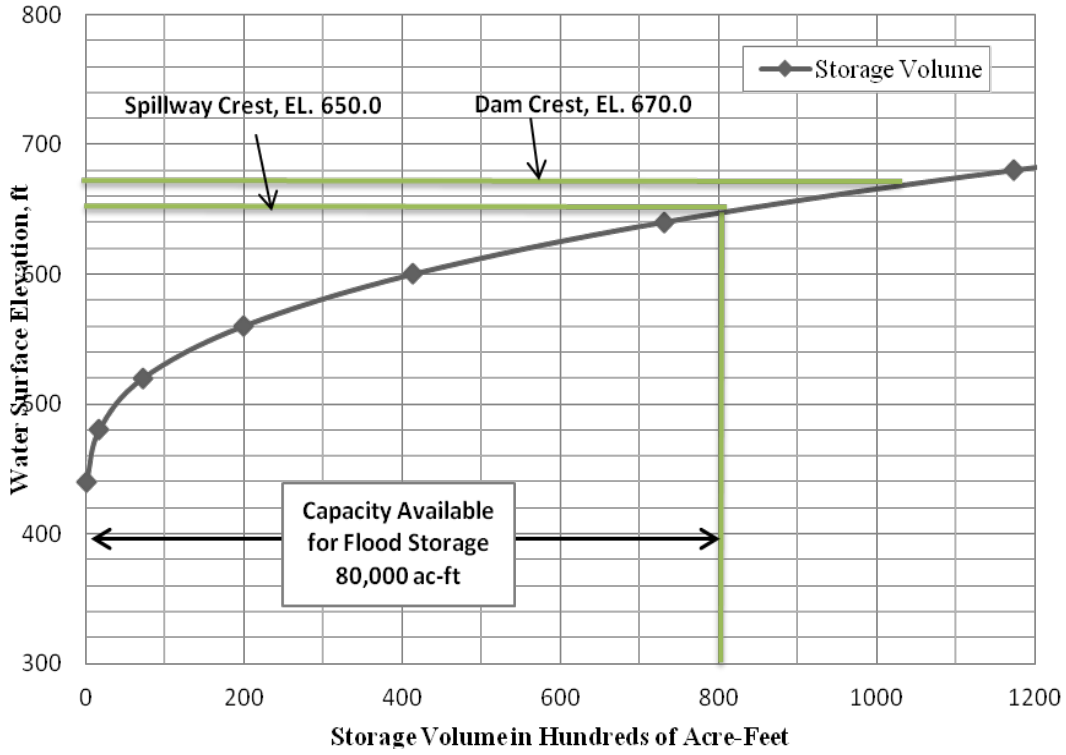
Heights of the Structures

The heights of the flood storage only structures were selected based on the amount of flood storage required, with an allowance for freeboard. Freeboard, the difference in height between the spillway level and the structure crest, was selected to ensure water does not overtop the structure. The height of each multi-purpose structure was determined by selecting the water surface elevation needed for hydroelectric energy production and then adding the storage volume required for flood storage, with an allowance for freeboard.

Flood Storage Structures

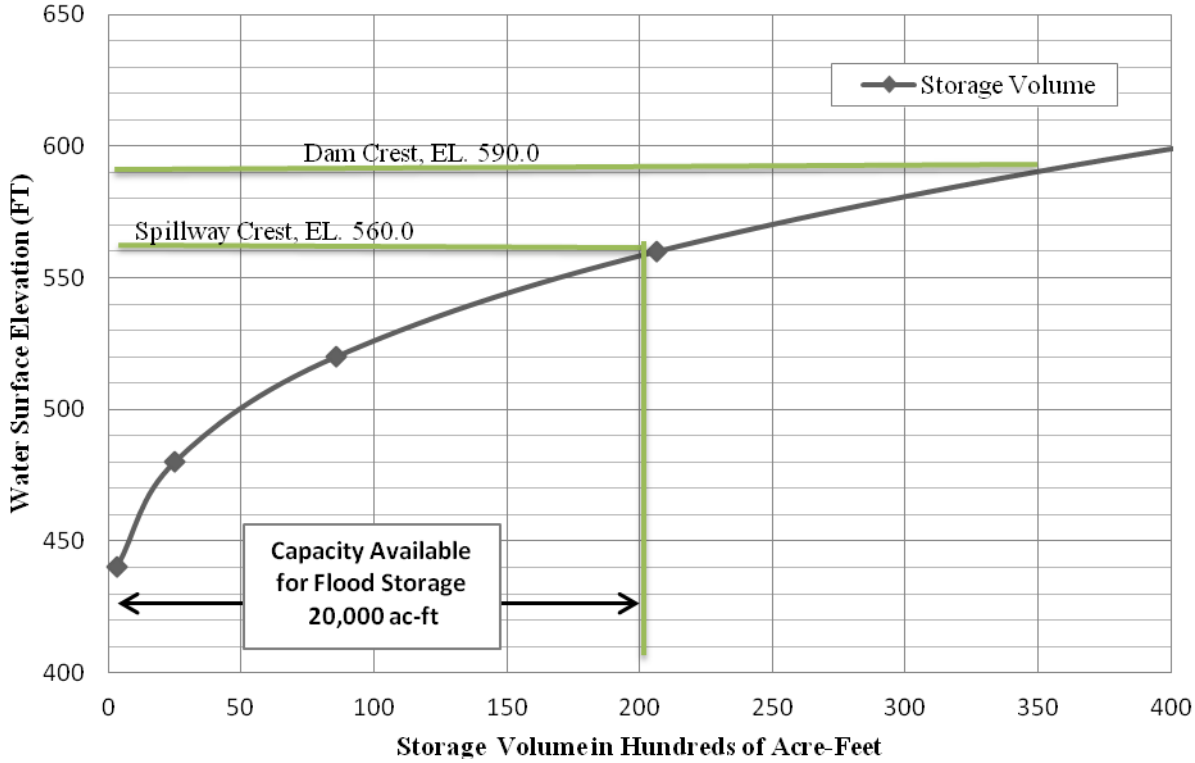
Figures 3 and 4 show how the height of each flood storage structure was determined. Total storage volume needed for the Upper Chehalis flood structure is assumed at 80,000 ac-ft. The maximum surface area of the reservoir when full of flood waters is El. 650.0. The structure crest elevation would be El. 670.0, allowing 20 ft for freeboard. See Figure 3 below. The maximum height of the Upper Chehalis Flood structure is estimated to be 238 ft, based on lowest ground elevation below the crest (lowest streambed elevation is at 432 feet).

Figure 3
Upper Chehalis Reservoir Storage Volume Curve, Flood Storage Only



The maximum storage volume needed for the South Fork flood structure is 20,000 ac-ft. When full with flood waters, the reservoir elevation is El. 560.0. See Figure 4. The structure crest would be El. 590.0 allowing 30 ft for freeboard. The South Fork Flood structure would have a maximum structural height of approximately 170 ft.

