CAPITOL LAKE — DESCHUTES ESTUARY

Long-Term Management Project Environmental Impact Statement

Hydrodynamics and Sediment Transport Numerical Modeling Methodology for Capitol Lake – Deschutes Estuary

Prepared for:

Washington State Department of Enterprise Services

1500 Jefferson Street SE
Olympia, WA 98501

Prepared by:

Moffatt & Nichol

August 30, 2019

This document presents the proposed methodology to assess discipline-specific impacts of the alternatives being considered for the Capitol Lake – Deschutes Estuary Long-Term Management Project. This document has been reviewed by an independent third-party expert or experts and the methodology has been presented to, and discussed with, the resource agencies and local governments on the Technical Work Group. The methodology described has been prepared early in the Environmental Impact Statement (EIS) process, as alternatives are being optimized, and may reasonably evolve as conceptual design, modeling, and analysis of the alternatives progresses. The results of this discipline-specific analysis will be presented in a Discipline Report, which will be attached to and summarized in the Draft EIS. Public comment will be solicited on the Draft EIS, consistent with rules of the State Environmental Policy Act.

Table of Contents

Tables

Figures

List of Acronyms and Abbreviations

Acronyms/ Abbreviations	Definition
CO-OPS	Center for Operational Oceanographic Products and Services (
EIS	Environmental Impact Statement
Enterprise Services	Washington State Department of Enterprise Services
kg/m³	Kilograms per cubic meter
kg/m²/s	Kilograms per cubic meter per second
M&N	Moffatt & Nichol
m³/s	Cubic meters per second
μm	Micrometers
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
RMS	Root mean square
RTC	Real time control
SLR	Sea Level Rise
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey

1.0 Introduction

The Capitol Lake – Deschutes Estuary includes the 260-acre Capitol Lake Basin, located on the Washington State Capitol Campus, in Olympia, Washington (Figure 1.1). The waterbody has long been a valued community amenity. Capitol Lake was formed in 1951 following construction of a dam and provided an important recreational resource. Historically, the Deschutes Estuary was used by local tribes for subsistence and ceremonial purposes. Today, the expansive waterbody is closed to active public use. It is plagued by environmental issues including the presence of invasive species, violations of water quality standards, and inadequate sediment management.

The Washington State Department of Enterprise Services (Enterprise Services) is responsible for the stewardship, preservation, operation, and maintenance of the Capitol Lake Basin. The 260-acre Capitol Lake Basin is maintained by Enterprise Services under long-term lease agreement from the Washington Department of Natural Resources.

In 2016, as part of Phase 1 of long-term planning, a diverse group of stakeholders, in collaboration with the state, identified shared goals for long-term management and agreed an Environmental Impact Study (EIS) was needed to evaluate a range of alternatives and identify a preferred alternative. In 2018, the state began the EIS process. The EIS will evaluate four alternatives, including:

- **Managed Lake Alternative**: Similar to the current configuration of Capitol Lake with additional strategies to manage sediment accumulation and water quality. The Managed Lake Alternative would retain the 5th Avenue Dam and tide gate in its current configuration to maintain the reflecting pool and Capitol Lake Basin.

- **Estuary Alternative**: Full tidal hydrology would be restored throughout the basin. Sediment would be managed through initial dredging in Capitol Lake Basin and recurring maintenance dredging in Budd Inlet.

- **Hybrid Alternative**: Allows management of the basin by establishing a tidal estuary in the western portion of the North Basin, and throughout the Middle and South Basins. A retaining wall would also be constructed resulting in a reflecting pool adjacent to Heritage Park in the North Basin.

- **No Action Alternative**: The No Action Alternative is intended to represent the most likely future for the project area if the project is not implemented.

These long-term management alternatives will be evaluated against the shared project goals of: improving water quality; managing sediment accumulation and future deposition; improving ecological functions; and enhancing community use of the resource. Refer to Figure 1.1 for the project area for long-term management. The Final EIS will identify a preferred environmentally and economically sustainable long-term management alternative for the Capitol Lake – Deschutes Estuary.

Figure 1.1 Area Map

CAPITOL LAKE – DESCHUTES ESTUARY

Olympia, WA

The EIS process leverages momentum from the previous phase by continuing engagement with the existing Work Groups, which include the local governments, resource agencies, and tribe. It also provides for expanded engagement opportunities for the public, such as a community sounding board. **Additional information, including additional background context, description of project alternatives, and project goals, can be found at the project website: www.capitollakedeschutesestuaryeis.org.**

1.1   DISCIPLINE-SPECIFIC METHODOLOGY

Historically, the Deschutes Estuary and the area that is now Capitol Lake was a part of Budd Inlet, consisting of intertidal mudflats that typically form at the mouths of estuaries. Construction of the 5th Avenue Dam has blocked the tidal exchange between the Deschutes River and Budd Inlet and has prevented saltwater flooding of the mudflats.

Capitol Lake now provides a settling basin for sediments transported by the Deschutes River. Possible changes in hydrodynamics and sediment transport from existing conditions have been identified by the EIS Project Team as a probable significant impact or benefit of the long-term management alternatives. All alternatives will be evaluated for the ability to meet the project goal of managing sediment accumulation and future deposition.

This document has been prepared by Moffatt & Nichol (M&N), the hydrodynamics and sediment transport lead for the Capitol Lake – Deschutes Estuary Long-Term Management Project EIS. The proposed methodology proposed has been developed following an initial review of existing background documents, available data, comments received during the scoping period, and coordination with the EIS Project Team. The purpose of this document is to outline the approach for the numerical modeling of hydrodynamics and sediment transport to evaluate long-term management alternatives quantitatively.

The sections below provide a summary of the process approach that will be used to numerically model hydrodynamics and sediment transport within the system, to investigate, evaluate, and describe the potential effects from construction and operation of the long-term management alternatives, across various disciplines. Numerical modeling of the project alternatives will (1) characterize existing conditions within the study area, (2) identify potential impacts and benefits of the alternatives, and (3) in coordination with the EIS Project Team, recommend mitigation measures that could be implemented to avoid or minimize potential adverse impacts.

1.2   STUDY AREA FOR HYDRODYNAMICS AND SEDIMENT TRANSPORT

The study area for hydrodynamics and sediment transport is defined by the Capitol Lake Basin[1], which extends from the south end at Tumwater Falls in the City of Tumwater to the north end at the 5th Avenue Dam in the City of Olympia (Figure 1.1). The study area continues downstream of the basin, to

---

[1] The Capitol Lake Basin was created from the Deschutes Estuary in southern Puget Sound by constructing an earthen dam, 80-foot-wide tide gate, and concrete spillways in 1951. The modern assembly consists of two radial gates to regulate lake level and a fish ladder to allow fish to pass the dam and access upstream habitat.

Gull Harbor, to capture the area that may be affected by sediment transport under certain long-term management alternatives.

1.3   MODELING OBJECTIVE

The objective of the numerical modeling is to compare the four primary alternatives quantitatively under analysis scenarios in terms of: (a) maximum water surface elevations and depth-averaged flow velocities; (b) extent of potential upland flooding; (c) cumulative erosion and deposition patterns and respective sediment volumes.

