REVIEW PLAN

Lake Washington Ship Canal Probable Maximum Flood

Project Location: Seattle, WA
Project P2 Number: #324395
Study POC: CENWS-EN-HH-HE
NWD Original Approval Date: 13 December 2012
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December 10, 2012

US Army Corps of Engineers ®

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1. PURPOSE AND REQUIREMENTS

a. Purpose. This Review Plan (RP) defines the level of review for the Lake Washington Ship Canal Probable Maximum Flood (LWSC PMF Study).

b. References

(1) Engineering Circular (EC) 1165-2-209, Civil Works Review Policy, 31 January 2012
(2) NWD Implementation Guidance for EC 1165-2-209 Civil Works Review Policy

c. Review Product. The LWSC PMF Study is neither a decision document nor an implementation product; it may be classified as an "other work product" as described in the EC 1165-2-209 and the NWS Implementation Guidance. The study is an engineering analysis and modeling effort only. It was accomplished under the American Recovery and Investment Act (ARRA) funding, not under the Dam Safety Program. The analysis for the study cost approximately $225,000.

d. Vertical Alignment Conference Call Background.

Due to potential stakeholder controversy surrounding PMF studies, NWS and NWD participated in a Vertical Alignment conference call on March 26, 2012; participants included HQ-USACE, RMC, representatives from NWD, and Seattle District H&H and Dam Safety.

The Vertical Alignment Conference Call participants discussed the study and agreed that an Agency Technical Review (ATR) would be performed. Any further actions as a result of this study would be associated with Dam Safety issues and would be reviewed as part of a decision document or implementation project at a later date. HQ-USACE suggested that CENWO-ED-HE, Omaha District, would be the best-qualified for the review. NWD concurred. With the study showing possible abnormally high lake levels or loss of pool to tidal level, there may be controversy from the results. Should significant controversy arise following the ATR, NWS would consider seeking the expertise of a regional hydrology expert with the Bureau of Reclamation.

The Vertical Alignment Conference Call participants made a risk informed decision that Type I IEPR will not be required for this project. This risk informed decision was guided by criteria presented in EC 1165-2-209, Section 15, Risk Informed Decisions on Appropriate Reviews.

The results of the current study will be used by the District to recommend the PMF/IDF inflow and discharge for the LWSC project with approval by NWD Business Technical Division. Results of the study will inform the Emergency Action Plan (EAP) update and the Interim Risk Reduction Measures Plan, particularly the measures involving Lake level/frequency and the Large Lock Emergency Closure System (ECS).

e. Requirements. The EC 1165-2-209 outlines three levels of review: District Quality Control (DQC), Agency Technical Review (ATR), and Independent External Peer Review (IEPR) and establishes the procedures for ensuring the quality and credibility of U.S. Army Corps of Engineers (USACE) products. In addition to these three levels of review, products may be subject to policy and legal compliance review and, if applicable, model certification/approval.

- This study requires a DQC review.
- Seattle District has elected to have an ATR performed for this study.
- Engineering model certification/approval is provided.
- This study does not require a Type I IEPR (Vertical Alignment Conference Call participant's decision).
- This study has no design or construction activities for flood risk management; therefore, a Type II IEPR is not required.

2. REVIEW MANAGEMENT ORGANIZATION (RMO) COORDINATION

The Review Management Organization (RMO) for the **ATR** is Northwestern Division (NWD). NWD is the Major Subordinate Command (MSC) that coordinates and approves the review plan. Seattle District will post the approved review plan on its public website.

A MSC approval letter is required for each review plan and must be signed by the MSC Commander. The commander's approval should reflect vertical team input (involving district, MSC, PCX, and HQUSACE members) as to the appropriate scope and level of review for the decision document. A Vertical Team has already been informed of this project (see 1, d. above). Changes to the RP should be approved by following the process used for initially approving the plan. In all cases the MSC will review the decision on the level of review and any changes made in updates to the project.

