CAPITOL LAKE ALTERNATIVES ANALYSIS HYDRAULIC MODELING

Prepared for:

General Administration
STATE OF WASHINGTON


Tumwater Falls at flood stage – December 3, 2007 storm (source: DNR)

Prepared by:

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Executive Summary

Washington State Department of General Administration and the CLAMP Steering Committee are developing an understanding of the different future management alternatives for Capitol Lake. In particular, a goal of the CLAMP Steering Committee is to complete a study that evaluates the possibility of a restored estuary as an alternative to the continued management actions necessary to maintain a lake in this setting.

As one piece of this study, this report describes hydraulic model predictions of the flood risk associated with the different future management alternatives. Given the 50-year project lifetime, it is also necessary to consider how the flood risk in Olympia may be affected by climate change – both sea level rise and potential increases in peak river flows – in the future.

Moffatt & Nichol developed a numerical model to simulate flooding in Capitol Lake using the HEC-RAS software suite. The model of existing conditions was compared with newly available calibration data, including the flood of December 3, 2007, and adequate results were obtained. When the model was used to hindcast flood conditions over the 47-year period from Water Year 1962 to Water Year 2008, the return period flood conditions were almost one foot lower than those obtained in an earlier (2003) floodplain study by URS Group, Inc., and Dewberry.

Detailed examination of the results showed that flood levels in the Lake can be dramatically affected by the management of the Capitol Lake Dam. General Administration opens and closes the radial gates at the Capitol Lake Dam when the lake levels reach specified high and low setpoints. The intent is to maintain the lake at certain target lake levels: approximately +6.2 feet relative to NGVD29 in the summer, and +5.2 feet NGVD29 in the winter. The target lake levels can be temporarily reduced if a storm event is anticipated and during the storm itself. Present management of the Capitol Lake Dam appears more successful in reducing flooding compared to earlier approaches.

M&N modeled the following current and future lake conditions.

- Existing Lake Condition. The report investigates flood conditions with the existing lake bathymetry and potential modifications to existing management of the Capitol Lake Dam. In particular, the report investigates the assumption that improved flood prediction ability will always allow the radial gates at the dam to be opened and the lake to be lowered ahead of flood conditions.
- Managed Lake Condition. This includes dredging of the existing lake to the spillway elevation (-7.2 feet NGVD29). Modifications to the existing dam management are also investigated.
- Lake Condition with Sedimentation. This assumes the lake would not be dredged for the next 25 or 50 years.
- Estuary Restoration: Single Basin. This alternative would restore the Deschutes Estuary by removing the Capitol Lake Dam. The estuary bathymetry used in this report is based on the condition predicted 10 years after restoration (USGS 2008).
- Estuary Restoration: Dual Basin. This alternative would restore the Deschutes Estuary by removing the Capitol Lake Dam. The difference between the Single Basin and Dual Basin alternatives is that a separate reflecting pool will be constructed in the eastern part of the North Basin.

Table ES-1 summarizes the peak flood elevations for a subset of the current and future conditions. More cases are given in the body of this report. Lake Lowering is a dam management approach in which the target lake level is reduced to +1 foot relative to NGVD29 – approximately Mean Sea Level – before a major storm.

Table ES-1. Peak Elevations for Future Alternatives

Return Period, years	Peak Flood Elevations, feet NGVD29				
	Existing Lake, No Lake Lowering	Existing Lake, Lake Lowering	Dredged Lake, Lake Lowering	50 Years Added Sediment, Lake Lowering	Estuary Alternatives (Both Cases)
2	9.0	8.6	8.6	8.9	10.0
5	9.8	9.5	9.5	9.8	10.4
10	10.1	9.9	9.9	10.2	10.6
25	10.4	10.2	10.2	10.5	10.8
50	10.5	10.3	10.3	10.6	10.9
100	10.6	10.4	10.4	10.7	11.0

Note: The difference between the lake and estuary cases should be considered an upper limit

The increase in flood levels for the Estuary Alternatives should be considered an upper limit, for two reasons. First, the results for the Lake Alternative assume that the dam management continues to be near-optimal, and that there are no mechanical failures (such as the gates being jammed open or shut), human errors, or similar adverse events during the storms. Second, the results for the Estuary Conditions are dependent on the tide levels in Budd Inlet, for which only a short period of record is available. The approach used to estimate the tide levels may overestimate the tide levels slightly (by 0.1 or 0.2 feet). However, the model definitely supports the conclusion that the peak flood elevations for the Estuary Alternatives are higher than for the Lake Alternatives – in almost all storms the dam management is able to keep the peak lake elevation below the peak tides in Budd Inlet.

The differences between the various lake (non-estuary) conditions are relatively small for the high return period events. Dredging the lake and implementing the lake lowering decreases the 100-year flood elevation by less than 0.3 feet. The differences between the lake conditions are larger, up to nearly one foot, for the two-year flood.

The high return period floods result from high river flow events that last for more than 24 hours and span multiple high tides. For a relatively short storm, increasing the available storage by lowering the lake in advance does decrease the peak flood elevation. As the tide rises on the Budd Inlet side, flows from the Deschutes River fill the lake. The peak flood elevation occurs at the moment when the ebbing tide level drops below the rising lake level. If the lake starts at a lower elevation and more flood storage is available then this peak flood elevation is lower.

For a longer storm, General Administration attempts to drain the lake after the first high tide has receded. However, the radial gates are limited in their ability to drain the lake to very low levels (close to or below Mean Sea Level (MSL)). As the second and later high tides approach, the lake begins at a higher initial elevation irrespective of the target lake level. The higher flood levels are almost independent of the target lake level. Similarly, the additional storage provided by dredging the lake is mostly below MSL: this storage remains ineffective through much of the longer storm events. The critical aspect of the dam management is that the radial gates are opened as soon as possible after each high tide recedes. The results presented in this report assume this is done irrespective of the target lake level.

Under both Estuary Alternatives – Single Basin and Dual Basin – the peak flood elevations are completely dominated by the tidal elevations. At high tide, the water level in the Middle and North Basins of the restored estuary is essentially equal to the tide level in Budd Inlet. Results are identical for both Estuary Alternatives. Frequent high water levels (2-year and 5-year) are up to one foot higher under the Estuary Alternatives compared to the lake conditions; the more infrequent floods (50-year and higher) are up to one-half foot higher under the Estuary Alternatives.

The inclusion of sea level rise in the model does not change the general conclusions. The peak flood elevations increase less rapidly than the mean sea level for the lake scenarios, while they increase directly with the mean sea level for the estuary. Table ES-2 summarizes the flood elevations for a mid-level sea level increase of 1.0 feet. The case of no lake lowering is not included: it is anticipated that lake lowering to +1 foot NGVD29 will be implemented in future. Instead, the table shows the effect of adding a potential third gate (or other structure such as pipes with check valves under Deschutes Parkway) to allow the lake to drain more rapidly.

Table ES-2. Peak Elevations for Future Alternatives, 1-foot Increase in Sea Level

Return Period, years	Peak Flood Elevations, feet NGVD29				
	Existing Lake, Lake Lowering	Dredged Lake, Lake Lowering	50 Years Added Sediment, Lake Lowering	Existing Bathymetry, Third Gate	Estuary Alternatives (Both Cases)
2	9.2	9.0	9.7	8.9	11.0
5	10.2	10.0	10.6	9.9	11.4
10	10.7	10.6	11.0	10.3	11.6
25	11.0	11.0	11.3	10.7	11.8
50	11.2	11.2	11.5	10.9	11.9
100	11.3	11.3	11.6	11.1	12.0

A nominal 50 percent increase in the runoff from the Deschutes River was also considered as a possible consequence of future climate change. This increased the 100-year flood elevation for the Lake Alternative by 1.1 feet – a significant amount. It had no effect on the 100-year flood elevation for the Estuary Alternatives.

The main conclusions of this report are as follows.

- The different lake and dam management scenarios – dredging and further lowering the lake in advance of storm events – have relatively little effect on peak flood elevations. The critical aspect of dam management is that, during a storm event, the radial gates are opened to lower the lake as soon as possible after each high tide recedes. The results suggest that the existing dam management is close to optimal. The results also suggest that, from a flood management perspective, there is no immediate urgency in dredging Capitol Lake
- Under the Estuary Alternatives, the peak flood elevations are dominated by the tidal elevations and are up to half a foot higher than under the Lake Alternative. This increase is larger for the more frequent high water levels (2-year and 5-year). However, at present sea levels, the peak flood elevations are no higher than the existing 100-year FEMA floodplain elevation.
- The potential for future sea level rise does not change these results. The peak flood elevations increase slightly less rapidly than the mean sea level for the Lake Alternative, while they increase directly with the mean sea level for the Estuary Alternatives. In contrast, increases in runoff from the Deschutes River can increase the peak flood elevations significantly for the Lake Alternatives, while they have essentially no effect on the peak flood elevations for the Estuary Alternatives.

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1. Introduction

1.1 Background

Capitol Lake was created in 1951 through the construction of the Capitol Lake Dam, which disconnected the Deschutes River from Budd Inlet. The construction of the dam in 1951 fulfilled the 1911 vision of architects White and Wilder by providing a reflecting pool for the State Capitol Building.

Capitol Lake is increasingly unsustainable in its current configuration. Sediment from the Deschutes River and Percival Creek is filling in the lake; environmental concerns mean that ongoing dredging of the lake is increasingly difficult and expensive. The lake is on the state list of impaired waterbodies for fecal coliform bacteria and total phosphorus. The noxious weeds purple loosestrife and eurasian milfoil are invading the lake. The need for a new lake management plan surfaced in 1996, when the State was attempting to gain permits for the construction of Heritage Park on the eastern shore of the North Basin and maintenance dredging the Middle Basin and Percival Cove.

The Capitol Lake Adaptive Management Plan (CLAMP) was developed in response to these concerns (CLAMP Steering Committee 1999). A key Management Objective in the 2002 CLAMP 10-Year Plan (CLAMP Steering Committee 2002) was to complete a study that would evaluate the possibility of a restored estuary as an alternative to the continued management actions necessary to maintain the lake as it currently exists.

1.2 Existing Conditions and Future Alternatives

The purpose of this report is to develop an understanding of the flood risk associated with the different possible future management alternatives: continued management of the lake as a lake, and restoration of the Deschutes Estuary with or without a separate reflecting pool. The US Army Corps of Engineers' River Analysis System (HEC-RAS) software (USACE 2008) is used to predict peak flood conditions under existing conditions and under the future management conditions. Additionally, given the 50-year project lifetime under consideration, this report considers the likely effects of climate change on flood conditions. Both increases in mean sea level and the possibility of increased peak flows from the Deschutes River are considered.

In more detail, the following conditions are modeled.

- <u>Existing (Status Quo) Lake Condition</u>. The report investigates flood conditions with the existing lake bathymetry and potential modifications to existing operations of the Capitol Lake Dam. In particular, the report investigates the assumption that improved flood prediction ability will always allow the radial gates at the dam to be opened and the lake to be lowered ahead of flood conditions.
- <u>Managed Lake Condition.</u> This includes dredging of the existing lake to the spillway elevation (-7.2 feet NGVD29). Modifications to the existing dam operations are also investigated.
- <u>Lake Condition with Sedimentation.</u> This assumes the lake would not be dredged for the next 25 or 50 years. However, the modified dam operations assumed for the Managed Lake Condition would be implemented.
- <u>Estuary Restoration: Single Basin.</u> This alternative would restore the Deschutes Estuary by removing the Capitol Lake Dam. The estuary bathymetry used in this report is based on the condition predicted 10 years after restoration (USGS 2008).

- Estuary Restoration: Dual Basin. This alternative would restore the Deschutes Estuary by removing the Capitol Lake Dam. The difference between the Single Basin and Dual Basin alternatives is that a separate reflecting pool will be constructed in the eastern part of the North Basin.

1.3 Typical Elevations in Olympia

Figure 1 shows typical contour elevations in Olympia, in the area surrounding the North Basin of Capitol Lake. The lowest-lying areas are in Heritage Park and downtown Olympia, with significant areas at and even below elevations of +10 to +11 feet NGVD29. The contours date from 2002 and do not show recent construction of a berm at +11.5 feet NGVD29 along much of the perimeter of Heritage Park. More details of the vulnerable infrastructure in the Olympia area are given in Moffatt & Nichol 2008a.

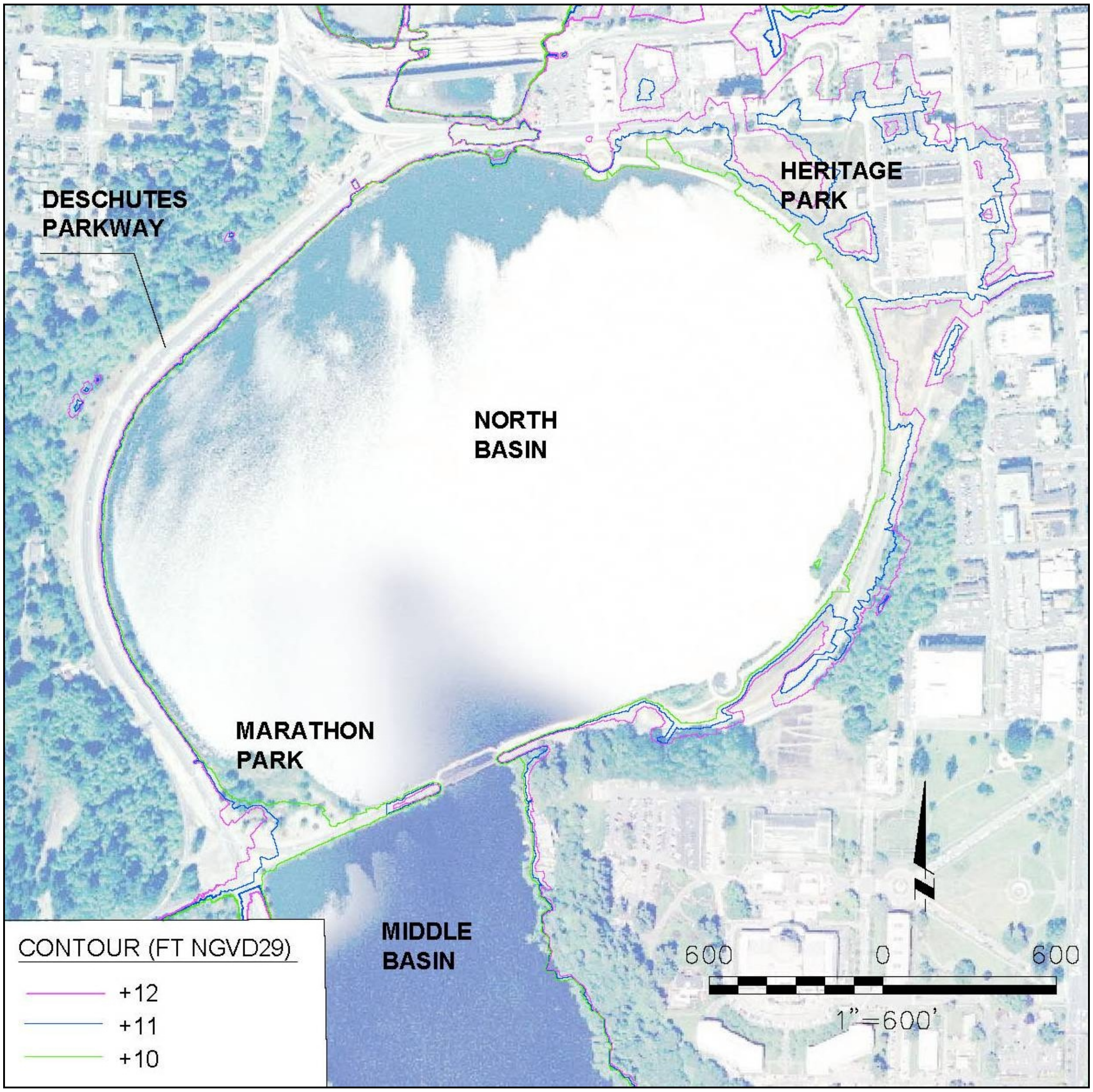


Figure 1. Elevations in Olympia surrounding the North Basin

All elevations in this report are given relative to NGVD29, the National Geodetic Vertical Datum of 1929. NGVD29 is close to Mean Sea Level (MSL) – in Olympia, Mean Sea Level is approximately one foot above NGVD29. It is common for elevations in Olympia to be quoted relative to NGVD29, although it is often stated that the elevations are relative to MSL. Table 1 gives a number of elevations, including tidal elevations in Budd Inlet, relative to NGVD29.

