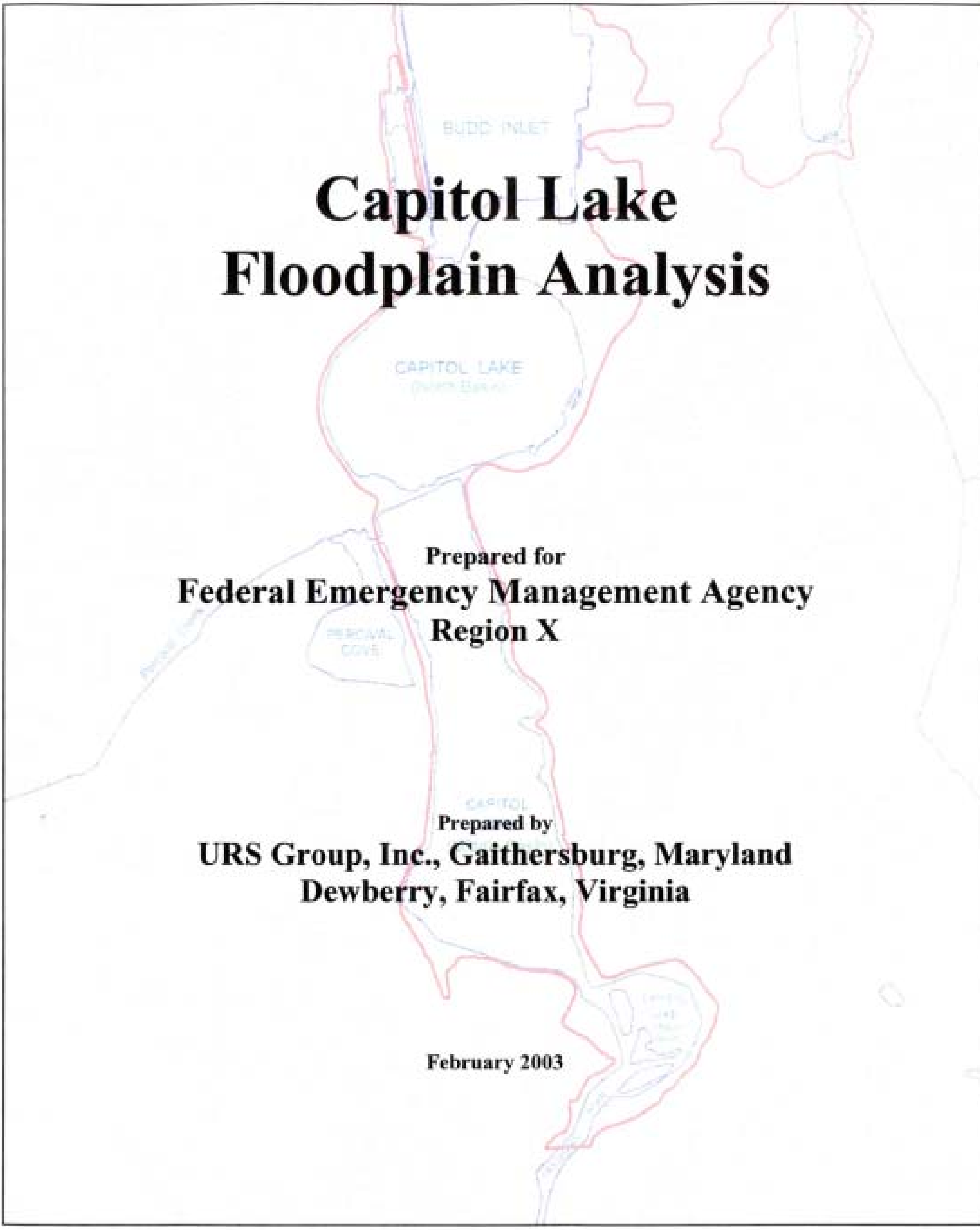

Capitol Lake Floodplain Analysis

Prepared for

Federal Emergency Management Agency
Region X

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February 2003

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1.0 Introduction

This report summarizes the results of a continuous simulation study developed to establish the flood elevations for Capitol Lake in Olympia, Washington. This study supports Letter of Map Revision (LOMR) requests to update the impacted portions of the effective Flood Insurance Studies (FISs) for the City of Olympia, dated August 17, 1981; the City of Tumwater, dated April 3, 1984; and the unincorporated areas of Thurston County, dated December 1, 1982. The results of the study reflect an increase in the Base (1% annual chance, or 100-year) Flood Elevation (BFE) and a larger 100-year floodplain for Capitol Lake and a portion of the Budd Inlet, immediately downstream of the lake.

This study was conducted for the Federal Emergency Management Agency (FEMA) by Dewberry under contract with URS Group, Inc. The hydrologic analysis for this study was performed by Aqua Terra Consultants and URS Group, Inc. Dewberry was responsible for the development of the hydraulic model and the determination of Capitol Lake flood levels. MWH Americas, Inc., performed a quality review of the hydraulic model.

The funding for the study was provided by FEMA under the Hazard Mitigation Technical Assistance Contract Number FMW-2000-CO-0247, Task Order 073.

1.1 Capitol Lake: Location

Capitol Lake is located upstream of 5th Avenue and extends northwards to the bridges for Burlington Northern/ Santa Fe (BN/ SF) railroad and Interstate 5 (I-5). The Deschutes Parkway is located west of the lake and generally follows the lake's shoreline. Figure 1- Capitol Lake Location Map, shows the location of Capitol Lake in relation to Budd Inlet, the Deschutes River, and bridges. Deschutes River (drainage area of approximately 200 square miles at mouth) flows in a northwesterly direction into Capitol Lake before it joins the Budd Inlet of the Puget Sound. Percival Creek, a small tributary (with a drainage area of 4 square miles) to the Deschutes River, joins Capitol Lake.

The U.S. Geological Survey (USGS) operates two stream gages in the Deschutes River watershed. The drainage area of the watershed is 89.8 square miles at the location of the stream gage 12079000 near Rainier; the drainage area of the watershed at the stream gage 1280010 near Tumwater is 162 square miles. The USGS operated the stream gage 1208000 near Olympia until 1964. The drainage area of the watershed near the Olympia gage is 160 square miles.

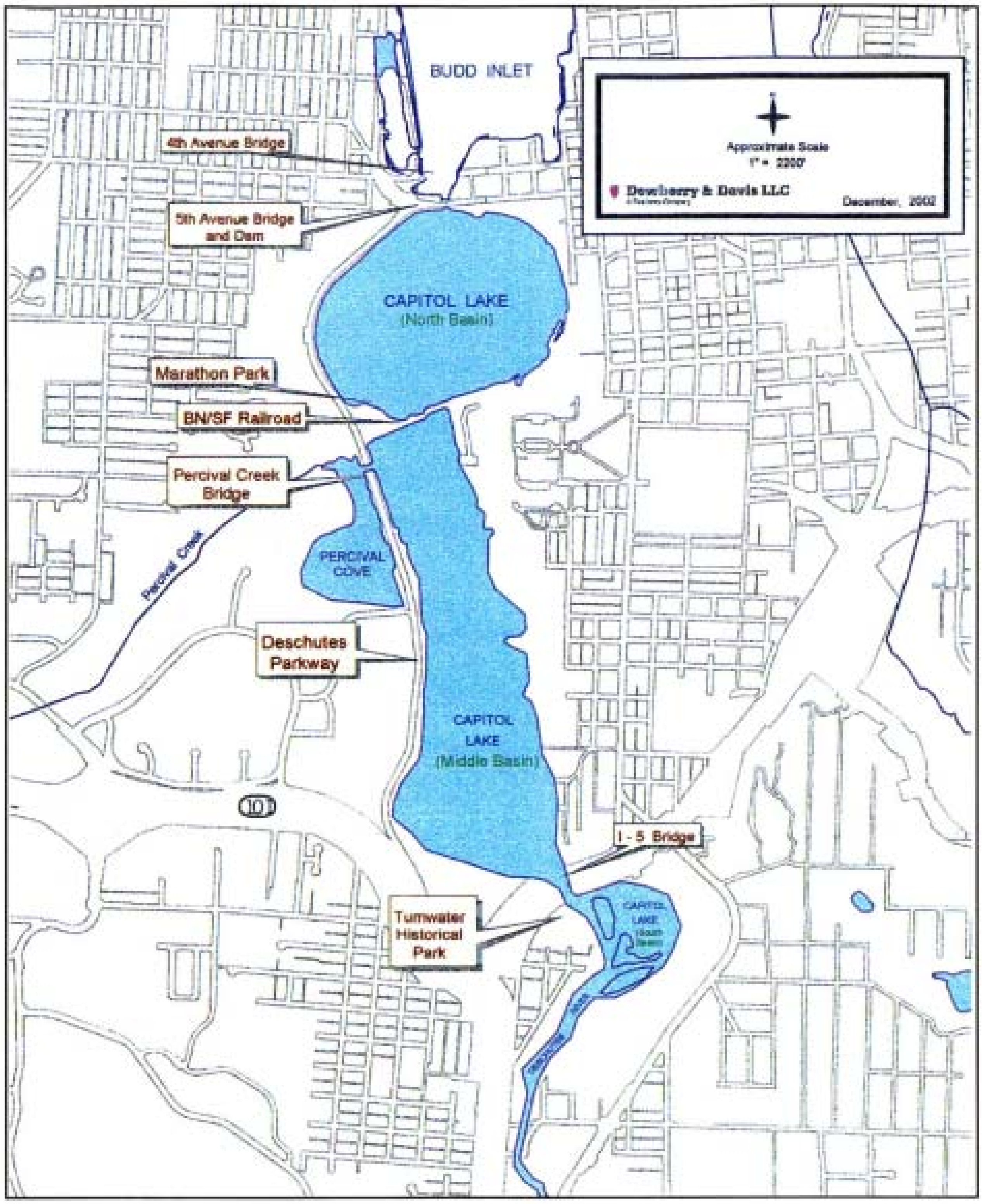

Figure 1 - Capitol Lake Location Map

Figure 2- Capitol Lake Watershed and Stream Gages, illustrates the locations of the watershed boundaries and the stream gages. Table 1- Deschutes River Stream Gage Information, summarizes the stream gage records available at the three sites.

Table 1 - Deschutes River Stream Gage Information

Stream Gage (USGS Gage Number)	Drainage Area (Sq. Mi.)	Type of Recording	Period of Record
Rainier (12079000)	89.8	Daily	6-1-1949 to 10-20-1975
		Daily	6-1-1987 to 9-30-1998
		Hourly	10-1-1987 to 9-20-2001
Tumwater (12080010)	162	Daily	1-26-1948 to 10-30-1954
		Daily	6-1-1957 to 6-30-1964
		Daily	10-1-1990 to 9-30-2000
		Hourly	9-29-1990 to 9-20-2001
Olympia (12080000)	160	Daily	1-26-1948 to 10-31-1954
		Daily	6-1-1957 to 6-30-1964

1.2 Capitol Lake: Background

Prior to the construction of a dam under the 5th Avenue bridge in 1951, the Capitol Lake area was an estuary where freshwater from Deschutes River joined freely with the marine waters of Budd Inlet. Constructing the dam created Capitol Lake, a shallow fresh water lake with a surface area of 270 acres. Two radial gates built on the dam are responsible for the regulation of the lake level. The operation of the gates, automated by a control system, maintains target lake levels and prevents intrusion of marine waters into the lake. The timing and duration of the radial gate openings depend on Deschutes River and Percival Creek inflows. To facilitate the fish passage, the dam has a fish gate, which consists of a weir fitted with a movable vertical plate. The fish gate remains open between March and October. Photographs of the radial gates and the fish gate are provided in Appendix 1.