The hydrodynamic and sediment transport model will be used to simulate alternatives under existing conditions and one "future condition." The EIS Project Team evaluated best available science on Sea Level Rise (SLR) including City of Olympia SLR plan (City of Olympia 2019) as well as latest projections developed for the State of Washington (Miller et al. 2018) to develop the "future condition."

1.4   BACKGROUND STUDIES

United States Geological Survey (USGS) previously conducted hydrodynamic and sediment transport numerical modeling studies (George et al. 2006 and Stevens et al. 2008). These previous studies have provided an in-depth understanding of the system and possible changes. This modeling effort will build upon and improve the previously conducted modeling work. The USGS team who conducted the previous studies has graciously offered to provide their insights to the M&N team throughout the EIS project, as needed.

2.0 Methodological Description and Setup

2.1   MODELING SYSTEM

Numerical modeling of both hydrodynamics and sediment transport will be conducted using the Delft3D version 4.03 software package. Delft3D is an open source modeling system developed by Deltares (Deltares 2014) and is one of the primary modeling systems used worldwide for simulation of estuarine and coastal processes. This modeling system can simulate various physical processes including waves, currents, and sediment transport, water quality, and ecology in the coastal, riverine, and estuarine environments. The Delft3D model is well suited for the requirements of this assessment because of its capabilities to model the required processes including hydrodynamics, sediment transport, and morphology. The Delft3D modeling system was used for previous USGS modeling studies (see George et al. 2006 and Stevens et al. 2008) of the project system.

The three-dimensional (3D) version of the Delft3D software will be used for hydrodynamics and sediment transport simulations. The sediment transport and morphology modules in Delft3D will be used to evaluate the potential impacts to the sediment transport conditions. The model can compute bedload and suspended load transport of non-cohesive sediment fractions (sand and gravel) and suspended load transport of cohesive sediment (silt and clay) fractions, allowing for a mixture of up to 99 fractions.

To evaluate possible influence of salinity on sedimentation patterns and magnitude, limited sensitivity testing with and without salinity will be performed. This sensitivity testing can evaluate influence of density driven flows and flocculation on sedimentation results.

2.2   MODELING DOMAIN AND MESH

The hydrodynamic and sediment transport models will use a curvilinear boundary fitted grid. The model domain will extend from the mouth of the Deschutes River to outer Budd Inlet, terminating just north of Gull Harbor. A grid with a close to uniform resolution will be used for the model. A grid size of approximately 25 m2 is proposed to capture the geometric features with a higher spatial resolution compared to that used previously in USGS studies.

2.2.1 Coordinate System and Vertical Datum

Model elevations will be referenced to North American Vertical Datum of 1988 (NAVD88) in meters since Delft3D uses the metric system. However, elevations will be reported in feet, referenced to NAVD88. The horizontal coordinate system will be Washington State Plane South, North American Datum of 1983 (NAD83) in feet.

2.2.2 Model Elevation

Model elevations will be developed using five bathymetry and topography survey datasets listed below. Coverage areas of these surveys are shown in Figure 2.1. The datasets are listed in order of increasing priority as datasets overlap in some areas:

- 2014 National Oceanic and Atmospheric Administration (NOAA) Digital Elevation Model (DEM) compiled from multiple sources covering the entire Puget Sound (NOAA 2014);

- 2015 City of Olympia Light Detection and Ranging (LiDAR) survey covering the upland area;

- 2016-2017 Western Washington 3DEP QL1 LiDAR project;

- 2004 USGS survey data in the entire Capitol Lake (North, Middle and South Basin), Percival Cove, under I-5 bridge and southern Budd Inlet;

- 2019 U.S. Army Corps of Engineers (USACE) survey data in the federal channel and turning basin;

- 2013 TerraSond survey in the entire Capitol Lake (North, Middle, and South Basin), Percival Cove, and under I-5 bridge;

- 2019 eTrac bathymetry survey for the entire Capitol Lake scheduled for November 2019. Bathymetry survey will be reviewed, and quality checked to evaluate possible influence of vegetation on the survey.

EIS Project Team is currently developing alternatives for further analysis as part of a measurable evaluation process, which uses objective and measurable metrics to comparatively evaluate concepts and optimize project alternatives. Design of the optimized developed alternatives will include components relevant to this modeling effort such as dredge plans and width of openings. These details will be incorporated into the model elevation for each alternative.

Figure 2.1 Bathymetry and Topography Datasets

Legend

- 🟥 Survey 2013
- 🟧 USACE 2019
- 🟦 USGS 2004
- 🟩 LiDAR 2015
- 🟩 NOAADEM 2014

3.0 Hydrodynamics

3.1 BOUNDARY CONDITIONS – RIVER INFLOW

River discharge data from four stream gages were collected from the USGS National Water Information System. The gage locations, the Deschutes River watershed and un-gaged small watersheds are shown in Figure 3.1 (Thurston County 2019). Discharge observations in 15 min intervals and daily discharges are available at the four stations. Detailed information about the data is listed in Table 3.1.

Table 3.1 USGS Stream Gages

Gage Name	Station ID	Period of Record	Frequency	Data Gap(s)
Deschutes River near Rainier, WA	12079000	10/06/1987 to present	15 min	-
		06/01/1949 to present	daily	-
Deschutes River at E Street Bridge at Tumwater, WA	12080010	10/01/1990 to present	15 min	-
		05/01/1945 to present	daily	10/31/1954-6/1/1957; 6/30/1964-10/1/1990
Black Lake Ditch near Olympia, WA	12078720	2/23/1988 to 3/19/1990	15 min	
		02/22/1988 to 3/18/1990	daily	
Percival Creek near Olympia, WA	12078730	03/01/1988 to 3/1/1990	15 min	
		03/01/1988 to 2/28/1990	daily	