Table 1. Tidal and Other Elevations Relative to NGVD29

Item / Quantity	Elevation (feet, NGVD29)
Highest Observed Tide in Budd Inlet (12/15/1977) *	+10.54
Mean Higher High Water (MHHW)	+7.16
Mean Sea Level (MSL)	+0.96
NGVD29 Datum	0.00
Mean Lower Low Water	-7.40
Lowest Observed Tide in Budd Inlet *	-11.73
Summer Lake Levels	+6 to +7
Winter Lake Levels	+4.5 to +5.5
Top of Arc of Statehood	+10.9
Lowest Point in Downtown Olympia (7th and Columbia)	+8.4
Deschutes Parkway along the North Basin	+12 to +14
Capitol Lake Dam: Gate Sill	-7.2
Capitol Lake Dam: 5th Avenue Road Deck at Dam	+16 to +17

* NOAA measured tides in Budd Inlet only for the period April 1977 to March 1978. These were the extreme tides observed during that period, and the high tide was exceptionally high. However, it is possible higher tides have occurred since 1977.

1.4 Climate Change

Two effects of climate change are considered here: the potential for increases in the mean sea level and the potential for increases in the peak flow from the Deschutes River.

The University of Washington Climate Impacts Group and the Washington State Department of Ecology (2008) provides estimates of future increases in mean sea level as shown in Table 2.

Table 2. Estimates of Washington (Puget Sound) Sea Level Change

	Increase Relative to 1980-1999 Average	
Estimate	**By 2050**	**By 2100**
Very Low	3”	6”
Medium	6”	13”
Very High	22”	50”

In order to capture the range of variability over the next 50 years, this report considers increases of 6 inches, 12 inches, and 24 inches (0.5 feet, 1.0 foot, and 2.0 feet) relative to 1980-1999 average conditions. The tides used in the modeling are based on the 1983-2001 tidal epoch, the latest epoch used by NOAA. The period 1983-2001 is sufficiently close to the period 1980-1999 (mid-points three years apart) that the increases shown in Table 2 can reasonably be taken relative to the 1983-2001 epoch.

To date, the analysis of climate change and its effects on river flows in the Pacific Northwest has generally focused on river basins such as the Columbia that are dominated by snowmelt (e.g., Mote *et al* 2003). In contrast, the Deschutes River basin is rain-dominant: floods are mostly associated with rainstorms. It appears that the effect of future climate change on rain-dominant basins is relatively small (Hamlet and Lettenmaier 2007). To bound the effects of potentially larger rainfall events and associated runoff on flooding in Olympia, this report considers one illustrative case: 50 percent increase in runoff associated with a 1.0-foot increase in mean sea level.

2. Model Setup and Calibration

2.1 Overview

The hydraulic model of Capitol Lake and its environs developed by Moffatt & Nichol is heavily dependent on the earlier modeling work performed for FEMA (URS Group and Dewberry 2003, referred to herein as the 2003 *Capitol Lake Floodplain Analysis*). As described in Appendix A, early in the analysis process it was decided to replace this earlier model, based on the FEQ software (USGS 1997) with a recent version of the more widely used and sophisticated HEC-RAS software (USACE 2008). However, the hydraulic model based on the HEC-RAS software inherits many of the modeling assumptions and other data from the earlier work.

2.2 HEC-RAS Model Connectivity and Bathymetry

As described in Section 1.2, the modeling work investigated five different alternatives: three lake conditions and two estuary alternatives.

Figure 2 illustrates the model connectivity for the three lake conditions (existing, dredged, and with additional sedimentation).

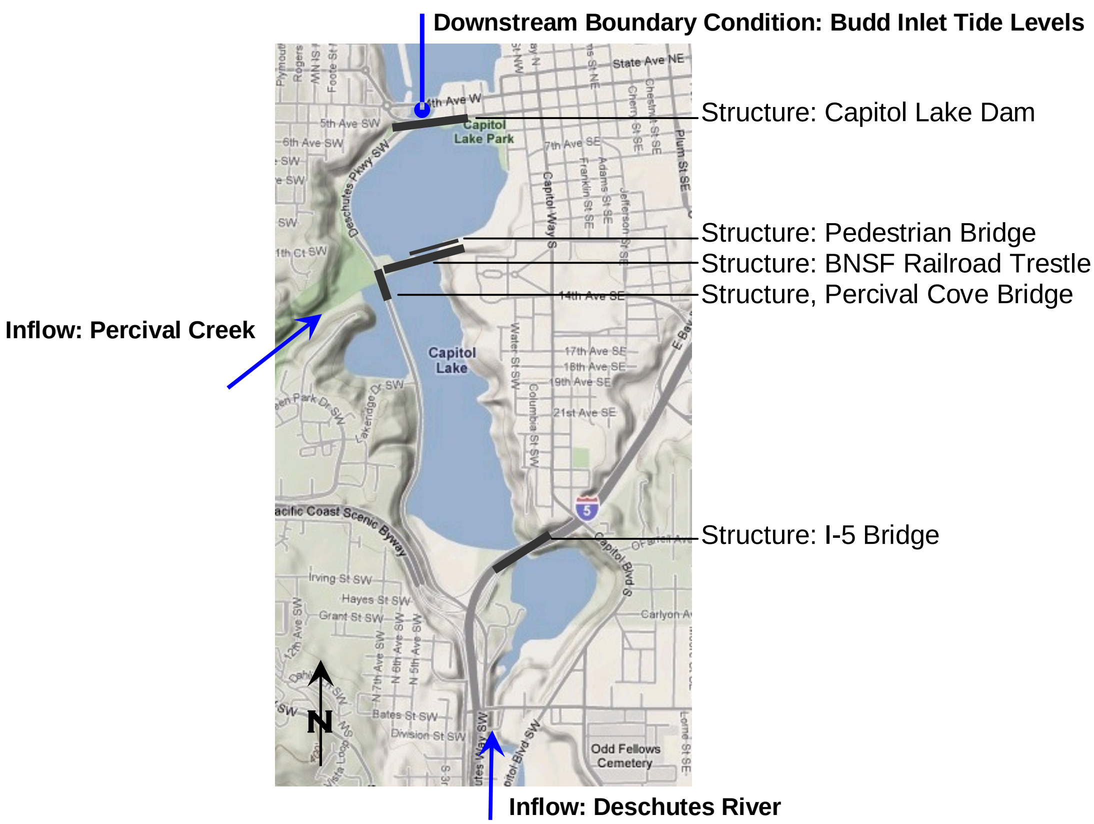


Figure 2. Model Connectivity for Lake Conditions (Map source: Google Maps)

For the lake, the flow rates from Deschutes River and Percival Creek provide the upstream boundary conditions. The downstream boundary condition is the tidal elevation in Budd Inlet and is defined immediately north of the Fifth Avenue Dam. Five structures are included in the model: the Capitol

Lake Dam and radial gates; the BNSF Railroad Trestle and the pedestrian bridge immediately to its north; the Percival Cove Bridge; and the I-5 Bridge.

For the two estuary conditions, the bathymetry was extended north to cover the whole of Budd Inlet. The downstream boundary condition was defined at the north end of Budd Inlet. This allowed the large tidally influenced flows at the mouth of the estuary to be modeled more accurately. Figure 3 illustrates the model connectivity for this case.

Figure 3. Model Connectivity for Estuary Conditions (Map source: Google Maps)

Figure 4 through Figure 7 illustrate the bathymetry south of the Capitol Lake Dam (for the lake conditions) and south of the Fifth Avenue Bridge (for the estuary conditions). Areas marked as Upland are generally at +12 feet NGVD29 or higher.

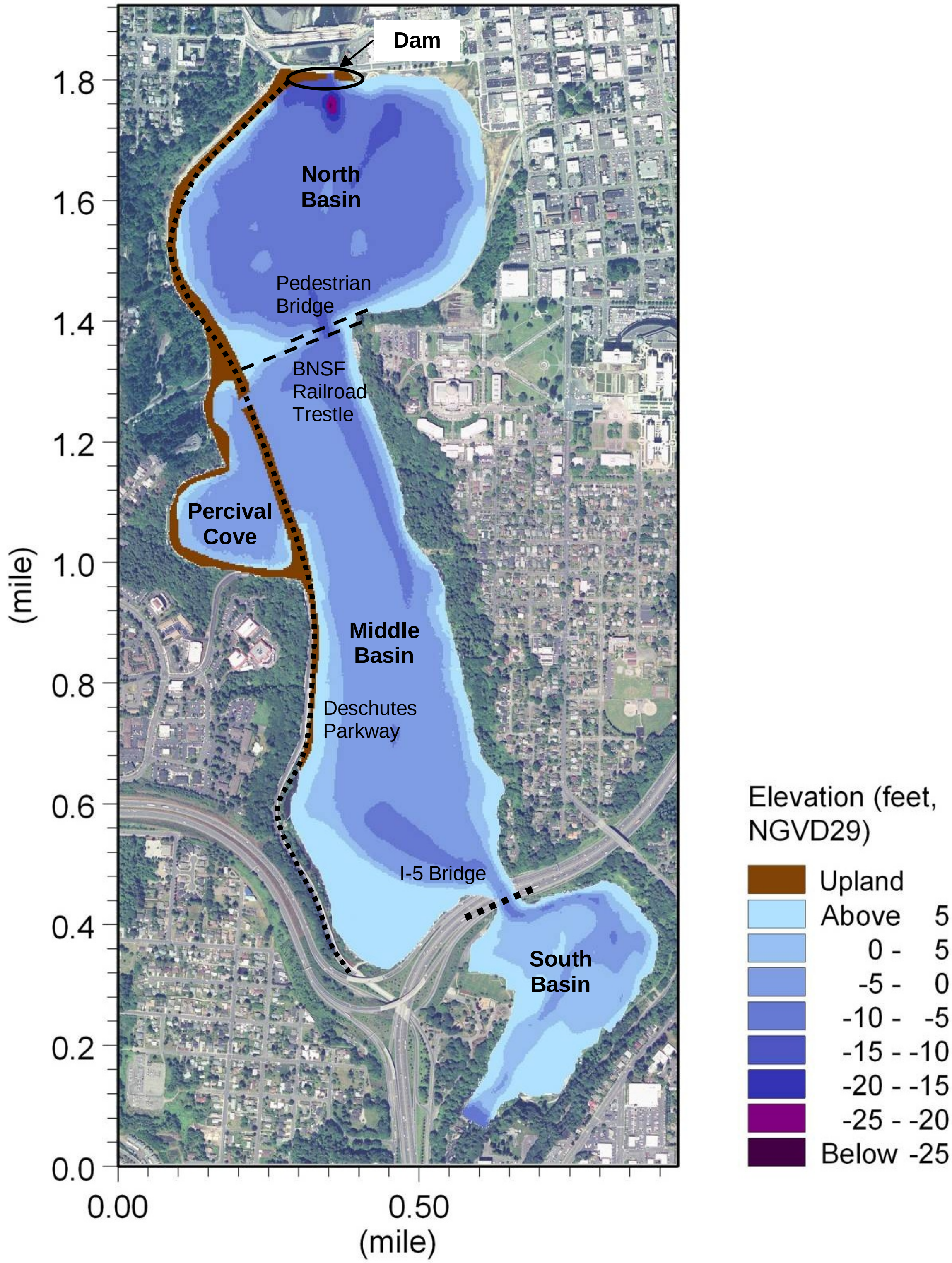


Figure 4. Existing (Status Quo) Lake Condition

Bathymetry for the Existing or Status Quo lake condition is based on bathymetry compiled by USGS in 2006 from a variety of sources and provided to Moffatt & Nichol as a GIS shapefile.