3. STUDY INFORMATION

a. Study Area Description. The study location is the Lake Washington Basin which covers approximately 600 square miles from the Puget Sound to the Central Cascade Mountains. The Chittenden Locks in the Lake Washington Ship Canal complex is in Seattle, Washington. The project is owned and operated by the US Army Corps of Engineers.

b. LWSC Project Description. The primary authorized purpose of the project was to provide an 8 mile long navigation channel between Lake Washington and Puget Sound (Figure 1). There is no authorized flood control for the project. The locks and dam were constructed between 1916 through 1923. Lake Washington was lowered approximately 9 feet to the level of Lake Union and the water was raised from sea level at the Salmon Bay Narrows to the level of Lake Union. Lake Washington's original outlet was through the Black River at the southern end into the Duwamish River to the Puget Sound. Once the Lake was lowered, the Cedar River was permanently routed into Lake Washington and the Black River channel abandoned. The Cedar River contributes approximately 50% of the inflow to Lake Washington.

The Hiram M. Chittenden Locks part of the project consists of a small and large lock, a concrete gravity dam and spillway, saltwater drain, guide walls, and fish ladder. Upstream, the project consists of a 6.5 mile long canal between the locks, Lake Union, and Lake Washington. Lake Washington has approximately 48,000 acre feet of storage within the authorized 2 foot operating range of elevations 20 to 22 feet.

The shoreline is highly developed with numerous commercial business and floating homes. There are 2 major freeways that cross the lake on floating bridges, I-90 and SR-520. A new 520 bridge is under construction. Downstream of the locks, the project consists of a 1.5 mile long navigation channel under the Burlington Northern Railway Bridge to the Puget Sound. The project is a major element in Seattle's economy and provides transit to 80,000 vessels per year. The project is also a popular tourist attraction, receiving approximately one million visitors per year.

Infrastructure around the Lake and in the Ship Canal is dependent on the narrow operating range of the Lake. Passing the PMF flood through the project requires using the Large Lock Emergency Closure System (ECS) as an auxiliary spillway. And stopping uncontrolled flow from a large lock gate failure also depends on use of the ECS. Our recent Major Rehabilitation Study found that the ECS components such as the bulkheads and the crane are unreliable and may not operate as planned. This could result in a rise or fall of the Lake level of several feet. Failure of the project to either pass large floods or to stop uncontrolled releases will have catastrophic consequences for the floating bridges, commercial businesses including the fish fleet, floating homes, and other infrastructure dependent on the narrow operating range.

Based on ER 1110-8-2 (FR) guidance for Inflow Design floods (IDF), the LWSC project meets the requirements of a Standard 1 dam. Due to the catastrophic consequences associated with uncontrolled releases or failure to pass large floods, Standard 1 applies and the IDF would be computed from the probable maximum precipitation, which produces the Probable Maximum Flood (PMF). The analysis of upstream impacts with the pool area shall consider warning time, rate of rise and loss of pool, and depths for all floods up to and including the PMF. Downstream impacts are expected to be minimal as the project discharges into the Puget Sound.

c. Study Description. The LWSC PMF Study Scope of Work was designed using ER 1110-8-2 (FR) guidance for Inflow Design floods (IDF). Tasks included conducting the hydrologic and hydraulic study to simulate Probable Maximum Flood (PMF) and the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year events through the LWSC project.
Dam failure scenarios include failure of the Large Lock gates, resulting in loss of pool. Water surface elevations will be estimated at the locks and for Lake Washington as these may be different due to the flow constriction imposed by Montlake Cut.

To review and analyze the PMF, the Probable Maximum Precipitation (PMP) was developed using HMR 57. The existing hydrology models were acquired to compute the runoff for the (PMF) given the PMP and two historical flood events were used to validate these models.

Frequency based storms were developed using the NOAA Atlas 2 and Technical Paper-49 from the National Weather Service. The validated hydrology models were used along with the rainfall data to compute the runoff for the frequency based storm events. A Lake Washington Basin HEC-RAS model was developed which included the Sammamish River and the lower Cedar River. The hydrographs from the rainfall-runoff analysis were incorporated into the HEC-RAS model and run for with and without dam failure, for all floods up to and including the PMF.