August 2019　　　　　　　*Numerical Modeling Methodology*　　　　　　　Page 4-1

Figure 3.1 USGS Gages, as well as Capitol Lake — Deschutes Estuary Gaged and Un-Gaged Watersheds
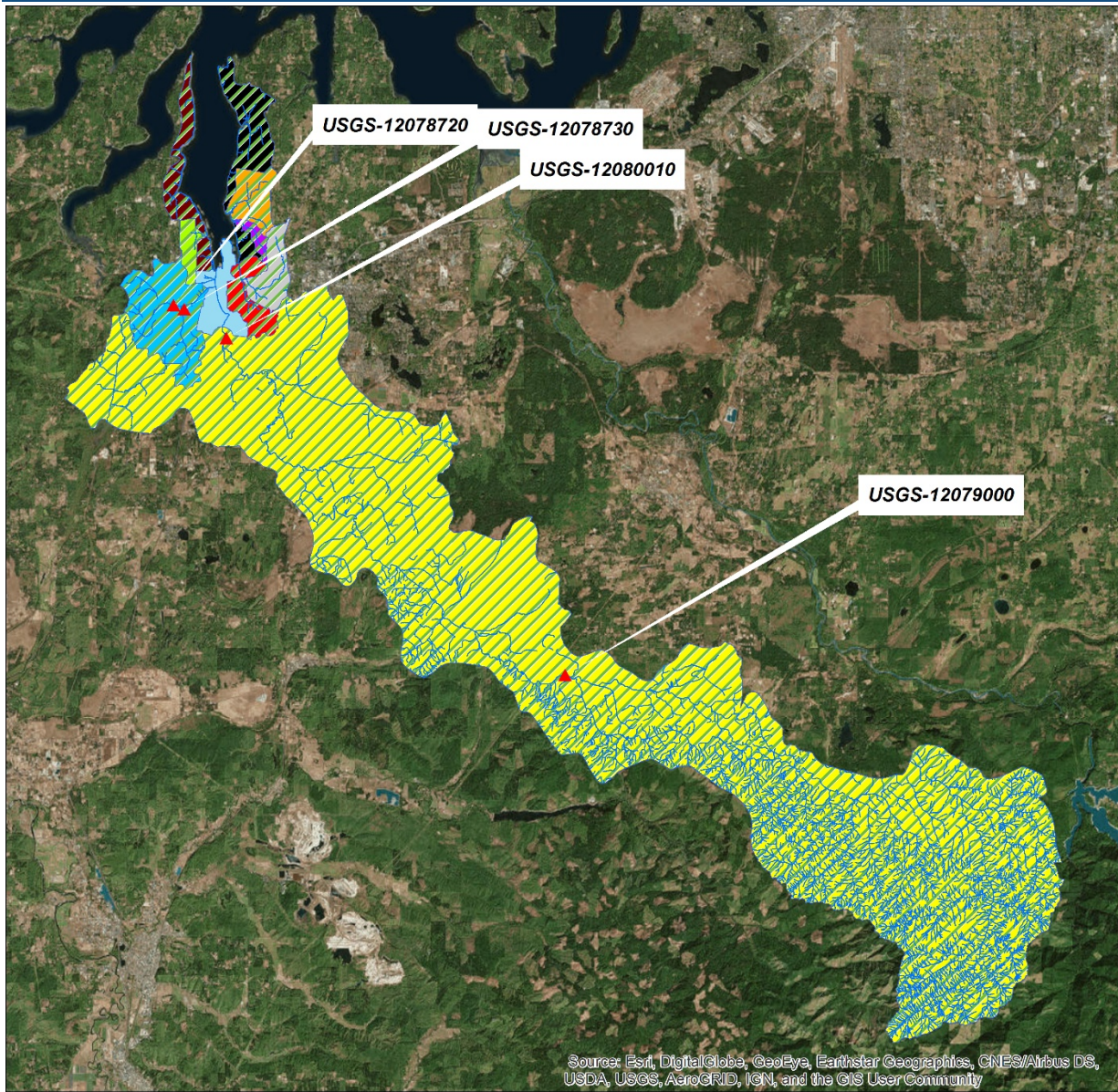
Legend
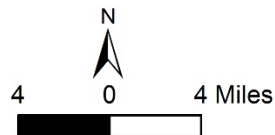
- ▲ USGS gage
- — Streamline
- East_Bay
- Ellis_Creek
- Mission_Creek
- Indian_Creek
- Moxlie_Creek
- Capitol_Lake
- Percival_Creek
- Schneider
- West_Bay
- Deschutes River

N

4   0   4 Miles

To capture peak discharges, which may significantly affect morphological changes in the lake, discharge measurements with 15 min intervals will be used as boundary condition inputs instead of daily data. Two open boundaries will be set: one at the Deschutes River mouth and one at Percival Cove. The un-gaged watersheds will use point discharge to represent the flow inputs. Rainfall will be included into the model as a fraction of un-gaged watersheds. Approaches to construct those boundary conditions are listed below.

- Deschutes River boundary: the USGS station at E Street Bridge in Tumwater (Station 12080010) is the closest station to the lake with almost 30 years of 15-min measurements (see Figure 3.1). Streamflow data from this station will be used as the upstream discharge boundary condition at the Deschutes River mouth.

- Percival Cove boundary: Two stations at Percival Cove, Station 12078720 and Station 12078730, both have about 2 years of measurements from 1988 to 1990. Because of the short period of observations and lack of recent measurements, the following analysis is proposed to construct boundary conditions at Percival Cove—Time series of discharge data can be calculated at Station 12078720 and Station 12078730 based on their discharge statistics relationships with the USGS station at E Street Bridge in Tumwater (Station 12080010), and then the two stations can be summed to obtain the total discharge at Percival Cove. Analysis of delays between discharge time series from USGS gages will be performed to determine whether a time shift for the discharges from tributaries is needed. The scaling factors to calculate discharges at Percival Cove from Deschutes River are listed in Table 3.2. Based on the discharge statistics comparison in Table 3.2, scaling factors ranging from 0.06 to 0.12 will be used to calculate discharges at the Percival Cove boundary from the Deschutes River boundary, depending on the discharge values.

Table 3.2 Discharge Statistics and Scaling Factors

	12080010	12078720		12078730		Percival Cove
	Discharge (m^3/s)	Discharge (m^3/s)	Scaling Factor	Discharge (m^3/s)	Scaling Factor	Total Scaling Factor
Min	1.25	0.03	0.024	0.05	0.040	0.064
10%	2.62	0.14	0.053	0.06	0.023	0.076
25%	3.74	0.31	0.083	0.07	0.019	0.102
50%	7.53	0.71	0.094	0.14	0.019	0.113
75%	14.67	1.53	0.104	0.25	0.017	0.121
90%	25.66	2.27	0.088	0.42	0.016	0.104
95%	36.25	2.83	0.078	0.62	0.017	0.095
99%	68.81	4.02	0.058	1.16	0.017	0.075
Max	243.53	8.55	0.035	4.87	0.020	0.055
Mean	11.98	1.01	0.084	0.21	0.018	0.102

- Point discharge of un-gaged watersheds: For those un-gaged watersheds shown in Figure 3.1, it is proposed to use point discharges instead of open boundaries. The discharge from the un-gaged drainage basin will be estimated based on the measured discharges and their associated watershed areas. The discharges will be computed using scaling factors based on the ratio of un-gaged and gaged watershed areas.

3.2   BOUNDARY CONDITIONS – TIDE

Water levels from three stations were collected in Budd Inlet and Capitol Lake. They are from various resources including the NOAA's Center for Operational Oceanographic Products and Services (CO-OPS), USGS, and Enterprise Services. Detailed information about the data is listed in Table 3.3. The station locations are shown in Figure 3.2. It should be noted that the DES-5th Avenue station contains two water level gages on each side of the lake dam with the same data coverage and intervals.

Table 3.3   Water Level Gage Station Information

Station Name	Station ID	Period of Record	Frequency	Data Gap(s)	Source
Budd Inlet, South of Gull Harbor, WA	9446807	04/26/1996 to 12/3/1996	6 min	-	NOAA CO-OPS
		04/26/1996 to 12/3/1996	60 min	-	
Olympia	N/A	11/05/2018 to present	15 min	1/26/2019-2/4/2019; 2/7/2019-2/23/2019; 3/11/2019-3/12/2019	USGS
5th Avenue Dam	N/A	04/27/2016 to 4/1/2019	5 min	7/16/2016-7/20/2016; 2/27/2018-4/25/2018	DES[†]

Note:

† Water level measurements are available on the lake side.