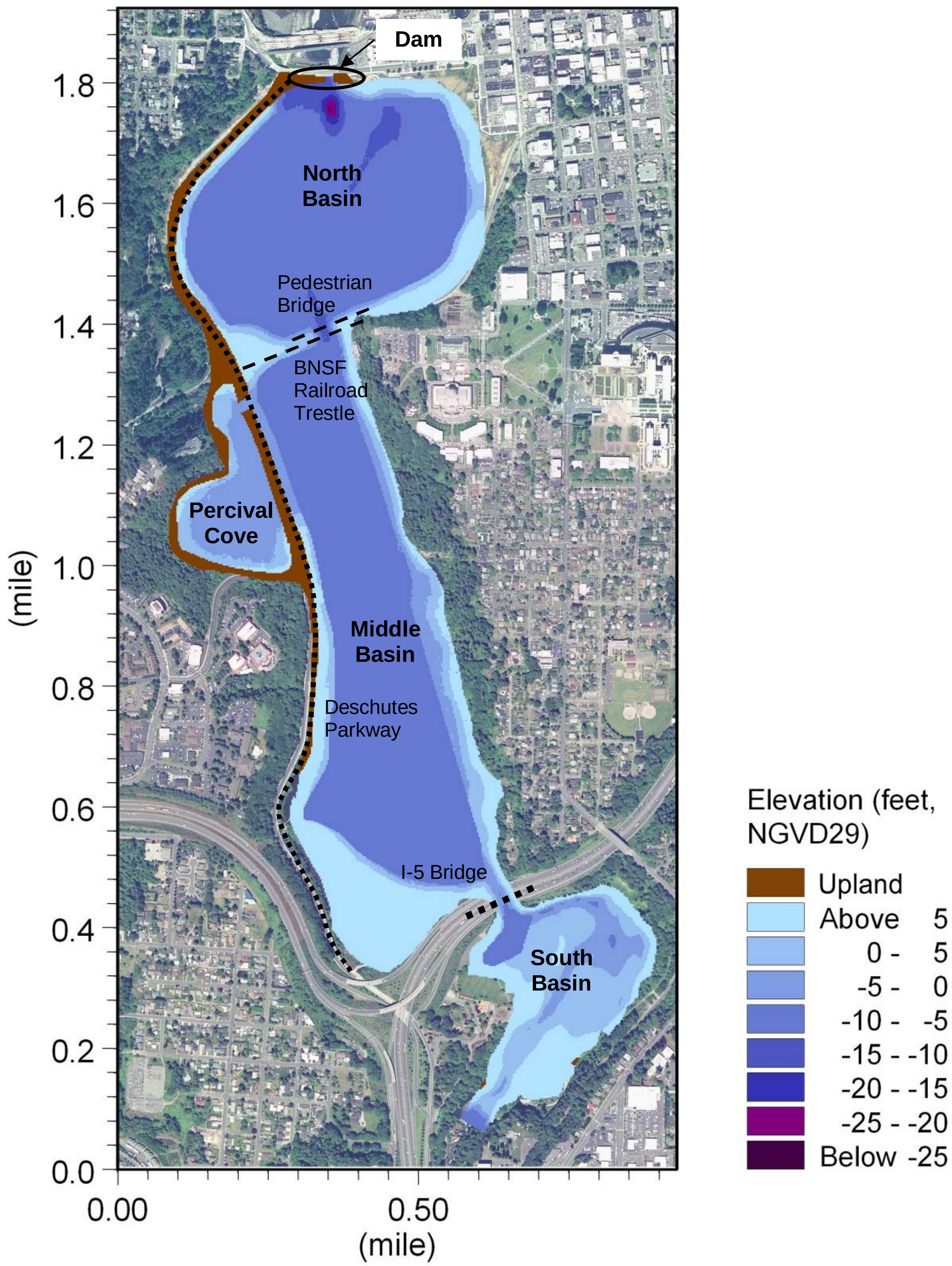


Figure 5. Managed Lake Condition

Bathymetry for the Managed Lake Condition takes the Existing Condition and dredges the North and Middle Basins, and a small area in the South Basin, to a minimum depth of -7.2 feet NGVD29 (the dam sill elevation). No dredging is performed within 100 feet of the shoreline.

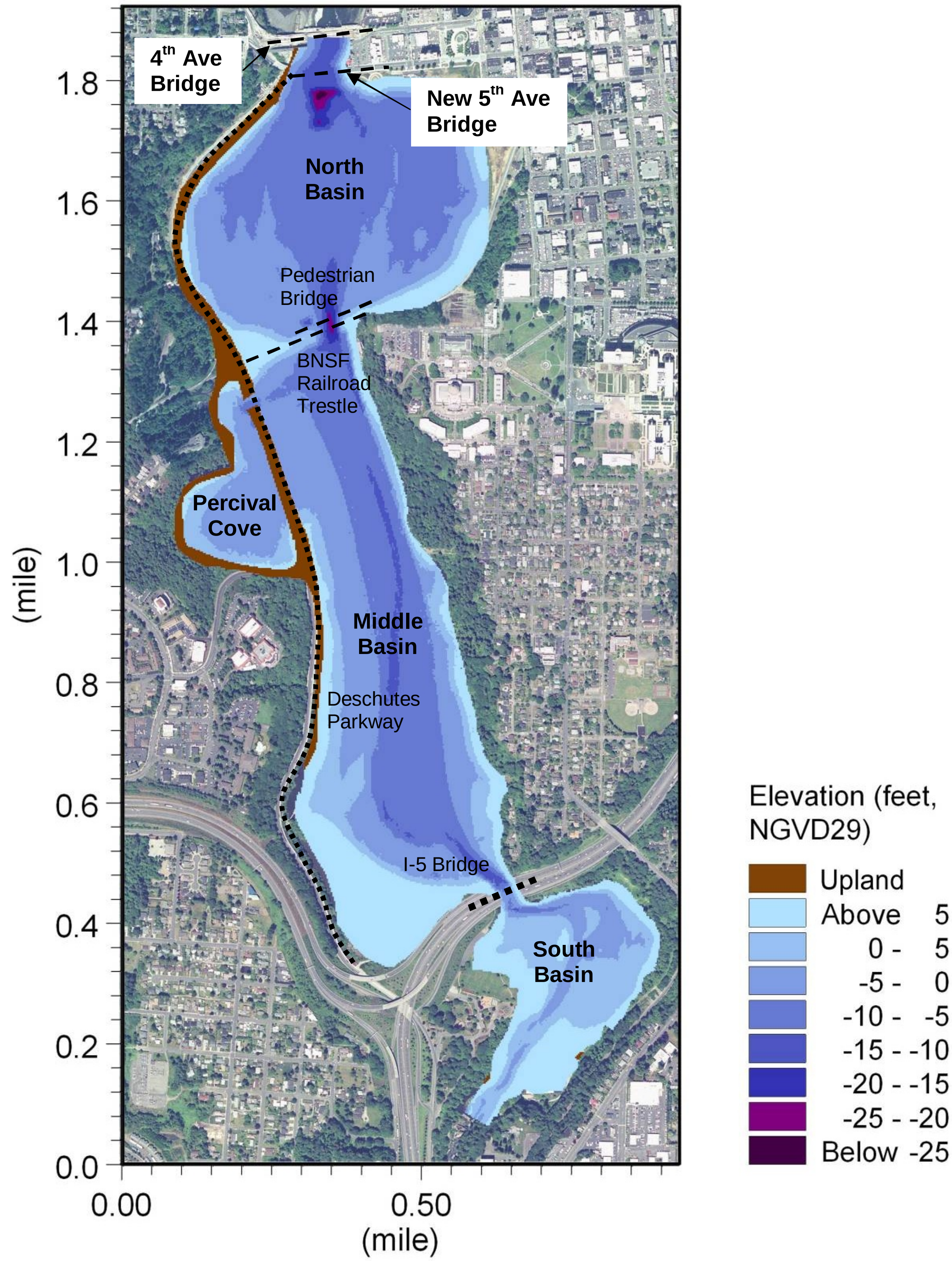


Figure 6. Estuary Restoration: Single Basin

Bathymetry for the single basin estuary restoration is based on the bathymetry predicted by USGS after 10 years of evolution (USGS 2008) and provided to Moffatt & Nichol as a text file. The bathymetry provided by USGS includes Budd Inlet, not shown in this figure.

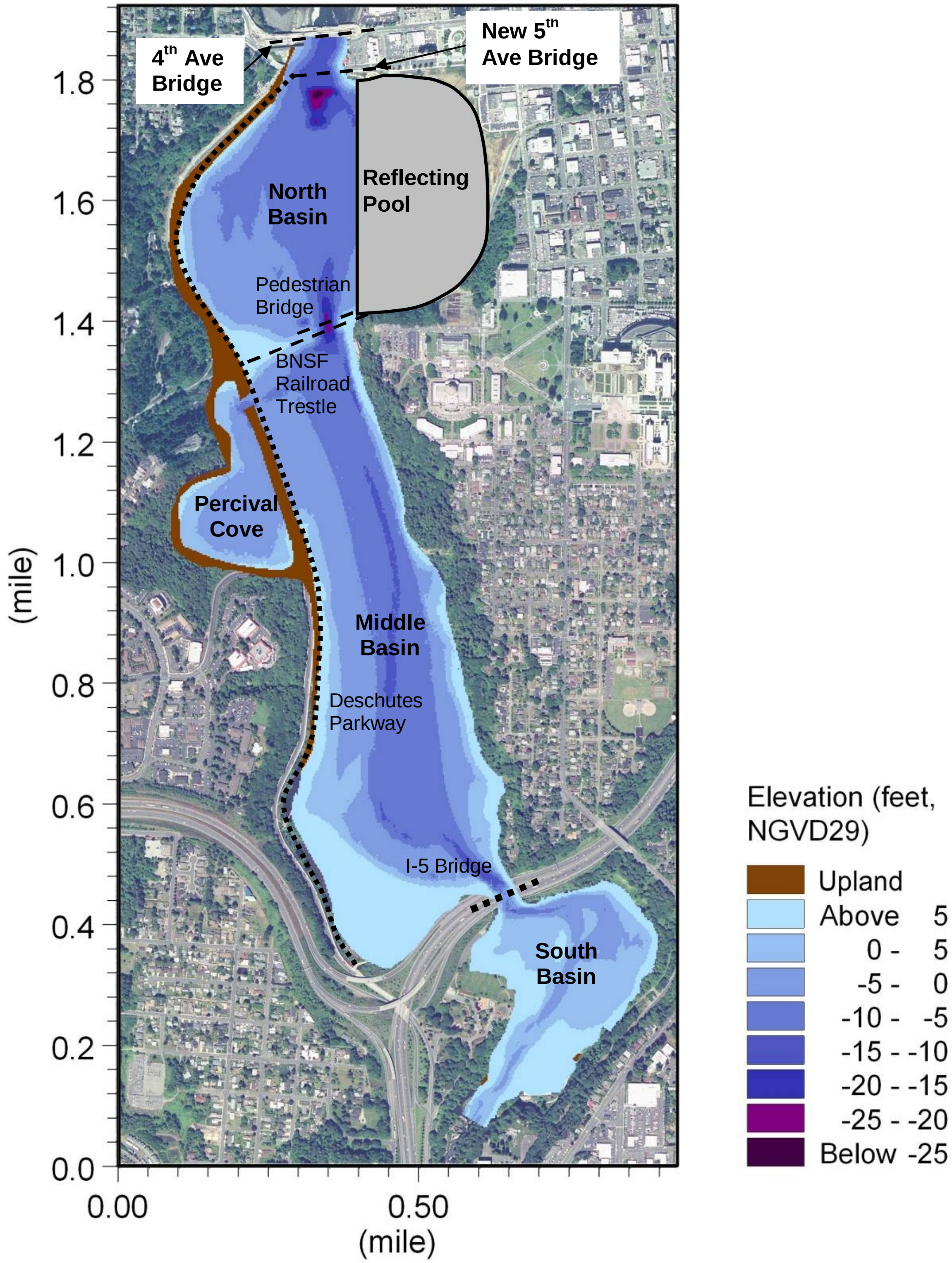


Figure 7. Estuary Restoration: Dual Basin

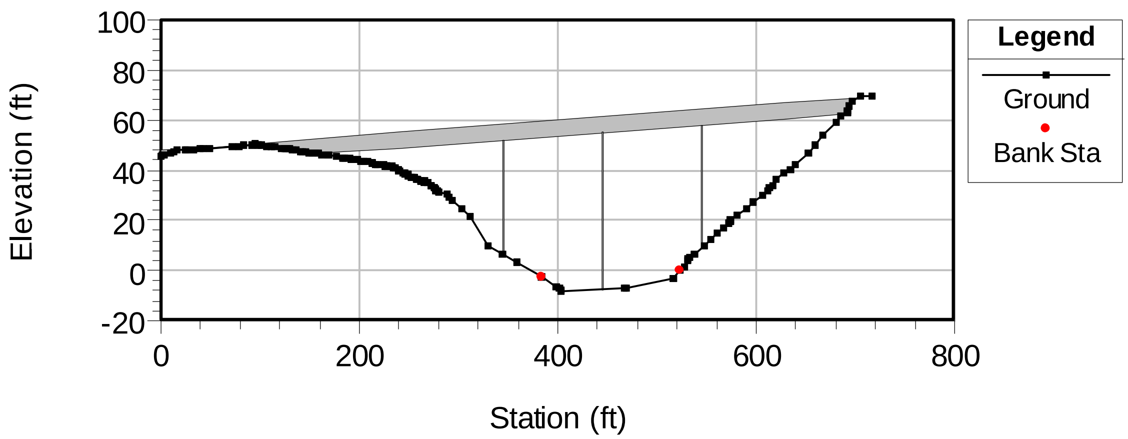
Bathymetry for the dual basin estuary restoration takes the Estuary Restoration: Single Basin configuration and excludes the area of the reflecting pool. The barrier for the reflecting pool is at an elevation of +11.50 feet NGVD29 (Moffatt & Nichol 2007), so that the potential for flood storage within the reflecting pool is realized only if the water surface elevation in the North Basin exceeds this level.

2.3 Model Structures

2.3.1 Bridge Structures

Four bridges are included in the HEC-RAS model of lake conditions: the I-5 Bridge, the BNSF Railroad Trestle, the adjacent pedestrian bridge, and the Percival Cove Bridge. The HEC-RAS model of estuary conditions includes two additional bridges: the existing Fourth Avenue Bridge and a new Fifth Avenue Bridge that would replace the Capitol Lake Dam. The Fourth Avenue Bridge is not included in the model of lake conditions because that model does not include Budd Inlet north of the dam.

Figure 8 illustrates the model definition for the I-5 Bridge, together with a photograph of the bridge. The photograph of the I-5 Bridge was taken at very low water (during a lake drawdown event).



Source: WDFW

Figure 8. I-5 Bridge: HEC-RAS Model Setup and Photograph

The HEC-RAS model schematics in this section show the bridges as from the upstream (south) side.

Figure 9 illustrates the BNSF Railroad Trestle (the pedestrian bridge is on the left of this photograph), and Figure 10 illustrates the pedestrian bridge immediately downstream (to the north). Both photographs are taken from the west, near Marathon Park.