Figure 4
South Fork Reservoir Storage Volume Curve - Flood Storage Only

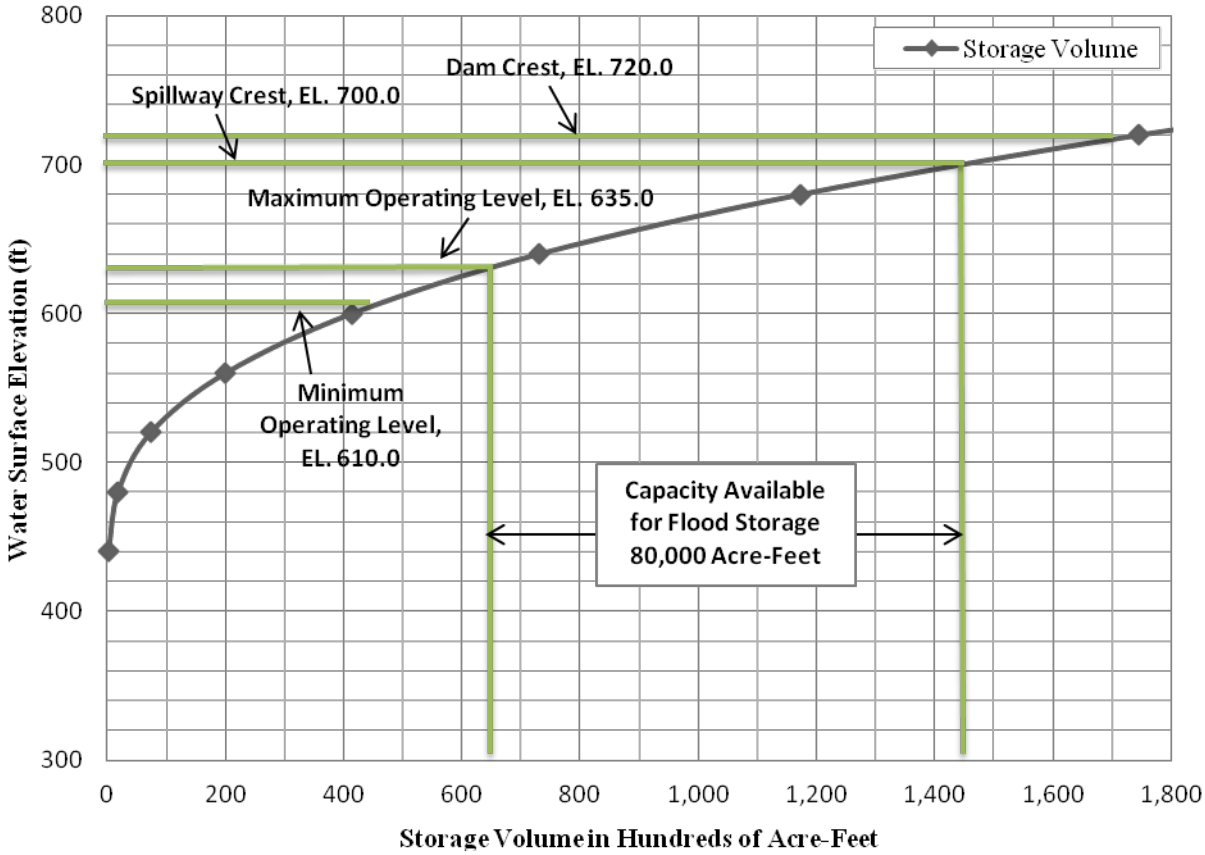


Multi-Purpose Structures

No specific criteria were considered for selecting the maximum operating water surface elevations for hydroelectric operation other than to produce a reasonable amount of power generation. An energy production model was developed for each project, which is discussed in the Hydroelectric Projects section.

The maximum amount of head selected for the Upper Chehalis site to generate hydropower is 195 ft. This translates to a water surface elevation of 635.0 ft, with the proposed powerhouse site at El. 440.0, based on topography at the site. The maximum volume of water for the hydro operation would be approximately 65,000 ac-ft at this elevation See Figure 5 below.

Figure 5
Upper Chehalis Reservoir Storage Volume Curve

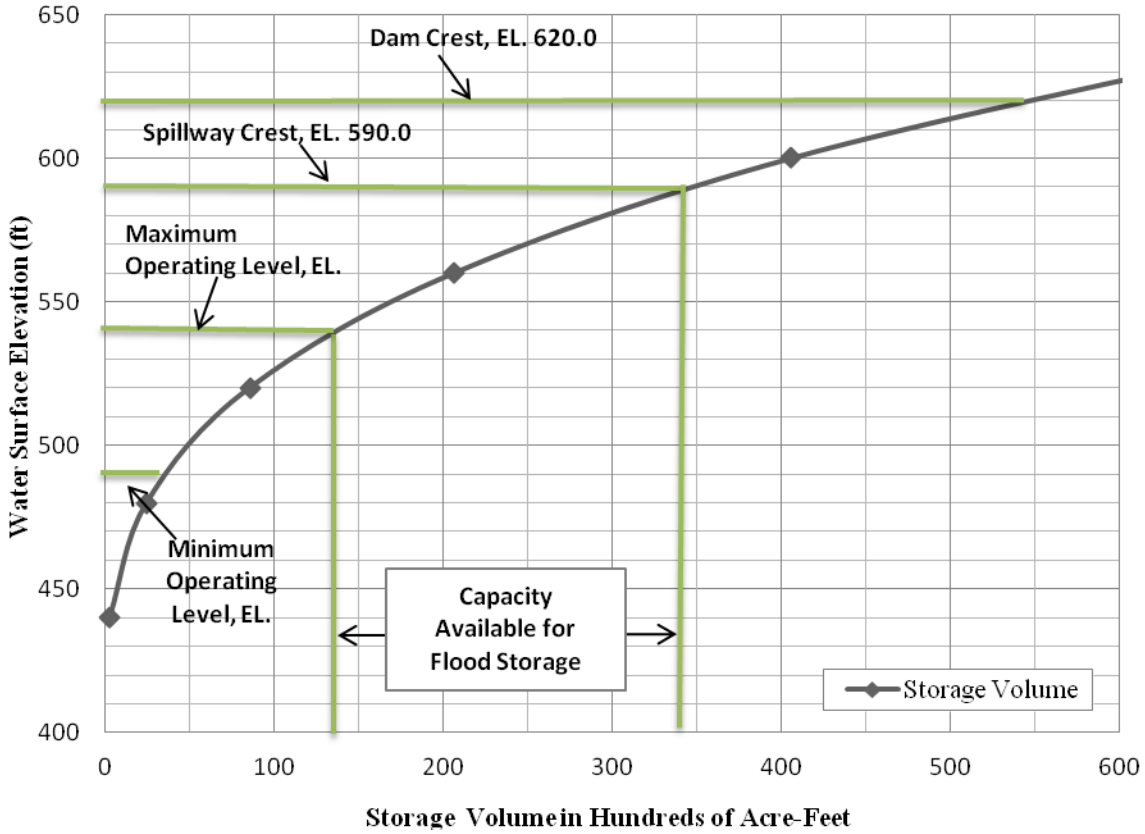


Capturing an additional 80,000 ac-ft for flood storage would raise the water surface 65 ft to El. 700.0, assuming the reservoir is at its approximate maximum operating level of El. 635.0. This elevation corresponds to the maximum reservoir capacity of 145,000 ac-ft, which would have a water surface area of approximately 1,450 acres at the level of the spillway crest (Figure 1).

The structure crest elevation would be El. 720.0, allowing 20 ft for freeboard. See Figure 3 above. The maximum structural height of the Upper Chehalis structure is estimated to be 288 ft, based on lowest ground elevation below the crest (lowest streambed elevation is at 432 feet).

The maximum head selected for the South Fork project was 130 ft, which translates to an operating water surface elevation of El. 540.0. At this elevation, the storage volume would be approximately 13,500 ac-ft. With an additional 20,000 ac-ft for flood storage, the maximum reservoir capacity would be 33,500 ac-ft, with the spillway crest elevation of El. 590.0. See Figure 2. The structure crest would be at El. 620.0 allowing 30 ft for freeboard. See Figure 6. The South Fork multi-purpose structure would have a maximum height of approximately 200 ft.

Figure 6
South Fork Reservoir Storage Volume Curve



Flood Storage Project Operations

When natural flows exceed a predetermined threshold, the flood storage only structures will begin to hold back water. In the case of the multi-purpose projects, water must be released from the reservoirs when flooding begins; otherwise, the reservoirs would quickly fill and waters would be released through the uncontrolled spillway. The maximum amount of water that can be safely released from each structure ("Pre-determined" flow) has not been established at this time. However, several example "pre-determined" flows (outflows) from each structure were evaluated to determine their effects on the frequency of flooding. Maximum "pre-determined" flows were modeled by plotting the cumulative storage, which is essentially inflow minus outflow, for the 70 years of gage data.

Upper Chehalis Project

The Upper Chehalis flood storage only structure will begin to hold back water once flows exceed a "pre-determined maximum" flow threshold. A constant pre-determined release from the reservoir of flood water begins when the reservoir is above the natural streambed. The outflow continues after a flood event until the reservoir is emptied.

In the case of the multi-purpose structure, storage volume available for flood storage is 80,000 ac-ft, and the water surface elevation when flooding begins is El. 635.0. The reservoir level may be lower, depending on the time of year, but is not considered for evaluation of maximum flows. A constant maximum flow release from the reservoir begins when the reservoir level exceeds El. 635.0. The outflow continues until the level drops to El. 635.0.

A regulation plan will have to be analyzed and developed in greater detail, however, the impact of different "pre-determined maximum" flow threshold was developed. Figures 7 and 8 illustrate the two "pre-determined maximum" flow scenarios analyzed. These figures apply to both the flood storage and multi-purpose structures. Figure 7 shows that with 80,000 ac-ft of flood storage and a maximum release of 732 cfs (the maximum turbine flow), the reservoir could have contained all but 10 flood events. When flows from flood storage are increased to 1,000 cfs, all but two flood events are contained (1996 and 2007, see Figure 8).[5] These analyses include historic flows from the period of record, or 70 years of flow data at the USGS gage near Doty.

[5] Given higher release volumes, all historic flood events might be contained. The appropriate "pre-determined maximum" flow has not been determined and would be part of a future, more detailed analysis.