Figure 3.2 Location Map of Water Level Measurement Stations

For hydrodynamic model runs, tidal boundary conditions will be specified at the offshore boundary using astronomical tidal constituents from Gull Harbor in eastern Budd Inlet (NOAA Station 9446807) with estimated residual water level based on meteorological records. The water level will vary in space (along the boundary) and in time. Based on the initial calibration results for water levels, tidal constituents at the offshore boundaries may require adjustment. The adjustments are done as a part of model calibration to better match lake level measurements at the 5th Avenue Dam.

3.3   DAM OPERATION

The modern assembly of the 5th Avenue Dam consists of two radial gates to regulate lake level and a fish ladder. Photographs of the 5th Avenue Dam taken from downstream and upstream are shown in Figure 3.3 and Figure 3.4, respectively. The three openings, from left to right looking from the downstream (north) side (Figure 3.3), are: the fish ladder; the 24-foot-wide East Gate; and the 36-foot-wide West Gate.

Figure 3.3 Photo of the 5th Avenue Dam Looking South Toward Capitol Lake

Figure 3.4 Photo of the 5th Avenue Dam Looking North from Upstream

The gate operation logic based on a lower and an upper setpoint for the lake level is as follows:

- The first priority is to close both gates if the tide level (downstream of the gates) is at or above the lake level – this avoids saltwater from Budd Inlet flowing 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 different time periods.

- The second priority is to close the gate if the lake level is below the lower setpoint;

- 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. Detailed description of the 5th Avenue Dam operation was provided in M&N (2008).

In Delft3D, time varying gate openings can be modeled with real time control (RTC), and a complex gate operation logic can be implemented. Gate opening with real operation logic and associated discharge from the gate will be implemented in the Delft3D model.

3.4   MODEL CALIBRATION/VALIDATION

For the No Action and Managed Lake Alternatives, water levels and flow velocities within the Capitol Lake are primarily controlled by the gate operation. The main purpose of the calibration for these two alternatives is to replicate the measured water levels at the 5th Avenue Dam inside the lake under

different flow conditions. For the Estuary and Hybrid Alternatives, water levels and flow velocities within the Capitol Lake are controlled by tides and river discharge. Since the configuration associated with the Estuary and Hybrid Alternatives does not exist, there are no measured data to be used for calibration. Limited sensitivity testing and comparison with previous USGS modeling studies will be conducted to increase confidence that dynamics of the system are captured.

3.4.1   Calibration/Validation Data and Period

Water levels at the 5th Avenue station inside the lake will be used as calibration data for the hydrodynamic model for the No Action and Managed Lake Alternatives. Water levels at this station are available from 4/27/2016 to 4/1/2019 (Table 3). Based on availability of the calibration data and discharge values at USGS Station 12080010 (Figure), three calibration periods are proposed around the peak event[2] during 02/10/2017 (Figure 3.6) with three different gate opening conditions based on the dam gate operation logic described above.

- Calibration period 1 (Low Flow): 02/04/2017 00:00 – 02/09/2017 00:00.

- Calibration period 2 (Medium Flow): 02/09/2017 14:00 – 02/12/2017 20:00.

- Calibration period 3 (High Flow): 02/15/2017 20:00 - 02/19/2017 20:00.

In Delft3D, time varying gate openings can be modeled with RTC, and a complex gate operation logic can be implemented. However, due to lack of detailed gate opening information, several rounds of iteration will be needed to accurately produce the lake levels in the model.

---

[2] Peak event from the available period of record for water level measurements at the dam (4/27/2016 to 4/1/2019)

Figure 3.5 Deschutes River Discharge (15-min Average) at USGS Station 12080010 and Hourly Water Level Measurement at 5ᵗʰ Avenue Dam
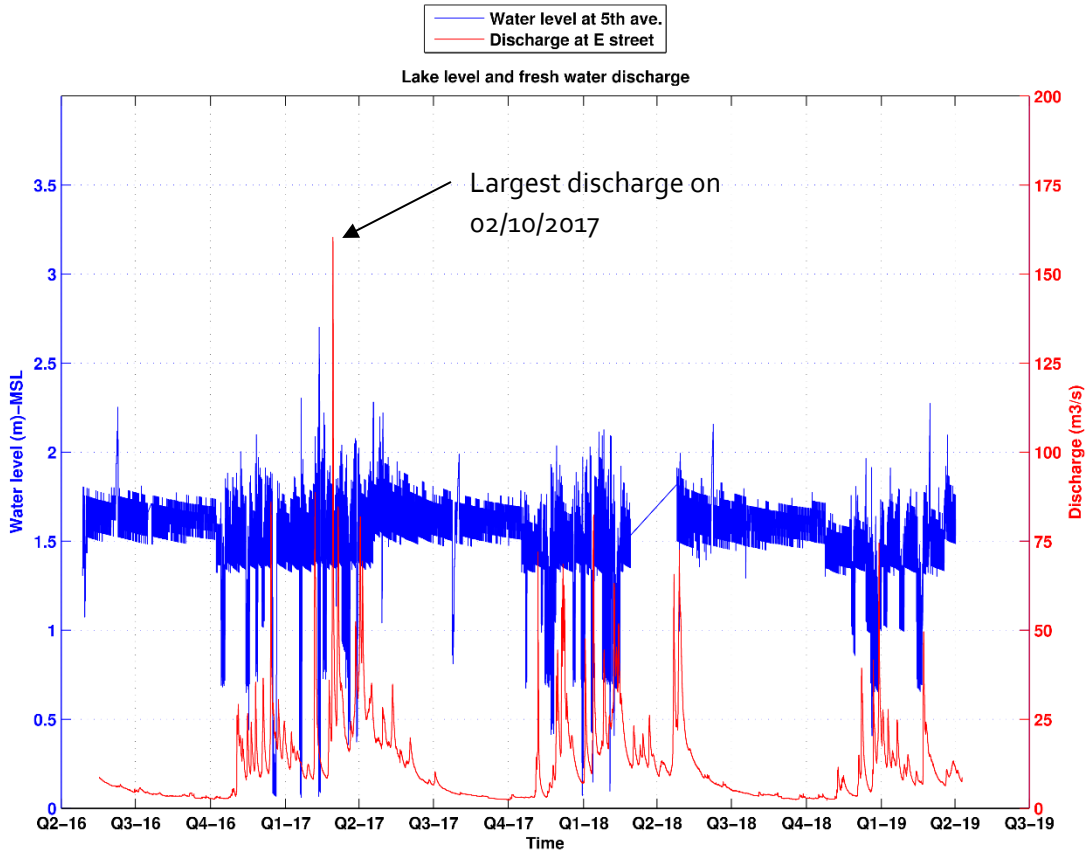
Figure 3.6 Three Hydrodynamic Calibration Periods (low, medium, and high flow) during 02/2017
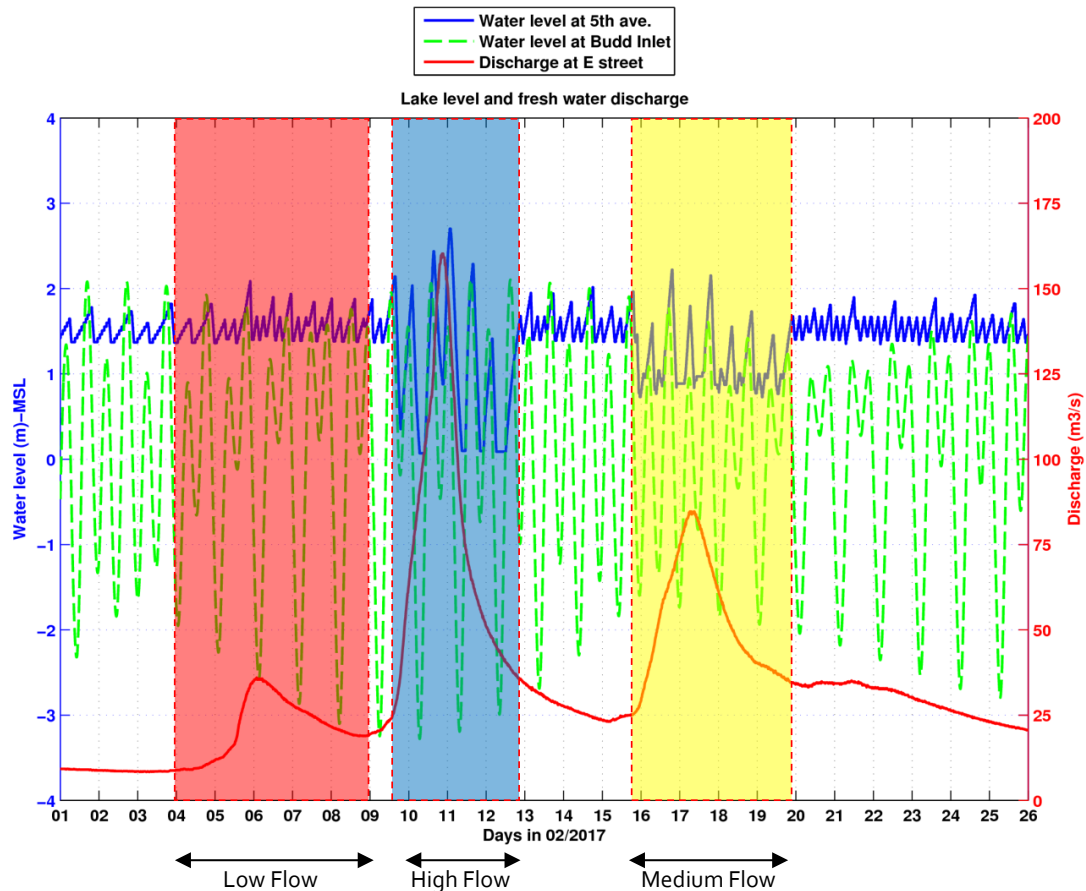
3.4.2   Calibration/Validation Parameters

