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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Prepared by:

EES Consulting

570 Kirkland Way, Suite 200
Kirkland, Washington 98033

A registered professional engineering corporation with offices in
Kirkland, WA; Bellingham, WA; and Portland, OR

Telephone: (425) 889-2700 Facsimile: (425) 889-2725

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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 the frequency and severity of flooding on the Chehalis River by means of flood retention structures, using as a starting point an initial conceptual study commissioned by the Lewis County Public Utility District (Phase I).

During the Phase I study, locations for two potential flood storage structures and reservoirs were identified and analyzed. The first site, the “Upper Chehalis” site, is located on the Upper Chehalis River approximately two miles upstream from Pe Ell, at approximately River Mile (RM) 106. The second site, the “South Fork” site, is located on the South Fork of the Chehalis River upstream of Boistfort at approximately RM 19. 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 provided at these two sites for flood water retention in a hydraulic model of the Chehalis Basin upstream of Porter. 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. Shannon & Wilson concluded that no geotechnical impediments exist to the development of flood storage facilities at the identified sites that could not be addressed; further sub-surface investigation is needed in later phases of the project. 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 scope of work for Phase IIB, two options were developed for each of the identified sites: one a structure used solely flood storage, and the other a multi-purpose facility that could also release water for summer flow augmentation and to 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 feet above Mean Sea Level (“MSL”) 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,[1] 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. After adding 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 at the top of the structure 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. 590.0. With 30 ft of freeboard, the crest elevation is 620.0. 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 include 30% contingencies in view of the level of design and the 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

[1] All heights expressed as "elevation" ("El.") refer to elevation in feet above Mean Sea Level.

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 by Anchor QEA are necessary for further decisions about fish passage design concepts to be developed for the structures. Additional work that will 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 the frequency and severity of flooding on the Chehalis River by means of flood retention structures. This phase of the analysis builds expands and elaborates on an initial high-level study (the "Phase I" study) commissioned by the Lewis County Public Utility District.

During the 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 the South Fork site).

The Phase I study determined that flood reduction could potentially be achieved 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. This modeling indicated that the storage would reduce 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 that affect design and construction at the two potential sites. 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."[2] The Washington Department of Ecology reviewed Shannon & Wilson's work, and concurred in their findings in a letter dated December 1, 2009.[3]

This report describes Phase IIB work that EES Consulting (EESC) performed in further investigating the feasibility of storage reservoirs to mitigate Chehalis River flooding. While the primary purpose of the structures is to mitigate 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 scope of work 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 work conducted in Phase I, but added more detail and information to the design and cost estimation. The results of the Phase IIB engineering study have been compiled and are presented in this report.

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[2] Shannon & Wilson. October 28, 2009. *Reconnaissance-Level Geotechnical Report Proposed Chehalis River and South Fork Structure Sites*. Page ii. Seattle, WA.
[3] 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,[4] 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 presented in Attachment 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 Attachment 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 also considered concrete structures but concluded that they would be neither practical nor economical given the site conditions. The appropriate type of earthfill structure is discussed in Shannon & Wilson's geotechnical report.[5]

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 must be included, but additional work currently underway by Anchor QEA will be needed to better define this component.

[4] For additional information, please see the 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.

[5] 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 are shown in Figures 1 and 2 for the Upper Chehalis and South Fork reservoirs, respectively. 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