The following list provides a general overview of the steps followed for modeling and routing the frequency events and PMF events.

1. **Review existing regional hydrological models.** Existing hydrologic models were used to perform the rainfall-runoff computations. The EPA rainfall-runoff model, Hydrological Simulation Program-Fortran (HSPF) (Bicknell et al., 1997) was used to model the Lake Washington and Sammamish River basins. The Cedar River watershed downstream to Lake Washington was modeled by a hydrologic model based on HSPF developed by Hydrocomp for Seattle Public Utilities (SPU) - the Hydrocomp Forecast and Analysis Model (HFAM II).

2. **Hydrologic model validation.** The models were validated by comparing model results to historic measurements. Model parameters had been adjusted (within reasonable limits) until the model was able to reproduce, as accurately as possible, observed peak flows and volumes.

3. **Simulation of the frequency events using the validated hydrology models.** Precipitation for the 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent chance exceedance rainfall events was developed using procedures from NOAA Atlas 2 Volume IX-Washington (NOAA, 1974) for the rainfall durations less than 24 hours, and Technical Paper 49 (Weather Bureau, 1964) for 2 to 10 day durations and input into the HSPF and HFAMII models. Output from the HSPF and HFAMII models was input into HEC-RAS as inflow boundary conditions.

4. **Simulation of the PMF event using the validated hydrology models.** Precipitation data for the probable maximum precipitation (PMP) event was developed following guidelines from the Hydrometeorological Report No. 57 (NOAA, 1994) for storm depth, pattern, and areal reduction. The PMP was input into hydrological models to determine the PMF flowing into Lake Washington. Output from the HSPF and HFAMII models was input into HEC-RAS as inflow boundary conditions.

5. **Develop Lake Washington Basin model with existing HEC-RAS models.** The hydraulic analysis began by expanding the existing HEC-RAS model of the Sammamish River Basin by importing channel and floodplain information for Lake Washington and the LWSC from HEC-GeoRas. To accurately assess how the flows from the Cedar River would affect the water surface levels in Lake Washington, the existing HEC-RAS model of the Cedar River was incorporated and modified by adding levees, storage and ineffective flow areas. Additional data was entered into the HEC-RAS model based on information gathered during field visits and from using standard engineering equations to estimate model parameters.

6. **Simulation of Dam Failure Scenarios.** Various failure modes were developed and will be used by the USACE Modeling, Mapping & Consequences Center (MM&C).

d. Factors Affecting the Scope and Level of Review. Factors that determine the level of review for the LWSC PMF Study are as follows:

- Potential controversial nature of Probable Maximum Flood (PMF) determination.
- The study will provide input for a NWS recommendation for the IDF inflow and discharge for the LWSC project.
- The study will provide input for the EAP.
- The study will provide input for the IRRMP.
- The study followed USACE guidance for computing the PMP, the PMF, and the dam failure scenarios. There were no novel methods, complex challenges for interpretation, precedent-setting methods or models, or recommendations to change prevailing practices.

Current Total Project Cost. The analysis for the study cost approximately $225,000. The estimated cost for the ATR is $14400.00.

e. Project Delivery Team (PDT). Before posting to websites for public disclosure of the RP, it may be necessary to remove names and contact information for Corps employees to comply with security policies and the Privacy Act of 1974, (5 U.S.C. § 552a).