In the hydrodynamic calibration process, time varying gate openings with real operation logic will be used to adjust the model to match the measured water level at the lake. There will not be any specific calibration parameters because the gate opening logic is the most significant factor to control the lake level.

3.4.3   Goodness of Fit and Calibration Metrics

To quantify model performance in simulating measured lake level, statistical parameters will be used to assess model calibration and validation results. These include the mean error (ME), root mean square (RMS) error, normalized RMS error, mean absolute error (MAE), correlation coefficient (R), index of agreement (d), and time delay or lag (ΔT).

3.5   PRODUCTION RUNS

The calibrated 3D hydrodynamic model will be used to simulate alternatives under the existing and future conditions. At the upstream river inflow boundary, a 100-yr return period flooding event will be used. At the downstream water level boundary, the typical spring tide will be used. The "future condition" includes a 100-yr return period flooding event combined with the typical spring tide plus 2 feet of SLR.

3.6   MODEL RESULTS

Results of the hydrodynamic simulations will be presented as site plan maps of max depth-averaged velocities and maximum water surface elevations for all alternatives. Time histories of water surface elevations and depth-averaged velocities will also be presented at observation points to cover the entire modeling domain.

4.0 Sediment Transport

A 3D hydrodynamic and sediment transport model will be developed. Limited sensitivity testing will be conducted to evaluate salinity and its possible influence on sedimentation patterns and magnitude.

4.1 SEDIMENT PROPERTIES

Four sediment classes of clay, silt, sand and gravel will be used for modeling sediment transport. Several parameters are needed for sediment transport and morphological simulations, and Table 4.1 lists the proposed parameters adapted from previous studies (George et al., 2006 and Stevens et al., 2008). In Delft3D sediment transport, only sediment density and median grain size are needed for input into the model for non-cohesive sediment including sand and gravel. For cohesive sediment such as clay and slit, more parameters are needed such as critical shear stress for erosion and the erosion rate as provided in Table 4.1. Other parameters for cohesive sediment including critical shear stress for sedimentation and settling velocity will also be input into the model.

Table 4.1   Sediment Properties and Inputs from USGS Studies (George et al. 2006 and Stevens et al. 2008)

Class	Median Grain Size D$_{50}$ (µm)	Dry Sediment Density (kg/m^3)	Critical Shear Stress for Erosion (pa)	Erosion Rate (kg/m^2/s)
Clay	-	316 -594	0.18 -0.78	0.001-0.0147
Silt	-	316 -594	0.18 -0.78	0.001-0.0147
Sand	200	1,600	-	-
Gravel	2000	1,600	-	-

4.2 BOUNDARY CONDITIONS – RIVER INFLOW

Boundary conditions of river inflow for the sediment transport will be the same as those in the hydrodynamic model, which will include two open boundaries at the Deschutes River mouth and

Percival Cove, and point discharges to represent un-gaged watersheds. Discharge measurements with 15 min interval will be used as boundary condition inputs.

4.3   BOUNDARY CONDITIONS – SEDIMENT LOAD

The existing sediment rating curve for the Deschutes River dates to 1974 (Mih and Orsborn 1974). This rating curve was developed using limited field measurements gathered by Nelson (1974) and can be used to estimate the suspended sediment transport to Capitol Lake. Additionally, sediment load to the Capitol Lake has been estimated by comparing surveys of the lakebed. George et al. (2006) compiled existing estimates of sediment load to the Capitol Lake obtained by previous studies. These estimates show significant inter-annual variability of sediment load ranging from 22,000 m³/yr to 42,000 m³/yr (see George et al., 2006 for a list of these studies).