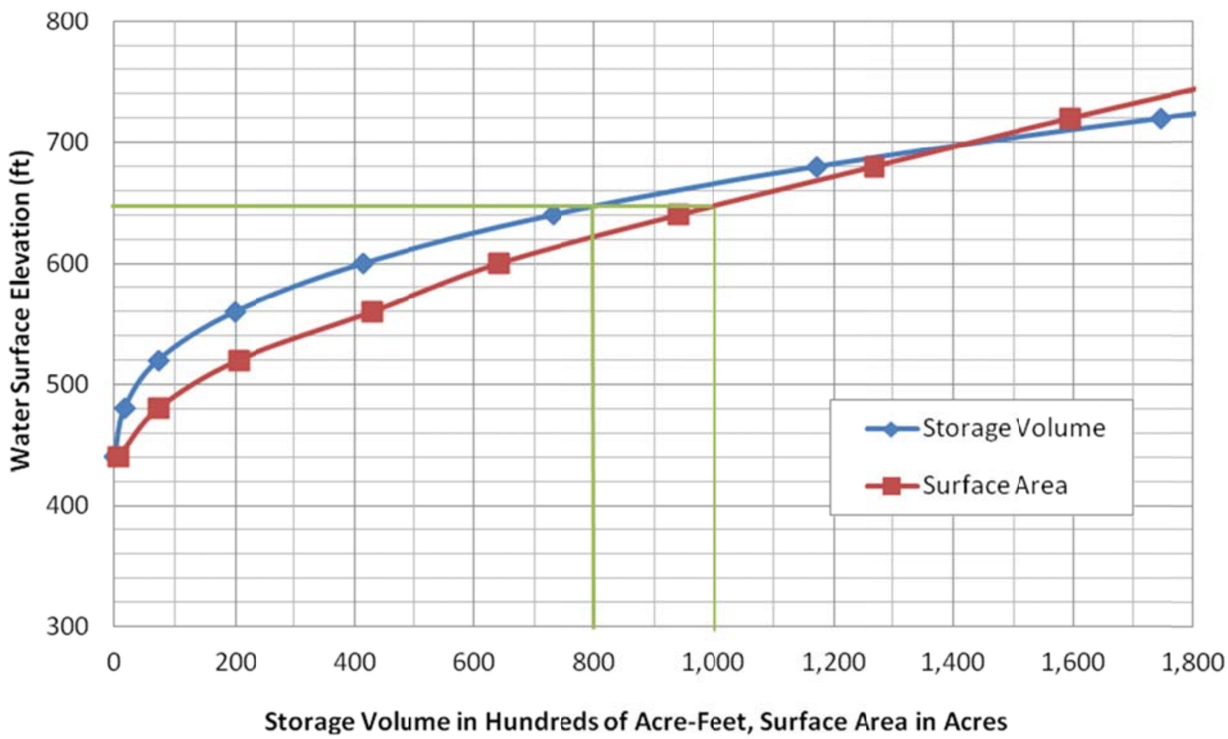
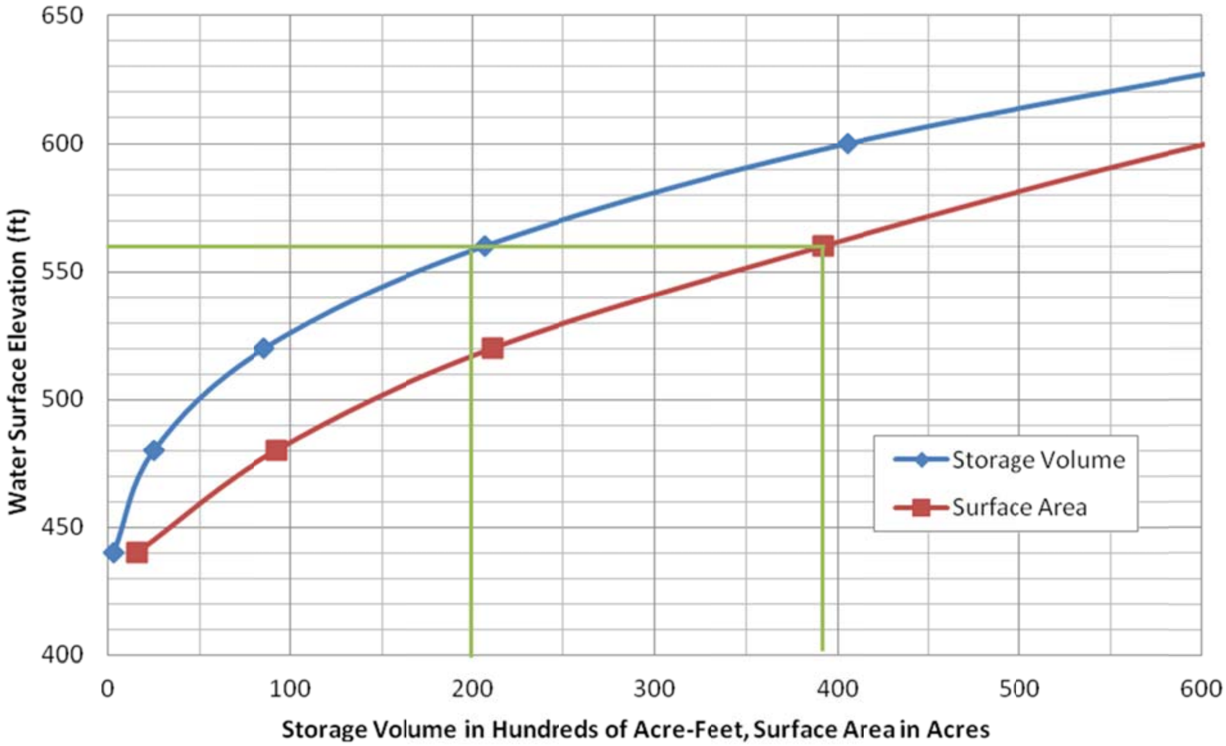


Figure 2
South Fork Chehalis Reservoir Surface Area and Storage Volume Curves



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.

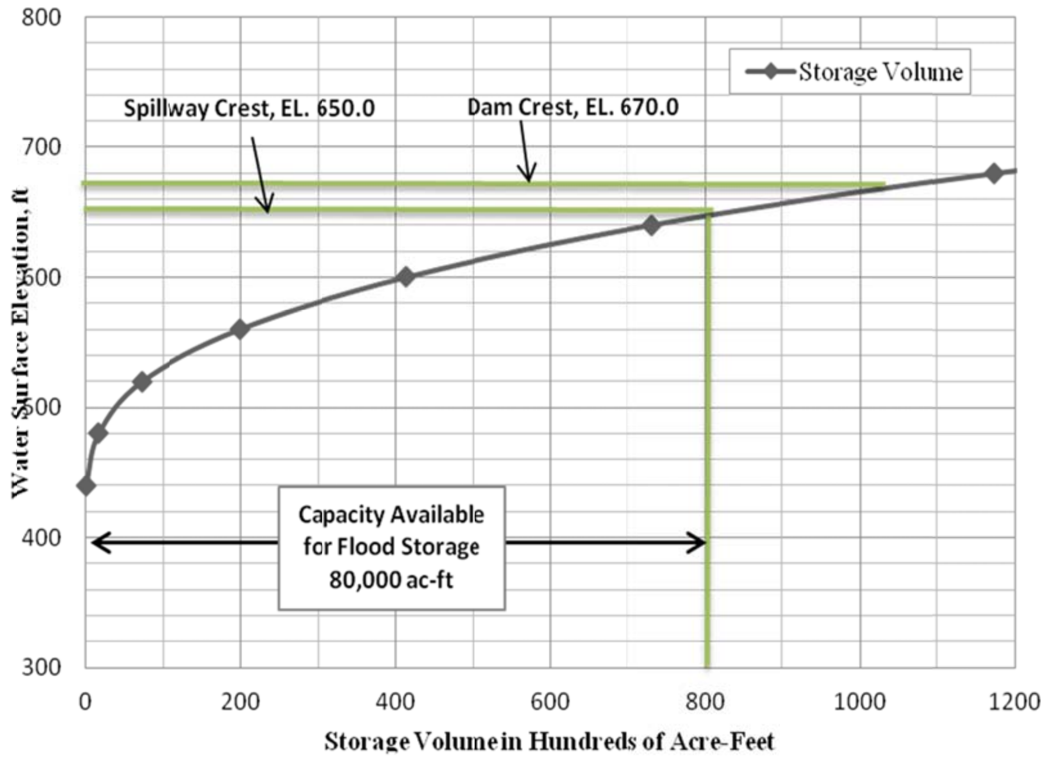
Heights of the Structures

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 under extreme flooding conditions. 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