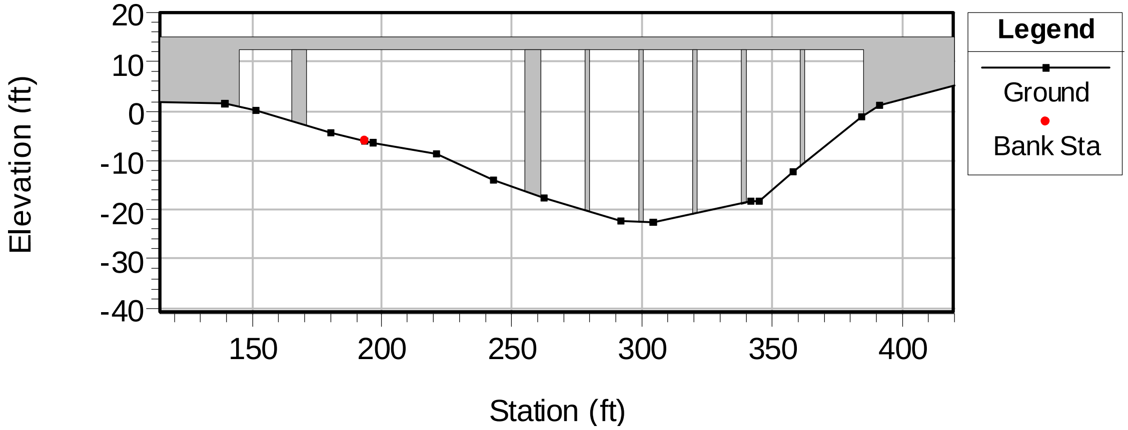


Figure 9. BNSF Railroad Trestle: HEC-RAS Model Setup and Photograph

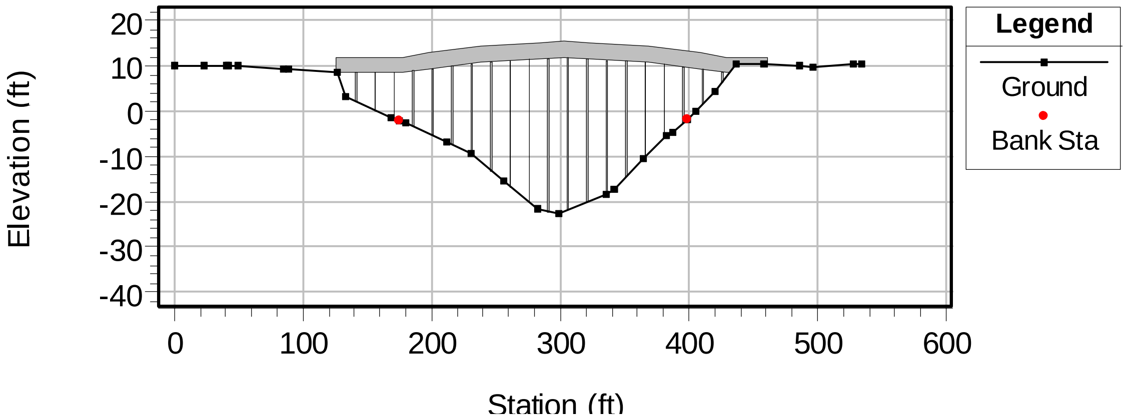
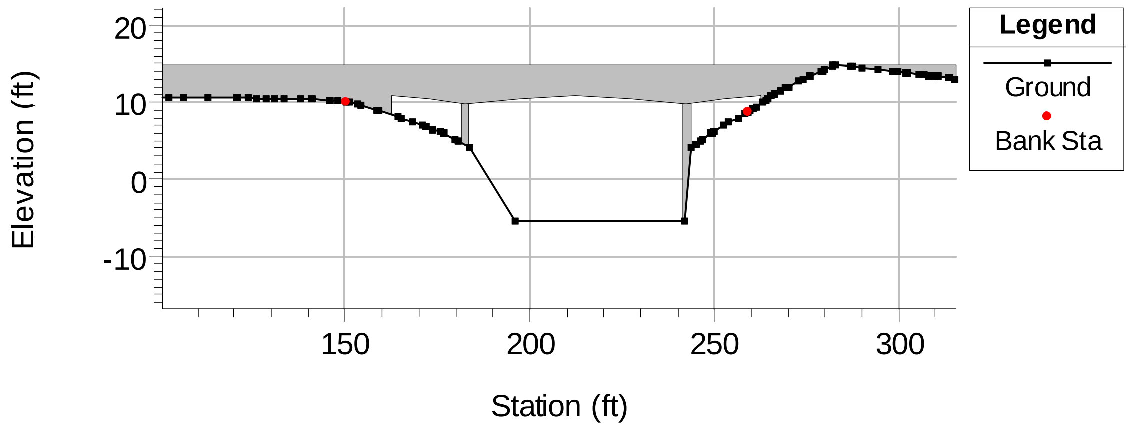


Figure 10. Pedestrian Bridge: HEC-RAS Model Setup and Photograph

Figure 11 illustrates the bridge that separates the Middle Basin of Capitol Lake from Percival Cove. The photograph is taken from the Railroad Bridge between the North and Middle Basins.



Source: EDAW

Figure 11. Percival Cove Bridge: HEC-RAS Model Setup and Photograph

The bridges at the mouth of Capitol Lake are included in the estuary models only – the area north of the Capitol Lake Dam is not included in the lake model. Figure 12 illustrates the existing Fourth Avenue Bridge. The photograph is taken from the west side of Budd Inlet immediately south (upstream) of the bridge but downstream of the dam.

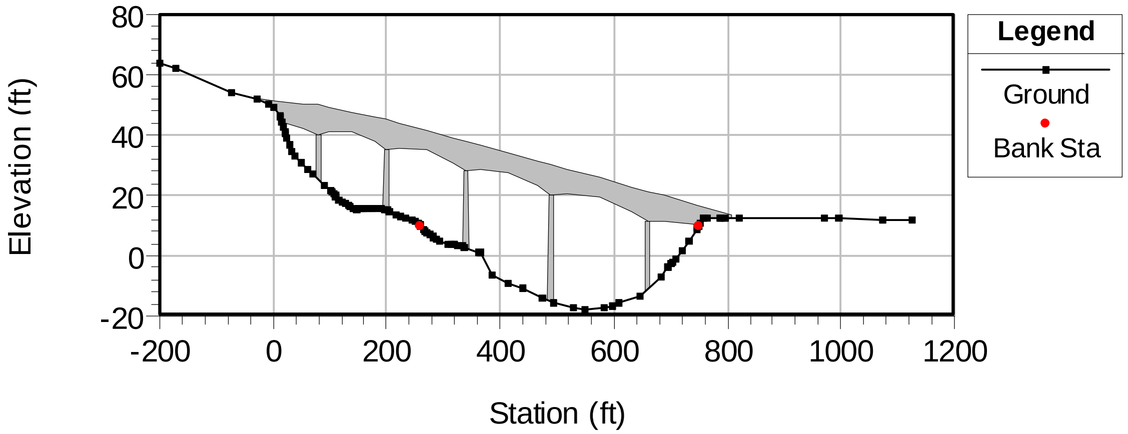
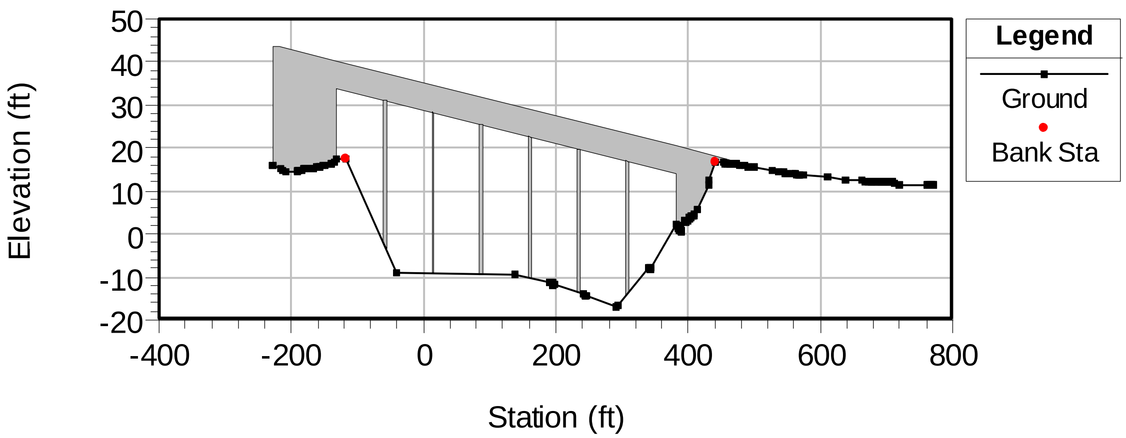
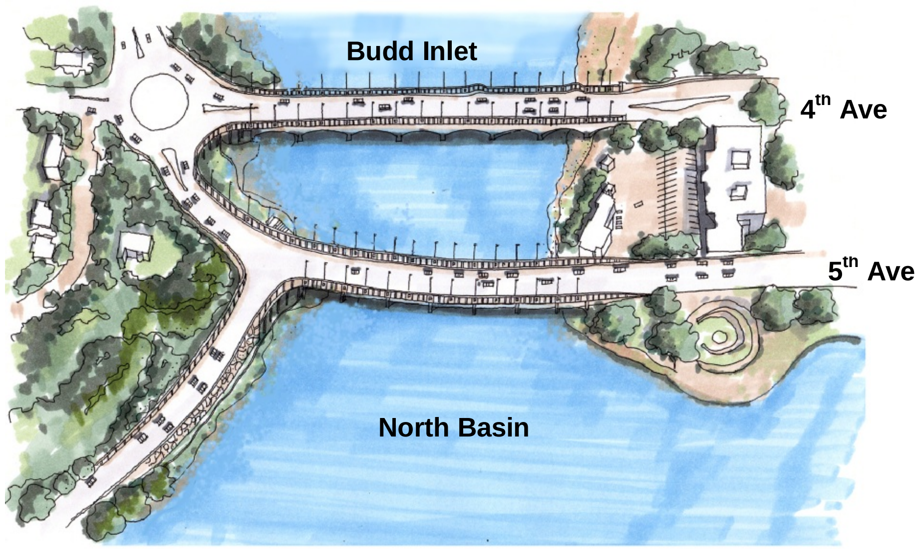


Figure 12. Fourth Avenue Bridge: HEC-RAS Model Setup and Photograph

Figure 13 shows the HEC-RAS model setup for the new Fifth Avenue Bridge that would be constructed to replace the Capitol Lake Dam. This bridge would be immediately south of the existing Fourth Avenue Bridge.





Source: EDAW

Figure 13. New Fifth Avenue Bridge: HEC-RAS Model Setup and Conceptual Sketch of Fourth and Fifth Avenue Bridges

2.3.2 Capitol Lake Dam

The structure of the Capitol Lake Dam is modeled using the geometry described in the 2003 *Capitol Lake Floodplain Analysis*. The HEC-RAS model schematic, together with photographs taken from downstream and upstream (at the radial gates) is shown in Figure 14. The three openings, from left to right looking north (from the upstream side), are: the fish ladder; the 24-feet wide East Gate; and the 36-feet wide West Gate. Moffatt & Nichol understands the gate logic to be as follows, based on a lower and an upper setpoint for the lake level:

- The first priority is to close both gates if the tide level (downstream of the gate) is at or above the lake level – this avoids flow from Budd Inlet into the lake. A very small buffer of 1.5 inches is applied to this rule: that is, the gate is only open if the lake level is at least 1.5 inches above the tide level. A larger buffer may have been applied in the past.
- The second priority is to close the gate if the lake level is below the lower setpoint; and
- The third priority is to open the gate if the lake level is above the upper setpoint.

Different setpoints are defined for the East Gate and the West Gate: the West Gate is normally closed unless the additional opening is needed to drain the lake during a storm event. Additionally, different setpoints are used for the winter (October through March) and summer (April through September) months. The fish ladder is always open in the summer and always closed in the winter.

Details of the model geometry (identical to the FEQ model) and control logic (modified for the HEC-RAS model) are given in Table 3 and are illustrated in Figure 14.

Table 3. Capitol Lake Dam Geometry and Logic Setpoints

Quantity	Fish Ladder	East Gate	West Gate
Bottom Elevation (feet, NGVD29)	+4.5	-7.2	-7.2
Width (feet)	9.5	24	36
Maximum gate opening (feet)	12.5	11.9	11.9
Upper setpoint: summer (feet, NGVD29)	Always open	6.5	6.7
Lower setpoint: summer (feet, NGVD29)	Always open	5.7	5.7
Upper setpoint: winter (feet, NGVD29)	Always closed	5.5 *	5.7 *
Lower setpoint: winter (feet, NGVD29)	Always closed	4.7 *	4.7 *
Opening rate (feet/minute)	Not applicable	0.4	0.4
Closing rate (feet/minute)	Not applicable	0.6	0.6

* Winter setpoints can vary in response to predicted storms according to the dam management practice

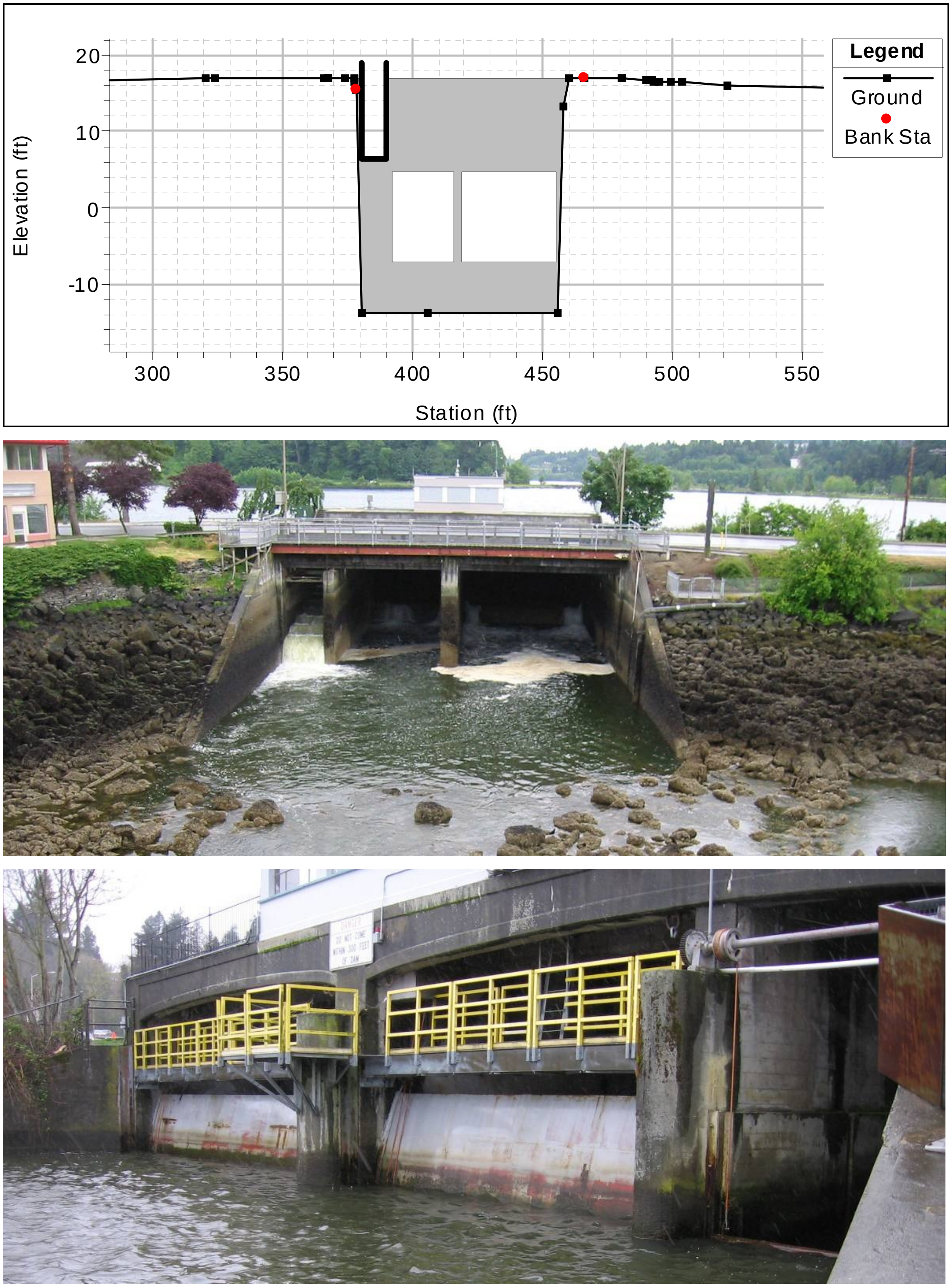


Figure 14. Capitol Lake Dam: HEC-RAS Model Setup and Photographs

The two models have limitations that do not allow the logic described above to be followed precisely. However, the FEQ model limitations are much more significant than the HEC-RAS model limitations. (The version of the HEC-RAS model available in 2003, when the FEQ model was developed, had no capability for gate logic – the FEQ model was the best available at the time).