Figure 7
Upper Chehalis Flood Evaluation with 732 cfs "Pre-determined" Release Flow

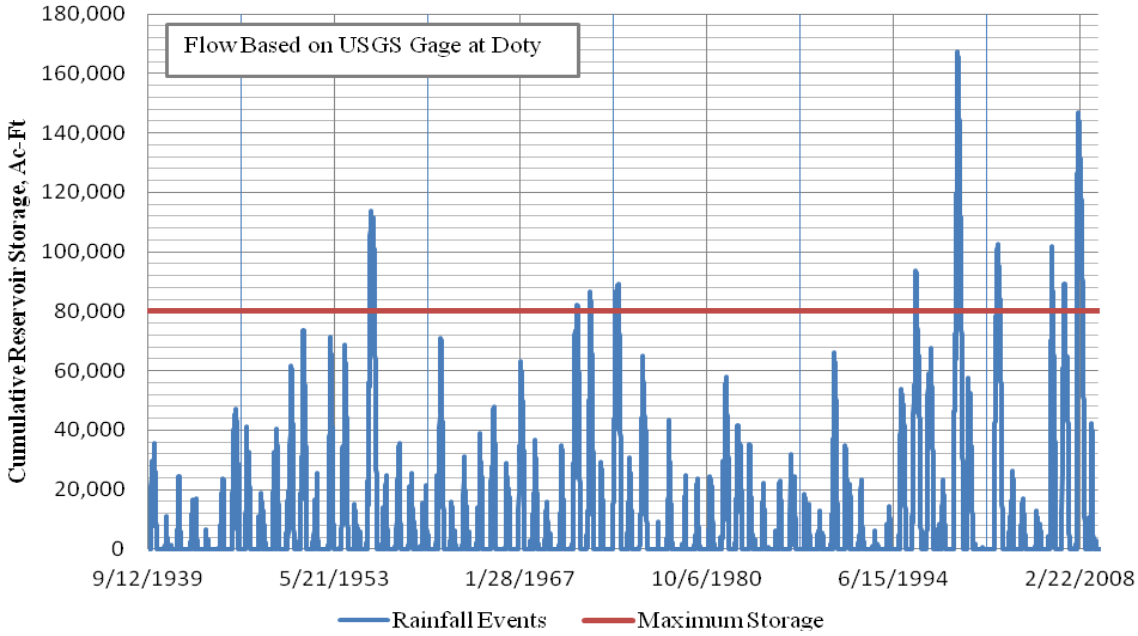
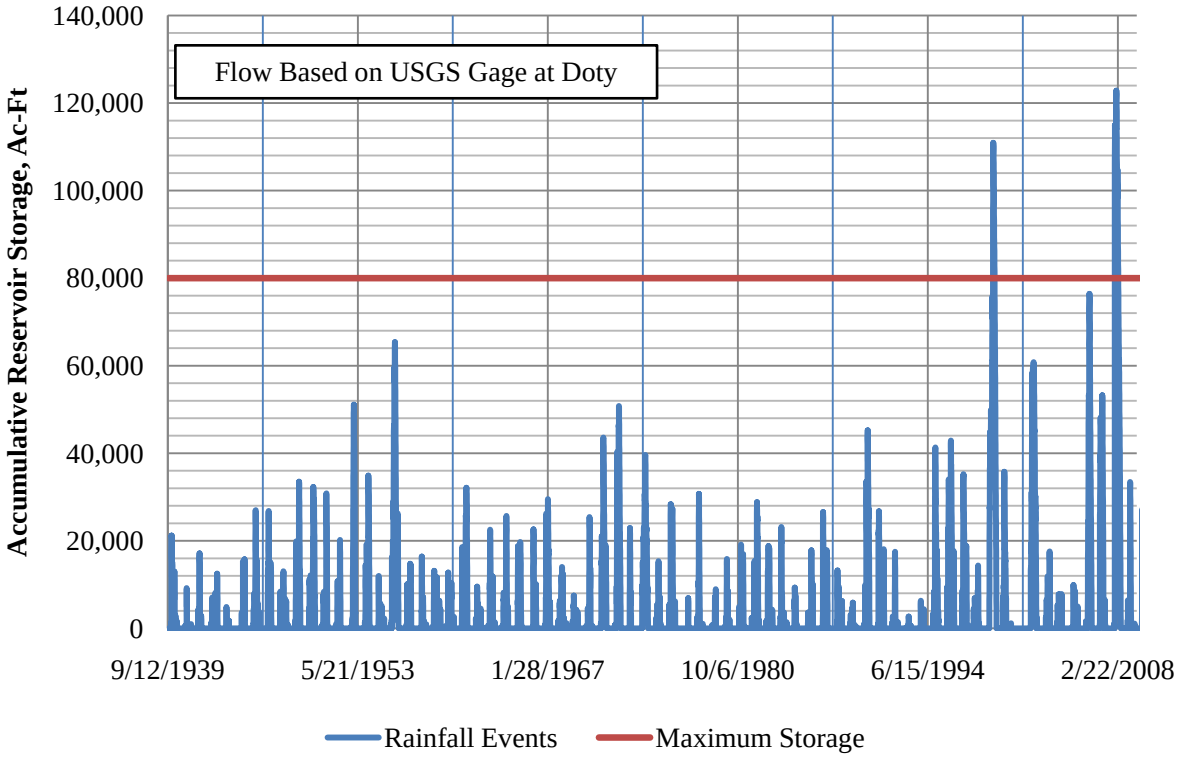


Figure 8
Upper Chehalis Flood Evaluation with 1,000 cfs "Pre-determined" Release Flow



South Fork Project

The flood storage only structure would begin to hold back water once flows exceed a "pre-determined maximum" flow threshold. A constant maximum flow release of flood water from the reservoir would begin when the reservoir is above the natural streambed. The outflow would continue after a flood event until the reservoir is emptied.

The South Fork multi-purpose structure would operate in the same way as the Upper Chehalis project. Whenever the reservoir level exceeds El. 540.0, the reservoir would begin releasing water. The South Fork structure has a maximum storage volume of 20,000 ac-ft available to mitigate flooding. Once the reservoir returned to El. 540.0, the maximum flow release would be discontinued.

Approximately 20 occurrences of uncontrolled spill would have resulted by continuously releasing 220 cfs (the maximum turbine flow) during flood events over the past 70 years. Figure 9 illustrates the results of the "pre-determined maximum" flow analysis using 220 cfs. The number of spill occurrences decreases to three when the amount of flow released is increased to 350 cfs. See Figure 10. The figures below apply to both the flood storage only and multi-purpose structures.

Figure 9
South Fork Flood Evaluation with 220 cfs "Pre-determined" Release Flow

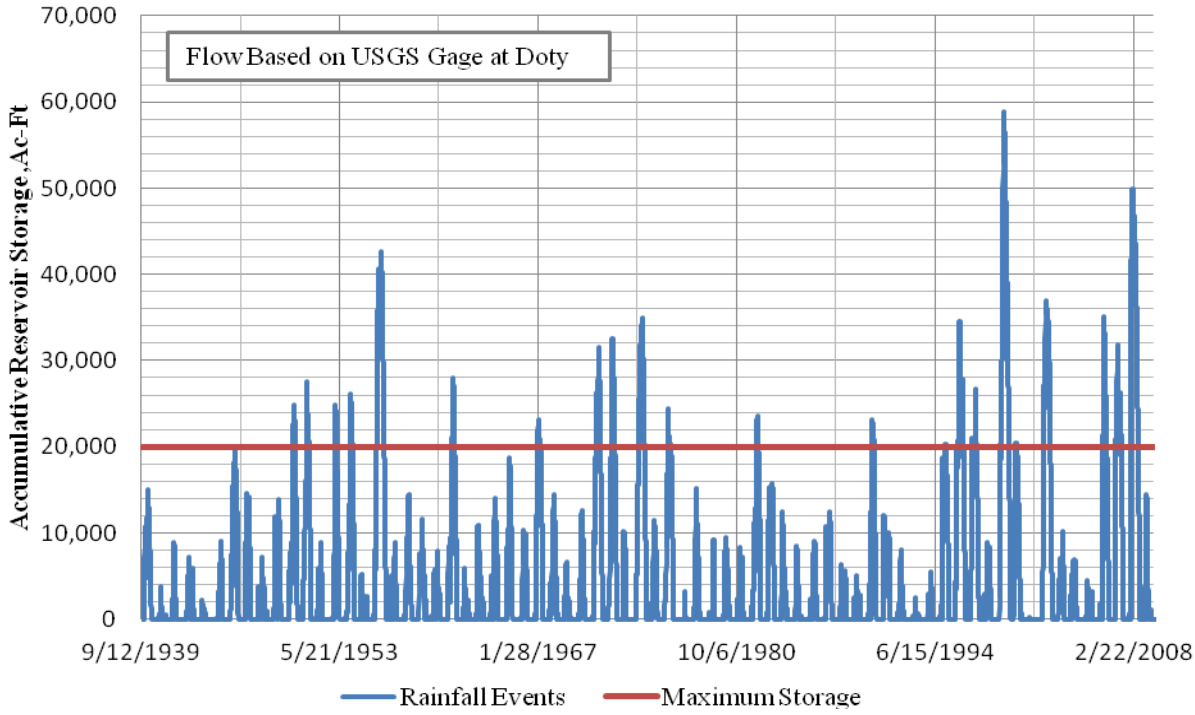
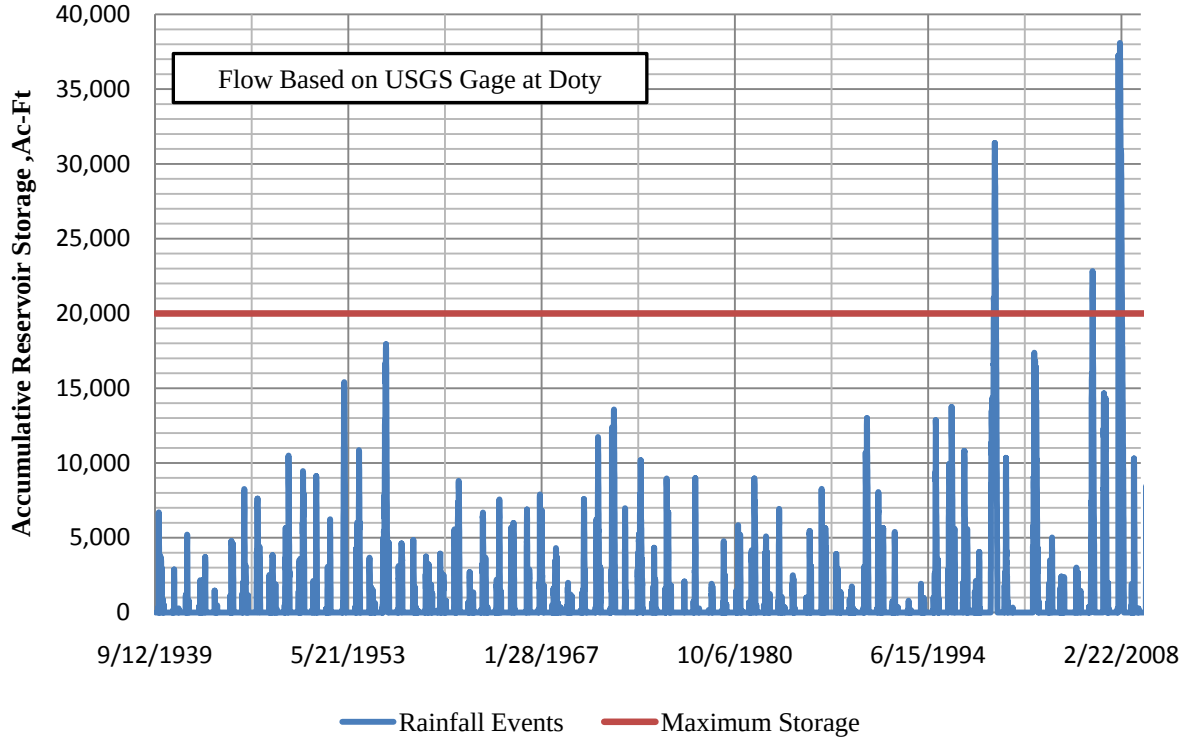