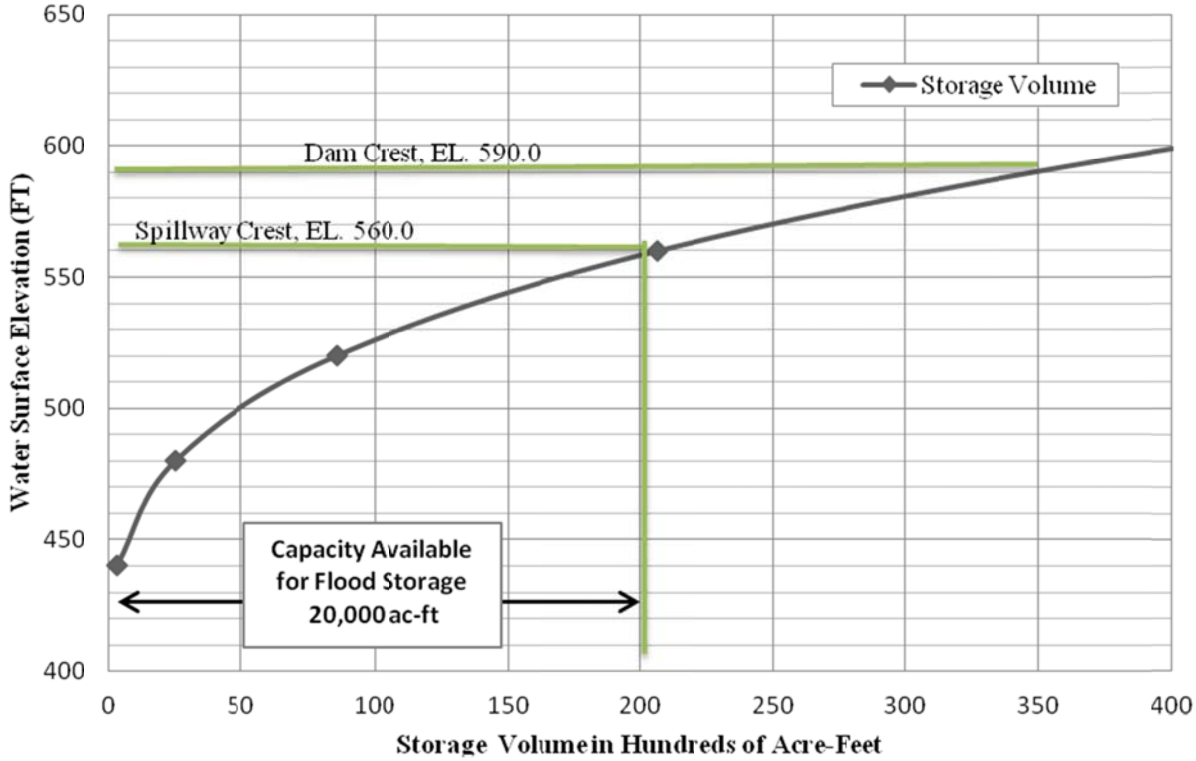
Figures 3 and 4 show how the height of each flood storage structure was determined. Total storage volume needed for the Upper Chehalis flood structure is assumed at 80,000 ac-ft. The maximum surface area of the reservoir when full of flood waters is El. 650.0. The structure crest elevation would be El. 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