For purposes of the hydraulic analysis, Capitol Lake was divided into three separate basins: North, Middle, and South. The 5th Avenue Dam and the gates regulate the flow of water from Capitol Lake to Budd Inlet. In addition to the dam, there are two bridges, the BN/SF railroad bridge and the I-5 road bridge that impact the Capitol Lake flow. The North Basin is the portion of Capitol Lake between the 5th Avenue Dam on the downstream end and the BN/SF railroad bridge. The middle portion of Capitol Lake between the BN/SF railroad bridge and the I-5 Bridge is identified as the Middle Basin. The South Basin is the portion of Capitol Lake upstream of the I-5 Bridge. Percival Creek joins the Middle Basin of the Capitol Lake just upstream of the BN/SF Railroad. The layout of Capitol Lake is shown in Figure 1. A more detailed representation of the watershed map can be found in Attachment A.

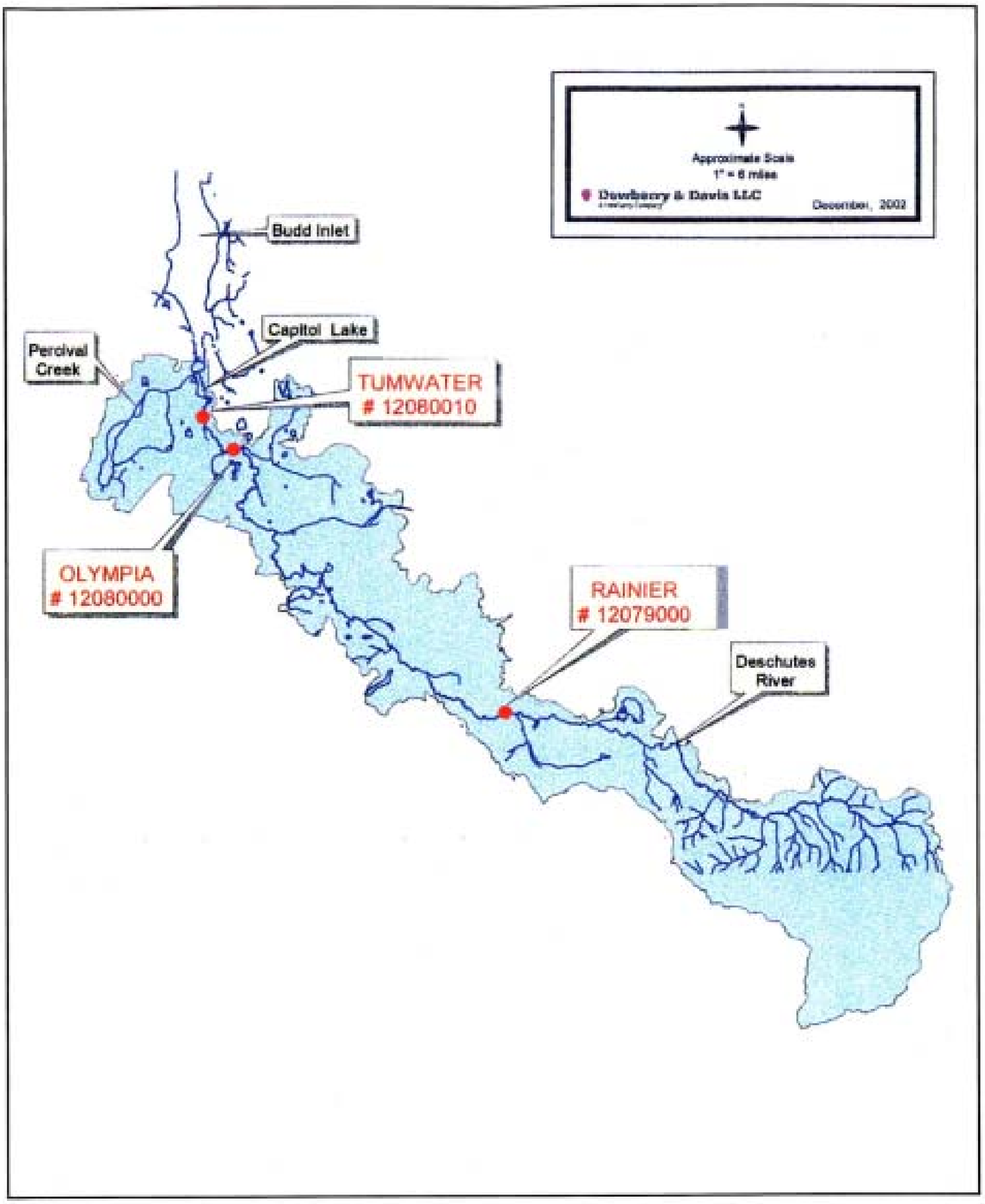

Figure 2 - Capitol Lake Watershed and Stream Gages

1.3 Existing Watershed Studies

The Capitol Lake water-surface elevation was determined for the Flood Insurance Studies (FISs) for the City of Olympia (FEMA 1981), City of Tumwater (FEMA, 1984), and Thurston County (FEMA 1982). The Capitol Lake flood elevations established for the FISs are based on stillwater elevations computed for Budd Inlet and field observations made during a 1975 historic high tide and Capitol Lake flooding event.

Capitol Lake hydrology and hydraulics were analyzed for two studies conducted by the Cities of Lacey, Olympia, Tumwater, and Thurston County (LOTT) partnership and the Washington State Department of General Administration (WSDGA). A Budd Inlet water quality study (Aura Nova Consultants, et at., 1998) was conducted in 1998 by LOTT. In 2000, the WSDGA conducted a Capitol Lake floodplain analysis (Entranco, Inc., 2001) and a bridge scour analysis (Entranco, Inc., 2000). The Budd Inlet water quality study and the WSDGA floodplain analysis used unsteady flow analyses and attempted to reflect the different flow scenarios created by the operation of the 5th Avenue radial gates. The WSDGA bridge scour analysis used steady state HEC-RAS backwater modeling.

The March 2002 draft report[6] published by the WSDGA summarizes the broad objectives of a Capitol Lake Adaptive Management Plan (CLAMP) for a 10-year period between 2002 and 2012. The draft report makes reference to this current study, and notes that the current results would assist CLAMP to "Develop a flood hazard management strategy to protect the lands adjacent to Capitol Lake."

The methodologies used for the lake level determination in the existing watershed studies are summarized below.

Flood Insurance Study

The floodplain analyses for the FISs were conducted by the USGS. The flood levels for the Capitol Lake defined in the FIS are based on the stillwater elevations of the Budd Inlet and observations made during a December 15, 1977, historic high tide and lake flooding event. The effects of wave action, wave crest height, and wave run-up were not considered in establishing the Capitol Lake flood levels for the FIS.

The tidal peak elevation-frequency relationship was developed by analyzing 71 years of annual peak tides recorded at the Seattle Tidal Station (National Oceanic and Atmospheric Administration [NOAA] "Tide Listings," 1975). Log Pearson Type III (LPIII) analysis with a skew factor of 0.2 was used to establish the peak elevation-frequency relationship. This relationship was then transferred to Budd Inlet near Olympia using the tide prediction tables (NOAA, National Ocean Survey, "Tide Tables, High and Low Water Predictions, 1975, West Coast of North and South America," 1975).

The historic high tide for Budd Inlet at Olympia occurred on December 15, 1977. On this date, Capitol Lake levels reached flood heights. Field observations indicated that the lake level was 0.4 foot higher than the high tide observed. This observation was used to define the flood levels for Capitol Lake. The lake flood elevations were obtained by adding 0.4 to the 10-, 50-, 100-, and 500-year stillwater elevations computed for Budd Inlet at Olympia.

Effective flood elevations for Budd Inlet and Capitol Lake are shown below:

	Budd Inlet	**Capitol Lake**
10-year:	*10.1 feet*	*10.5 feet*
50-year:	*10.4 feet*	*10.8 feet*
100-year:	*10.6 feet*	*11.0 feet*
500-year:	*10.8 feet*	*11.2 feet*

1988 Budd Inlet Water Quality Study conducted for LOTT

The water quality analyses were conducted by Aura Nova Consultants for the LOTT. The Capitol Lake discharge is the major freshwater inflow into the Budd Inlet and a hydraulic model of the lake was developed to determine discharges from the lake. The Deschutes River flow into Capitol Lake was obtained from the Tumwater stream gaging station. As part of the study, a rainfall-runoff model, TPRSM; and storage routing models, Capitol Lake Routing Method 1 (CLRM 1) and CLRM 2; were developed. The CLRM 1 computations were performed using an EXCEL spreadsheet. CLRM 2 was developed using Visual Basic 5.0.

The TPRSM model was calibrated to predict daily flows for Percival Creek. The storage routing model computed the gate position, discharge through the gates, and the lake water level. The final report provides a summary of the dimensions of the discharge structures at the 5th Avenue dam and the gate operational logic used by the control system METASYS.

The 100-year water level for Capitol Lake was not developed for this study.

2000 Capitol Lake Flood Analysis for WSDGA

The Capitol Lake Flood Analysis was conducted for the WSDGA as part of the CLAMP. The hydrologic and hydraulic analyses were performed by Entranco, Inc and reflected different flow scenarios for Capitol Lake. One of the scenarios considered for analysis reflected the existing flow conditions of the Capitol Lake. This study used XPSWMM unsteady flow model to perform the hydraulic computations. A 100-year hydrograph was developed and XPSWMM model was used to rout this hydrograph through Capitol Lake and 5th Avenue dam. Simple cross sections were used to model the bridge flows for the I-5 bridge and the BN/SF railroad bridge. In addition, the radial gate operation was not reflected in the XPSWMM model; instead, the hydraulic model assumed the gates to be open during the simulation time.

The 27 years of annual peak flows for Deschutes River recorded at gauging stations at Olympia (1947-1964) and Tumwater (1990-1996) were used to determine the 10-, 50-, 100-, and 500-year peak inflows to Capitol Lake. The hydrograph was generated based on an Entranco's observation reported in a 1984 Capitol Lake study[7].

The Budd Inlet tide levels near Olympia were determined based on the tide levels recorded by NOAA at the tide gage 9447130 for Budd Inlet near Seattle. The hydraulic model assumed the Budd Inlet tide levels to be at the two-year level. The maximum tide level was assumed to coincide with the peaking time of the inflow hydrograph.

This study predicted a 100-year water level of 12.7 feet for Capitol Lake.