Figure 10
South Fork Flood Evaluation with 350 cfs "Pre-determined" Release Flow



Hydroelectric Project Operations

Energy production models were developed to calculate the potential average annual energy production for each multi-purpose project. The models use daily average inflow, reservoir storage curves, and flow releases to calculate daily energy production and ending reservoir levels. The sizes of the desired generating units were found through an iterative process. The selected unit sizes are based on maintaining a water budget so that the reservoirs fill to the same initial level at the beginning of each year.

In this report, flow data were based on the USGS gage at Doty.[6] The Doty gage is used because of its proximity to the proposed structure sites.[7] The gage has a period of record of more than 70 years from 1939 to present. The gage flows were correlated to the structure sites by a ratio of the drainage areas. The drainage area of the Doty gage is 113 sq mi and has a daily average discharge of 349 cfs. The drainage areas are 68.8 sq mi and 22.5 sq mi for the Upper Chehalis and South Fork sites, respectively.

Upper Chehalis Project

The Upper Chehalis model was initialized with a reservoir level at El. 630.0 on January 1st of each year. This level corresponds to a storage volume of 62,000 ac-ft and 190 ft of head for hydropower operations and summer flow augmentation (based on the powerhouse tailwater elevation being at 440 ft). Model iterations determined that a hydropower plant about 10,000 kW (10 MW) in size can hold reservoir levels close to El. 630.0 from December through March. In March, flows in the Upper Chehalis River begin to fall below turbine flows (732 cfs), and if the 10 MW plant continued to operate, the reservoir level would drop quickly. Therefore, on April 1, hydropower production is cut to 1,700 kW or 140 cfs in outflow; this is maintained throughout the summer. The reduced flow keeps the reservoir, and operating head at reasonable levels throughout the summer. In an average year, runoff has increased by November 24 such that the full 10 MW of production is resumed and reservoir levels are held near El. 630.0 through year end. The unit operations are adjusted so that the model calculates a reservoir elevation on December 31, at or very near El. 630.0, the elevation of January 1 of the same calendar year. This ensures that the water budget year to year is balanced.

The hydro generation analysis for the Upper Chehalis provided the following outcomes:

- A hydropower plant with two turbines, one rated at 8.3 MW and one at 1.7 MW, for a total capacity of 10 MW is recommended.
- Annual average energy production was calculated at 39,952 MWh.

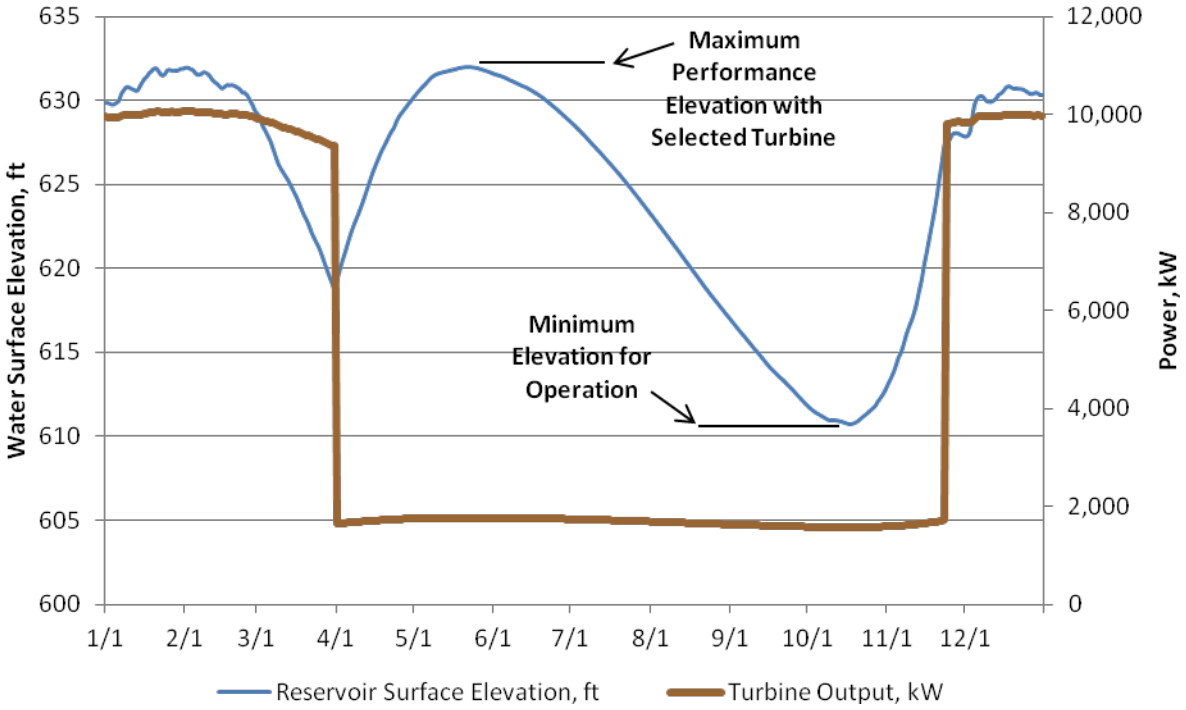
[6] The Phase I analysis relied on the gage data near Grand Mound because the Doty gage washed out in the 2007 flood. However, feedback suggested using the Doty gage due to its proximity, and incorporating the USGS estimates for the 2007 flood.

[7] The USGS gage near Wildwood is the gage nearest the South Fork site; however, the period of record is shorter (since 1999) and data us collected only part of the year (October through April).