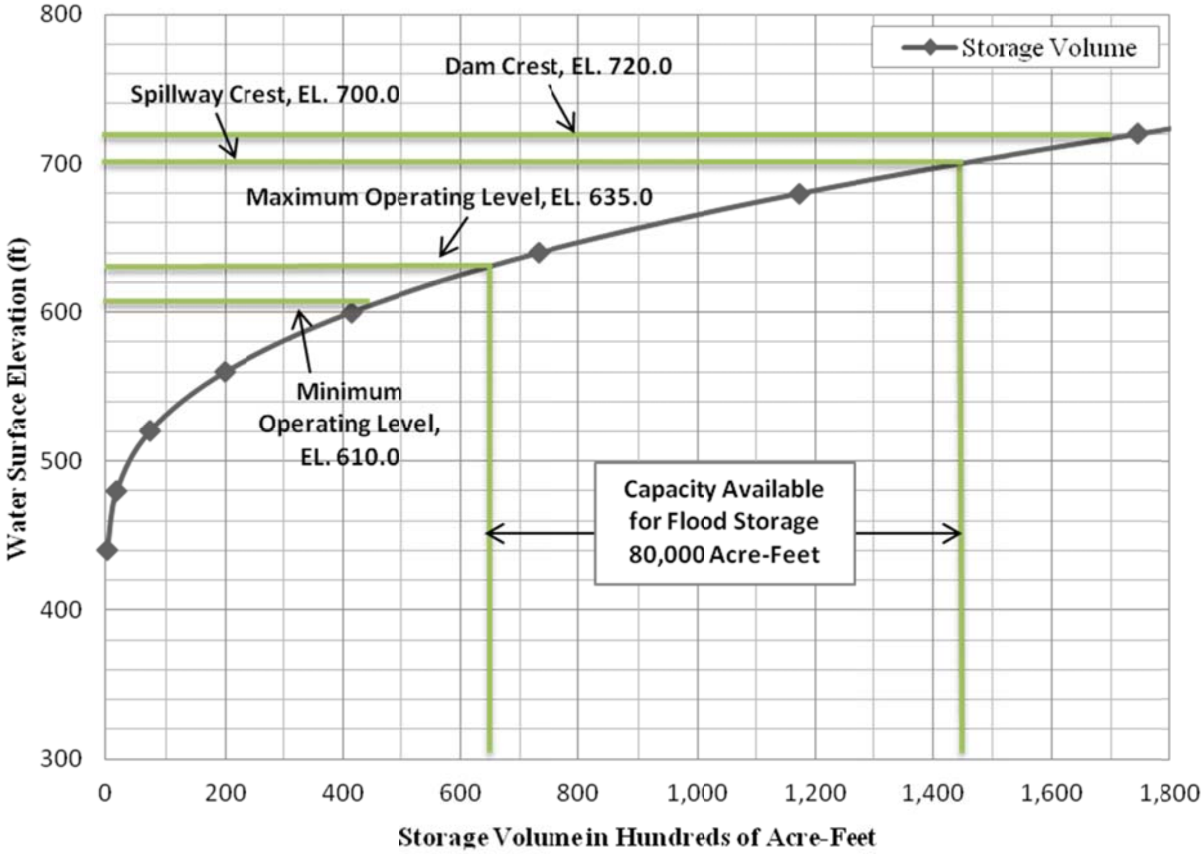


Multi-Purpose Structures

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

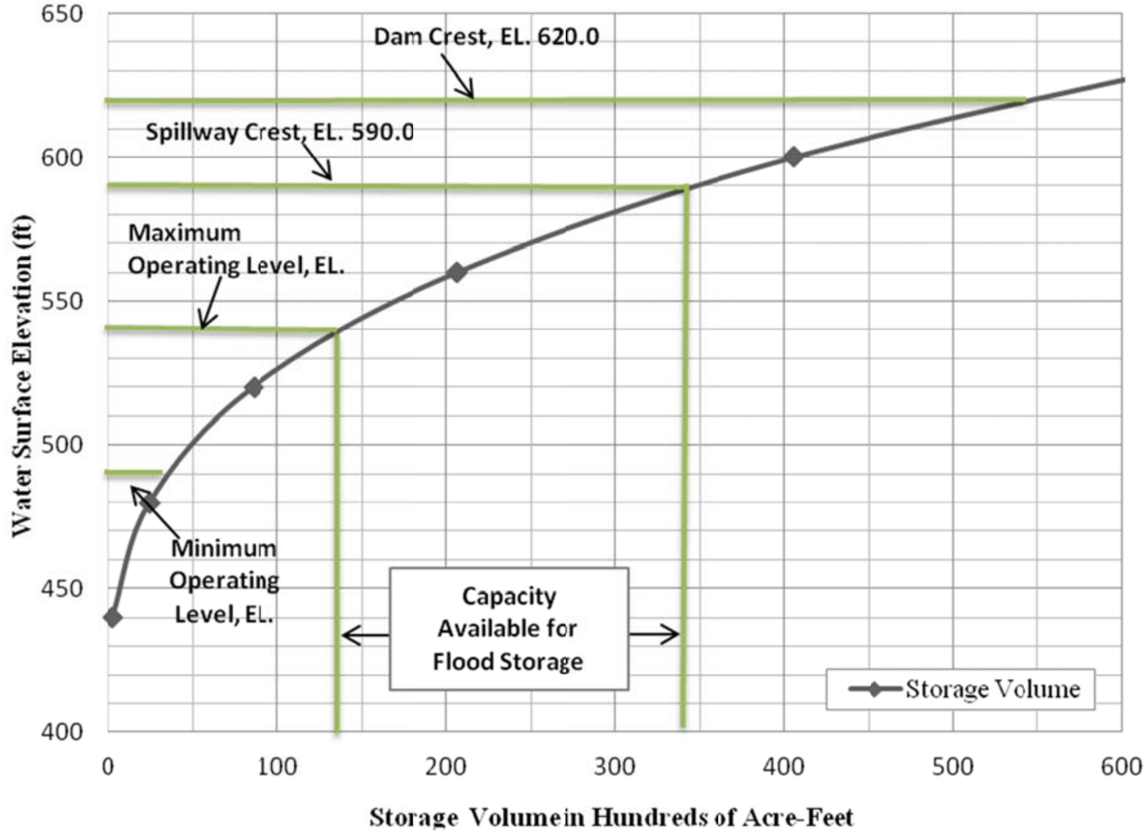


Capturing an additional 80,000 ac-ft for flood storage would raise the water surface 65 ft to El. 700.0, assuming the reservoir is at its approximate maximum operating level of El. 635.0. This elevation corresponds to the maximum reservoir capacity of 145,000 ac-ft, which would have a water surface area 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 6. 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. Because the flood storage only structure would only be used intermittently, it will be important to ensure that flood gates are fully functional in between uses, and that vegetation is properly managed.

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 water surface level within the reservoir 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 thresholds 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. If the outflow amount is increased from 732 cfs to 1,000 cfs, all but two flood events are contained (1996 and 2007, see Figure 8).[6] In events like those in 1996 and 2007, the structure would help decrease flood levels but would not prevent all flooding. In addition, these structures will not prevent flooding elsewhere in the Basin, but can be a tool to help manage flood waters. These analyses include historic flows from the period of record, or 70 years of flow data at the USGS gage near Doty.