PDT Roster				
Name	**Discipline/Role**	**District/Agency**	**email**	**Phone**
	LWSC Project Manager	CENWS-OD-LW		
	Hydraulic Engineer Lead	CENWS-EN-HH-HE		

4. REVIEW FUNDAMENTALS

a. General. All draft products and deliverables will be reviewed within the district to assure the overall integrity of the report and technical appendices before approval by the District Commander.

b. Products for Review. The product identified for review is the LWSC PMF Study Report including the supporting models.

c. Documentation of ATR. DrChecks review software will be used to document all ATR comments, responses and associated resolutions accomplished throughout the review process. Comments should be limited to those that are required to ensure adequacy of the product. The four key parts of a quality review comment will normally include:

(1) The review concern – identify the product's information deficiency or incorrect application of policy, guidance, or procedures;
(2) The basis for the concern – cite the appropriate law, policy, guidance, or procedure that has not been properly followed;
(3) The significance of the concern – indicate the importance of the concern with regard to its potential impact on the plan selection, recommended plan components, efficiency (cost),

effectiveness (function/outputs), implementation responsibilities, safety, Federal interest, or public acceptability; and;

(4) Where appropriate, provide a suggested action needed to resolve the comment or concern.

In some situations, especially addressing incomplete or unclear information, comments may seek clarification in order to then assess whether further specific concerns may exist.

The ATR documentation in DrChecks will include the text of each concern, the PDT response, a brief summary of the pertinent points in any discussion, including any vertical team coordination (the vertical team includes the district, RMO, MSC, and HQUSACE), and the agreed upon resolution. If an ATR concern cannot be satisfactorily resolved between the ATR team and the PDT, it will be elevated to the vertical team for further resolution in accordance with the policy issue resolution process described in either ER 1110-2-12 or ER 1105-2-100, Appendix H, as appropriate. Unresolved concerns can be closed in DrChecks with a notation that the concern has been elevated to the vertical team for resolution.

ATR shall be certified when all ATR concerns are either resolved or referred to the vertical team for resolution and the ATR documentation is complete. The ATR Lead will prepare a Statement of Technical Review certifying that the issues raised by the ATR team have been resolved (or elevated to the vertical team).

5. DISTRICT QUALITY CONTROL (DQC)

DQC will be performed by Seattle District. All draft products and deliverables will be reviewed within the district as they are developed by the PDT to ensure they meet project and customer objectives, comply with regulatory and engineering guidance, and meet customer expectations of quality.

6. AGENCY TECHNICAL REVIEW (ATR)

a. General. ATR for other work products will be managed and performed outside of the home District and the MSC will serve as the RMO (EC 1165-2-209, Section 9 (2)). During the Vertical Alignment Conference Call, HQ-USACE suggested that Omaha District would be best-qualified for the hydrology review. Omaha District has not been involved with this study thus far. NWD concurred. The study will also have staff from the Hydrologic Engineering Center (HEC) involved for ATR review of the HEC-RAS modeling.

b. Objective of the ATR. The ATR shall ensure that the product is consistent with established criteria, guidance, procedures, and policy. The ATR will assess whether the analyses presented are technically correct and comply with published USACE guidance.

c. Required ATR Team Expertise. ATR team and required expertise

ATR Team Members/Disciplines	**Expertise Required**

ATR Lead and Hydrology Reviewer Hydrology/Hydraulics	The ATR lead should be a senior professional with experience in determining PMP events for the IDF and PMF in the Pacific Northwest, reviewing the HFAM/HSPF routing models, and conducting an ATR. (Refer to Models used in Table 1) The lead should also have the necessary skills and experience to lead a virtual team through the ATR process. HQUSACE suggested and NWD concurred Omaha District be a good lead.
Hydraulic Reviewer, Hydrology/Hydraulics	The Hydraulic reviewer should be a senior Hydraulic Engineer with experience in HEC-RAS, including geoRAS, dam break analysis, and flood routing. Reviewer should also have experience with conducting frequency analysis and reservoir sensitivity analysis. (Refer to Models used in Table 1)

d. Proposed ATR Team Roster. Before posting to websites for public disclosure of the RP, it may be necessary to remove names and contact information for Corps employees to comply with security policies and the Privacy Act.