- A minimum instream flow release of 20 cfs would be maintained year round if the unit is not operating, although for the arrangement described here, the powerhouse operates 24 hours per day and the stream flow would be higher.[8]

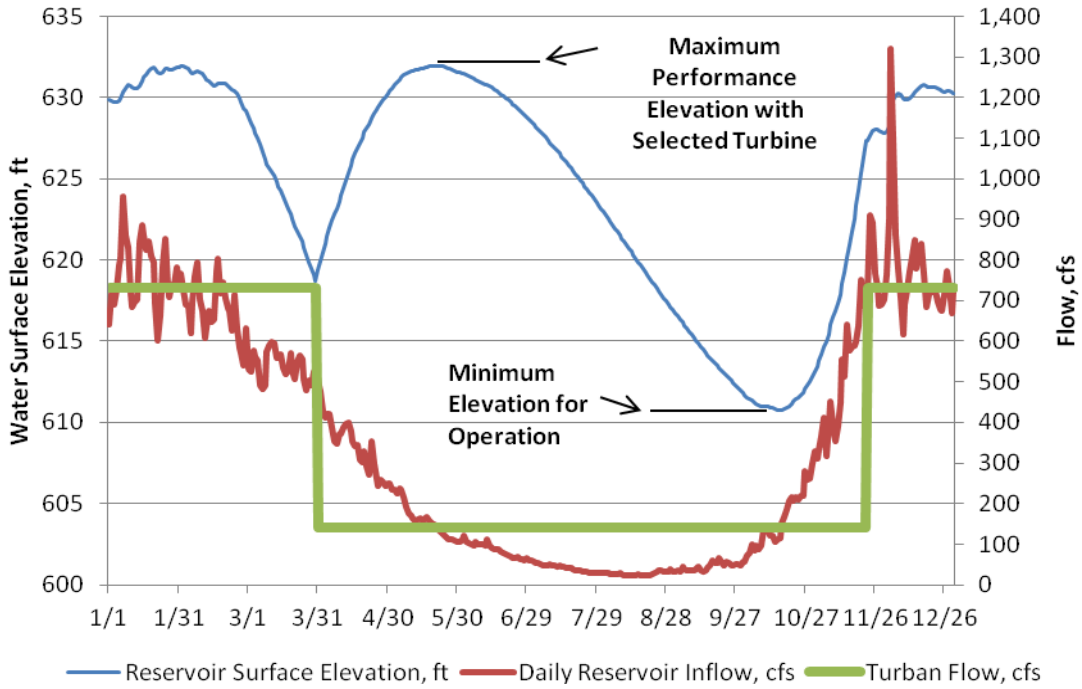
Figures 11 and 12 illustrate the reservoir and powerhouse operation over the course of an average year. The hydroelectric production has increased moderately from the results in the Phase I analysis, based on adjusted Doty gage information.

Figure 11
Upper Chehalis Turbine Output Based on Average Water Year



[8] Further study is required to determine appropriate minimum instream flows.

Figure 12
Upper Chehalis Turbine Analysis Based on Average Water Year



South Fork Project

The South Fork model was initialized to have a reservoir level on January 1 each year of El. 510. This level results in storage volume of 7,060 ac-ft and 100 ft of head for hydropower operations and summer flow augmentation, based on the powerhouse tailwater elevation of 410 ft. Through model iterations, it was determined that a hydropower plant of about 2 MW in size can hold reservoir levels within a reasonable range for the period January 1 to April 1. After April 1, river flows begin to fall. If a 2 MW plant continued to operate, the reservoir level would drop quickly. Therefore, on April 1, hydropower production is reduced to 300 kW with an outflow of 40 cfs. This production level is maintained throughout the summer. The reduction in power production, and subsequently the reduction in outflow, keeps the reservoir and operating head at reasonable levels throughout the summer. The reservoir level reaches its maximum operating water surface of El. 540.0 at the beginning of June and then begins to drop until October. On November 4, operation of the full 2 MW of production is resumed, and the reservoir levels increase to El. 510.0 by year-end, as winter rains increase flows in the South Fork Chehalis River. The unit operations are adjusted so that the model calculates a reservoir elevation on December 31, at or very near the El. 510.0, where it started on January 1; the adjustments ensures that the water budget is balanced year to year.

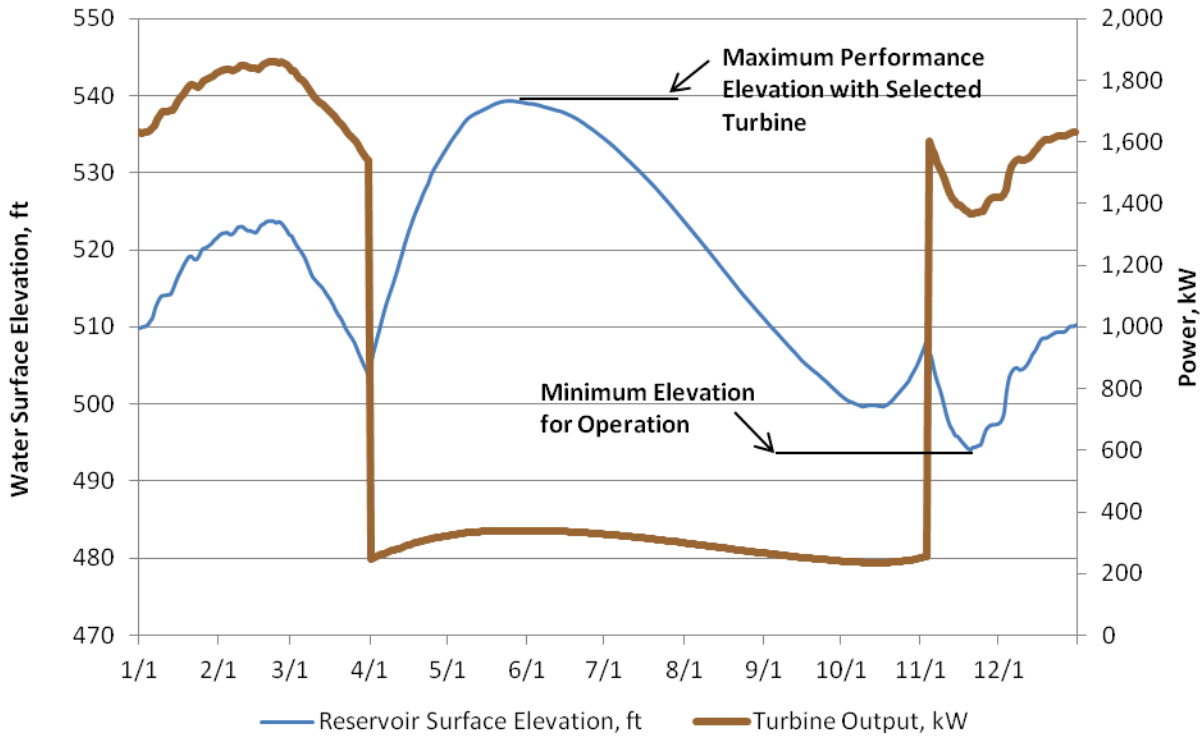
The following are the results of the hydro generation analysis for the South Fork:

- A hydropower plant with two turbines, one rated at 1.7 MW and one at 0.3 MW, for a total capacity of 2 MW is recommended.
- Annual average energy production was calculated at 7,401 MWh.

- An instream flow release of 10 cfs would be maintained year round if the unit is not operating. For the arrangement recommended here, however, the powerhouse would operate 24 hours per day in an average water year and the streamflow would be significantly higher.[9]

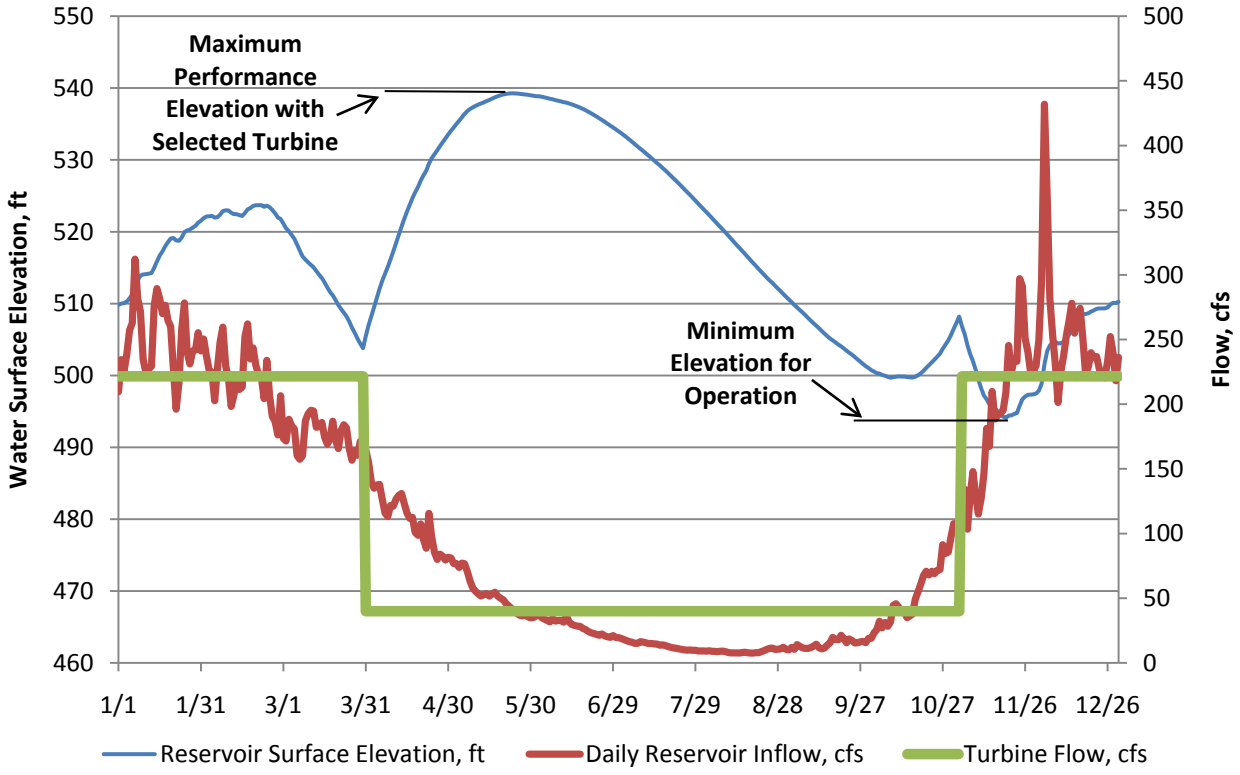
Figures 13 and 14 illustrate the operation of the reservoir and generation over the course of a year.