[6] 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

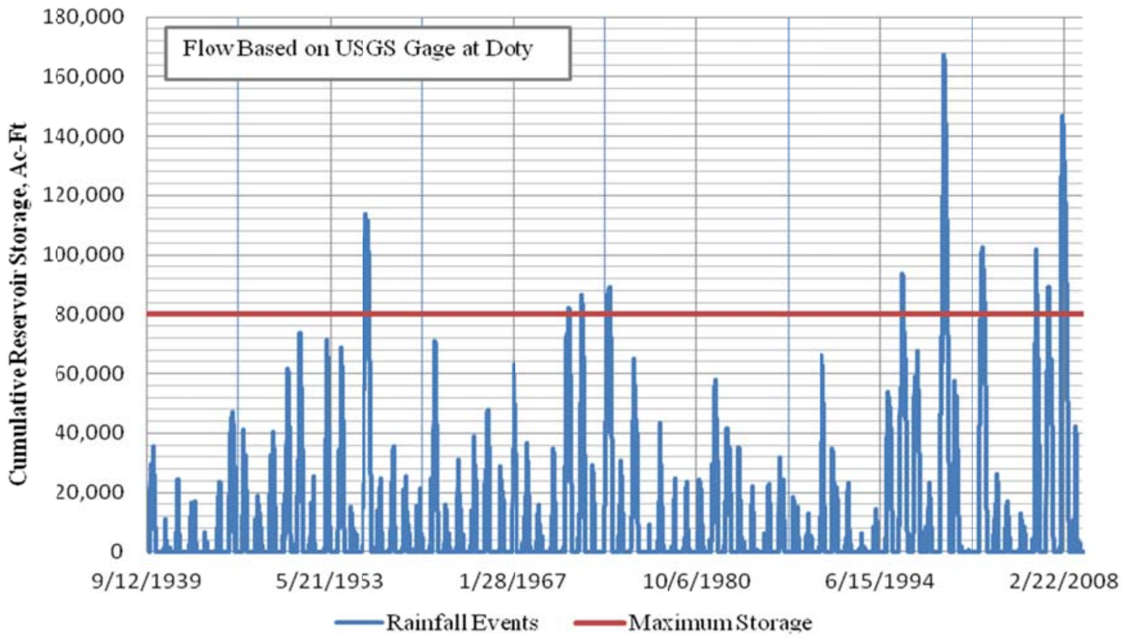
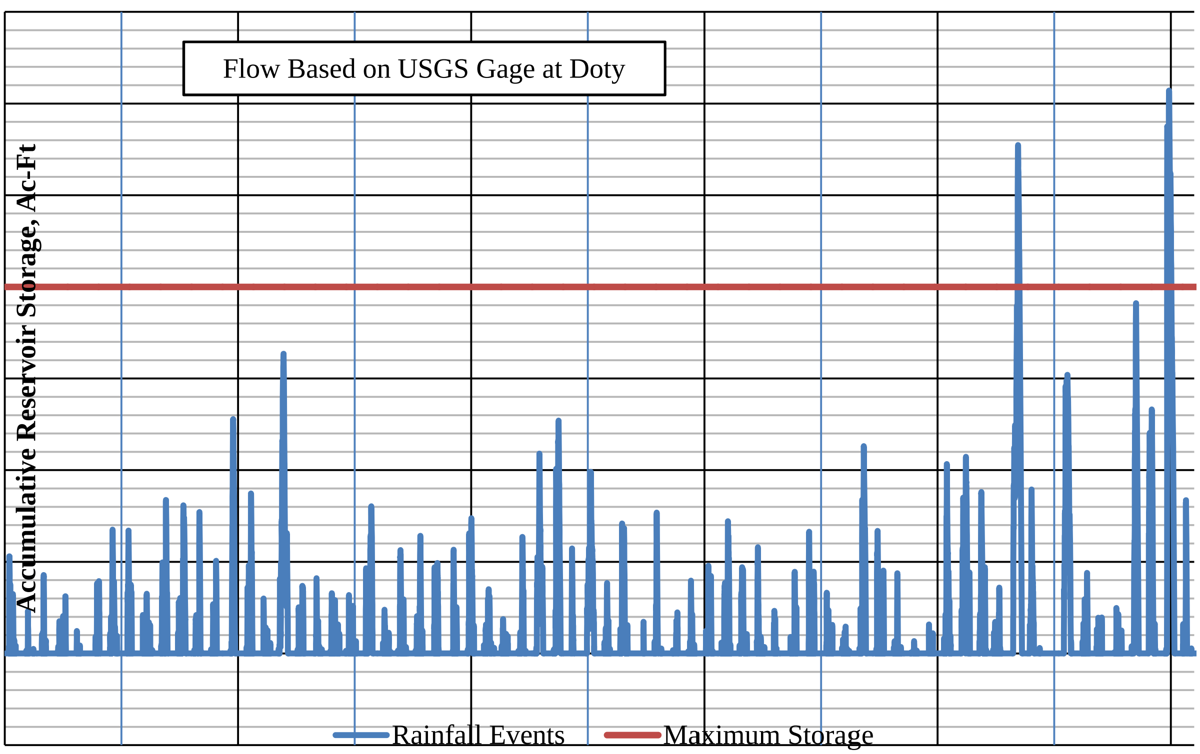


Figure 8
Upper Chehalis Flood Evaluation with 1,000 cfs "Pre-determined" Release Flow



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 water surface level within the reservoir has 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