Sediment load to the Capitol Lake will be based on the existing sediment rating curve and may need to be adjusted to match the estimated average annual sedimentation rate[3] in the Capitol Lake. Sediment load will be calculated by multiplying the river discharge and sediment concentrations at the upstream boundaries. Sediment concentrations at the offshore boundary will be set to zero. For cohesive sediment (clay and silt), the sediment class concentrations will be estimated by multiplying the expected flux percentage of each sediment class (Table 4.2 [from George et al. 2006]) and the total concentration. For non-cohesive sediment (sand and gravel), equilibrium boundary conditions will be applied by specifying that, at all open inflow boundaries, the flow should enter carrying the same concentration of sediment as computed in the interior of the model. This means that the sediment load entering through the boundaries will be near-perfectly adapted to the local flow conditions and will avoid dramatic accretion or erosion near the model boundaries (Deltares 2014).

Table 4.2   Sediment Flux Percentage for Each Sediment Class (George et al. 2006)

Class	%
Clay	28.4
Silt	40.8
Sand	28.4
Gravel	3.4

4.4   BOUNDARY CONDITIONS – TIDE

The sediment transport model will simulate a significantly longer time period than the hydrodynamic model (five years compared to weeks) and will focus more on the long-term effects. Therefore, a real-time tide boundary, which simulates the complex semi-diurnal inequality during the spring-neap tidal

---

[3] This rate will be estimated based on comparison of TerraSond (2013) or USGS (2004/2005) bathymetry surveys with the bathymetry survey scheduled for November 2019 as part of the Capitol Lake – Deschutes Estuary Long-Term Management Project EIS.

cycle is not needed (Latteux 1995). Instead, a harmonic "morphological tide" was generated for tidal forcing by multiplying M2, the amplitude of the largest component, by 1.1 (George et al. 2006).

4.5 PROPOSED LONG-TERM MORPHOLOGICAL SIMULATION METHODOLOGY

Long-term simulations with a high-resolution, multi-dimensional morphologic model such as Delft3D typically take significant computational time and resources. The computational time to run a 3D high-resolution Delft3D model including salinity is prohibitive for morphodynamic timescales. For example, George et al. (2006) stated that it took 12.5 days of computation time to carry out a 14-day simulation (Table 2.12 of George et al., 2006).

Ultimately, the modeling approach should include a practical runtime. Therefore, a compromise is often made between the following parameters:

- model resolution,
- accuracy of representation of the river hydrograph in the model (e.g. running representative river conditions rather than an actual river hydrograph),
- simplification and speedup methods of morphological simulations (e.g. using morphological factors), and
- number of simulations required to evaluate the range of predicted morphological changes.

The recommended balance between all these parameters is described below in the proposed methodology and provides the necessary information to evaluate alternatives as part of the EIS project. If model runtimes for the proposed methodology are not practical, modeling methodology will have to be adjusted to make the runtimes reasonable.

Figure shows the 30-yr long time series of river discharge in Deschutes River at E Street Bridge at Tumwater, WA (USGS station 12080010). It can be observed that river discharges vary significantly between years, with the peak value ranging from below 50 m^3/s to 250 m^3/s. This yearly variation makes it difficult to select one representative time period, for example one year, to accurately evaluate the long-term impacts, with a reasonable amount of computational effort.

Table lists the discharge statistics for the 30-year period at E Street Bridge. The annual average flow of the Deschutes River is about 12 m^3/s with a very strong seasonal fluctuation. From Table , it can be observed that the wet season spans from November to April and the dry season spans from May to October. The seasonal variation significantly impacts sediment delivery pattern to the lake. A 1974 study established that 80-85% of the annual sediment load arrives by flood events that occur during only 8% of the year (Mih and Orsborn 1974). As a result, sequences of dry season, wet season and large flood events during simulation will alter the sediment/erosion conditions even if the overall statistics are the same. Therefore, construction of the discharge classes and their sequences based on the annual river discharge statistics may result in a realization of river conditions but may not represent the entire range or potential variability in discharge event sequence.

Figure 4.1 Deschutes River Discharge (15-min Average) at E Street Bridge (1990 to 2019)
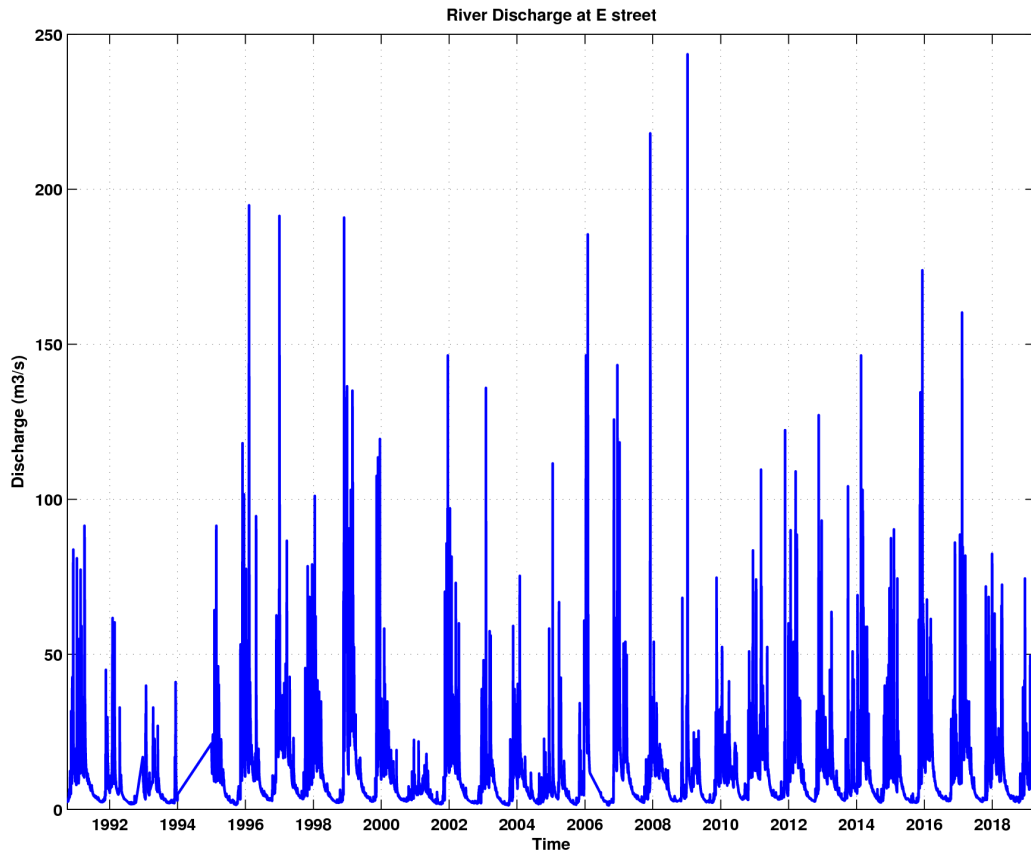