Figure 13
South Fork Turbine Output Based on Average Water Year



[9] Further study is required to determine appropriate minimum instream flows.

Figure 14
South Fork Turbine Analysis Based on Average Water Year



Project Arrangement

EESC studied several different configurations of structures, spillways, and intake towers for the projects. Drawings were prepared and sent to Shannon & Wilson for review and comment. Shannon & Wilson's review comments are included in Appendix A. EESC incorporated these comments, and prepared the preliminary drawings presented in Appendices B and C.

Upper Chehalis Project

The principal project features for the Upper Chehalis flood storage only project are the structure, spillway, and tunnel. Similarly, the principal project features for the Upper Chehalis multi-purpose project are the structure, spillway, intake tower and tunnel. Pertinent project data are given in Table 1 below. Additional work is needed on fish passage facilities once the fisheries study is completed by Anchor QEA.

Table 1
Upper Chehalis Project Data

	Flood Storage	Multi-Purpose
Structural Height	238 ft	288 ft
Hydraulic Height (Normal Operating Depth at Structure)	NA	203 ft
Streambed at Structure Axis (Elevation)	432 ft	432 ft
Crest Elevation	670 ft	720 ft
Crest Length	1,450 ft	1,800 ft
Crest Width	40 ft	40 ft
Base Width	1,300 ft	1,600 ft
Volume of Structure Construction Materials	5,458,100 cubic yards	8,921,600 cubic yards
Total Water Storage at Elevation	80,000 acre-ft at 650 ft	145,000 acre-ft at 700 ft
Maximum Water Surface Elevation	669.5 ft	719.5 ft
Spillway Capacity at Elevation	50,000 cfs at 669.5 ft	50,000 cfs at 719.5 ft
Flood Storage Volume	80,000 acre-ft	80,000 acre-ft

Upper Chehalis Multi-Purpose Project Detail

Drawings 2 through 5, presented in Appendix B, show the preferred arrangement plan, sections, and elevations for the Upper Chehalis multi-purpose project option. The structure is an earthfill, zoned, embankment type with an impervious core. The embankment slopes required for stability are 3 horizontal (H) to 1 vertical (V) (3H:1V) on the upstream side and 2.5H:1V on the downstream side. The crest width is 40 ft, conservatively wide enough for construction activities and a roadway over the structure. The crest length of the structure is approximately 1,800 ft at El. 720.0.

The structure's spillway is located on the right abutment. It is a side-channel spillway in which flow falls into a narrow trough, then turns 90 degrees, and continues in a steep main discharge channel. A stilling basin is at the end of the spillway chute to dissipate energy and deliver the water safely to the river.

Several factors affect the design of the spillway, but having ample capacity is of paramount importance. The required capacity should be based on probable maximum flood (PMF) studies[10]. At this preliminary design stage, the spillway shown on the drawings has a crest length of 500 ft and could pass approximately 50,000 cfs before overtopping the structure crest. Estimated maximum flow at the Upper Chehalis site in the December 2007 flood event was 38,400 cfs.

The outlet works for this project consist of a tall intake tower and a tunnel in the left abutment. Typical of large structure projects, a tunnel is needed to divert water around the structure site so the structure can be constructed. For the Upper Chehalis project, the tunnel would need to be approximately 1,800 ft long. The preliminary size of the tunnel is 12 ft in diameter. The size is based on a turbine flow of 735 cfs.

Tunnel discharge would be controlled by a freestanding vertical intake tower anchored to the abutment at the tunnel entrance. Details of the intake structure design were not within the scope of this Phase IIB work and would be part of future design engineering work. The intake tower is assumed to have multi-level intakes where water could be selectively withdrawn from various levels of the reservoir. Selective withdrawal is used to improve downstream water temperatures, dissolved oxygen and sediment considerations. Physical hydraulic model studies of the intake are recommended to be included during final design.

The downstream tunnel portal would terminate with an 8.5 ft diameter pipe connecting the tunnel to the powerhouse. The powerhouse is expected to be 150 ft long by 50 ft wide. Water passing through the powerhouse would discharge into a short tailrace before returning to the river. The powerhouse would house two Francis turbines, each directly connected to a synchronous generator. The nameplate rating of the generators would be 9 MW and 2 MW. The generators would operate at a voltage compatible with current PUD distribution voltage in the area (12.5 kV).

A 4 ft diameter pipe would be installed upstream of the powerhouse to bypass flow to the river during outages. The pipe would be equipped with a Howell-Bunger valve to dissipate energy.

Upstream and downstream fish passage facilities are expected to be required at the structure. Details of these facilities are beyond the scope of this study, as additional information regarding fish is required and would be incorporated after the completion of fish studies. Several alternatives, such as surface collection, bypasses, and trap-and-haul may be possible for up and downstream fish passage and will need to be studied once more is known through the fish studies by Anchor QEA about the specific needs and requirements of the fish populations present.

[10] PMF studies have not been completed for this study and would be part of more detailed design.

South Fork Project

The arrangement of the South Fork Project would be very similar to the Upper Chehalis project. The principal project features for the flood storage only project are the structure, spillway, and tunnel. The principal project features for the multi-purpose project are the structure, spillway, intake tower and tunnel. Fish passage facilities would need to be included, but there is not yet sufficient information to include them in the design work. Pertinent project data are given in Table 2 below.

Table 2
South Fork Chehalis Project Data

	Flood Storage	Multi-Purpose
Structural Height	170 ft	200 ft
Hydraulic Height (Normal Operating Depth at Structure)	NA	120 ft
Streambed at Structure Axis (Elevation)	420 ft	420 ft
Crest Elevation	590 ft	620 ft
Crest Length	1,750 ft	1,880 ft
Crest Width	40 ft	40 ft
Base Width	860 ft	1,025 ft
Volume of Structure Construction Materials	3,345,900 cubic yards	7,814,800 cubic yards
Total Water Storage at Elevation	20,000 acre-ft at 560 ft	35,000 acre-ft at 590 ft
Maximum Water Surface Elevation	589.5 ft	619.5 ft
Spillway Capacity at Elevation	24,000 cfs at 589.5 ft	24,000 cfs at 619.5 ft
Flood Storage Volume	20,000 acre-ft	20,000 acre-ft

South Fork Multi-Purpose Structure Detail

Drawings 2 through 5 presented in Appendix C show the preferred arrangement plan, sections and elevations for the South Fork multi-purpose project option. The structure is an earthfill, zoned, embankment type with an impervious core. The embankment slopes required for stability are the same as for the Upper Chehalis Project (3H:1V on the upstream side and 2.5H:1V on the downstream side). The crest width is 40 ft, conservatively wide enough for construction activities and a roadway. The crest length of the structure is approximately 1,880 ft in length at El. 620.

The structure's spillway is located on the left abutment. It is a concrete-lined, chute spillway, which terminates with a stilling basin. The spillway has a crest length of 50 ft and a capacity of 24,000 cfs before overtopping the structure crest. The required capacity should also be based on probable maximum flood (PMF) studies[11].

[11] PMF studies have not been completed for this study and would be part of more detailed design efforts.

The outlet works for this project consist of a tall intake tower and a combination tunnel and pipe. The configuration and alignment are somewhat less favorable than the Upper Chehalis project because of location and topography. The tunnel/pipe would be located beneath the structure, which is not the most desirable configuration. It is more ideal to locate the outlet works within the abutment; however, the topography rules this out at this location. The topography upstream and downstream of the structure is relatively flat and the river has a large bend at the structure site. The ground rises sharply along the structure axis on the right side. This portion of the outlet works would need to be tunneled, or it would require a deep excavation of approximately 120 ft.

The conduit between the intake tower and powerhouse is sized at 5 ft in diameter, based on the turbine flow. Diversion and care of water during construction may require a larger conduit depending on hydrologic considerations. Discharge would be controlled by a freestanding vertical intake tower anchored to the foundation at the tunnel entrance. Details of the intake structure design would be part of future engineering study. The intake tower is assumed to have multi-level intakes where water could be selectively withdrawn from various levels of the reservoir. As with the Upper Chehalis multi-purpose project, this would enable summer flow augmentation and provide improved downstream water temperatures, and dissolved oxygen.

The powerhouse is expected to be 125 ft long by 50 ft wide. Water passing through the powerhouse would discharge into a short tailrace before returning to the river. The powerhouse would house two Francis turbines, each directly connected to a synchronous generator. The nameplate rating of the generators would be 2 MW and 0.5 MW. The generators would operate at a voltage compatible with current PUD distribution voltage in the area (12.5 kV).