- The FEQ model does not allow the first condition – intended to rule out flow from Budd Inlet into the lake – to be implemented directly. The FEQ model does not allow the gate to be closed based on a difference between two water surface elevations; nor does it allow a one-way structure (such as a tide gate) to be added to the model to force downstream-only flow.

  It is possible to force the gates to open and close at specific times, by changing the control logic based on the date and time. However, this is a very unnatural and time-consuming approach. As shown in Appendix A, M&N was unable to develop an acceptable model calibration even with the gate openings carefully hand-tuned. Consequently, this approach was not developed further.

- The HEC-RAS model does not allow upper and lower setpoints to be modified in response to predicted (future) storm events. M&N used two different approaches to address this limitation. The first was to keep the control points at a relatively low level throughout winter months. This represents the most aggressive dam management scheme. The second approach was to trigger a decrease in the control point based on the real-time Deschutes River inflow (at the E Street Gauge). This represents a "last minute" dam management scheme: an attempt to lower the lake level is made only once the storm event has started. As described in Section 3.2, the flood levels were lower for the more aggressive dam management scheme, but the difference was small (generally less than 0.1 feet). The use of the two approaches to bracket the flood levels therefore appears adequate.

The lake level measurements provided by Washington State Department of General Administration (see Section 2.3.6) suggest that the lower and upper setpoints are occasionally set to the summer values even during the winter months. The modeling described here does not attempt to take this into account.

2.3.3 Deschutes River Inflows

Deschutes River inflows were derived from the following sources.

- 1961 to 1990: Hydrologic simulation of the inflows, provided with the FEQ model setup. The simulation was prepared using the HSPF model originally developed for the EPA (Bicknell *et al* 1997).
- 1990 to 1999: Hourly observed flows at the E Street Gauge, routed to the upper model boundary, provided with the FEQ model setup.
- 1999 to December 11, 2007: 15-minute observed flows at the E Street Gauge, used directly. These measurements were provided by the USGS Washington Water Science Center, Tacoma, WA. Significantly, this period of record included the storm of December 3, 2007.

The E Street Gauge is operated by the USGS: Gauge 12080010, Deschutes River at E-Street Bridge at Tumwater, WA. The gauge is located approximately one-half mile from the upper model boundary.

2.3.4 Percival Creek Inflows

Percival Creek inflows were derived from the following sources:

- 1961 to 1999: Hydrologic simulation of the inflows, provided with the FEQ model setup. The simulation was prepared using HSPF, similar to the Deschutes River inflows from 1961 to 1990.
- 1999 to December 2007: Monthly mean values provided by the USGS Washington Water Science Center.

The Percival Creek Gauge is operated by the USGS: 12078730, Percival Creek near Olympia, WA. It is located approximately one mile upstream of the relevant model boundary. The Percival Creek inflows are small (peaks typically no more than 5 percent) compared to the Deschutes River inflows. Test cases run without any Percival Creek inflows have typically been indistinguishable from those with the inflows. Consequently, it seems adequate to use the monthly mean values as a base flow condition.

2.3.5 Tides

The Olympia, Budd Inlet gauge is located approximately one-half mile from the Capitol Lake Dam, within Budd Inlet at the Port of Olympia's wharf. This gauge was only operated for one year, April 1977 through March 1978, so values for that gauge cannot be used to define the model boundary conditions. The following tidal elevations were used:

- 1961 to 2006: The residual values (i.e., the differences between the measured and predicted tides) at the Seattle tide gauge (9447130) were calculated and added to the predicted tidal elevations for the Olympia, Budd Inlet (9446969) location. Measured values at Seattle were obtained from NOAA 2008. The residual values capture meteorological effects such as storm surge; the predicted tides capture the astronomical components.
- 2007: Measured values provided by General Administration immediately downstream (north) of the Dam were used for the upper portion of the tidal range. Since this gauge does not measure tidal elevations below approximately Mean Sea Level (approx. +1 foot NGVD29), the lower portion of the tidal range was calculated using the same approach as the earlier periods.

The composite tidal elevations constructed from predictions for Olympia plus residual values for Seattle, worked reasonably well.

- The peak tide measured by NOAA during the 1977-1978 period was +10.5 feet NGVD29. The predicted tide for Olympia at that time was only +9.9 feet; the composite approach gave +10.9 feet NGVD29.
- The peak tide measured by GA during 2007 was +9.4 feet NGVD29. The predicted tide for Olympia at that time was only +7.3 feet; the composite approach gave +9.5 feet NGVD29.

The use of the residual values at Seattle is not ideal: meteorological conditions are not identical at Olympia and Seattle. It is possible for storm surge and other meteorological effects on the still water level to increase moving into the Puget Sound, such that the residual effects can increase along with the astronomical tides. However, the results presented here do not support using an increased residual: if anything, the composite approach slightly overestimates the peak tides. The present approach appears to make the best use of the available data.

2.3.6 Calibration Data

Calibration data were provided by Washington State Department of General Administration, and were significantly improved compared to those available to the earlier modeling effort. The following information was provided with a 15-minute interval for the period January 2007 through March 2008:

- Lake level immediately upstream of the Capitol Lake Dam;
- Tide level immediately downstream of the Capitol Lake Dam (levels below approximately mean sea level were not measured);
- Gate opening and closing events.

River inflows for the model calibration are described in Sections 2.3.3 and 2.3.4.

3. Model Results

3.1 Existing Conditions

3.1.1 Introduction

The model of existing conditions provides a meaningful baseline for the assessment of future alternatives. The model was calibrated based on the available data described in Section 2.3.6.

A secondary purpose of the model of existing conditions is for comparison with the results of the 2003 *Capitol Lake Floodplain Analysis*. The two analyses are not expected to give identical results. Apart from the different assumptions inherent in the HEC-RAS and FEQ software packages, the present study includes updated (2006) bathymetry and extends the period of record by nine water years, to 2008. The present study also assumes more optimal management of the Capitol Lake Dam compared to the previous study.

All lake levels discussed in this section are for the North Basin. Peak flood levels in the Middle and South Basins can be a few inches higher.

3.1.2 Model Calibration

The model calibration covered two periods: a low-flow period in July 2007, and the recent December 3, 2007 storm event. Appendix A describes attempts to calibrate the FEQ model described in the 2003 *Capitol Lake Floodplain Analysis* to these two events.

Figure 15 illustrates the calibration for the low-flow period. The saw-tooth pattern of the measured lake elevations and the range of the fluctuations are well captured by the model.

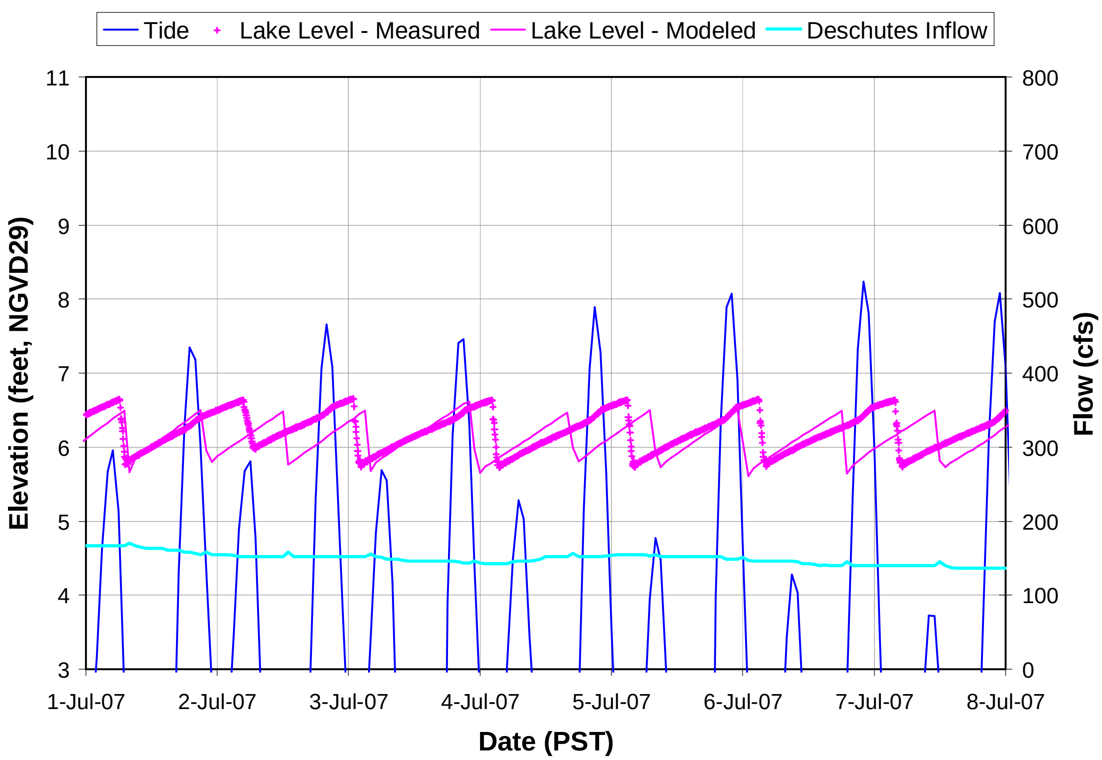


Figure 15. Low-Flow Model Calibration

Figure 16 illustrates the model calibration for the December 3, 2007 storm event. The calibration modified the standard dam management logic to match this event. First, the lower lake setpoint was set close to the summer value, at +5.8 feet NGVD29, prior to the storm. The limits of the saw-tooth pattern before December 3 clearly support this higher setpoint. Second, the lake setpoint was decreased by two feet during the first peak of the storm. As previously mentioned, the existence of human intervention in the management of the dam presents difficulties in long-term modeling of storm conditions for the Lake Alternative.

The measured and modeled curves lie close together through the first high tide of the storm on December 3. The modeled peak water surface elevation is +9.2 feet NGVD29, compared to the measured value of +8.8 feet NGVD29. The pattern of the later peaks is generally well-matched, although the model overpredicts the second peak on December 5 by 0.5 feet.

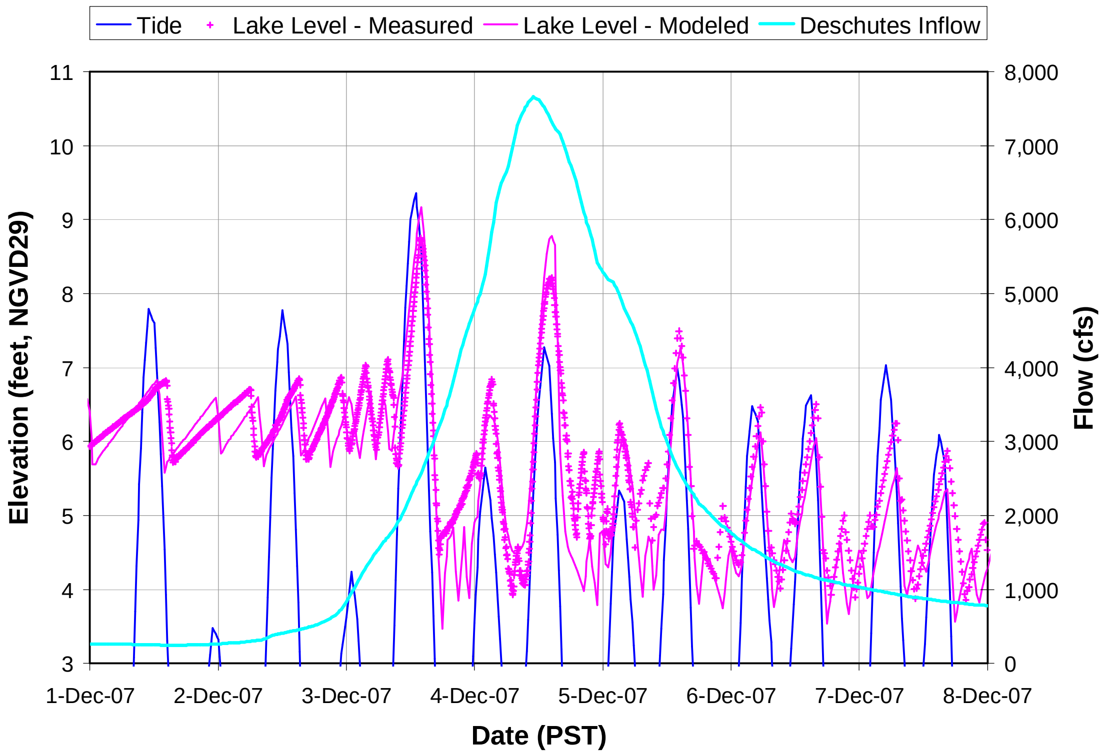


Figure 16. Model Calibration for the December 3, 2007 Storm

The final calibration event is the storm of record, the December 1977 flood.

Water year 1978 included the December 15, 1977 flood. The FEMA Flood Insurance Study issued shortly after that flood (FEMA 1981) noted that the peak flood elevation in Capitol Lake was 0.4 feet higher than the peak tide for this storm. During this flood, the peak tidal elevation was 10.54 feet NGVD29. Based on current operations, the peak flood elevation in the North Basin is lower than this – only 10.0 feet NGVD29. Additionally, based on current operations, the peak flood operation would occur on December 13 rather than December 15 – when the high tide was almost as high as the peak, and the inflow from the Deschutes River was close to its peak. The 2003 *Capitol Lake Floodplain Analysis* also found that the peak lake elevation on December 15 was below the peak tidal elevation on that day.

Several modifications to the gate operations were needed to match the peak flood elevation and the observation that the peak occurred on December 15, after the peak of the Deschutes River flow. As suggested by the 1981 FEMA Flood Insurance Study, the initial target lake level was set close to

Mean Higher High Water, or +7.15 feet NGVD29. The gates were opened only if the lake level was 6 inches higher than the tide level, compared to the current buffer (during major storms) of 1.5 inches. Finally, it was necessary to assume a 30-minute delay in opening the West Gate on December 15. With these modifications, the peak flood elevation was +10.8 feet NGVD29, or 0.3 feet higher than the peak tide elevation – consistent with the observations.