2000 Hydraulic Scour Analysis for WSDGA

The Capitol Hydraulic Scour Analysis was conducted for the WSDGA as part of the CLAMP. The peak flow discharges computed for the Capitol Lake Flood Analysis is used to study the hydraulic scour in the vicinity of the I-5, the BN/SF, the 5th Avenue and the 4th Avenue road bridges. HEC-RAS steady state analyses were used in the analysis. The HEC-RAS model developed for the bridge scour analysis defined the bridge openings, bridge approach areas and the bridge departure areas. The models are provided in the CD (given as Attachment C) and formed the basis of the bridge models developed for the current study.

1.4 Capitol Lake Discharge Structures and Dam Operation

Structural and operational data for the 5th Avenue dam, its discharge structures, and their operation were compiled from the 1998 Budd Inlet Study, 2000 Capitol Lake Flood Analysis[5], a WSDGA document titled, "Capitol Lake Dam Operation for Flood Control"(Washington State Department of General Administration, undated), and telephone conversations with WSDGA personnel responsible for the operation. The WSDGA document and records of relevant phone conversations are in the CD provided as Attachment C. Photographs of these discharge structures are included in Appendix 1.

The Capitol Lake discharges water through two radial gates, East Gate and West Gate, a fish gate, and a siphon connecting the lake and Budd Inlet. During high floods, there will be overland flow to Budd Inlet through the low-lying areas east of Capitol Lake. In addition, the lake waters are lost to seepage, evaporation and leeks through closed gates.

This study assumes that flow through the siphon (maximum rate of 10 cubic feet per second) and the losses due to seepage, evaporation, and gate leeks are minor compared to the discharges through the radial gates and the fish gate. Capitol Lake is assumed to discharge flows through the radial gates, fish gates and when appropriate, through overland flow. The dam and the radial gates are shown on Figure 3, 5th Avenue Dam and Radial Gates. Figure 4- Schematic Diagram of Capitol Lake Discharge Structures, shows the dimensions of the radial gates and the fish gate. The dimensions of the dam and discharge structures are summarized in Table 2- Dimensions of Capitol Lake Discharge Structures.

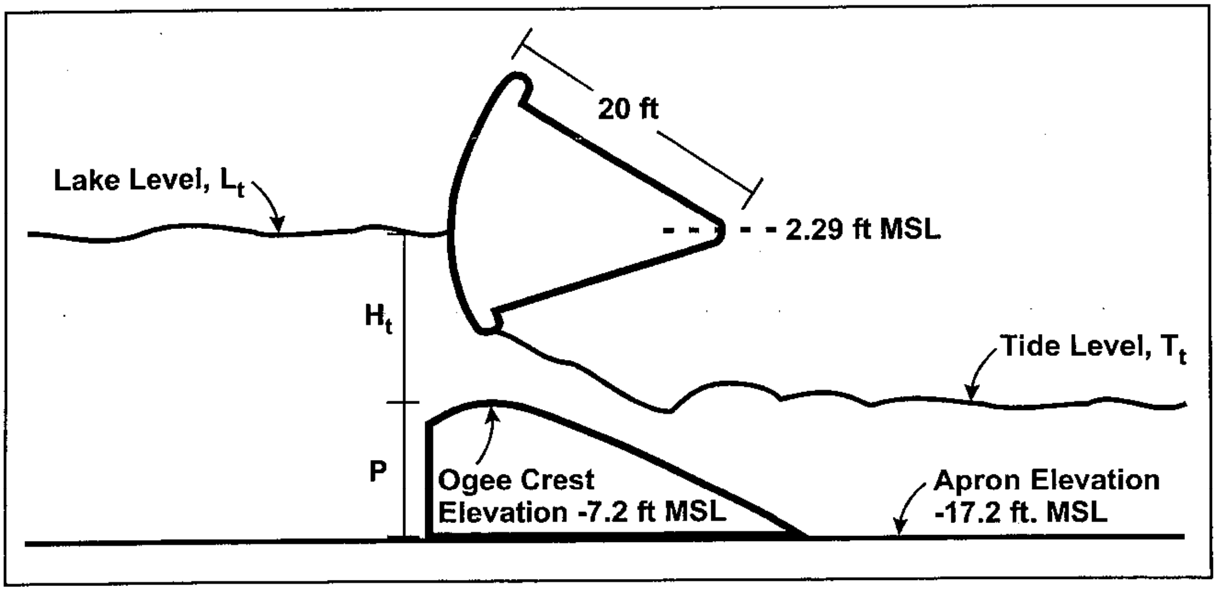

Figure 3 - 5th Avenue Dam and Radial Gates

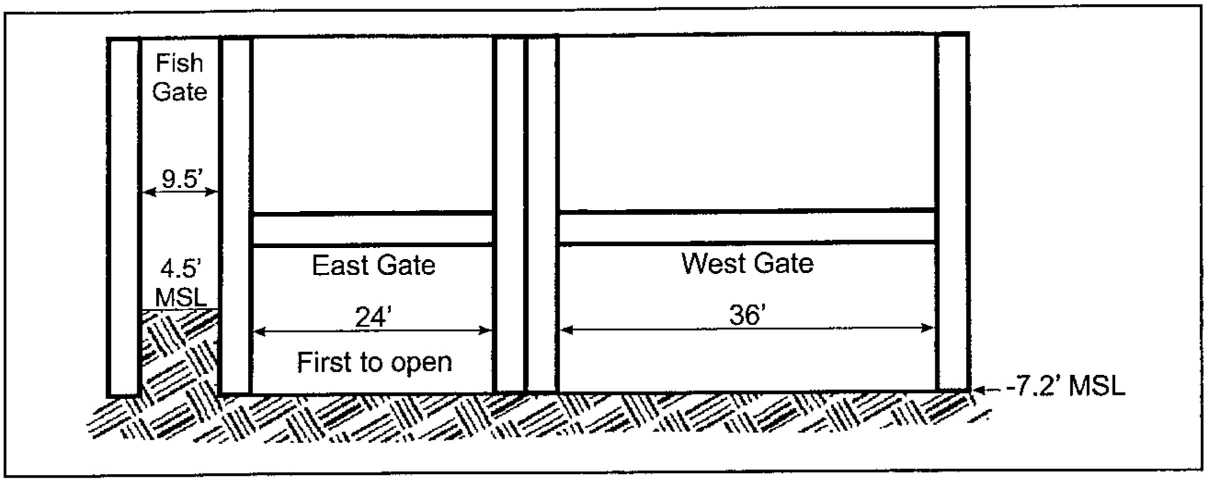

Figure 4 - Schematic Diagram of Capitol Lake Discharge Structures

Table 2 - Dimensions of Capitol Lake Discharge Structures

Component	Dimension
Dam	
Apron Elevation	-17.2 feet MSL
Crest Elevation	-7.2 feet MSL
Height	10 feet
Radial Gates	
Trunnion Axis Elevation	2.29 feet MSL
Gate Radius	20 feet
Maximum Opening: Elevation of Gate's Lower Edge	4.8 feet MSL
Design Head	12.4 feet
East Gate – Width	24 feet
West Gate – Width	36 feet
Fish Gate	
Width	9.5 feet
Crest Elevation	4.5 feet MSL
Height from Apron Elevation	21.7 feet

Radial Gates

The East and West radial gates are built on the dam. They are controlled by METASYS control system and regulate the releases from Capitol Lake. Electronic sensors continuously measure the water level of the Capitol Lake and the tide level of Budd Inlet. The timing and duration of the releases are triggered by the elevations monitored by the sensors. The gates are operated to maintain a target lake level and to prevent the intrusion of brine waters into the lake. During periods of the day when the gates are open, Capitol Lake discharges normally. As soon as the gates close, the flow stops. Capitol Lake reaches full flow mode to no-flow mode several times a day. During the winter, releases may occur three to four times a day. While, in the summer when river flows are lower, releases may occur only once or twice a day.

Fish Gate

The fish gate within the dam consists of a weir fitted with a vertical plate. The gate is 9.5 feet wide. When open, the top of the weir is kept lower than the lake level. Current practice is to keep the fish gate open during the summer months only. The gate facilitates fish passage between the Budd Inlet and the lake.

Dam Operation

The operation of the dam is automated by a METASYS control system. The METASYS control system relies on real-time data to operate the radial gates. The sensors on either side of the dam relay real-time lake and Budd Inlet water-surface elevations. In addition, the current position of the East Gate and West Gate is tracked by METASYS.

The objectives of the operation are:
- to prevent brine water intrusion during high tides;
- to maintain the target lake level; and
- to prevent flooding of the land adjoining Capitol Lake.

Different target lake levels are maintained for Capitol Lake during summer months than for winter months. Target lake levels are given in Table 3- Capitol Lake Target Lake Levels.

Table 3 - Capitol Lake Target Lake Levels

Season	Period	Lake Level (MSL)
Summer	March 16 to October 14	6.22 MSL
Winter	October 14 to March 16	5.26 MSL

When the elevation of the lake rises above the target level, the METASYS opens the East Gate as soon as the Budd Inlet tide level goes below the lake level. If the lake continues to rise to half a foot above the target level, the West Gate opens and the East Gate will reach 80% of its full open position within 10 to 15 minutes. The West Gate also can be opened to 80% of its full open position. However, the last 20% opening must be done manually. The manual opening is done by gate operators, who are required to be present during periods of high inflows from the Deschutes River.

The gates remain closed for periods of high tide in Budd Inlet. During periods of high tide, the lake levels may increase beyond the target level. The gates open again when the lake level is at least a half of foot greater than the tide level. Once the lake level drops below the target level, the gates are closed by the METASYS. These operations are illustrated as a decision tree shown in Figure 5- Decision Tree, Dam Operation.