A 4 ft diameter pipe would be installed upstream of the powerhouse to bypass flow to the river during outages. The pipe would be equipped with a Howell-Bunger valve to dissipate energy.

Upstream and downstream fish passage facilities are expected to be required at the structure. Details of these facilities are beyond the scope of this study. Several alternatives, such as surface collection, bypasses, trap-and-haul, may be possible for fish passage. Information from the fish studies by Anchor QEA will inform fish passage planning.

Cost Estimates

The estimated costs of development and construction for the flood storage only structures are $165 million for the Upper Chehalis project and $93 million for the South Fork project. These costs are estimated based on upstream trap-and-haul for fish passage and smaller structure size (compared with the multi-purpose projects). The estimated costs of development and construction for the multi-purpose structures are $245 million for the Upper Chehalis Project and $149 million for the South Fork Project. The multi-purpose structure cost estimates include cost estimates for upstream and downstream fish passage.[12] The cost estimates developed for each project are presented in Appendix D. The total estimated costs are believed to be accurate within 30% (estimates include 30% contingency).[13]

These estimates represent EESC's opinion of the probable project development costs at this stage. The estimates are based on the preliminary drawings, material quantity take-off, construction cost guides, recent construction bids, literature research, opinion, judgment and allowances. EESC requested assistance from Shannon & Wilson, who provided unit construction costs for selected items such as embankment and tunneling (see July 22, 2010 letter from Shannon & Wilson in Appendix A).

Costs for acquisition of land and land rights, Federal Energy Regulatory Commission licensing, state and local permits, and Bonneville Power Administration coordination fees have been included. However, project owner internal and legal costs have not. Time for construction is estimated at four years.

[12] Fish passage costs were estimated based on EESC experience with other projects. As the estimates are reviewed and compared to other projects, it is important to notice that the construction cost of retrofit fish passage projects are much higher than the cost of building the same facility as part of a new retention facility.

[13] A contingency of 30% is standard practice for conceptual design estimates. As EESC based the design and cost estimate on information available from site survey data and a site reconnaissance report available for the sites (from Shannon & Wilson); it is the opinion of EESC that a 30% contingency is reasonable.

Next Steps

Next steps for development of the Chehalis River flood storage projects would be detailed structure design studies. These would require additional and more detailed geotechnical studies, including core drilling. It is anticipated that results of the fisheries studies currently underway will support decision making for fish passage design concepts to be developed for the structures. Additional work anticipated to be required includes probable maximum flood studies, possible hydraulic modeling of fish passage designs, and further refinement of cost estimates.

Appendix A
Shannon & Wilson Letters

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

ALASKA
CALIFORNIA
COLORADO
FLORIDA
MISSOURI
OREGON
WASHINGTON

June 2, 2010

EES Consulting, Inc.
570 Kirkland Way, Suite 200
Kirkland, WA 98033

Attn: Mr. Scott E. Mahnken, P.E.

RE: CONCEPTUAL PLANS AND PROFILES, SOUTH FORK AND UPPER CHEHALIS DAMS, LEWIS COUNTY, WASHINGTON

Shannon & Wilson prepared a Geologic Reconnaissance Study dated October 27, 2009, and a Reconnaissance-level Geotechnical Report dated October 28, 2009, for the South Fork and Upper Chehalis dams. This letter provides supplemental comments related to geotechnical and engineering geologic issues at the sites based on your preliminary plans and profiles dated May 10 and 12, 2010, along with the Preliminary Information dated May 10, 2010, that you provided to us.

UPPER CHEHALIS DAM

The crest alignment for this structure has moved approximately 600 feet downstream and rotated about 20 degrees to the northwest from the layout included in our October 2009 reports. The downstream toe of the dam is near the extent of our geologic mapping and some of the downstream appurtenant structures are outside of our geologic mapping area.

- It appears that the uppermost portion of the right abutment and the emergency spillway will be founded in McIntosh Formation bedrock. The McIntosh Formation is a weak marine siltstone/claystone. Seepage mitigation measures may be necessary if the normal pool elevation is above the elevation of the geologic contact between the McIntosh Formation and the underlying igneous volcanic rocks.
- Our geologic mapping did not include the ravine into which the proposed emergency spillway will discharge. Landslides may be present in this area. As a first step to assessing the presence of landslides, we will review the LiDAR data for readily visible

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indications of past slope instability. Geologic maps indicate bedrock in this area to be the McIntosh Formation. The weak nature of this rock makes it susceptible to erosion. Colluvium overlying bedrock is also erodible. At best, spillway flows could cause significant erosion and sedimentation of the Chehalis River channel downstream of the dam; at worst, headcutting could create a dam safety concern. Depending on the erosion potential, potential environmental impacts, and regulatory constraints, a spillway at this location may require that the discharge channel be concrete-lined or that other erosion protection measures be implemented.

- There are landslides on both the left and right banks of the river channel above the proposed valve house, powerhouse, and switchyard. Reconnaissance, explorations, study, and analyses will be required to assess the potential hazard to the proposed facilities posed by these landslides and to assess alternatives for landslide mitigation and facility construction. The Federal Energy Regulatory Commission (FERC) will likely require mitigation of landslide hazards or relocation of the facilities if in their opinion the landslides present an unacceptable risk to the facilities. As a first step to assessing the location and extent of landslides, we will review the LiDAR data to estimate where facilities might need to be relocated to.
- It appears that hydraulic control for the penstock/outlet is proposed to be located at the gate shaft near the dam crest. A permanently charged pipe below the upstream shell is a potential dam safety issue and presents maintenance challenges. Consideration should be given to including a gate at the intake structure so that the entire length of the pipe can be drained for inspection and maintenance.
- Where the outlet pipe will be buried below the dam embankment, we recommend that the pipe be designed with as few bends as possible or with long-radius bends to reduce thrust block requirements and the potential for stress concentrations that could lead to cracking of the earth embankment. For planning purposes, we recommend that the pipe be assumed to be benched into bedrock and concrete-encased for its full length where it is below the dam embankment.
- The dam does not appear to have a low-level outlet. Inability to drain the bottom 150 feet of the reservoir is a potential dam safety issue. Some means to drain the reservoir to within a few tens of feet of its upstream toe elevation should be provided.
- The single intake on the penstock will not allow reservoir water to be blended to manage environmental quality and temperature of water discharged downstream. Multiple-level outlets that allow for blending of water will likely be required. The issue of water quality and the need for a multi-level intake should be considered as the design progresses.
- Would it be worth considering re-use of the diversion tunnel as a low-level outlet? Would it be possible to use the diversion tunnel as the permanent penstock, with multi-level inlet gates and bifurcation valves downstream of the dam to direct water to the

powerhouse and to discharge directly to the stream? Maintenance of, access to, and sediment deposition around the low-level outlet intake should be considered.

- It may be possible to construct a vertical shaft on the left abutment with the diversion tunnel at the bottom and inlets at multiple elevations. Depending on the location of the shaft, a stub tower could be constructed above the shaft, if necessary. Tunneling through the abutment and tapping into the shaft is one way that multiple-level intakes might be constructed.
- The information provided to us states that an 8-foot-diameter tunnel is about the smallest practicable size constructible. We agree that an 8-foot-diameter tunnel is about the smallest practical diameter for construction using a conventional tunnel boring machine (TBM). A smaller diameter tunnel constructed using the drill-and-shoot excavation method may be feasible. Use of the drill-and-shoot method may require mitigation of blast damage for seepage control. Tunnels smaller than 8 feet in diameter could be constructed using microtunneling machines. Microtunneling is typically performed by remotely operating the TBM and jacking the machine using tunnel liner pipe that is advanced behind the machine as the tunnel is bored. One or more intermediate shafts/jacking stations and/or intermediate jacks would likely be required for microtunneling techniques to be used to bore the proposed 1,700-foot-long tunnel.
- A blanket drain and toe drain should be incorporated below the embankment shell downstream of the dam core. The blanket drain would consist of a layer of high permeability filter and drainage sand that is a foot or two thick and placed against the abutments below the embankment downstream of the dam core. The toe drain would consist of a high permeability zone of open angular rock that extends from the chimney filter/drain downstream of the core to discharge at the dam toe. This rock would be encapsulated in one or more filter-compatible soil and gravel layers.
- The channel adjacent to the powerhouse should be armored to protect the site from erosion by water exiting the diversion tunnel.
- Some thickness of existing soil should be assumed to be removed from the existing ground prior to dam embankment construction as part of the foundation preparation process. Excavation and removal of some or all of material within landslide zones that underlie the dam footprint will likely also be required to provide adequate foundation and embankment stability. Assessment of these excavation volumes would be part of later geotechnical services for the project as the design advances. These excavations will increase the volume of excavation and fill required for the project relative to the volumes that would be computed based on the current sketches.

SOUTH FORK CHEHALIS DAM

The crest alignment for the South Fork Chehalis Dam has moved about 150 feet downstream from the layout included in our reports with minimal rotation.