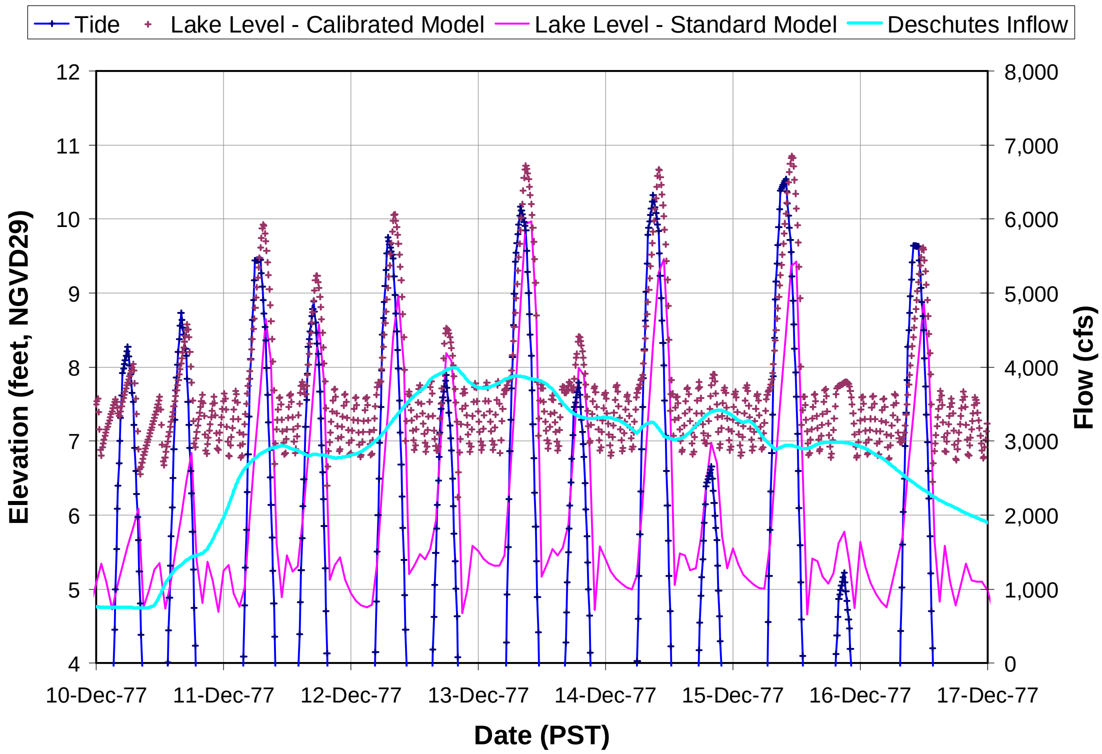


Figure 17. Model Calibration for the December 1977 Storm

Another possible reason for the discrepancy between the standard model results and the observations is that the tides in Budd Inlet may have differed from those assumed here. The tides may have remained high for a longer period, or the low tides may have remained relatively high, because of the strong north winds and wave action at the time. Given the lack of data for this event, this possibility has not been investigated further.

The conclusions regarding model calibration are as follows.

- The model hydraulics appear to match the observed hydraulics well: no "tweaking" of the physical model parameters (e.g., Manning numbers) was needed to obtain a good match.
- The peak flood elevations can be extremely sensitive to details of the gate operations, specifically the promptness with which the gates are opened at low tide when the peak Deschutes hydrograph spans multiple tidal cycles. The modeling suggests that, based on current gate operations, the lake level during the December 1977 storm would crest below +10.0 feet NGVD29.
- Because the present study is intended to compare flood risks under the Lake and Estuary Alternatives, consistent operations throughout the period of record are assumed. This gives flood elevations for different return periods (or probabilities) that are consistent with current management practices. However, it does not necessarily reproduce the historical record.

3.1.3 Flood Frequency Analysis and Comparison with Previous Work

Table 4 gives the annual peak elevations in the North Basin under the assumption that the lake is ***not*** lowered before each storm event – instead, the standard winter setpoints are used throughout. This provides the worst case for flood conditions in Olympia. Results from the 2003 *Capitol Lake Floodplain Study*, which are generally comparable, are shown for comparison. Historically, flooding has occurred when the water in the lake reached a level of +10 feet NGVD29 or more. Even before the perimeter of Capitol Lake is overtopped, water can back up into the stormwater system that serves the low-lying parts of downtown Olympia.

Table 4. Annual Peak Elevations for Existing Conditions, No Lake Lowering

Water Year	Predicted Elevations (ft, NGVD29)	2003 Predictions (ft, NGVD29)	Water Year	Predicted Elevations (ft, NGVD29)	2003 Predictions (ft, NGVD29)
1962	7.90	7.84	1986	9.47	9.08
1963	8.28	8.23	1987	10.22	10.19
1964	8.26	8.25	1988	8.53	8.51
1965	10.04	9.73	1989	8.38	7.94
1966	8.26	8.43	1990	9.29	8.64
1967	9.83	9.81	1991	9.42	8.40
1968	9.00	8.76	1992	8.01	8.07
1969	9.20	8.30	1993	7.38	7.44
1970	8.38	9.05	1994	7.17	7.78
1971	10.55	9.11	1995	9.20	9.03
1972	10.10	10.32	1996	10.27	11.02
1973	8.67	9.28	1997	10.02	10.73
1974	10.28	10.81	1998	9.18	9.22
1975	7.65	7.82	1999	10.00	10.33
1976	9.66	9.45	2000	9.20	End of run
1977	6.93	6.96	2001	6.80	
1978 (1)	9.97	9.78	2002	8.95	
1979	7.83	7.39	2003	9.29	
1980	8.21	8.22	2004	7.29	
1981	9.73	9.60	2005	7.61	
1982	8.71	8.19	2006	10.42	
1983	9.72	9.37	2007	9.17	
1984	9.50	9.73	2008 (2)	8.74	
1985	7.45	7.58			

(1) This water year includes the December 1977 flood. The results shown here assume current flood management practices, rather than the practices that took place historically.

(2) The full water year has not been modeled: however, the December 3, 2007 storm event was the peak for this year

Table 5 gives the return period flood elevations for the North Basin based on the present results, the *Capitol Lake Floodplain Study*, and the 1981 Flood Insurance Study (FEMA 1981). The present values for the 50- and 100-year return period flood elevations are significantly lower than those given in the 2003 *Capitol Lake Floodplain Study*, even though many of the individual peaks are similar. The 1981 Flood Insurance Study gives values intermediate between the 2003 and the present study.

Table 5. Peak Elevations for Existing Conditions: Current and Earlier Studies

Return Period, years	Peak Flood Elevations, feet NGVD29		
	Current Results	2003 Floodplain Study	1981 Flood Insurance Study
2	9.0	*	*
5	9.8	*	*
10	10.1	10.4	10.5
25	10.4	*	*
50	10.5	11.3	10.8
100	10.6	11.5	11.0

* Values not provided in the previous studies

Figure 18 illustrates the flood frequency analyses that give the more recent return period values in Table 5. The present analysis uses the Generalized Extreme Value Distribution, and fits the distribution to the data values using the maximum likelihood approach. This is the method recommended by current FEMA guidelines (FEMA 2004). In the 2003 analysis, the distribution was fitted to the data using probability paper. This is a less rigorous but valid method of calculating return period values.

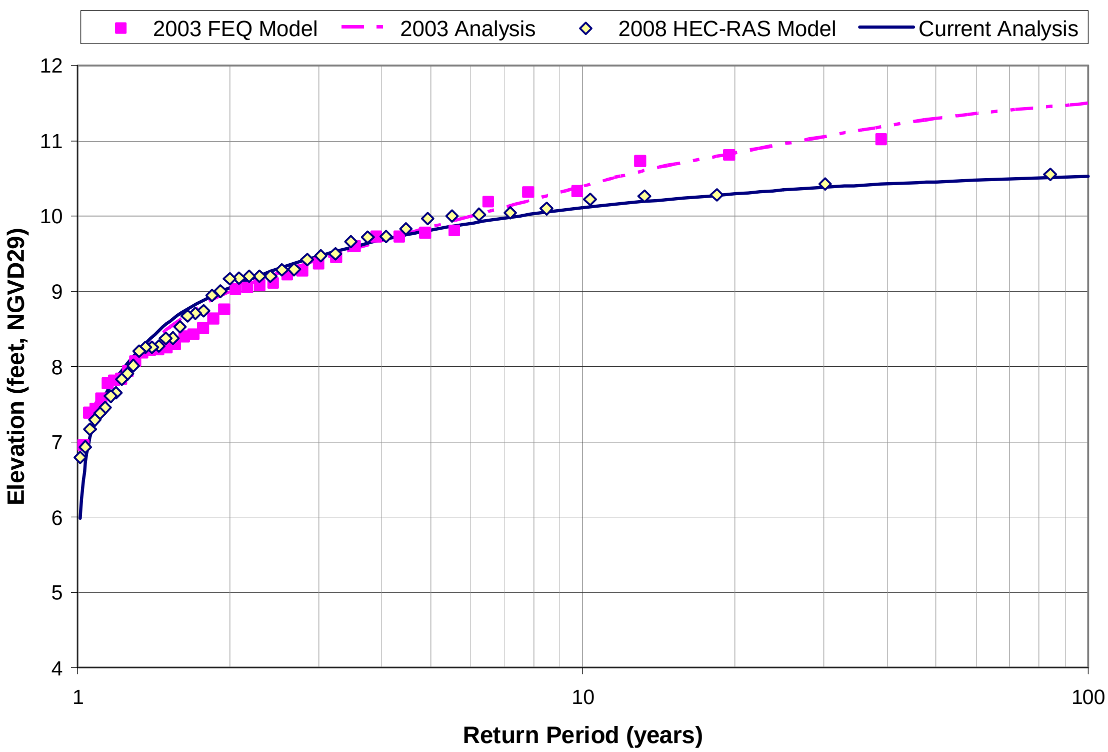


Figure 18. Flood Frequency Analysis: Comparison of 2003 and Present Results

Figure 18 demonstrates that the relatively high peak floodplain elevations in the 2003 study result from three individual flood peaks predicted by the FEQ model: a peak of +10.8 feet NGVD29 in the 1974 water year, and peaks of +11.0 and +10.7 feet in 1996 and 1997. No significant flooding occurred in downtown Olympia during the later periods. The 2003 study notes that the February 1996 flood elevation is reduced to +9.8 feet NGVD29 if the target lake level is reduced to +3 or +4 feet NGVD29.

These results highlight the importance of proper dam management. They also suggest a difficulty with developing definite flood elevations given the current approach to dam management, in which the lake is lowered manually during the course of each significant storm event. This is not a criticism of the current dam management, which has worked well in recent years: it is recognition of the fact that hydraulic models are not well suited to capturing the performance of a manually operated system. The results presented in this report assume that the dam management continues to follow the present patterns, and that there are no unfortunate delays in opening the gates, mechanical problems, or other adverse events. The results presented in the earlier (1981 and 2003) floodplain studies have assumed less successful dam management.

3.1.4 Dam Management Scenarios

The results shown in Table 5 are not truly representative of existing conditions, because they neglect one feature of the current dam management. When a significant storm event is predicted, the radial gates are opened to lower the lake levels in advance.

Table 6 gives the peak floodplain elevations for the current bathymetry and for five different gate management scenarios:

- No Lake Lowering: this is equivalent to the dam management underlying the results shown in Table 5. The lower setpoint for the gates, at which they close during the winter months, is +4.7 feet NGVD29; the upper setpoint is 0.8 feet higher for the East Gate and 1.0 feet higher for the West Gate.
- Last-Minute Lake Lowering to +3 feet: the lower setpoint for the gates is set to +3 feet NGVD29 when the Deschutes flow reaches 4,000 cubic feet per second (cfs). The upper setpoints remain at 0.8 and 1.0 feet higher than the lower setpoint. This corresponds to attempting to lower the lake once a storm is in progress.
- Aggressive Lake Lowering to +3, +1, or -1 feet NGVD29: the lower setpoint for the gates is set to +3, +1, or -1 feet NGVD29 throughout the winter season. The upper setpoints remain at 0.8 and 1.0 feet higher than the lower setpoint. This is equivalent to successfully predicting a storm in time to lower the lake during the preceding low tide.

Table 6. Peak Elevations for Existing Bathymetry, Different Dam Management Scenarios

Return Period, years	Peak Flood Elevations, feet NGVD29				
	No Lake Lowering	Last-Minute Lowering to +3 ft	Aggressive Lowering to +3 ft	Aggressive Lowering to +1 ft	Aggressive Lowering to -1 ft
2	9.0	9.0	8.8	8.6	8.4
5	9.8	9.7	9.6	9.5	9.5
10	10.1	10.0	10.0	9.9	9.9
25	10.4	10.3	10.3	10.2	10.2
50	10.5	10.4	10.4	10.3	10.3
100	10.6	10.5	10.5	10.4	10.4

The results show that the lake lowering has relatively little effect on the higher storm events: the most aggressive lake lowering only reduces the 100-year flood elevation by 0.2 feet. The lowering is more effective in decreasing the more frequent storm events; it has little effect on the higher floods.

Figure 19 illustrates the reason for the limited effectiveness of the more aggressive lake lowering approach on the higher flood events. The event shown here, in January 1971, is the highest modeled event. The high tide on January 27 (+10.0 feet NGVD29) occurs a few hours after a peak Deschutes flow of over 7,000 cfs. Three different gate management scenarios are shown: no lake lowering; aggressive lake lowering to +3 feet NGVD29; and aggressive lake lowering to -1 feet NGVD29. To avoid further complicating this figure, two additional scenarios (last-minute lowering to +3 and aggressive lowering to +1 foot NGVD29) are not shown.