Agency Technical Review (ATR) Team				
Name	**Discipline/ Role**	**District/Agency**	**email**	**Phone**
	ATR Lead and Hydrology Reviewer	CENWO-ED-HE		
	Hydraulic Model Reviewer	CEIWR-HEC-HH		

e. Documentation of ATR. The ATR team leader will prepare a Review Report which includes a summary of each unresolved issue; each unresolved issue will be raised to the vertical team for resolution.

ATR may be certified when all ATR concerns are either resolved or referred to USACE Headquarters (HQUSACE) for resolution and the ATR documentation is complete. Certification of ATR should be completed, based on work reviewed to date and final report.

7. MODEL CERTIFICATION AND APPROVAL

a. General. No planning models were used in the LWSC PMF Study. This section documents the use of the engineering models. As part of the USACE Scientific and Engineering Technology (SET) Initiative, the models used in this study are identified either as preferred

or allowed for use on Corps studies. The selection and application of the model and the input and output data is subject to DQC and ATR. The engineering models in Table 1 (page 11) are being used in the LWSC PMF Study.

b. Other. To comply with the Modeling, Mapping and Consequences (MM&C) Center requirements for inundation mapping, the data files followed the format outlined in the MM&C, specifically the format for the data structure for the hydrologic and hydraulic modeling exercises specified in Model Results Deliverable Guidance—Format and Organization.

Table 1. Engineering models used in the LWSC PMF Study.

Model Name and Version	**Brief Description of the Model and How It Will Be Applied in the Study**	**SET Status Certification / Approval Status**
HSPF (Hydrological Simulation Program-Fortran)	HSPF is a mathematically based computer code developed under U.S. Environmental Protection Agency (EPA) sponsorship to simulate water quantity and quality processes on a continuous basis in natural and man-made water systems. King County Water and Land Resources Division developed and calibrated HSPF models for the Sammamish River Watershed as part of its Sammamish-Washington Analysis and Modeling Program (SWAMP). A recent floodplain mapping study of the Sammamish included updated HSPF models for the Sammamish River basin. King County provided all of the HSPF models that cover the Lake Washington and Sammamish River Watersheds.	CoP Preferred
HFAM II (Hydrologic Forecasting and Analysis Model)	HFAM II is a comprehensive modeling system that simulates hydrologic processes (runoff from rainfall and snowmelt, channel flow). HFAM II is based on the Stanford, HSP, HSPF, SRFM and Seafm family of models (HSP and HSPF developed by HydroComp Inc.). It is a continuous simulation model that does historical or forecast analysis and it includes probabilistic or ensemble forecasts of streamflows, reservoir levels and releases or power production. The Cedar River HFAM II Model was developed by HydroComp Inc. for Seattle Public Utilities (City of Seattle) (SPU) and is used extensively for daily operations, forecasting, and studies. This model was chosen for LWSC PMF Study based on accuracy, time, efficiency, economics, and stakeholder acceptance.	Allowed for Use
HEC-RAS 4.0 (River Analysis System)	The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program provides the capability to perform one-dimensional steady and unsteady flow river hydraulics calculations. The program will be used for steady and unsteady flow analysis to evaluate the discharge capacity and lake levels for the 2 through 500 year and PMF flows. It will also be used to evaluate dam failure scenarios and elevation resulting from the loss of pool.	CoP Preferred
HEC-geoRAS	The Hydrologic Engineering Center's tool for ArcGIS is used to communicate between HEC-RAS and ArcGIS. Geographic data can be sent from ArcGIS to HEC-RAS, and HEC-RAS results can be sent back to ArcGIS.	CoP Preferred
HEC-SSP (Statistical Software Package)	The Hydrologic Engineering Center's Statistical Software Package supports performing flood flow frequency analyses based on Water Resources Council "Guidelines for Determining Flood Flow Frequency," Bulletin 17B Guidelines, general frequency analyses, volume frequency analyses, duration analyses, coincident frequency analyses, and curve combination analyses.	CoP Preferred
HEC-DSS/ DSSVUE	The Hydrologic Engineering Center's Data Storage System is a database system designed to efficiently store and retrieve scientific data that is typically sequential. Such data types include, but are not limited to, time series data, curve data, spatial-oriented gridded data, and others. The system was designed to make it easy for users and application programs to retrieve and store data. HEC-DSS is incorporated into most of HEC's major application programs.	CoP Preferred