- Preferred criteria (in order of importance) for an outlet pipe below an embankment dam are: (1) founded on bedrock, (2) straight, and (3) perpendicular to the crest. Obviously, all outlet conduits cannot be ideally constructed. The proposed alignment at the South Fork site is a concern for several reasons. Based on the geophysical survey by Phillip H. Duoos, the estimated top of bedrock below the alluvial terrace inside the horseshoe bend is about Elevation 435. Upstream of the proposed dam centerline, the invert of the proposed 42-inch pipe is very close to Elevation 435, so it may be difficult to achieve complete embedment in rock. The two sharp bends in the pipe may require large thrust blocks. Pipe bends concentrate stress and load and present a risk of failure. Since the pipe would be below the earth embankment, these concerns are potential dam safety issues. We understand that large radius bends and continuously welded steel pipe are being considered to partially address these issues.
- Will the 42-inch-diameter diversion pipe remain operational as a low-level outlet after dam construction or be backfilled? Inability to drain the bottom 40 feet of the reservoir may be a potential dam safety issue. Some means to drain the reservoir to an elevation lower than the intake elevation of 490 feet may be required.
- The 42-inch-diameter diversion pipe has sharp bends. As discussed above, the number of bends should be reduced to the minimum necessary. Would it be possible to shift the inlet and/or outlet locations for this diversion pipe to eliminate the bends and to align the pipe more perpendicular to the dam axis? It appears that the topography may be suitable to shift the inlet to the north and the outlet to the south. For planning purposes, the pipe should be assumed to be concrete-encased where it is below any part of the dam.
- The penstock conduit has no upstream valve control. Please refer our comment for the Upper Chehalis Dam regarding installing a permanently pressurized conduit below an earth embankment.
- Similar to the Upper Chehalis Dam, the penstock alignment on the left abutment appears to have several bends. As discussed above, the number of bends should be reduced to the minimum necessary. For planning purposes, the pipe should be assumed to be founded on bedrock and concrete-encased where it is below any part of the dam.
- See the discussion above for the Upper Chehalis Dam regarding the potential desirability of multiple levels of intake gates to blend water to meet discharge water quality and temperature requirements.

- The spillway channel will intersect a landslide between about Elevations 500 and 440. Measures to improve stability of this landslide may be required. It appears that the upper portion of the spillway channel will be in McIntosh Formation. Because of the erodibility of the McIntosh Formation and overlying colluvium, the spillway channel will need to be fully concrete-lined or other erosion protection measures implemented.
- The channel adjacent to the powerhouse should be armored to protect the site from erosion by water exiting the diversion pipe.
- As discussed for the Upper Chehalis Dam, a blanket drain and toe drain should be incorporated below the embankment shell downstream of the dam core.
- Excavation below the dam footprint to prepare the foundation and partially or fully remove landslide material should be considered in assessing areal impacts and volumes, as discussed above for the Upper Chehalis Dam.

CONCLUSION

Several geotechnical and engineering geologic issues will influence the ultimate layout and design of the proposed dam sites. Based on the current design level and current knowledge of the sites, we see no fatal technical flaws with the general concepts for the two dams. Some aspects of the designs may need to be revised as the design progresses and to meet regulatory requirements.

We are available to discuss these comments in more detail at your convenience. We have worked with the Dam Safety Branch at the Portland Regional Office of FERC and with the Washington State Department of Ecology Dam Safety Office on several projects. In our opinion, it would be beneficial to hold an informal meeting with these regulators early in the design process so that we can address concerns they may have.

Thank you again for the opportunity to participate in the design process for these dams.

Sincerely,

SHANNON & WILSON, INC.

STANLEY R. BOYLE
STATE OF WASHINGTON
35805
REGISTERED
PROFESSIONAL ENGINEER

6/2/10

Stanley R. Boyle, Ph.D., P.E.
Vice President

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SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

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July 22, 2010

EES Consulting, Inc.
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Kirkland, WA 98033

Attn: Mr. Scott E. Mahnken, P.E.

RE: OPINION OF PROBABLE UNIT CONSTRUCTION COSTS FOR SELECTED LINE ITEMS, CHEHALIS DAMS, LEWIS COUNTY, WASHINGTON

At your request, Shannon & Wilson has developed an Engineer's Opinion of probable unit construction costs for selected line items for the proposed Upper Chehalis and South Fork Chehalis dams. These line items include constructing the embankments (estimated to be 7.9 million cubic yards of fill and 4.3 million cubic yards of fill, respectively), riprap erosion protection, constructing a grout curtain, and construction of an approximately 1,800-foot-long, 12-foot-diameter rock tunnel.

For the earth embankment, riprap, and foundation grouting line items, we reviewed actual bid data from several contractors for two dam construction projects in Colorado. Using the Construction Cost Indices published by The Engineering News-Record for Denver, Colorado and Seattle, Washington, we both escalated the prices to July 2010 dollars and applied a geographic adjustment to account for regional pricing differences. Costs for the tunnel are based on our experience with similar underground projects.

EARTH EMBANKMENT

An earth dam embankment generally contains zones of different materials. Some zones (such as the core and shells) are comprised of relatively low-cost local borrow, and others (such as filters and drains) are comprised of more expensive processed aggregates. We understand that at this stage of the project, providing a single blended unit cost for the entire embankment is preferable. To this end, we calculated and summed the extended cost of the embankment line items in the available bid abstracts (excluding riprap) and divided this total by the total embankment volume to come up with a blended unit cost.

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Based on the available (escalated) bid data, we expect that the blended unit cost for embankment construction will be between $4.00 and $6.50 per cubic yard. This range assumes that an adequate quantity of suitable borrow material is available within a reasonable haul distance of the dam site(s). The higher end of range represents marginal soils that will require a larger quantity of processed aggregates for larger or more complex filter drains and/or transition zones. We recommend using a unit cost value of $5.50 per cubic yard, assuming a contingency factor is applied to the opinion of overall project cost.

RIPRAP

Erosion protection is often a significant cost item. We assume that the initial design will include bedded riprap on the upstream face of each dam. It is our opinion that riprap bedding can be produced from on-site materials, so it is included in the blended embankment cost above. However, in our opinion, the suitability of the on-site basalt for use as riprap is questionable, based on our field observations of its strength and durability. For this reason, we recommend that the cost of riprap be considered separately.

It is our opinion that the unit cost for imported riprap will be on the order of $50 to $60 per cubic yard. At this stage of design, we recommend using the high end of the cost range. We also recommend that the overall project cost contingency factor be applied to this line item.

GROUT CURTAIN

For the grout curtain, we calculated and summed the extended cost of pertinent line items for the Colorado dam projects and divided this total by the total cost of embankment construction. Accordingly, the cost of the grout curtain is provided as a percentage of the embankment construction cost. Because the size of the proposed Upper Chehalis and South Fork Chehalis dams is significantly larger than the dams from which we are deriving the unit costs, and because the design area of the grout curtains is unknown, it is our opinion that referencing the cost of grouting to the cost of the embankment is appropriate for a conceptual-level opinion of probable construction cost.

In our opinion, the cost of the grout curtain will be between 25 percent and 40 percent of the cost of the embankment. We recommend using a value of 33 percent of the embankment construction cost, assuming a contingency factor is applied to the opinion of overall project cost.

TUNNEL

In our opinion, the cost of mining the diversion/power conduit tunnel using a tunnel boring machine will be between $300 and $375 per diameter-foot, per foot of length. For a 12-foot outer diameter (O.D.) tunnel, this is between $3,600 and $4,500 per linear foot. The difference in cost will be largely dependent on the quality of the rock and the type of ground support that will be required. Given the limited subsurface information, we recommend using $333 per diameter-foot (or $4,000 per linear foot, assuming a 12-foot O.D. tunnel), and assuming a contingency factor is applied to the opinion of overall project cost.

This cost is only for the tunnel itself, and does not include a pipe or annular backfill. It also does not include the cost of a vertical shaft. The cost of sinking a shaft is considerably more expensive than driving the tunnel because the rate of production is much slower. In addition, the O.D. of a shaft is typically larger than the O.D. of the tunnel it will access. For a 12-foot O.D. tunnel, a 16- to 20-foot O.D. shaft would likely be required.

It is our opinion that the cost to sink a shaft (in rock) will be on the order of $1,500 to $2,000 per diameter-foot, per foot of depth, assuming a contingency factor is applied to the opinion of overall project cost.

CONTINGENCY

At this stage of design, and with minimal information available about subsurface conditions, available borrow volumes, and the engineering properties of the nearby soil and rock materials, we recommend that a minimum contingency factor of 30 percent be applied to the unit costs presented above. This contingency is intended to account unforeseen conditions that may be discovered as part of the preliminary and final design process, as well as the uncertainty inherent to developing a preliminary cost opinion.

CLOSURE

The costs presented herein are an opinion based on our experience with similar projects. No warranty or guarantee is offered or implied. Costs are in July 2010 dollars, indexed to western Washington state.

Thank you again for the opportunity to participate in the design process for these dams.

Sincerely,

SHANNON & WILSON, INC.

Stanley R. Boyle, Ph.D., P.E.
Vice President

SRW:SRB/srw