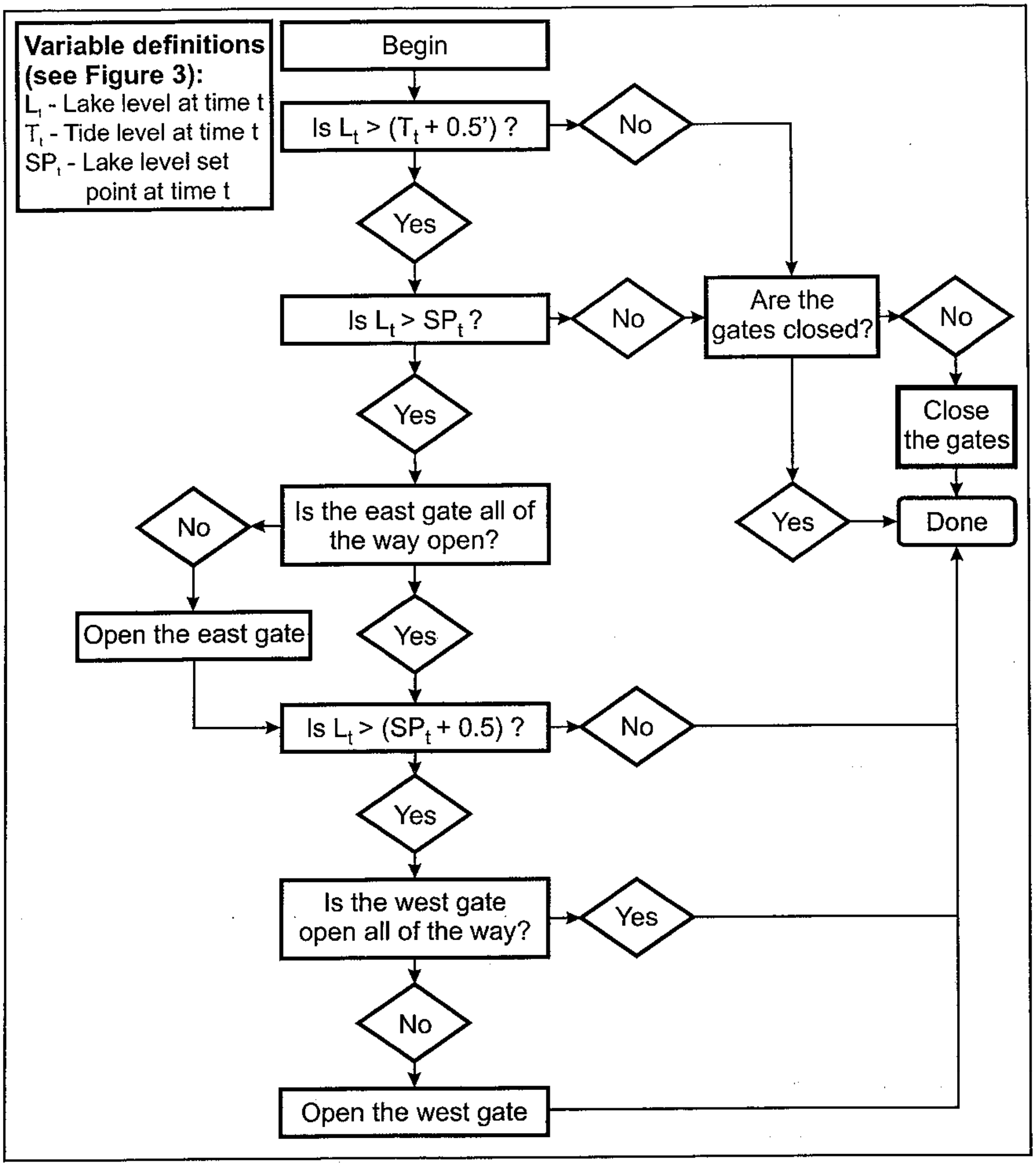

Figure 5 - Decision Tree, Dam Operation

During the winter months, the Deschutes River flows at Rainier stream gage station are closely watched. It has been observed that a flood peak at Rainier gage takes approximately 24 hours to reach Capitol Lake downstream. Therefore, anticipated Capitol Lake flooding is alleviated by lowering the lake level below the target level. The releases are achieved during periods of predicted low tides. Capitol Lake flooding is alleviated or reduced by creating extra storage in Capitol Lake. Note that Capitol Lake did not reach flood levels when the February 9, 1996, historic high flows of the Deschutes River were received. During this storm, multiple releases were necessary to prevent Capitol Lake from reaching flood levels.

2.0 Capitol Lake Flood Level Determination Methodology

The inflow, available storage, the discharge capacity of the outlet structures, and the tide levels of Budd Inlet contribute in determining the lake levels for Capitol Lake. Therefore, realistic lake level frequency relationship for Capitol Lake can be established only by considering the probabilities of inflow hydrographs as well as those of the Budd Inlet tide levels. Two approaches can be applied to determine the lake level frequency relationship - Conditional Probability Approach and Continuous Simulation Approach.

In the Conditional Probability Approach, the hydrologic and hydraulic models for Capitol Lake will be developed and used to compute lake elevations. The hydraulic model will simulate lake water surface elevations using the hydrographs computed by the hydrologic model for selected hypothetic storms (of known frequency). The radial gates can be assumed fully open and the lake elevations are computed for a set of known exterior tide levels (of known frequency). The conditional probability principles are then applied to establish the frequency for each lake level computed. The 10-, 50-, and 100-year lake levels are determined graphically by plotting the set of simulated lake levels and their frequencies on probability graph paper.

The Continuous Simulation Approach also requires the development of a hydrologic and hydraulic model for Capitol Lake. However, in this approach, the models are used to compute the lake elevations, which are continuously simulated for a long period of time. The hydrologic data available for Capitol Lake are sufficient to simulate lake levels for 38 years, from 1961 to 1999. The tide levels are recreated based on tide gage observations and the dam operation (of the radial gates) is modeled to follow the operational rules. The simulated lake elevation is analyzed statistically to compute flood levels for Capitol Lake.

The Continuous Simulation Approach has the advantage of reflecting the operation of the radial gates. In addition, continuous simulation analysis requires less effort than a Conditional Probability Approach. The hydraulic model developed to reflect the gate operation will prove to be a useful tool in future operations of the lake, specifically, when flood events are anticipated. Therefore, this study uses a Continuous Simulation Analysis to establish flood levels for Capitol Lake.

The simulated annual peak lake elevations are analyzed using graphical statistical procedures. The methodology applied for this study follows October 10, 2002 guidance given on the USGS Website (Reference: http://water.usgs.gov/wicp/acwi/hydrology/frequency/b17bfaq.html) for frequently asked questions on Bulletin 17B Guidelines. A full version of the draft guideline is provided in Appendix 2.

As explained in the aforementioned guideline, the LPIII statistical method is recommended in Bulletin 17-B to evaluate riverine flood-flow frequency analyses. The application of the LPIII to riverine flood-flow data is systematically tested and evaluated. According to the guideline, "...the Bulletin 17-B generalized skew map does not apply to lake levels, and it may be difficult or infeasible to develop generalized skews for lakes. In addition, lake levels do not have the natural zero value and the extreme variability and skewness of flood flows, so the use of log transforms of lake levels may not be necessary or beneficial." Therefore, the guideline states that the Bulletin 17-B should not be applied blindly to lake levels and recommended that graphical frequency analysis should be used. In addition, the Subcommittee recommended that the probability plotting positions be computed using the Bulletin 17-B formula, and plotting them versus untransformed lake levels on an arithmetic-normal probability grid. A visually fitted manually-drawn curve can be used to determine the frequency relationship of the lake-levels. These guidelines were followed to establish the lake level frequency relationship for Capitol Lake.

The development and calibration of Capitol Lake hydrologic and hydraulic models and the statistical analysis of the simulated results are summarized in the following text.

3.0 Hydrologic Analysis

Aqua Terra Consultants developed the hydrologic model for Capitol Lake using the Environmental Protection Agency's Hydrologic Simulation Program - FORTRAN (HSPF). The development and calibration of the HSPF model are summarized in the report titled, "Deschutes River HSPF Model Calibration Report," prepared by Aqua Terra Consultants. This report is presented as Appendix 3.

3.1 HSPF Model Calibration

The HSPF model was calibrated against the stream gage records available for the Deschutes River. No reliable flow records were available for Percival Creek. The period of 1961 to 1990 was selected for calibration. The 17 years of data for Rainier gage, three years of data available for the Olympia gage, and the three years of data available for Tumwater gage are used for calibration. This is summarized in Table 4 - Calibration Period for the HSPF Model.

Table 4 - Calibration Period for the HSPF Model

Stream Gage (USGS Gage Number)	Drainage Area (sq. mi.)	Years of Data
Rainier (12079000)	89.8	1961 to 1975 1988 to 1990
Tumwater (12080010) at E-Street	162	1961 to 1964
Olympia (12080000)	160	1961 to 1964

The HSPF regional parameters were used as a starting point for the calibration of the watershed model. Based upon professional judgment, changes were made to the hydrologic parameters to better reflect the existing hydrology of the watershed. Appendix 3 provides a complete listing of all of the parameters.

HSPF model results compared well the observation, except for the February 1996 event. The February 9, 1996, event is the largest event on record for the Capitol Lake area. The peak flow for the Deschutes River for this event at the Tumwater stream gage is published as 10,700 cubic feet per second (cfs). However, for this gage, the USGS has published an observed hydrograph that reaches a maximum of approximately 7,700 cfs. No higher flow data was recorded. The peak flow of 10,700 cfs is estimated by a slope-area computation. The HSPF model simulation predicted a peak flow of 8,600 cfs for this event, as shown in Figure 6- Hourly Stream Flow Data at Tumwater: Observed vs. Simulated. We have contacted the USGS regarding the differences between the published and simulated peak flows for the 1996 flood peak. The USGS has informed us that it will investigate the accuracy of the slope-area computations used to determine the 10,700 cfs peak flow.

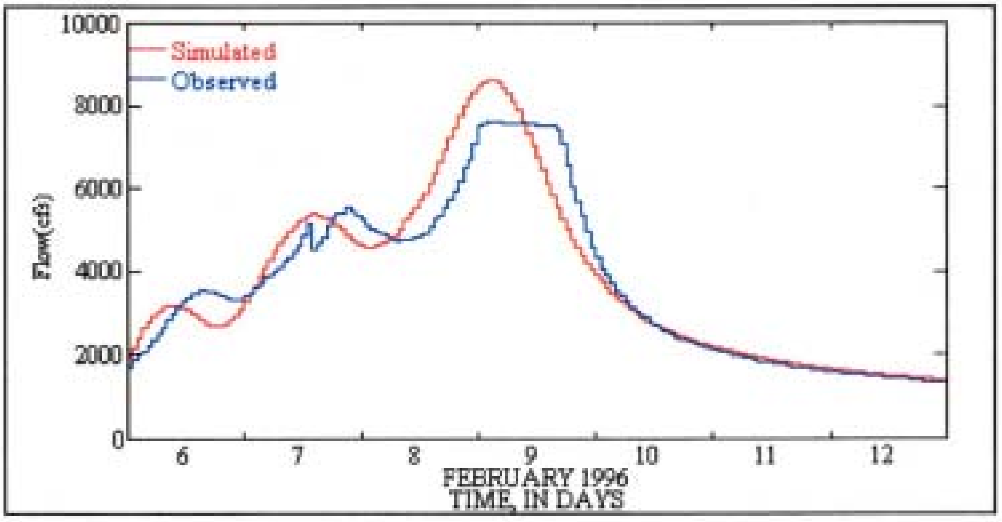

Figure 6 - Hourly Stream Flow Data at Tumwater: Observed vs. Simulated

3.2 HSPF Model Simulation

The calibrated HSPF model was used to simulate flow for Deschutes River and Percival Creek. Data necessary to model snow melt in the watershed were available for the period between 1962 and 1990. Hourly observed flow data were available at the Tumwater stream gage (at E Street). Flow simulations conducted with snow melt modeling between 1962 and 1990 were selected for the continuous simulation analysis. The flow data were extended to 1999 by using the HSPF model to route the observed hydrograph at E Street gage to the mouth of Capitol Lake. The continuous hydrograph for the period of 1962 to 1999 was used by the hydraulic model to compute the lake elevations.

4.0 Hydraulic Analysis

The water-surface elevation for Capitol Lake is impacted by tidal effects, the Deschutes River and Percival Creek flood flows, the operational rules, discharge characteristics of the 5th Avenue outlet structures, and the storage capacity of the lake. Two radial gates and the 9.5 feet wide movable sluice gate (fish gate) are the three major outlet structures. The radial gates are operated to prevent seawater intrusion from Budd Inlet and to maintain the lake elevation at a target level.