8. POLICY AND LEGAL COMPLIANCE REVIEW

All documents will be reviewed throughout the process for their compliance with law and policy. These reviews culminate in determinations that the recommendations in the reports and the supporting analyses and coordination comply with law and policy, and warrant approval or further recommendation to higher authority by the home MSC Commander. DQC and ATR augment and complement the policy review processes by addressing compliance with pertinent published Army policies, particularly policies on analytical methods and the presentation of findings in decision documents.

This review plan template is not intended to describe requirements and processes to conduct policy and legal compliance review, or legal sufficiency reviews.

9. REVIEW SCHEDULES AND COSTS

The DQC is currently underway. Completion expected by January 31, 2013. The ATR schedule and cost estimate are presented in Tables 2 and 3.

Table 2. **ATR Schedule.**

Review Milestone	**Review Products**	**Date Planned**
100% ATR review	LWSC PMF Study	February 2013
100% backcheck		March 2013
Report Completed		April 2013
ATR Certification		May 2013

Table 3 **ATR COSTS - Labor/Expenses.**

Review Milestone	**#reviewers/total hours**	**Approximate cost/hr**	**Totals**
100% ATR review	2/40	$120	$9600
100% backcheck	2/16	$120	$3840
ATR Certification	1/8	$120	$960
ATR Expenses (travel etc)	0		0
Total ATR costs			$14400

10. PUBLIC PARTICIPATION

Public participation was discussed by the Vertical Conference Call participants and is not planned at this time. Any further actions as a result of this study would be associated with Dam Safety issues and would be reviewed as part of a decision document or implementation project at a later date. The RP will be posted for comments on the District website.

11. REVIEW PLAN POINTS OF CONTACT

Questions and/or comments on this RP can be directed to the point of contact on the web page where this document is posted.

12. REVIEW PLAN SPECIFICS - APPROVAL

NWD will review this plan and route by NWD staffing sheet. If the plan is complete and appropriate for the risk and complexity of the project/products, the NWD will recommend approval by the appropriate Senior Executive Service (SES) in NWD. The NWD approval memorandum will be sent to the District POC responsible for the plan. The NWD approval memorandum shall be documented with the review plan, and the approval date should be noted on the cover sheet of this document.

Approved revisions should be recorded in the A-7 block below.

13. REVIEW PLAN REVISIONS

Revision Date	Description of Change	Page / Paragraph Number	Date Approved
Original	Original, 10 Dec 2012		13 Dec 2012
Revision 1, 08 Jan 2013	Removed names for posting and corrected cost for review.	Cost, page 13	Minor Changes, not re-approved.

14. ACRONYMS.

Acronyms	Defined
ATR	Agency Technical Review
DQC	District Quality Control
EC	Engineering Circular
EIS	Environmental Impact Statement
ER	Engineering Regulation
HQUSACE	Headquarters, U.S. Army Corps of Engineers
IEPR	Independent External Peer Review
LWSC	Lake Washington Ship Canal
NWD	Northwestern Division
NWS	North West Seattle
MSC	Major Subordinate Command
PCX	Planning Center of Expertise
PDT	Project Delivery Team
PMP	Project Management Plan
QA	Quality Assurance
QMP	Quality Management Plan
QMS	Quality Management System
RMC	Risk Management Center
RMO	Review Management Organization
RP	Review Plan
SES	Senior Executive Service
SAR	Safety Assurance Review (also referred as Type I IEPR)