River Discharge at E street

Table 4.3   Monthly Statistics of River Discharge (m³/s) at E Street Bridge

Statistics	25%	50%	75%	90%	95%	99%	Min	Max	Mean
January	10.93	16.25	25.91	41.91	55.78	94.92	3.14	243.53	21.75
February	10.28	14.67	22.94	35.68	50.69	95.71	3.82	194.82	19.72
March	10.36	15.8	23.05	35.96	48.7	77.31	3.26	109.59	19.39
April	10.02	12.57	17.16	23.79	29.73	52.67	4.76	94.58	14.83
May	6.77	8.55	11.1	14.33	15.91	23.45	3.48	52.39	9.39
June	4.47	5.58	6.94	8.89	10.93	16.99	3.03	26.96	6.13
July	3.12	3.88	4.47	5.18	5.52	6.82	1.9	8.1	3.88
August	2.49	3.09	3.65	4.05	4.3	4.76	1.47	11.55	3.11
September	2.15	2.62	3.12	3.82	4.93	8.44	1.25	88.35	2.94
October	2.5	3.12	4.73	9.12	14.67	27.35	1.36	104.21	4.95
November	4.9	9.49	18.69	32.85	46.16	91.46	1.95	190.86	15.04
December	8.21	14.27	24.38	43.61	59.47	98.54	1.98	218.04	20.46
Annual	3.74	7.53	14.67	25.66	36.25	68.81	1.25	243.53	11.98

Taking those factors into account, a modeling methodology based on lookup tables of river discharges versus sedimentation/erosion rates is proposed to simulate the long-term morphological changes with a real-time hydrograph. This approach will be applied to both calibration and production runs. This approach was previously used in a similar study for the Mississippi River morphological evolution near a borrow site (see M&N 2011), which was reviewed and approved by USACE representatives.

4.5.1   Initial Lookup Table

A series of Delft3D simulations is carried out for a range of constant discharges, for example, from 10 to 250 m³/s at 10 m³/s increments, using the initial bathymetry combined with the morphological tide. From the model results, a lookup table of sedimentation/erosion rates will be created. The lookup table will be used to estimate the sedimentation/erosion in each cell of the model domain for any given river discharge by interpolation.

4.5.2   Morphological Changes

After constructing the initial lookup table, it is possible to compute sedimentation/erosion rates for a time series of measured river discharges. The vertical changes in bed elevation will be computed by integrating the computed interpolated sedimentation/erosion rates over time with post-processing scripts in MATLAB software package. This will be done under the assumption that the sedimentation rates do not change significantly with small morphological changes. The total changes in bed elevation

will be checked after each incremental change and if they are significant (for example, if they exceed preset thresholds), then a new lookup table of sedimentation/erosion rates will be constructed.

4.5.3   Lookup Table Updates

During the morphological computations, the bathymetry for each cell will be updated after each time step in the discharge time series by adding the computed bed level change. However, after a period of time or during an extreme event, bathymetry may become significantly different from the initial, which can affect hydrodynamics and sediment transport and thus sedimentation rates. At that point, a new set of Delft3D simulations will be performed with the updated bathymetry. As a result of the new simulations, an updated lookup table of sedimentation/erosion rates versus river discharge will be calculated. The computation of the new lookup table will be triggered by changes in bathymetry, which exceed two threshold criteria: (a) one threshold is the percentage change in the local depth and (b) the other threshold is the absolute change of the local depth. Examples of thresholds (a) and (b) include if the local depth anywhere in the model domain changes by more than 10% and if the total change in local bathymetry is above 0.1 m, respectively. If either of the thresholds is exceeded, then a new lookup table will be calculated. These checks can be performed for the entire domain or a selected area of interest.

4.5.4   Strengths and Limitations of the Proposed Methodology

The described methodology provides the following strengths and limitations compared to other available methodologies for long-term morphological prediction including the methodology used by the USGS study (George et al. 2006):

- Numerical modeling can be performed for a higher number and greater range of river discharges compared to other methodologies. The number of river discharges define the lookup table resolution. In the previous USGS study of George et al. (2006) only five discharges were used, which did not cover the entire range of the measured river discharges.

- Delft3D simulations are performed individually for each steady-state river discharge condition with representative tidal conditions at the downstream boundary. This allows a greater control over the model simulations. For example, this approach allows using different roughness maps for each discharge, if needed.

- The methodology uses actual measured time series of river discharges and computes morphological changes in real time scale. Previously, morphological changes were computed using the morphological factor, which is a method to speedup morphological computations. However, the morphological factor was applied to the constant discharge conditions, which were preselected to represent the variability in river discharges, but not the actual discharges. Therefore, sequence of discharge events, their duration and range were not directly accounted for.

- The proposed methodology provides similar benefits for speeding up the model simulations similar to the methodology used in George et al. (2006) since the time-

consuming Delft3D simulations are only performed when significant changes in bathymetry occur. For example, during low discharge conditions, the morphological changes are expected to be small; therefore, the Delft3D simulations will not be performed until significant changes in bathymetry occur.

- Because the actual time series of river discharges can be modeled, it is possible to simulate several realizations of river discharge conditions. Such simulations can provide an insight on the range of morphological changes, such as to test various 'what if' scenarios, for example, under unusually wet or dry conditions.

Although a high number of constant river discharges can be simulated, a compromise is still made by discretizing the river discharge (compared to running the actual river discharge).

4.6   MODEL CALIBRATION/VALIDATION

The purpose of the calibration process for sediment transport model is to replicate sedimentation/erosion volume and pattern in the Capitol Lake Basin obtained by comparing available bathymetric surveys of the basin.

4.6.1   Calibration/Validation Data and Period

Bathymetry surveys inside the lake will be used as calibration data in the sediment transport/ morphological model. These survey data are available in 09/2004, 03/2013 and 11/2019. Based on the calibration data availability, two calibration periods for the sediment transport/morphological model are proposed below.

- Calibration period 1: 09/01/2004 – 04/01/2013 with initial lake bathymetry of 09/2004 survey.
- Calibration period 2: 04/01/2013 – 07/01/2019 with initial lake bathymetry of 03/2013 survey.

4.6.2   Calibration/Validation Parameters

Calibration parameters to match sedimentation/erosion volume and pattern within the Capitol Lake Basin include:

- For non-cohesive sediment (sand and gravel), the bottom roughness values, and sediment transport model parameters.
- For cohesive sediments (silt and clay), critical shear stresses, settling velocities and erosion rates.

It is worth noting that although total sediment loads will be bounded by the rating curves provided in Table 4.3, sediment loads for each sediment fraction will still need adjustment in the calibration run to reproduce the sedimentation/erosion patterns for each fraction as well as the total annual volume changes.

A previous study by USGS (George et al. 2006) also included a uniform constant wind and wave field in the sediment transport model to evaluate the stirring effect on sediments. Test cases with and without waves will be run to evaluate the wave effect on sediment transport in the lake. If the impacts of wind and wave field is significant, a uniform constant wind and wave field may be added to the sediment transport model.

4.6.3   Calibration/Validation Metrics

Unlike the hydrodynamic model calibration metrics, which will be based on time series comparisons, the sediment transport model will simply compare the total sedimentation volume and pattern during each calibration period between the model results and field surveys, and quantify the differences as calibration results.

4.6.4   Sensitivity Testing and Model Parameters

Limited sensitivity testing on a few key parameters (including salinity) will be performed to evaluate range of uncertainties associated with results. For model parameter selection and justification, this modeling effort will use and build upon the previous USGS studies (George et al. and Stevens et al. 2008).