4.1 Hydraulic Model of Capitol Lake

The Capitol Lake floodplain has been modeled using the one-dimensional unsteady flow program Full Equations Model (FEQ). FEQ was developed by Dr. Delbert Franz of Linsley, Kraeger Associates, Ltd., and supported by the USGS. FEQ is capable of simulating flow in a stream system by numerically solving the equations for unsteady flow in open channels and through control structures. The program separates the flows into three broad classes: (1) stream reaches (branches), (2) parts of the stream system for which complete information on flow and depth are not required (dummy branches), and (3) level-pool reservoirs. These three parts are then combined using different control structures, such as junctions, bridges, culverts, dams, spillways, weir, and others. The hydraulic characteristics of branches, level-pool reservoirs, and control structures are stored in function tables.

The function tables are generally computed by the companion program Full Equations Utilities (FEQUTL) or developed manually to a fixed format as required by FEQ. FEQ uses three types of function tables: one-dimensional tables that generally relate the hydraulic characteristics to upstream flow depth, two-dimensional tables that relate flow through control structures to upstream and downstream depth, and three-dimensional tables that relate flow through gated structures to upstream and downstream flow depth.

The FEQ program computes the flow, water-surface elevation, and other hydraulic properties throughout the stream system for given boundary and initial conditions. The model can also be applied in the simulation of a wide-range of stream configurations, and complex operation rules for dynamically operated control structures. The boundary conditions can be values such as time series of water-surface elevation, discharge, or the stage-discharge relationship at a node.

The demonstrated ability of FEQ to model the complex operational rules of the dynamically operated control structures was instrumental in selecting it for the Capitol Lake hydraulic analysis.

4.2 Capitol Lake FEQ Model Schematic

The schematic of an FEQ model in Figure 7 illustrates the FEQ representation of stream elements. These elements included in the model where flow and stage will be computed are represented as: branches, level-pool reservoirs, and dummy branches. As illustrated on the schematic diagram, the Capitol Lake FEQ model has the following components:

Level Pool Reservoirs:	South Basin, Middle Basin, and North Basin
Bridges:	I-5 bridge, BN/SF railroad bridge
Radial gates:	East Gate, West Gate
Weir:	Fish Gate, Overland flow
Branch:	Branch – Connection between the dam and Budd Inlet
Dummy Branches:	Percival Creek inflow and different types of flow occurring at bridges
Boundary Conditions:	Deschutes River Inflow
	Percival Creek Inflow
	Tide elevations of Budd Inlet

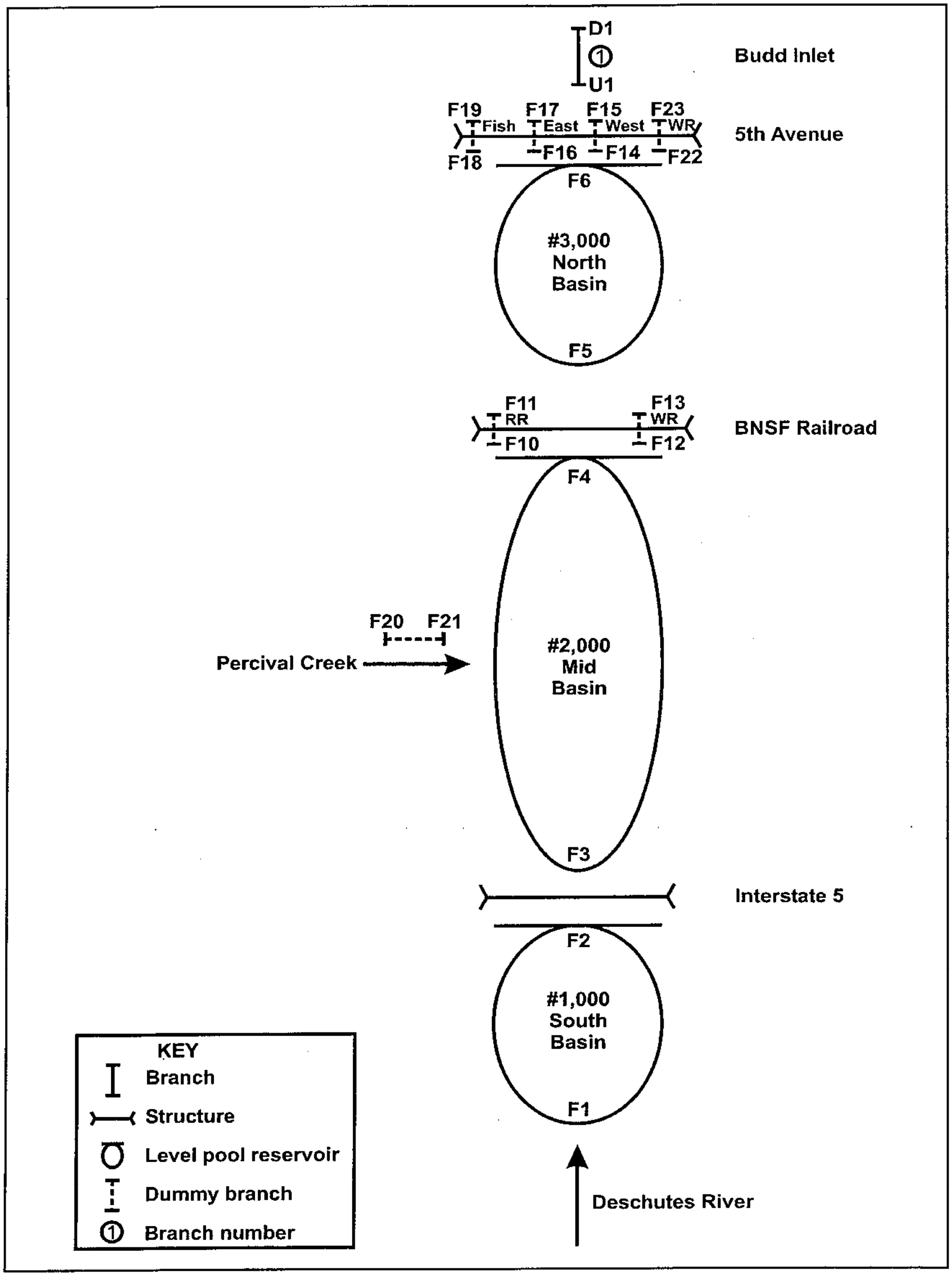

Figure 7 - FEQ Model Schematic for Capitol Lake

4.3 Boundary Conditions

The discharge boundary condition of the FEQ model is obtained from the HSPF model simulations of the Deschutes River and Percival Creek watersheds. The discharge time series developed for these streams by the HSPF analysis were used as input to the Capitol Lake FEQ model. The downstream boundary condition for the Capitol Lake FEQ model is the tide elevations of the Budd Inlet. The hourly tide elevations for the Budd Inlet, were computed from the observed water-surface elevations recorded at the Seattle tide gage 9447130, located in the Puget Sound in Seattle, Washington. This gage is maintained by the National Oceanic Atmospheric Administration (NOAA).

Discharges
The Deschutes River and the Percival Creek inflow were computed by the HSPF model developed by Aqua Terra. The flows were simulated by the HSPF model developed in the hydrologic analysis and stored in the Watershed Data Management (WDM) file format. The WDM format is incompatible with the data formats used in FEQ. Thus, a utility program called "WDMUTL" is used to export runoff from the WDM into a Point Time Series File (PTSF) to be used in the FEQ model. The PTSF for the Deschutes River contains the hourly discharges simulated upstream of the Capitol Lake North Basin. While, the PTSF for Percival Creek contains hourly discharges computed at the Deschutes Parkway Bridge. Table 5- FEQ Boundary Condition Data, Discharge Time Series, summarizes the discharge time series data used in the FEQ simulations.

Table 5 - FEQ Boundary Condition Data, Discharge Time Series

PTSF File	Stream	Period	Remark
capms.sim	Deschutes River at Capitol Lake	1962-1999	1962-1990 w/ snow melt; 1990-1999 E Street observed flow routed.
capall.sim	Deschutes River at Capitol Lake	1961-1990	With snowmelt simulation
eobser.sim	Deschutes River at E street	1990-1999	Hourly observed at E Street
Pall.sim	Percival Creek at Deschutes Pkwy.	1961-1990	With snowmelt simulation
pallns.sim	Percival Creek at Deschutes Pkwy.	1961-1999	Without snowmelt simulation
capallns.sim	Deschutes River at E Street	1955-1999	Without snowmelt
capmouth.sim	Deschutes River at Capitol Lake	1955-1999	Without snowmelt

Tide Elevations
The observed hourly water-surface elevations for the Seattle tide gage 9447130 are available at the following website: http://co-ops.nos.noaa.gov. The data for the time period of 1955 to 2002 were downloaded from the site. Transfer coefficients were also obtained on the NOAA webpage for tide predictions in order to transfer these observed data to the Capitol Lake area of Budd Inlet. These factors were applied to the Seattle observations to obtain the tide levels at Budd Inlet. The transfer coefficients obtained from the webpage are given below:

Time difference: 45 minutes for the high tide
57 minutes for the low tide
Height: Multiplier = 1.29
Multiplier = 1.08

The transfer of data was achieved by the use of an Excel Visual Basic Application program (VBA) developed for this task. The names of the time series files of the tide elevations at Budd Inlet can be found in Table 6- FEQ Boundary Condition Data, Hourly Tide Levels.

Table 6 - FEQ Boundary Condition Data, Hourly Tide Levels

File	Location	Period	Remark
Tide.sim	Budd Inlet, Olympia	1955-2002	PTSF file
All_adj.mrg	Budd Inlet, Olympia	1955-2002	ASCII file
Tide01.dat	Budd Inlet, Olympia	Hourly tide data for 2001	ASCII data
Tidexx.dat	Budd Inlet, Olympia	Hourly tide data for a year	Available for (45-01)

4.4 Function Tables for FEQ Model

The function tables used in the model are generally developed by FEQUTL models of the individual components modeled. These include the bridges, gates, and cross sections used in the Capitol Lake model. The function tables defining the stage-storage relationship of the level pool reservoirs used to model the Capitol Lake are manually created using a suitable text editor. The function tables used by the Capitol Lake FEQ model are listed in Appendix 4. Following is a summary on the development of the function tables used in the Capitol Lake FEQ model.

Level Pool Reservoirs
The surface area and storage capacity of the South, Middle, and North Basins of Capitol Lake are represented by FEQ Type 3 Tables 1000, 2000, and 3000. These data are stored on the file titled "Storage.tab" and included in Appendix 4.

The surface area and storage capacity were defined for elevations 0 to 30 feet MSL. The area for lower elevations (less than 10.0 feet MSL) were taken from a XP SWMM analysis reported on an August 2000 report titled, "Capitol Lake Adoptive Management Plan 1999 to 2001 Phase One – Task 2 Flood Analysis," by Entranco, Inc. The remaining surface areas were measured digitally using the digital topographic map of Thurston County.