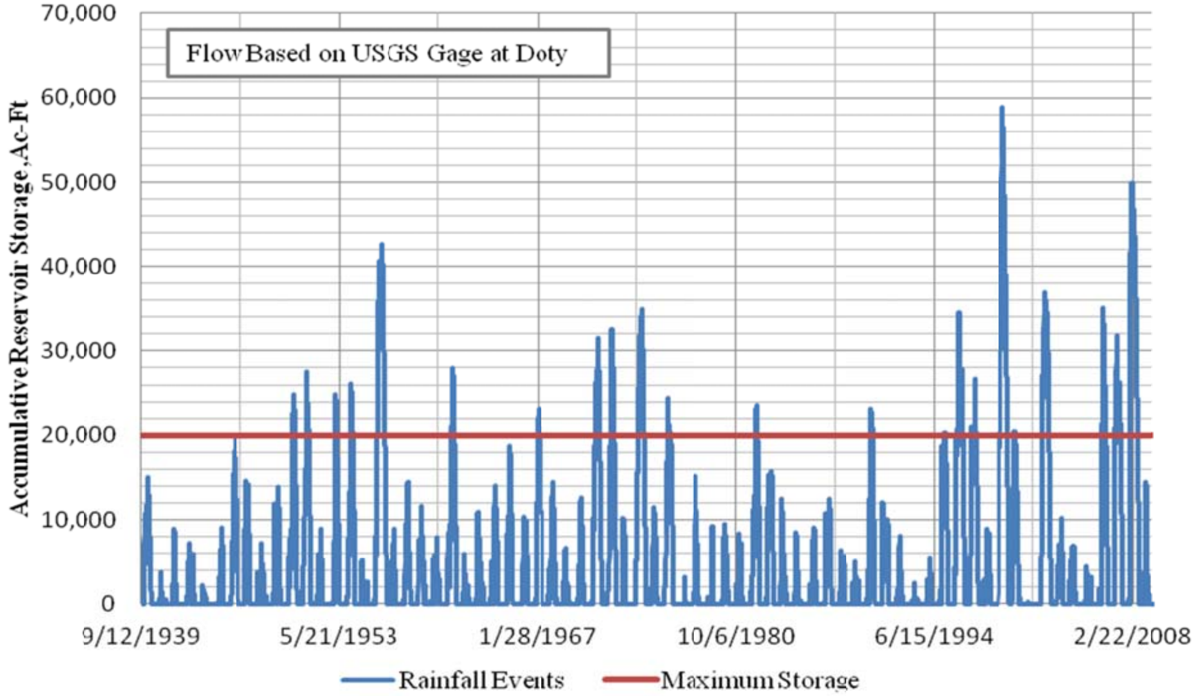
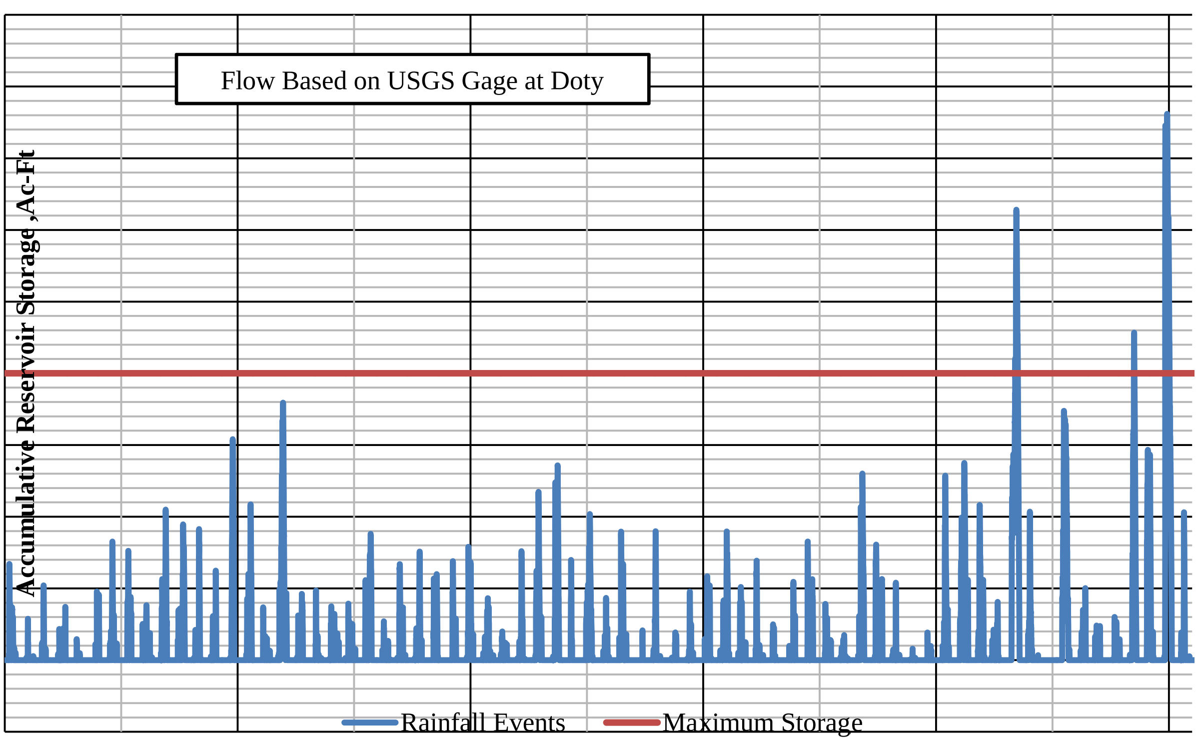


Figure 10
South Fork Flood Evaluation with 350 cfs "Pre-determined" Release Flow



Hydroelectric Project Operations

Energy production models were developed to calculate the potential average annual energy production for each multi-purpose project. The energy model is an Excel-based model that uses daily average inflow, reservoir storage volume curves, and flow releases to calculate daily energy production and ending reservoir levels. Other user-selectable inputs include turbine capacity, maximum operating level, minimum operating level, and turbine operating rules.[7] 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.[8] The Doty gage is used because of its proximity to the proposed structure sites.[9] 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 can be resumed and reservoir levels 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:

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[7] For example, the model user determines when the turbines operate at full capacity or whether just the smaller turbine operates.