4.7   PRODUCTION RUNS

The calibrated 3D sediment transport model will be used to simulate alternatives under existing and future conditions. At the upstream river inflow boundary, a 5-year period of actual river discharges will be used. The model results by USGS (George et al. 2006) indicated that an equilibrium state was reached within the first three to five years after removing the 5th Avenue Dam, therefore, a 5-year production run period is expected to be sufficient to capture the long-term impacts from each alternative. Test cases will be run to evaluate if a 5-year period is adequate for reaching a dynamic equilibrium. Additionally, to predict the future sediment/erosion rate range, a series of five to ten 5-year-long simulations will be selected from the 30-year period with the available discharge data (Figure 4.2). For example, a 5-year period from 10/01/2006 (10/01 is the start of a water year defined by USGS) to 10/01/2011 is highlighted in red in Figure 4.2 to form one of the 5-year realizations. At the downstream water level boundary, a "morphological tide" will be used.

Figure 4.2 Deschutes River Discharge (15-min average) Measured at E Street Bridge USGS Gage with the Selected 5-Year Realization (2007-2012)

River Discharge at E street

5-Year Realization
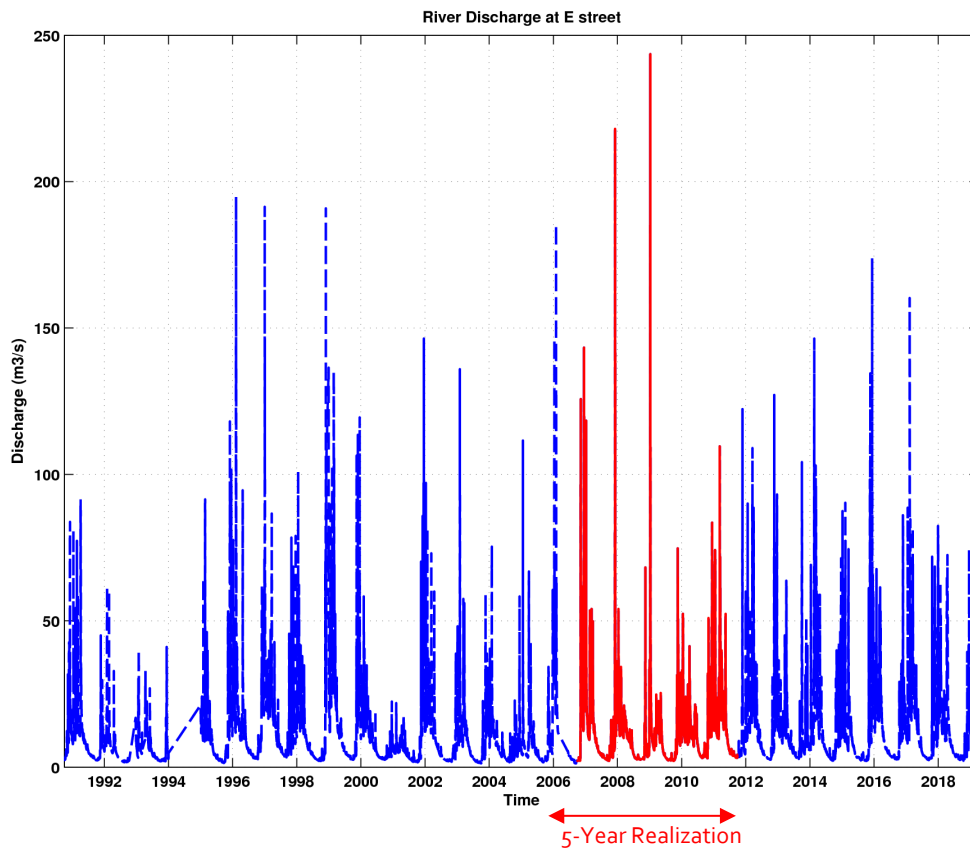
4.8   MODEL RESULTS

Results of the simulations will be presented as sediment fluxes at cross-sections of interest, erosion and deposition maps for each sediment grain size class, and sediment volume changes inside the lake and other regions of interest (polygons). Model results will serve as a platform for the effects analysis across a variety of disciplines (including fish/wildlife, wetlands/vegetation, navigation, public services/utilities, economics, and design/cost).

4.9   IDENTIFICATION OF MITIGATION MEASURES

Model results will be used to develop and recommend mitigation measures, in coordination with the EIS Project Team, that could be implemented to avoid or minimize potential adverse impacts as much as possible. Mitigation measures will be preliminarily assessed by identifying changes in sediment transport and deposition and may include control structures and sediment traps.

City of Olympia. 2019. *Olympia Sea Level Rise Response Plan*. March 2019.

Deltares. 2014. *Delft3D-FLOW, Hydro-Morphodynamics User Manual, Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments*. Version: 3.15.34158, dated 28 May 2014.

eTrac. 2019. Capitol Lake Hydrographic Survey, scheduled for November 2019. For Department of Enterprise Services.

George, D. A., G. Gelfenbaum, G. Lesser, and A.W. Stevens. 2006. *Deschutes estuary feasibility study—Hydrodynamics and sediment transport modeling*. United States Geological Survey Open File Report 2006–1318.

Herrera, 2019. *Capitol Lake sediment rating curve summary*.

Latteux, B., 1995. "Techniques for long-term morphological simulation under tidal action." Marine Geology. Vol. 126, 129-141.

Mih, W. and Orsborn, J. 1974. *Sediment removal and maintenance system for the upper basin of Capitol Lake Olympia, Washington*. Preliminary Report, Washington State University, Pullman, WA, 33 p.

Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M.,Grossman, E. 2018. "Projected Sea Level Rise for Washington State – A 2018 Assessment." A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project.

Moffatt & Nichol (M&N), 2008. *Capitol Lake alternatives analysis hydraulic modeling*.

Moffatt & Nichol (M&N). 2011. *Delft3D Borrow Area Modeling, Appendix D of Mississippi River Long Distance Sediment Pipeline, Overall Planning and Development, OCPR*. M&N Project No. 6865, dated Jan 14, 2011.

National Oceanic and Atmospheric Administration (NOAA). 2014. *Digital Elevation Model of Puget Sound, Washington: Procedures, Data Sources, and Analysis*. Prepared for the National Tsunami Hazard Mitigation Program (NTHMP) by the NOAA National Geophysical Data Center (NGDC) June 24, 2014.

Stevens, A. W., G. Gelfenbaum, E. Elias, and A. Jones. 2008. *Incorporation of fine-grained sediment erodibility measurements into sediment transport modeling, Capitol Lake, Washington*. United States Geological Survey Open File Report 2008–1340.

TerraSond. 2013. *Capitol Lakes Hydrographic Survey, Project No.: 2013-011*. Conducted for Floyd/Snider.

United States Army Corps of Engineers (USACE). 2013. *Federal Navigation Channel Condition Surveys in Budd Inlet*.

United States Geological Survey (USGS). 2005. *Capitol Lake, Washington, 2004 Data Summary*. Data Series 180.