Branches
Capitol Lake FEQ model used one branch, Branch 1, to represent the Budd Inlet immediately downstream of the 5th Avenue. Branch 1 is 280 feet long and is represented with cross sections 96, 97, and 98. These cross sections are taken from the HEC-RAS model developed for April 2000 report titled, "Capitol Lake Adaptive Management Plan 1999 to 2000 Phase One – Task 3 Hydraulic Scour Analysis" by Entranco, Inc. A copy of these cross sections is available on HEC-RAS model titled "capitol1.prj" in Attachment C (CD).

Bridges
Two bridges are reflected in the FEQ model, the I-5 bridge connecting the South and Middle Basins, and the BN/SF railroad bridge connecting the Middle and North Basins. For the range of flows analyzed for this project, low flow conditions will exist at the I-5 road bridge while, the BN/SF Railroad Bridge will exhibit low, pressure, and weir flows. Table 7- Two-dimensional Tables for Bridges, summarizes the two-dimensional tables that reflect the discharge relationship of the I-5 and BN/SF bridges. The WSPRO program (available in the FEQUTL program) was used to obtain the two-dimensional tables for low flow through the I-5 and BN/SF bridges. HEC-RAS was used to compute the parameters needed for BN/SF pressure flow. The FEQUTL program's EMBANKQ feature was used to model the BN/SF weir flow and the bridge cross sections. The approach cross section, and departure cross section were taken from the HEC-RAS model titled "capitol1.prj" prepared by Entranco, Inc. Appendix 5 summarizes the WSPRO, HEC-RAS and FEQUTL input data and the cross sections used for I-5 and BN/SF bridge models.

Table 7 - Two-dimensional Tables for Bridges

Bridge	Table	FEQUTL Input	File
I-5	59	i-5.in, wsproi-5.in, WSPRO14.utl	i-5.tab
BN/SF- low and pressure flow	80	wspro-rr.in, wsp-rr.dat, WSPRO14.utl HEC-RAS model, bnsfpr.prj	Bnsf-rr.tab
BN/SF – weir flow	801	Bns-wr.utl	Bnsf-wr.tab

Radial Gates and Weirs

Two dynamically operated radial gates – East Gate and West Gate are reflected in the Capitol Lake FEQ model. The radial gates discharge into the Budd Inlet and its water-surface elevations are controlled by the tide cycle. The closure of the gates occurs when the tide level becomes higher than the lake level.

FEQUTL's UFGATE option was used to compute the three-dimensional table that related the discharge characteristics of the gate with upstream and downstream water surface elevations and different gate openings. Figure 8- Radial Gate Parameters, illustrate the open/ close positions of the radial gates. In addition, Figure 8 provides a table of different lip angles (β) and corresponding gate openings (Δh) for the radial gate. These data are used by UFGATE to analyze the flow through the radial gates.

Weir flow equations are used by the FEQ program in computing the flow through the fish gate. The fish gate was not operated in response to the external tidal elevations and a small amount of sea water entered Capitol Lake during high tides. The tables provided for the fish gate have the weir coefficients necessary to compute the flow.

Table 8- Tables for Control Structures, summarizes the function tables developed for the outlet structures (East Gate, West Gate, and the Fish Gate) of the 5th Avenue dam and that for the overland flow.

Appendix 3 summarizes the FEQUTL/ and WSPRO input models used in modeling flow through the I-5, BN/SF bridges and the outlet structures of the 5th Avenue dam.

Table 8 - Tables for Control Structures

Gate/ Weir	Table	FEQUTL Input file	File
East Gate	701	5thave.utl	5thave.tab
West Gate	702	5thave.utl	5thave.tab
Fish Gate	709, 706, 708	Manually created: Discharge, submergence coefficients and gate opening fraction with crest elevation	Fish-gt.tab
Overland flow	897	Ovrland.utl	Ovrland.tab

$\beta^o(=90-\Theta)$	Δh(ft.)	Θ^o
97.2	11.9	-7.2°
94.9	11.2	-4.9°
92.0	10.2	-2.0°
89.2	9.2	0.8°
86.3	8.2	3.7°
83.4	7.2	6.6°
80.2	6.2	9.8°
77.0	5.2	13.0°
74.7	4.2	15.3°
71.7	3.2	18.3°
68.6	2.2	21.4°
65.5	1.2	24.5°
64.0	0.7	26.0°
61.7	0.0	28.3°

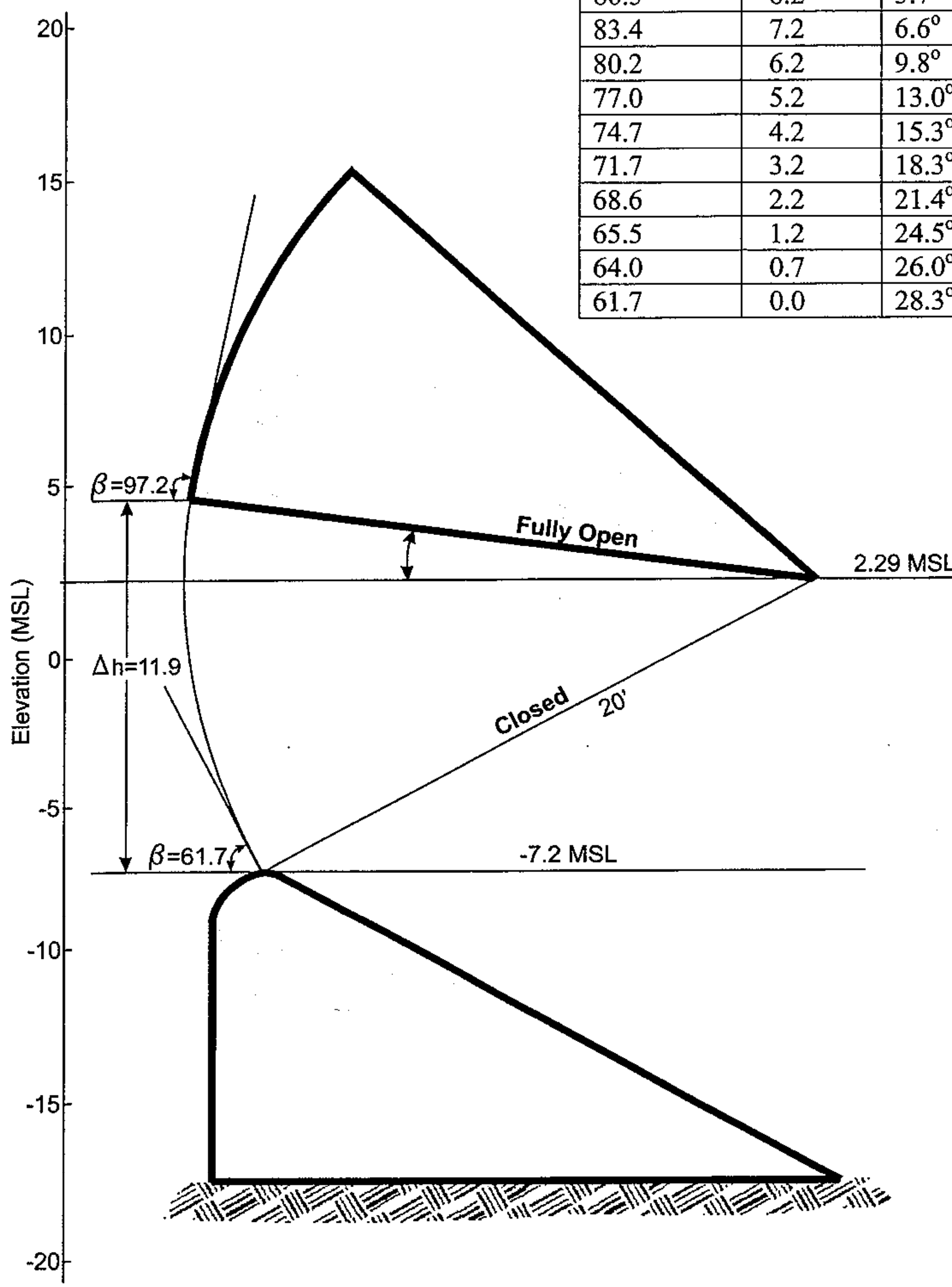

Figure 8 - Radial Gate Parameters

4.5 Capitol Lake FEQ Model

The operation of the 5th Avenue control structures – East Gate, West Gate, and the Fish Gate was reflected in the Capitol Lake analysis using the FEQ operation control block. The gate operation procedures were compiled from an undated document titled, "Capitol Lake Dam Operation for Flood Control," prepared by the State and an August 1998 report titled, "Budd Inlet Scientific Study Final Report," prepared by Brown and Caldwell, Inc., et al. The operational procedures were finalized based on conversations with the current and past State officials responsible for operating the gates. Table 9-Capitol Lake Dynamic Gate Operation Criteria summarizes the dynamic radial gate operation procedures reflected in the FEQ model. FEQ gate control model input assigned different priorities to the gate operations shown on Table 9. The highest priority (Priority – I) was assigned the gate closure operation which will prevent the saltwater intrusion into the Capitol Lake. The seasonal target water levels and the fish gate operation criterion are given below:

Summer (March 14 to October 16): Target lake level is 6.22 feet MSL and the fish gate remains open.
Winter (October 6 to March 14): Target lake level is 5.26 feet and the fish gate remains closed.

Table 9 - Capitol Lake Dynamic Gate Operation Criteria

Control Criterion	East Gate	West Gate	Priority
(Refer to Figure 3) Tt -Tide Level at time t; Lt – Lake Level at time t; S_t – Target Lake Level			
Tt < Lt	Check Lt with S_t	Check Lt with S_t	Priority – I
Tt > Lt	Closed	Closed	
Opening the Gates			
Lt= S_t	Open	Closed	Priority –II
Lt = S_t + 0.5 feet	Open	Open	
Lt > S_t + 0.5 feet	Open	Open	
Closing the Gates			Priority - II
Tt = S_t – 0.5 feet	Close	Close	
Lowering lake for impending storms	Open	Open	Lake level is manually lowered

The FEQ input for Capitol Lake is provided in Appendix 6.

4.6 FEQ Model Verification

Based on the gate operation records kept at the control room, which are provided in Appendix 7, the observations reported in the FIS, and conversations with State officials in charge of the 5th Avenue dam operation, we have obtained the following historic observations to verify the results of the FEQ model: ***1977 December 15th flooding and 1996 February 9th non-flooding.***

1977 December 15th Flood (flood level of 10.15 feet MSL)
The FIS reports of a December 15, 1975, lake flooding that was related to the high tide observed at the Budd Inlet. The FIS stated that the Capitol Lake flood level was 0.4 foot higher than the highest recorded tide level. Based on information available on the NOAA website, the 1975 peak lake level was estimated to be 10.15 feet. Using the discharge time series computed by the HSPF model, the FEQ model

computed a lake level of 9.8 feet MSL for the December 15, 1977, flood and this value is within 0.4 feet of the estimated lake level. Figure 9- Flood Simulations: December 15, 1977, shows the simulated lake level, the inflow, and the external tide level for this flood event.