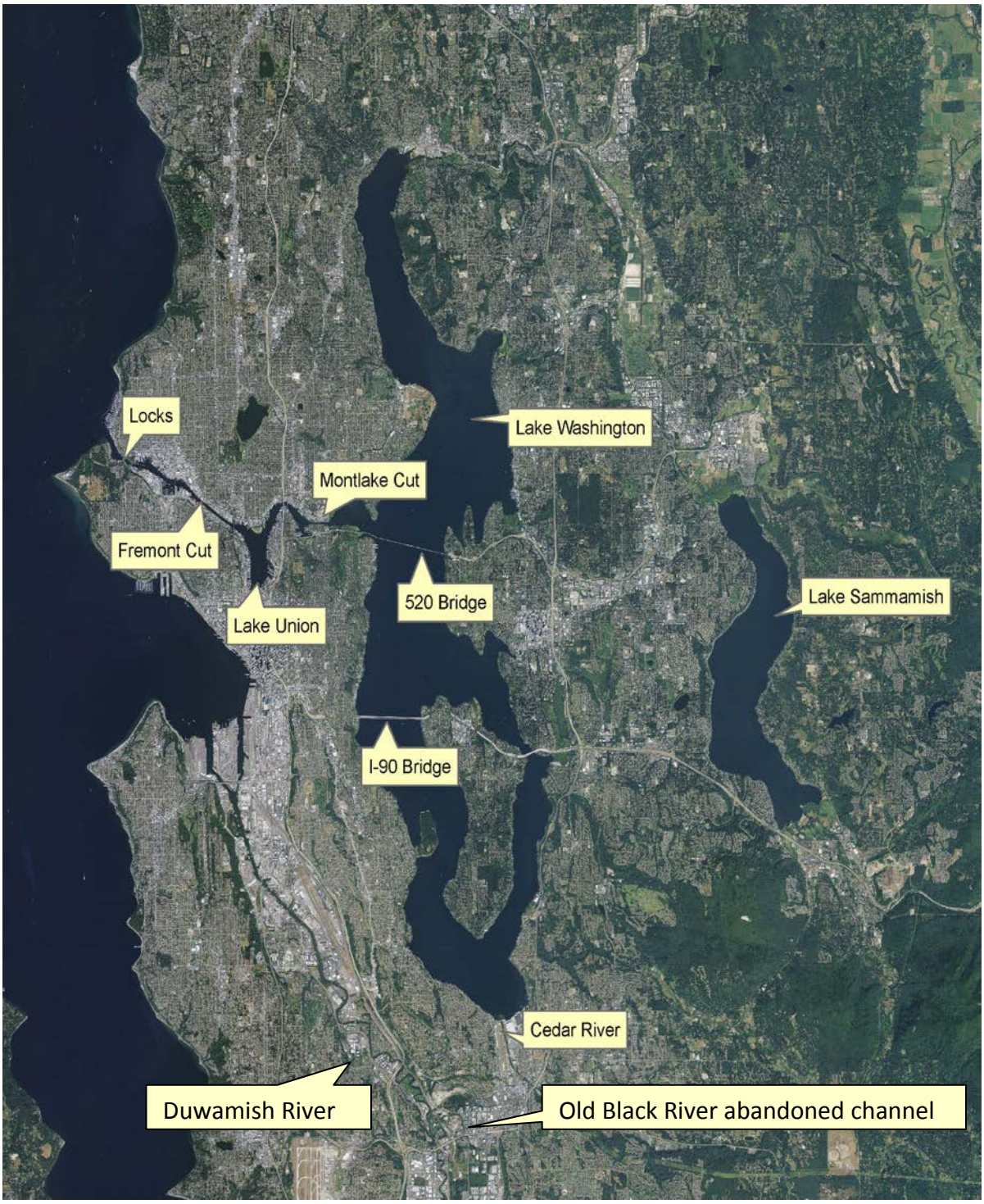

Figure 1. Watershed View with the Locks, Fremont Cut, Lake Union, Montlake Cut, Lake Washington, I-90 floating bridge, SR-520 floating bridge. The original outlet for Lake Washington was at the south end, through the Black River to the Duwamish River. Figure shows current Cedar and Duwamish Rivers configuration – before 1911, the Cedar flowed to the Duwamish through the Black River also.