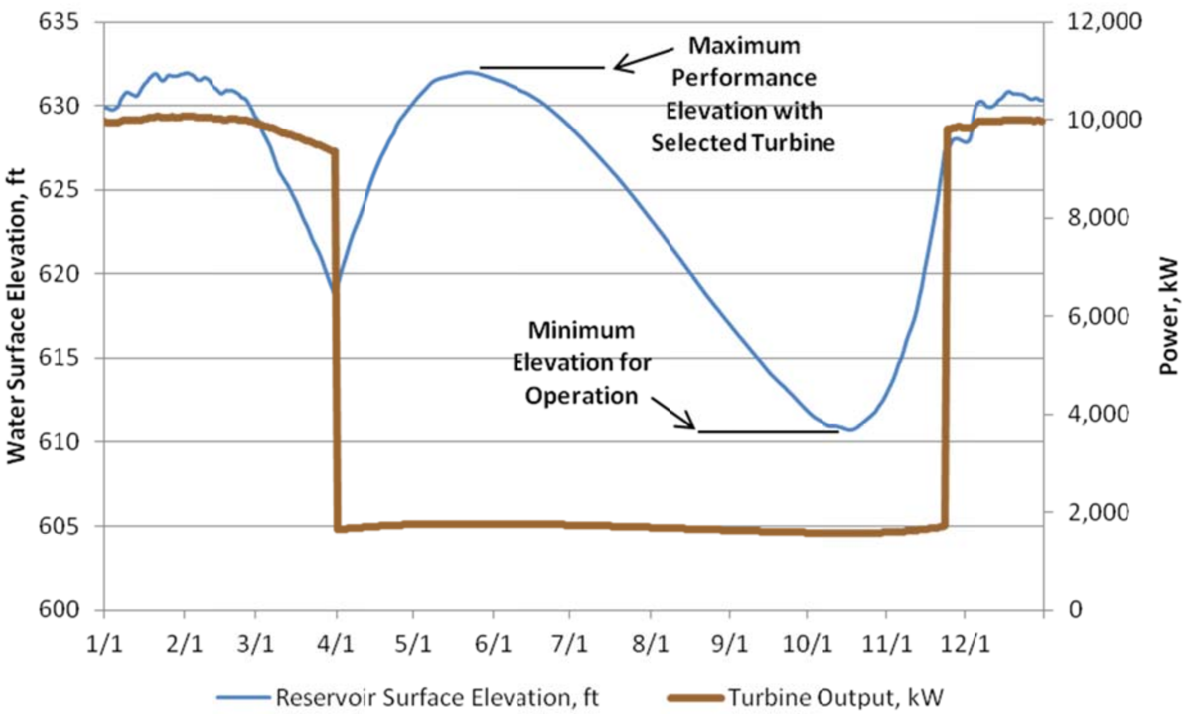
[8] The Phase I analysis relied on the gage data near Grand Mound because the Doty gage washed out in the 2007 flood. However, feedback from reviewers suggested using the Doty gage due to its proximity, and incorporating the USGS estimates for the 2007 flood.

[9] 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 hydropower plant with two turbines is recommended, 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.
- 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.[10]

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.

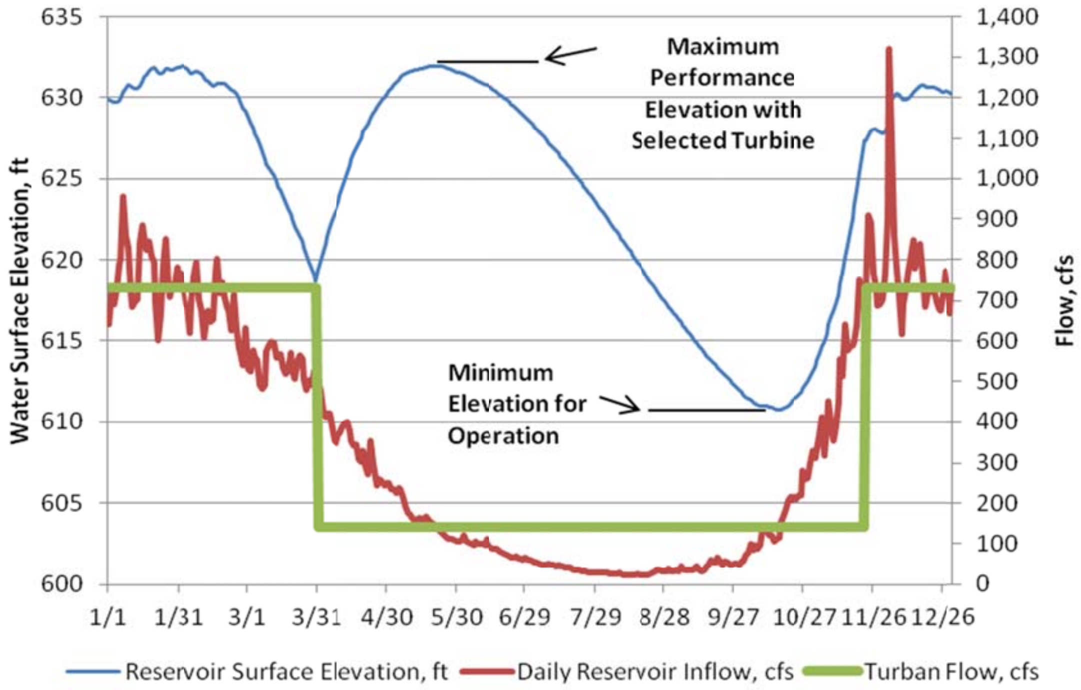
Figure 11
Upper Chehalis Turbine Output Based on Average Water Year[11]



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

[11] This Figure, as well as the following Figures 12-14, was developed from the energy model discussed at the beginning of this "Hydroelectric Project Operations" section. Drier-than-average and wetter-than-average water years would show different results for turbine operation. For example, in a drier-than-average year, turbine outflow would be reduced in the spring time much sooner compared with the average year, to ensure that water is available for summer flow augmentation. Comparable figures for such atypical years were not developed for the analysis.

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.