1996 February 9th Flood (no Capitol Lake flooding)

The highest flood of record for Deschutes River occurred on February 9, 1996, but since the lake was lowered the flooding was alleviated. The FEQ simulation without lowering the lake computes a maximum elevation of 11.02 feet MSL for Capitol Lake. However, a FEQ simulation with lowering of the Capitol Lake between February 6th and 10th during the low tide periods would cause only a maximum lake level of 9.8 feet MSL which will not cause flooding around the lake.

Figure 10, Flood Simulations: February 9, 1996, without Lake Lowering, and Figure 11- Flood Simulations: February 9, 1996, with Lake Lowering, illustrate the results of this simulation.

4.7 FEQ Model Simulation

The verified FEQ model is used to simulate the Capitol Lake water surface elevations from 1962 to 1999. The annual peak lake levels are identified using post processing programs and the annual peak data are analyzed statistically to determine the Capitol Lake BFE as presented in Section 5.

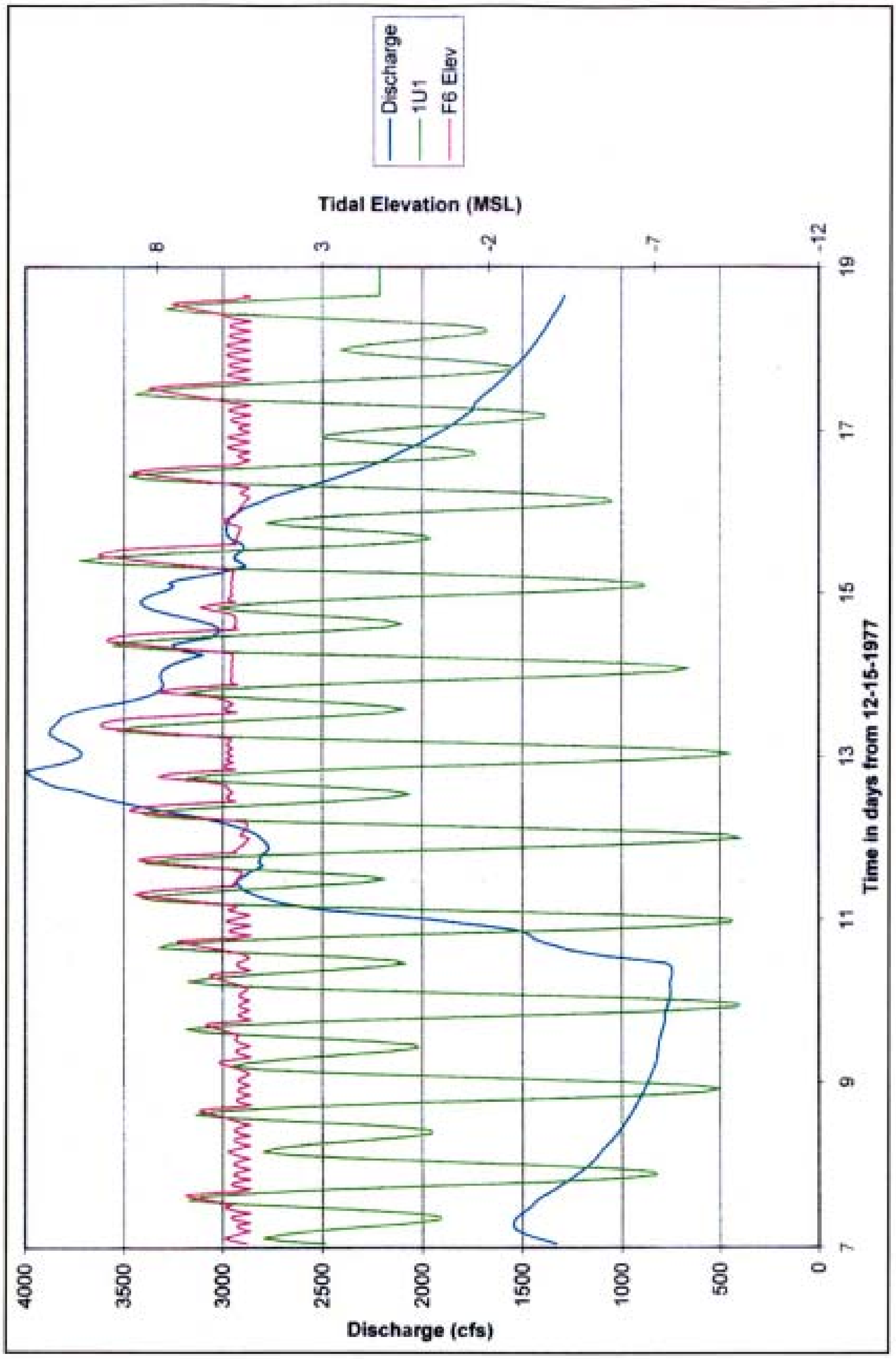

Figure 9 - Flood Simulations: December 15, 1977

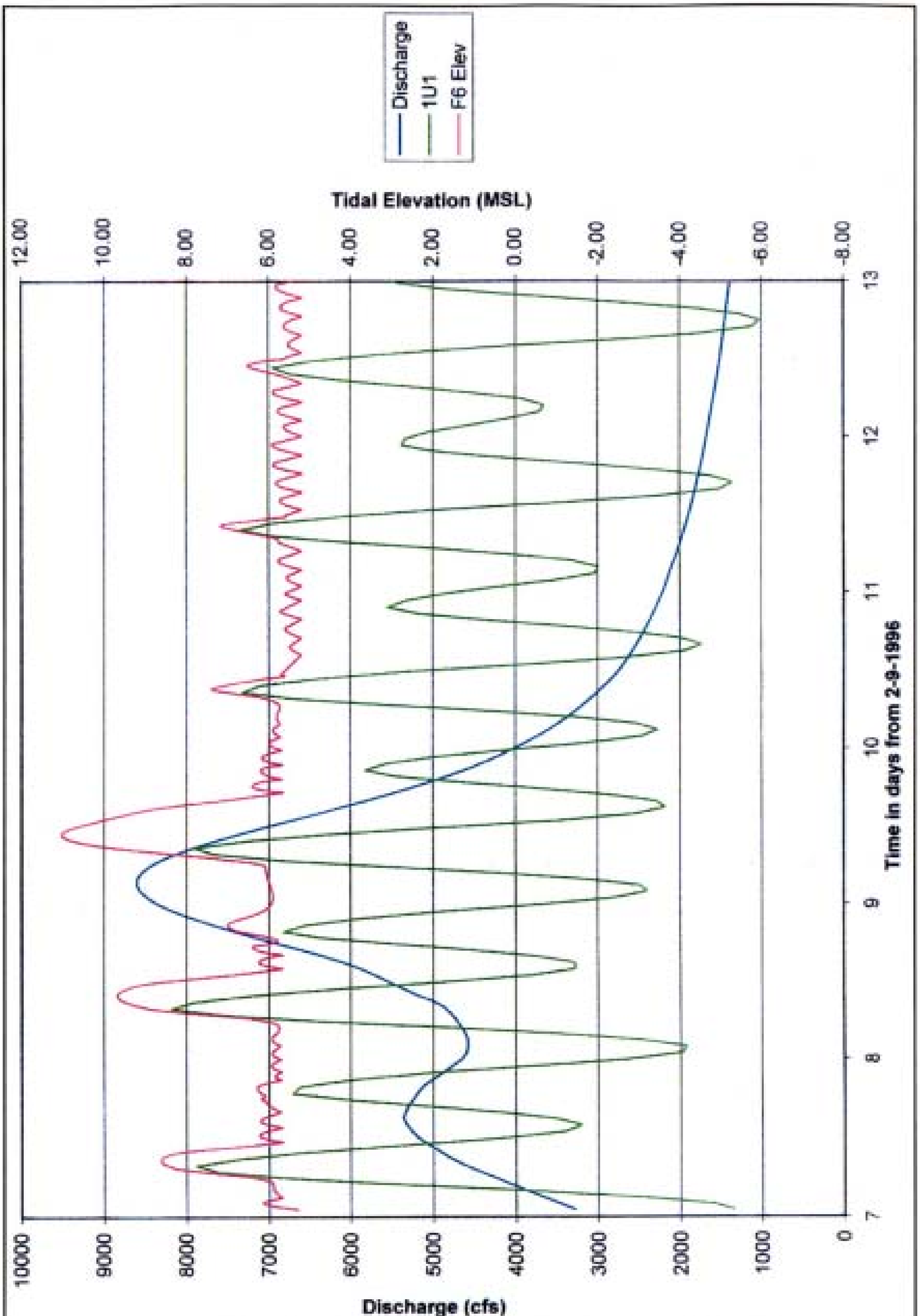

Figure 10 - Flood Simulations: February 9, 1996, without Lake Lowering

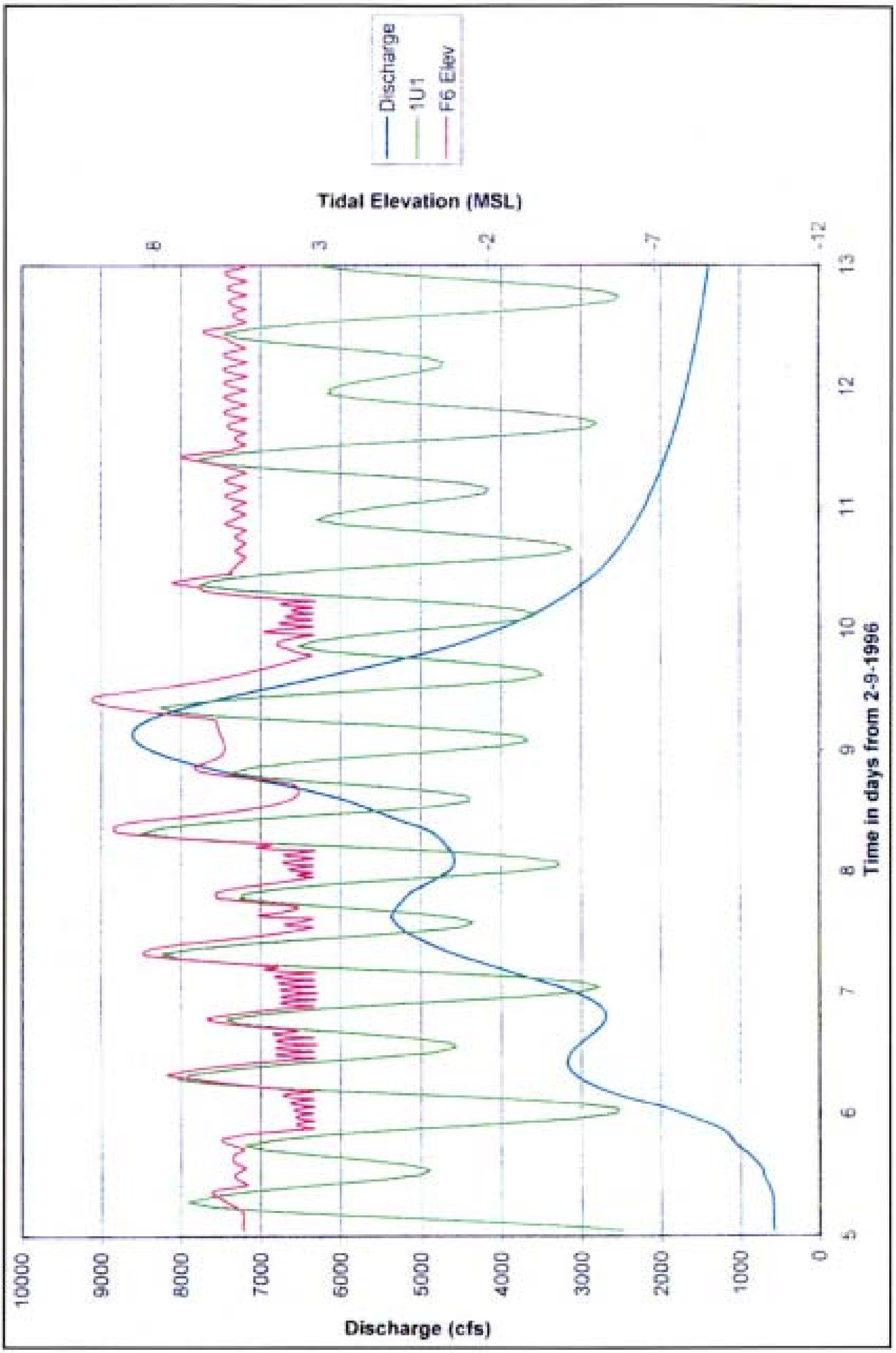

Figure 11 - Flood Simulations: February 9, 1996, with Lake Lowering

5.0 Statistical Analysis

The annual peak lake levels for 38 years between water years 1962 and 1999 were obtained from the FEQ special output file. A Visual Basic program titled "peakinput" was used to shorten the simulated output file. The simulated data for low flows (inflow discharge below 1,000 cfs) were truncated by the "peakinput" program. A FORTRAN program titled, "peaks" was used to find all the peak elevations (along with discharges and three-day volumes) simulated that occurred for the previously mentioned time period. As discussed in Section 2, a graphical frequency analysis was employed to the simulated annual peak elevation data (Appendix 8). Table 10- Capitol Lake Annual Peak Lake Levels, summarizes the computation used to obtain the Weibull plotting positions. Figure 12- Frequency Analysis of Capitol Lake Levels illustrates the plotting positions plotted on frequency paper.

The following flood elevations (elevation computed in MSL) were determined from the frequency analysis of the Capitol Lake levels.

Exceedance Frequency	Lake Elevation (Feet MSL)
10% Annual Chance (10-Year) Lake level	10.4
2% Annual Chance (50-Year) Lake Level	11.3
1% Annual Chance (100-Year) Lake Level	11.5

Table 10 - Capitol Lake Annual Peak Lake Levels

Capitol Lake peak elevations		capms.pk			
Year	Elevation	Year	Elevation	Rank	Weibull
1962	7.84	1977	6.96	1	0.026
1963	8.23	1979	7.39	2	0.051
1964	8.25	1993	7.44	3	0.077
1965	9.73	1985	7.58	4	0.103
1966	8.43	1994	7.78	5	0.128
1967	9.81	1975	7.82	6	0.154
1968	8.76	1962	7.84	7	0.179
1969	8.3	1989	7.94	8	0.205
1970	9.05	1992	8.07	9	0.231
1971	9.11	1982	8.19	10	0.256
1972	10.32	1980	8.22	11	0.282
1973	9.28	1963	8.23	12	0.308
1974	10.81	1964	8.25	13	0.333
1975	7.82	1969	8.3	14	0.359
1976	9.45	1991	8.4	15	0.385
1977	6.96	1966	8.43	16	0.410
1978	9.78	1988	8.51	17	0.436
1979	7.39	1990	8.64	18	0.462
1980	8.22	1968	8.76	19	0.487
1981	9.6	1995	9.03	20	0.513