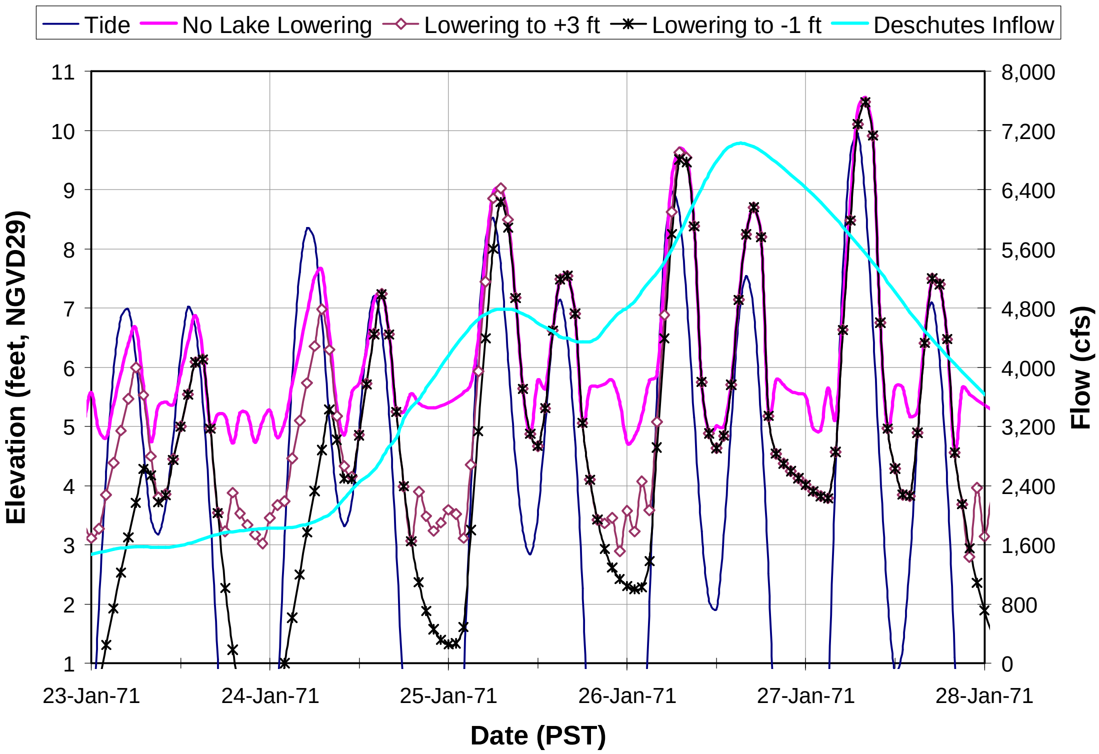


Figure 19. Effects of Lake Lowering on the January 1971 Storm

Before the Deschutes River flows begin to increase early on January 24, the different management scenarios are reflected in the different lake levels. The peak lake level at high tide on the morning of January 24 also varies between the different scenarios.

During the low tide that occurs late on January 24, the *Lowering to -1 ft* scenario is only able to release enough flow through the radial gates to decrease the lake level to +1.3 feet NGVD29. On the following night, as the Deschutes River flow continues to increase, the minimum lake level that can be achieved is +2.3 feet NGVD29; and on the night of January 26 the minimum lake level is +3.8 feet NGVD29. The capacity of the radial gates limits the extent to which the lake can be lowered during a storm event.

The more extreme events are of this kind: the high Deschutes River flows span two or more high tide cycles. The extreme lake lowering scenarios are relatively ineffective in decreasing the flood levels after the first high tide that coincides with high river flows.

3.2 Managed Lake Condition

The managed lake condition assumes the entire lake is dredged to an elevation of -7.2 feet NGVD29 (the elevation of the dam sill). This represents the maximum possible increase in storage for the lake. The total dredge volume under this scenario is approximately 875,000 cubic yards (Moffatt & Nichol 2008b). Four dam management schemes are modeled:

- No Lake Lowering: equivalent to the dam management underlying the results in Table 5.
- Lake Lowering to +3, +1, or -1 feet NGVD29: equivalent to the aggressive lake lowering scenarios considered in Table 6.

Table 7 gives the peak flood elevations for the different gate management scenarios. The results for existing bathymetry and no lake lowering are also shown.

Table 7. Peak Elevations for Dredged Lake Conditions, Different Management Options

Return Period, years	Peak Flood Elevations, feet NGVD29				
	Existing, No Lake Lowering	Dredged, No Lake Lowering	Dredged, Lowering to +3 ft	Dredged, Lowering to +1 ft	Dredged, Lowering to -1 ft
2	9.0	9.0	8.8	8.6	8.1
5	9.8	9.8	9.6	9.5	9.1
10	10.1	10.1	10.0	9.9	9.9
25	10.4	10.4	10.3	10.2	10.2
50	10.5	10.5	10.4	10.3	10.3
100	10.6	10.6	10.5	10.4	10.4

There is essentially no difference between the peak flood elevations for existing and dredged conditions with lake lowering. This is because the vast majority of the dredging occurs in parts of the lake where the bed elevations are already below 0 feet NGVD29. Since the lake levels remain above this level for most of a multi-day storm event, most of the storage remains ineffective.

One way of quantifying this is to calculate the increase in storage above any given lake elevation. This storage volume can be related to the number of hours of storage at a typical or extreme flood discharge.

Table 8 shows the increases in volume and time that would result from dredging for different lower target levels. Even with a target lake level of -3 feet NGVD29, the additional storage gained through dredging corresponds to only 0.4 hours for a moderate Deschutes River flood discharge of 4,000 cfs. With a major flooding event, the additional storage is about 10 minutes. With a target lake level of +3 feet NGVD29, the additional storage is negligible.

Table 8. Additional Live Storage Resulting from Lake Dredging

Target Lake Level (feet, NGVD29)	Added Storage, acre-feet	Hours of Storage at 4,000 cfs	Hours of Storage at 8,000 cfs
-7.2	544	1.6	0.8
-5	274	0.8	0.4
-3	118	0.4	0.2
-1	35	0.11	0.05
+1	11	0.03	0.02
+3	3	0.01	0.00

3.3 Estuary Alternatives

3.3.1 Single Basin Estuary Alternative

The Single Basin Estuary Alternative assumes that the Capitol Lake Dam is removed and that the restored Deschutes Estuary is connected to Budd Inlet by a 500-foot wide channel.

The model predicts that estuarine flood conditions are completely dominated by tide levels. The peak flood level in the North Basin each year is essentially equal to the peak tide level in that year. The model predicts that the water surface elevation in the restored estuary is essentially flat from the mouth of the restored estuary to deep within the Middle Basin. During the most significant flood events, the water in the South Basin can be actually lower than the water in the Middle and North Basins. Table 9 gives the annual peak elevations in the North Basin under the Single Basin Estuary Alternative. Results from Table 4, for the current lake condition with no lake lowering, are also shown.

Table 9. Annual Peak Elevations for Single Basin Estuary Conditions

Water Year	Estuary Condition (ft, NGVD29)	Current Lake Condition (ft, NGVD29)	Water Year	Estuary Condition (ft, NGVD29)	Current Lake Condition (ft, NGVD29)
1962	9.51	7.90	1986	9.48	9.47
1963	9.20	8.28	1987	10.89	10.22
1964	10.13	8.26	1988	10.39	8.53
1965	10.69	10.04	1989	9.29	8.38
1966	10.38	8.26	1990	9.48	9.29
1967	10.26	9.83	1991	10.09	9.42
1968	10.57	9.00	1992	9.73	8.01
1969	10.63	9.20	1993	9.53	7.38
1970	10.62	8.38	1994	9.76	7.17
1971	9.93	10.55	1995	9.82	9.20
1972	10.16	10.10	1996	10.09	10.27
1973	10.29	8.67	1997	9.86	10.02
1974	10.13	10.28	1998	10.39	9.18
1975	9.72	7.65	1999	9.61	10.00
1976	9.57	9.66	2000	9.36	9.20
1977	9.19	6.93	2001	9.67	6.80
1978 (1)	10.88	9.97	2002	9.96	8.95
1979	9.13	7.83	2003	10.46	9.29
1980	10.24	8.21	2004	10.60	7.29
1981	9.68	9.73	2005	9.97	7.61
1982	10.06	8.71	2006	10.70	10.42
1983	10.70	9.72	2007	9.69	9.17
1984	10.25	9.50	2008 (2)	9.35	8.74
1985	9.63	7.45			

(1) This water year includes the December 1977 flood. The measured high tide during this period was +10.54 feet NGVD29. The higher tide used in the modeling is based on the residuals analysis described earlier

(2) Results through the December 2007 storm event

For the estuary condition, the annual peak elevations lie between +9.1 and +10.9 feet NGVD29. Table 10 gives the peak flood elevations for different return periods for the Single Basin Estuary Alternative. The results from the 1981 Flood Insurance Study – which gave peak elevation in Budd Inlet, which would be equivalent to the estuary condition – are also given here. The extreme flood elevations are higher for this case than for the lake conditions – +11.0 feet NGVD29 for the 100-year flood, compared to +10.6 feet NGVD29 for the aggressively managed lake condition. Peak elevations of +10 feet NGVD29 occur frequently – the return period for these events is only two years.

Table 10. Peak Elevations for Estuary Alternatives: Current and Earlier Studies

Return Period, years	Peak Flood Elevations, feet NGVD29	
	Current Results	1981 Flood Insurance Study
2	10.0	*
5	10.4	*
10	10.6	10.1
25	10.8	*
50	10.8	10.4
100	11.0	10.6

* Values not provided in the 1981 Flood Insurance Study

3.3.2 Dual Basin Estuary Condition

The Single Basin Estuary Alternative assumes that the Capitol Lake Dam is removed and that the restored Deschutes Estuary is connected to Budd Inlet by a 500-foot wide channel. A separate reflecting pool will be constructed in the eastern part of the North Basin.

As with the single basin case, the flood conditions for the dual basin are completely dominated by high tide levels. The peak flood elevations are identical to those for the single basin case (Table 10).

3.3.3 Discussion

The results given here suggest the 100-year flood elevation in the area surrounding Capitol Lake will increase from the current level of +10.6 feet NGVD29 to +11.0 feet NGVD29 if the Estuary Alternative is implemented. The flood elevations are identical for the single and dual basin estuary conditions.

This difference of 0.4 feet in the 100-year flood elevations for the Lake and Estuary Alternatives may be an overestimate. Assumptions made in the modeling may slightly increase the flood elevation for the Lake Alternative and slightly decrease the flood elevation for the Estuary Alternatives.

- For the Lake Alternative: It is assumed the radial gates at the Capitol Lake Dam are very carefully managed during storm events. The gates are opened and the lake is allowed to drain once the lake level is only 1.5 inches higher than the tide level – a very small amount. If this buffer were an inch or two greater then the 100-year flood condition would increase by up to 0.2 feet. As shown in the calibration for the 1977 flood event, a delay of only 30 minutes in opening the gate after a high tide recedes can significantly affect the peak elevation at the next high tide.

  It is also assumed that there are no mechanical failures (such as the gates being jammed open or shut), human errors, or similar adverse events during the storms. Flood frequency analysis in the United States has typically not considered this type of failure, in contrast to the analysis of flood risks in the Netherlands (e.g., Vrijling 2001).

Both of these assumptions may cause the peak flood elevations for the Lake Alternative to be slightly underestimated.

- For the Estuary Alternatives: The peak flood elevations are equivalent to the peak tide elevations. The period of record for NOAA's tide measurements at Olympia is only one year (April 1977 to March 1978). Consequently, the tides used in modeling the lake and estuary alternatives were estimated from other information.

  The results given here are based on the best available long-term information, at the Seattle tide gauge: the residuals (meteorological effects) for Seattle are added to the predicted tides at Olympia to give the tidal elevations used in the modeling. This approach overestimates the December 1977 peak tide by 0.3 feet and the peak tide in 2007 by 0.1 feet (tidal elevations are currently being measured by Washington State Department of General Administration). There is not enough information available to determine whether these values point to a consistent overestimate of high tide levels, or simply the expected small random differences between estimated and actual tides.

  The peak flood elevations for the Estuary Alternatives are more sensitive to the tide level than the peak flood elevations for the Lake Alternative. Consequently, the need to estimate tide levels in Budd Inlet may cause the peak flood elevations for the Estuary Alternative to be slightly overestimated.

It is possible, therefore, that the 100-year flood elevations for the Lake and Estuary Alternatives differ by less than 0.4 feet. It is extremely unlikely that the 100-year flood elevation for the Estuary Alternatives would be less than for the Lake Alternative. For both the Lake and the Estuary Alternatives, the 100-year flood elevation predicted here remain at or below the predictions of earlier studies (FEMA 1981; URS Group and Dewberry 2003).

3.4 Effects of Climate Change

Two effects of climate change must be considered: potential increases in mean sea level and potential changes in the peak flows from the Deschutes River. Changes in mean sea level have been studied more extensively to date.

Table 11 shows the effect of increases in mean sea level for the managed lake condition, dredged to -7.2 feet NGVD29 and with lake lowering to a target lake level of +1 feet NGVD29 in advance of major storms. This table also gives an illustrative case for increases in peak flows from the Deschutes River: 50 percent increase in runoff associated with a 1.0-foot increase in mean sea level.

Table 11. Peak Elevations for Dredged Lake Conditions, Lake Lowering to +1 feet NGVD29, and Illustrative Increases in Mean Sea Level and Deschutes River Flows

Return Period, Years	Peak Flood Elevations, feet NGVD29				
	1990 Sea Level	Increase of 0.5 feet	Increase of 1.0 feet	Increase of 2.0 feet	Increase of 1.0 feet, Increased Peak Flows
2	8.6	8.8	9.2	9.9	10.3
5	9.5	9.8	10.2	11.0	11.3
10	9.9	10.3	10.7	11.4	11.7
25	10.2	10.6	11.0	11.8	12.1
50	10.3	10.8	11.2	11.9	12.2
100	10.4	10.9	11.3	12.1	12.4

The peak flood elevation increases slightly more slowly than the mean sea level. The present-day (1983-2001 epoch) 50-year flood elevation is likely to become more frequent as follows:

- An increase of 0.5 feet increases the frequency to that of a 10-year flood;
- An increase of 1.0 feet increases the frequency to that of a 5-year to 10-year flood;
- An increase of 2.0 feet increases the frequency to that of a 2-year to 5-year flood.

An increase of 50 percent in the runoff from the Deschutes River has a dramatic effect on the peak flood elevations, equivalent to an increase of 1 foot or more in mean sea level.

Under the estuary conditions, the peak flood elevation remains dominated by the peak tide conditions. Table 12 gives the predicted peak flood elevations for the estuary condition under the same assumptions regarding increases in mean sea level and runoff quantities. The results are identical for the two estuary alternatives, and increase directly with the mean sea level.

Table 12. Peak Elevations for Estuary Alternatives and Illustrative Increases in Mean Sea Level and Deschutes River Flows

Return Period, Years	Peak Flood Elevations, feet NGVD29				
	1990 Sea Level	Increase of 0.5 feet	Increase of 1.0 feet	Increase of 2.0 feet	Increase of 1.0 feet, Increased Peak Flows
2	10.0	10.5	11.0	12.0	11.0
5	10.4	10.9	11.4	12.4	11.4
10	10.6	11.1	11.6	12.6	11.6
25	10.8	11.3	11.8	12.8	11.8
50	10.9	11.4	11.9	12.9	11.9
100	11.0	11.5	12.0	13.0	12.0

The peak elevations for the Estuary Alternatives are unaffected by a 50 percent increase in runoff from the Deschutes River. This is not a sufficiently large increase to affect the dominance of the tides levels on the water levels in the estuary.