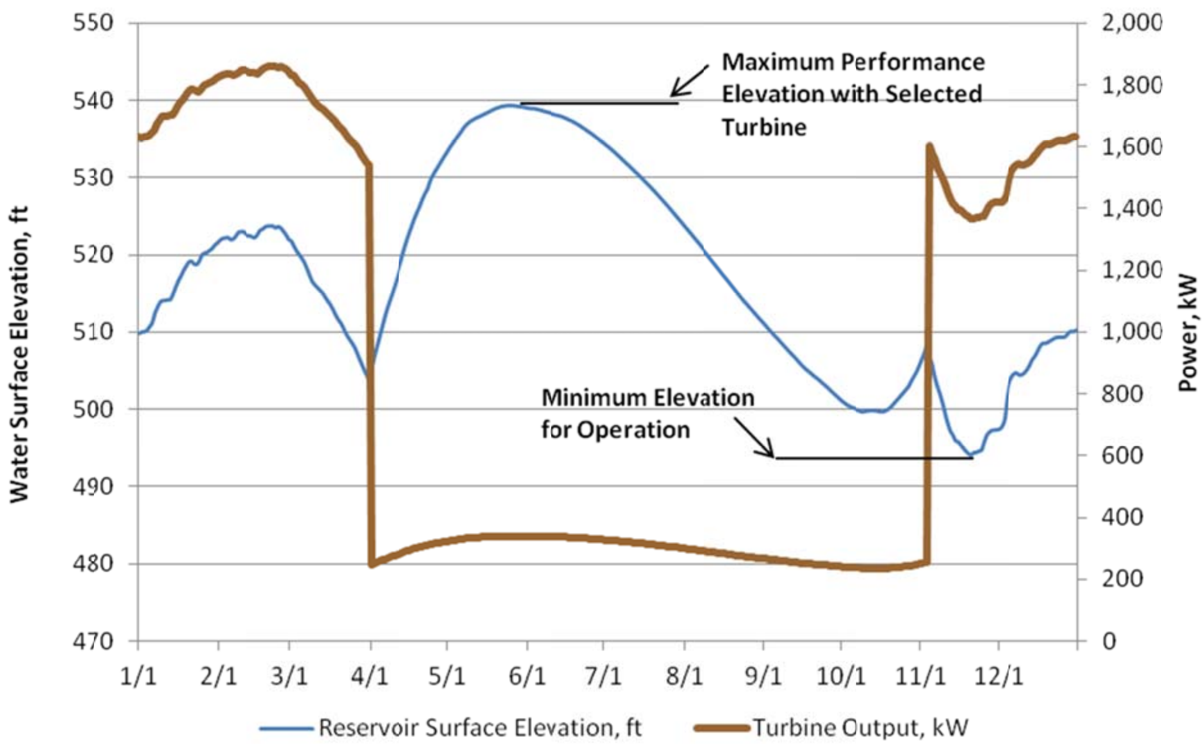
The following are the results of the hydro generation analysis for the South Fork:

- A hydropower plant with two turbines is recommended, 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 7,401 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.[12]

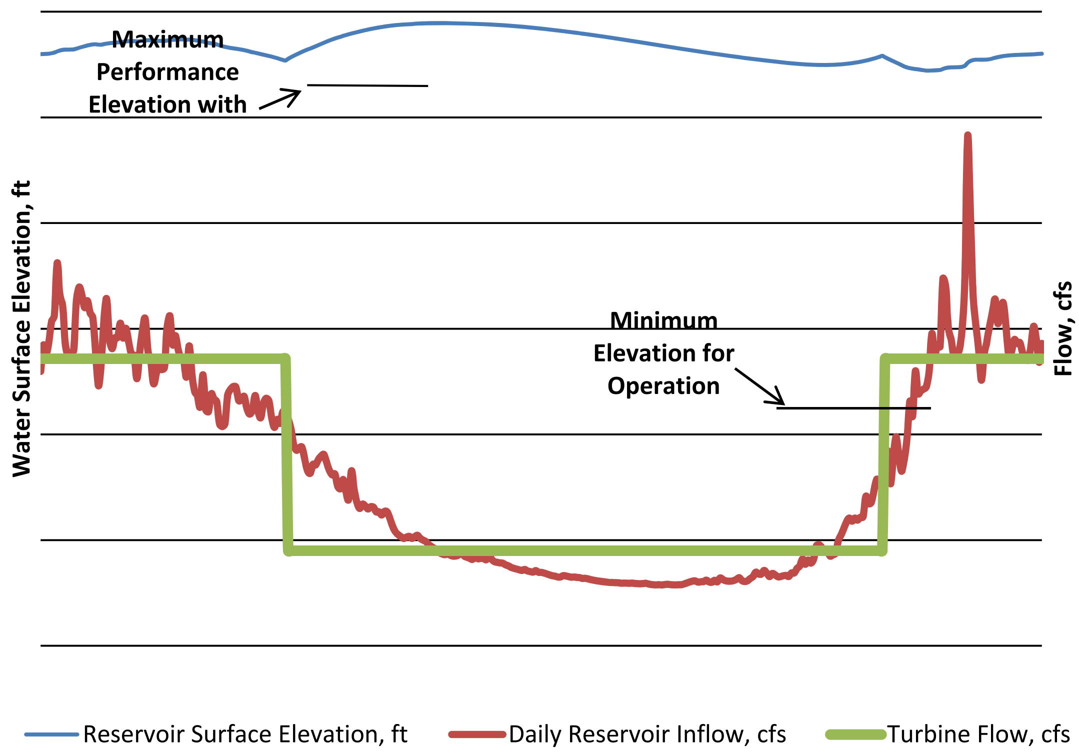
Figures 13 and 14 illustrate the operation of the reservoir and generation over the course of a year.

Figure 13
South Fork Turbine Output Based on Average Water Year



[12] 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 Attachment A. EESC incorporated these comments, and prepared the preliminary drawings presented in Attachments 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 Attachment 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 located at the end of the spillway chute dissipates energy and delivers 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[13]. 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 and is based on a turbine flow of 735 cfs. After construction is completed, this diversion tunnel will be retained to serve as a low-level outlet so the reservoir can be completely drained. This ability to drain the reservoir completely is an important consideration for maintenance and safety issues.

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. Taking advantage of possible natural water stratification phenomena within the reservoir, selective withdrawal is used to improve such water quality parameters as 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 is required and will 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

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

passage and must be evaluated once more is known through the fish studies by Anchor QEA about the specific needs and requirements of the fish populations present.

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 must 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 Attachment 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 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.[14]

[14] 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 could enable summer flow augmentation and facilitate management to improve downstream water quality parameters such as water temperature and dissolved oxygen levels. Additional analysis is needed on this subject.

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, and trap-and-haul, may be possible to accomplish 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.[15] The cost estimates developed for each project are presented in Attachment D. The total estimated costs are believed to be accurate within 30% (estimates include 30% contingency).[16]

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, professional 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 Attachment 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, internal project owner and legal costs have not. Time for construction is estimated at four years.

[15] 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.
[16] 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

A list of additional studies is included in the main body of the Phase IIB Report.

Attachment A
Shannon & Wilson Letters

Attachment B
Upper Chehalis Structure Preliminary Drawings

Attachment C
South Fork Structure Preliminary Drawings

Attachment D
Upper Chehalis and South Fork
Structure Preliminary Cost Estimates