1982	8.19	1970	9.05	21	0.538
1983	9.37	1986	9.08	22	0.564
1984	9.73	1971	9.11	23	0.590
1985	7.58	1998	9.22	24	0.615
1986	9.08	1973	9.28	25	0.641
1987	10.19	1983	9.37	26	0.667
1988	8.51	1976	9.45	27	0.692
1989	7.94	1981	9.6	28	0.718
1990	8.64	1984	9.73	29	0.744
1991	8.4	1965	9.73	30	0.769
1992	8.07	1978	9.78	31	0.795
1993	7.44	1967	9.81	32	0.821
1994	7.78	1987	10.19	33	0.846
1995	9.03	1972	10.32	34	0.872
1996	11.02	1999	10.33	35	0.897
1997	10.73	1997	10.73	36	0.923
1998	9.22	1974	10.81	37	0.949
1999	10.33	1996	11.02	38	0.974
		Count	38		
		Maximum	11.02		
		Minimum	6.96		
		Average	8.91		
		Std. D.	4.6169		

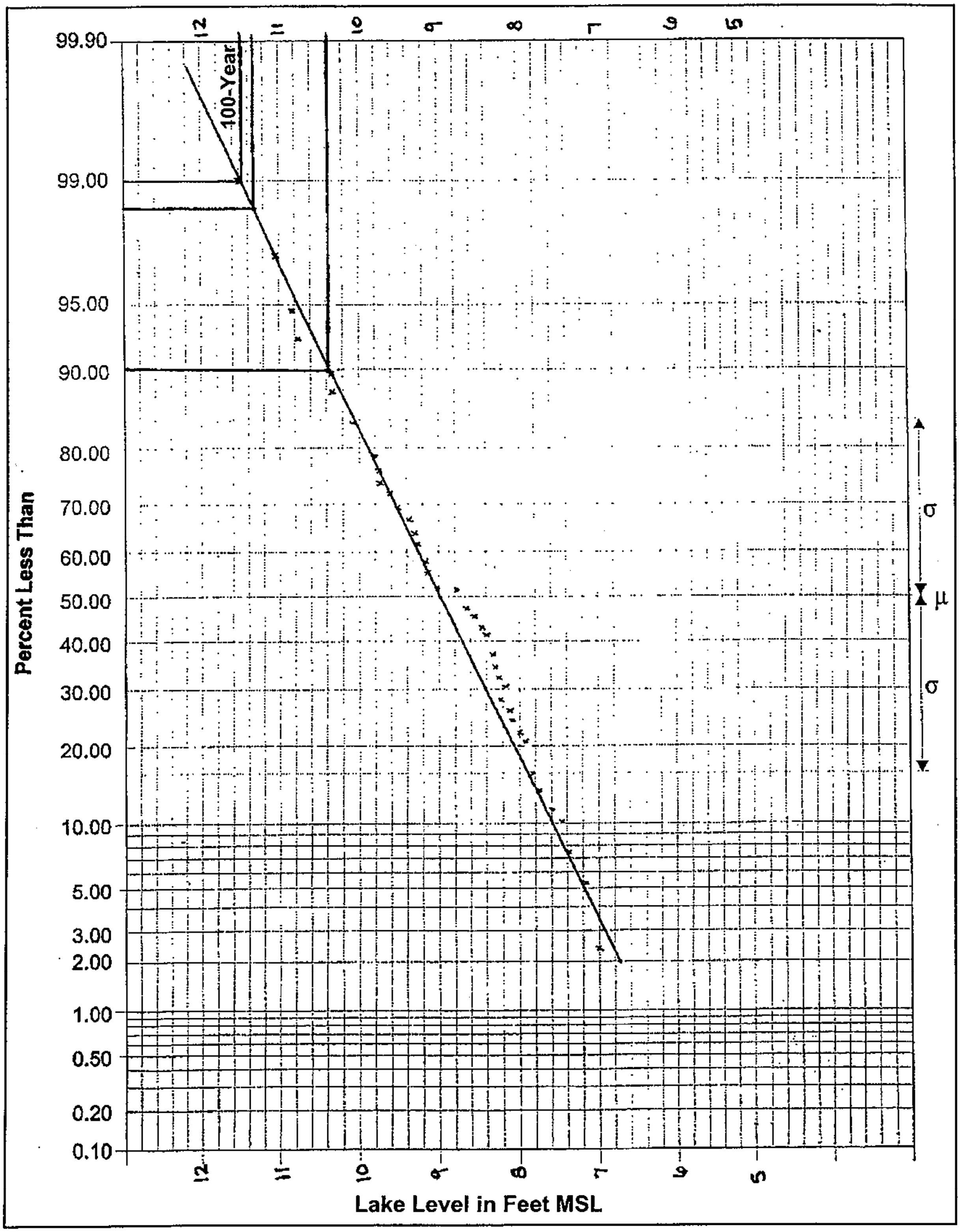

Figure 12 - Frequency Analysis of Capitol Lake Levels

6.0 Mapping

The results of the current analysis will be reflected on the FISs of three communities, the City of Olympia, Thurston County (Unincorporated Areas), and the City of Tumwater and the map panels that are affected by this revision are as follows:

- City of Olympia Flood Insurance Rate Map(FIRM) number 530191, panels 0004 B and 0006 B, both dated February 17, 1982;
- The unincorporated areas of Thurston County FIRM number 530188, panels 0168 C and 0169 C, both dated December 1, 1982; and
- City of Tumwater FIRM number 530192, panels 0001 C and 0002 C, both dated April 3, 1984.

The maps provided in Attachment B of this report, reflect the revised 1% annual chance floodplain delineation on a contour map, as well as an aerial photograph (both maps are shown at 1"=400' scale). Since no topographic survey was performed for this study, the contour map and the aerial photograph were prepared by GIS Applications specialist at the Thurston Regional Planning Council located in Olympia, Washington and supplied to Dewberry for this revision.

This FIS revision will reflect more up-to-date hydraulic information for Capitol Lake. Since there is more recent contour information for this area than what was used for the effective study, the 1% annual chance floodplain for Budd Inlet was redelineated. The Capitol Lake revised 1% annual chance floodplain boundary is shown on the maps provided as Attachment B.

7.0 Conclusion

Based on the data provided in this report and the modeling that has been submitted to support LOMR requests, the 1% annual chance water-surface elevation of Capitol Lake should be revised to an elevation of 11.5 feet MSL. In addition to the new lake elevation, the floodplain should be redelineated on the above-mentioned FIRM panels.

8.0 References Cited

Aura Nova Consultants, et al., Budd Inlet Scientific Study Final Report, Chapter 6, dated August 1998.

Entranco, Inc., Phase One-Task 2 Flood Analysis, Capitol Lake Adaptive Management Plan 1999 to 2001, dated August 24, 2001.

Entranco, Inc., Phase One-Task 3 Hydraulic Scour Analysis, Capitol Lake Adaptive Management Plan 1999 to 2001, dated April 18, 2000.

FEMA, Flood Insurance Study, City of Olympia, Washington, dated August 17, 1981.

FEMA, Flood Insurance Study, Thurston County Unincorporated Areas, Washington, dated December 1, 1982.

FEMA, Flood Insurance Study, City of Tumwater, Washington, dated April 3, 1984.

Washington State Department of General Administration, Capitol Lake Dam operation for Flood Control, Washington, Undated.