3.5 Other Potential Lake Scenarios

Two additional potential future lake management options have been investigated:

- Continued sedimentation of Capitol Lake, with no ongoing dredging, over the next 25 or 50 years;
- Maintenance dredging of Capitol Lake to maintain the current bathymetry, together with installation of a third radial gate, 24-feet wide, operated in parallel with the existing gates.

Continued sedimentation at the existing rate of about 35,000 cubic yards per year would increase the lake bed elevation by up to 3 feet in 25 years and up to 6 feet in 50 years. (The average increase over the entire lake would be slightly less than this; however some areas such as the South Basin were excluded from siltation for this analysis).

The two lake management scenarios were analyzed based on an increase of 1.0 feet in mean sea level and the results are shown in Table 13.

Table 13. Peak Elevations for Potential Future Lake Scenarios with 1.0 feet Increase in Mean Sea Level

Return Period, Years	Peak Flood Elevations with 1.0 feet Sea Level Rise, feet NGVD29			
	Existing Bathymetry and Dam	Continued Sedimentation for 25 Years	Continued Sedimentation for 50 Years	No Sedimentation, Third Gate
2	9.2	9.3	9.7	8.9
5	10.2	10.3	10.6	9.9
10	10.7	10.7	11.0	10.3
25	11.0	11.1	11.3	10.7
50	11.2	11.3	11.5	10.9
100	11.3	11.4	11.6	11.1

These results suggest that, from the point of view of flood protection, there is no immediate urgency in dredging Capitol Lake. (There may be other reasons for urgency).

Construction of a third gate would have a small but noticeable effect on peak flood elevations. This could be part of an ongoing lake management strategy. There are several alternative structural solutions: for example, multiple pipes with check valves could be installed under Deschutes Parkway. This report does not attempt to address the costs or structural feasibility of this management strategy.

4. Conclusions

Under the Lake Alternative, the different lake management scenarios considered – dredging and a decrease in the target lake elevations to as low as -1 feet NGVD29 – have relatively little effect on peak flood elevations relative to the existing lake management. This suggests that existing lake management is close to optimal. It also suggests that, from a flood management perspective, there is no immediate urgency in dredging Capitol Lake. It does not follow that the lake should not be dredged – there are other considerations including water quality and other environmental criteria, and in a time frame of 25 to 50 years the ongoing sedimentation will exacerbate flooding in Olympia.

Under the Estuary Alternatives, the peak flood elevations are completely dominated by the tidal elevations and are a few tenths of a foot higher than under the Lake Alternative. This increase is more significant for the more frequent high water levels (2-year and 5-year) compared to the more infrequent floods (50-year and higher). However, the peak flood elevations are no higher than those predicted by earlier studies (FEMA 1981; URS Group and Dewberry 2003).

Table 14 summarizes the results. The *Existing Lake and Dam Management* condition assumes that the lake level is not changed from its standard winter levels in response to an upcoming storm event. The *Existing Lake and Lake Lowering* condition assumes that the lake level is lowered to +1.0 feet NGVD29 well in advance of an upcoming storm event. The *Dredged Lake and Lake Lowering* condition assumes further that the lake is dredged to a bed elevation of -7.2 feet NGVD29 (the elevation of the dam sill). The results for the Estuary Alternatives are the same whether the Single or Dual Basin alternative is selected.

The increase of 0.4 feet in the 100-year flood elevation for the Estuary Alternatives compared to the existing condition should be considered an upper limit. In particular, the operation of the Capitol Lake Dam provides a single point of failure for the Lake Alternative.

Table 14. Peak Elevations for Different Future Alternatives, Present-Day Sea Level

Return Period, Years	Peak Flood Elevations, feet NGVD29			
	Existing Lake and Dam Management	Existing Lake and Lake Lowering	Dredged Lake and Lake Lowering	Estuary Alternatives
2	9.0	8.6	8.6	10.0
5	9.8	9.5	9.5	10.4
10	10.1	9.9	9.9	10.6
25	10.4	10.2	10.2	10.8
50	10.5	10.3	10.3	10.9
100	10.6	10.4	10.4	11.0

The inclusion of sea level rise in the model does not change the conclusions. The peak flood elevations increase slightly less rapidly than the mean sea level for the Lake Alternative, while they increase directly with the mean sea level for the Estuary Alternatives.

Table 15 summarizes the flood elevations for a mid-level sea level increase of 1.0 feet. This table also shows the effect of not dredging the lake for 25 years – so that the lake bed is up to 3 feet higher than it is at present. All the lake options assume the lake level is lowered to +1.0 feet NGVD29 in advance of significant storm events. While the effect of the increase in mean sea level is significant, the differences between the lake management alternatives are relatively slight. The 100-year flood elevation for the Estuary Alternatives is up to 0.7 feet higher compared to the Lake Alternatives. As with Table 14, this should be considered an upper limit on the differences between the alternatives.

Table 15. Peak Elevations for Different Future Alternatives, 1.0 feet Increase in Mean Sea Level

Return Period, Years	Peak Flood Elevations, feet NGVD29			
	Existing Lake and Lake Lowering	Dredged Lake and Lake Lowering	25-Years Sedimentation in Lake	Estuary Alternatives
2	9.2	9.2	9.3	11.0
5	10.2	10.2	10.3	11.4
10	10.7	10.7	10.7	11.6
25	11.0	11.0	11.1	11.8
50	11.2	11.2	11.3	11.9
100	11.3	11.3	11.4	12.0

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Appendix A. FEQ Model Calibration

Moffatt & Nichol (M&N) was initially tasked to use the existing FEQ model (URS Group and Dewberry 2003) to investigate the relative flood risks associated with the different lake and estuary alternatives. This section describes M&N's efforts to calibrate the FEQ model based on recently available measurements of the lake and tide water surface elevations. This available information goes well beyond the data available to the original preparers of the FEQ model.

The bulk of M&N's calibration efforts focused on the logic used to model the operation of the radial gates at the Capitol Lake Dam. This gate logic is based on two quantities, or *keys*: the water surface elevation in the lake (key ELEV) and the downstream tidal elevation (key U1)

For each key, two elevations (LL and LU, a lower and upper limit) are defined. Each key has an *upper zone* above LU, a *lower zone* below LL, and a *null zone* between LU and LL; different actions are defined for each zone. Table A-1 shows the values of LL and LU for each key, together with the priorities assigned to the actions for each zone, for the East Gate summer operation (target water surface elevation is +6.22 feet, NGVD29).

Table A-1. FEQ Logic Parameters for East Gate Control during Summer Operation

KEY	Lower Limit LL (ft, NGVD29)	Upper Limit LU (ft, NGVD29)	Priorities		
			Lower Zone	Null Zone	Upper Zone
U1	0.5	99	1	4	6
ELEV	5.72	6.72	2	5	3

The gate logic is as follows.

- The first priority is to close the gate if the tide level (U1) is below the lower limit (LL) for the tide: that is, if the tide level drops into the lower zone, below +0.5 feet NGVD29.
- The second priority is to close the gate if the lake level (ELEV) is below the lower limit (LL) for the lake: that is, if the lake level drops in the lower zone.
- The third priority is to open the gate if the lake level (ELEV) is above the upper limit (LU) for the lake; that is, if the lake level is in the upper zone.
- The gate openings are unchanged if the water surface elevations are in the null zones.
- The condition of the tide level (U1) rising into the upper zone never occurs.

The modeled operation of the gates does not follow M&N's understanding of the actual gate operation. The discrepancy is almost certainly due to limitations in the FEQ model. The FEQ model does not allow the gate logic to compare the tide level directly to the lake level. Consequently, the logic "if the lake level is too high and is above that of Puget Sound, then open the east gate" cannot be implemented within the FEQ model. For specific floods, the gate logic can be manipulated by actively adjusting the lower and upper limits.

A second discrepancy between the modeled operation and M&N's understanding of the actual gate operation is associated with the selection of the lower limit (LL) for the tide level. It is not clear why the gates would close when the tide level drops below 0.5 feet NGVD29. M&N's calibration efforts did not include changing this portion of the gate logic, because it appears to produce adequate results for the calibration of stable lake conditions.

Figure A-1 illustrates the results for a low-flow period during July, 2007. The pink lines and crosses respectively give the modeled and measured water surface elevations immediately upstream of the dam. The range of the fluctuations is less than for the measured data, and the sawtooth pattern is replaced with a pattern of fluctuations that is more sensitive to the tide levels. Generally, however, this portion of the calibration appears adequate for the purposes of the hydraulic modeling study and assessment of flood risk associated with the different Capitol Lake alternatives. M&N did not expend significant effort in attempting to improve this portion of the model calibration.

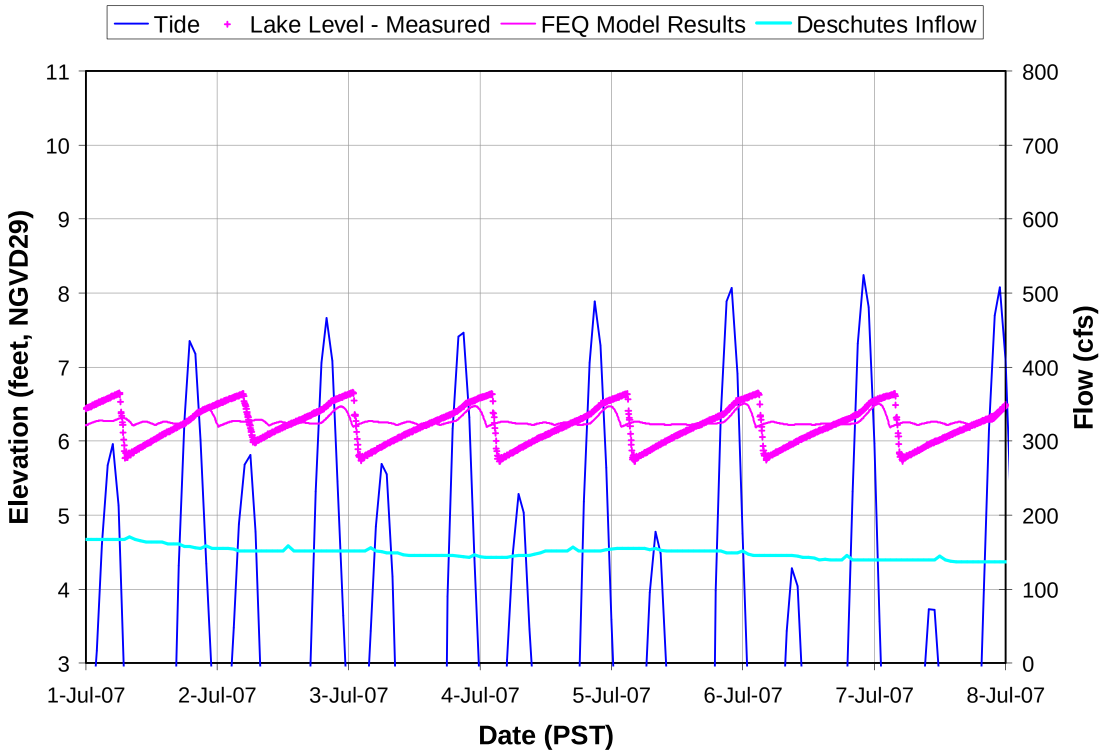

Figure A-1. Calibration Results for July 2007

The original FEQ model files set the lower limit (LL) for the lake water surface elevation (ELEV) to 6.22 feet, and the upper limit (LU) to 6.23 feet during the summer. While this achieved the target water surface elevation of 6.22 feet, the small null-zone resulted in rapid gate opening and closing and a much smaller range of water levels than actually observed. Expanding the null zone (between LL and LU) by 0.5 feet above and below the target water surface elevation resulted in a more stable gate operation and the calibration results shown above.

The calibration for the December 2007 storm was less successful. Figure A-2 illustrates the best results obtained to date. While the model results match the monitoring data well for the first major peak, the model over-predicts the elevation of the second major peak (on December 4) by well over 1 foot.

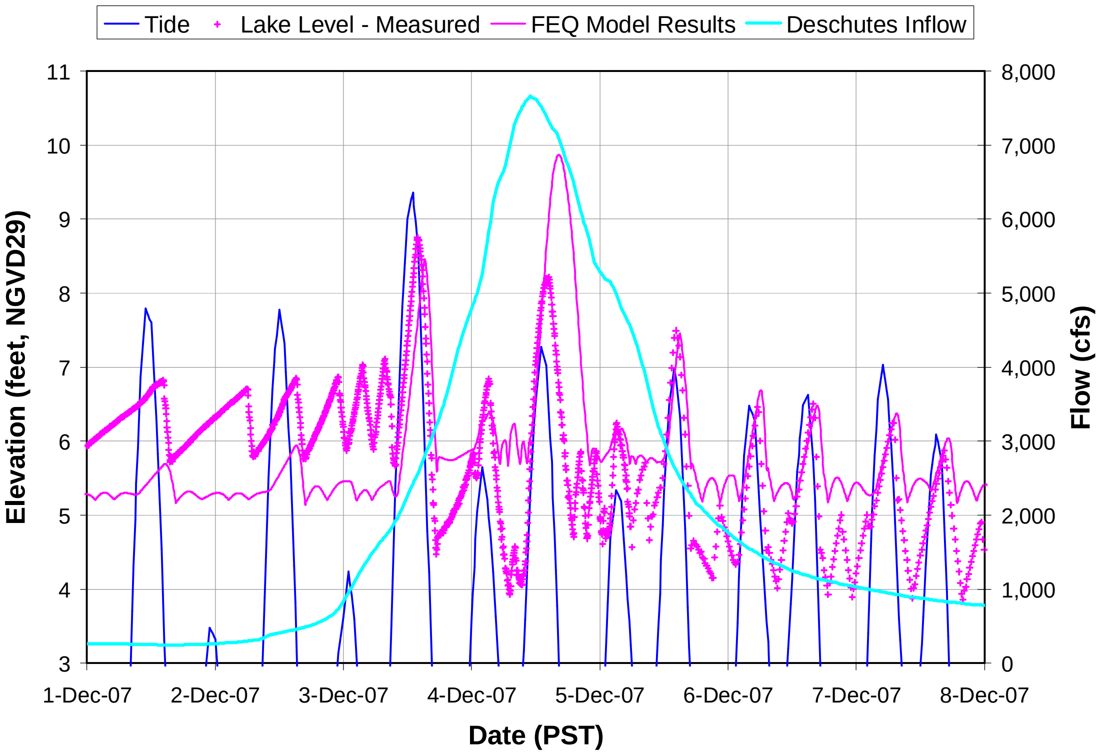

Figure A-2. Calibration Results for December 2007

In order to obtain the results in Figure A-2, the lower and upper limits LL and LU for the different keys were manipulated so that the gates would open and close at the times indicated by the monitoring results. In other words, the discrepancy between the measured and model peaks results from the hydraulic portion of the modeling – not from limitations in the gate logic. (The limitations in the capabilities of the FEQ model, and the resulting need for detailed manipulation gate logic, are time-consuming from a modeling standpoint, and detract from the objective nature of any flood modeling study).