Phase 1 Report

Addressing Temperature and Dissolved Oxygen in the Lake Washington Ship Canal

June 2023

LONG LIVE THE KINGS

LAKE WASHINGTON CEDAR SAMMAMISH WATERSHED

Acknowledgements

Treaty Rights

The Muckleshoot Indian Tribe and the Suquamish Indian Tribe each hold adjudicated treaty rights, which include the right to co-manage and harvest fish and other resources that originate from WRIA 8 at their respective usual and accustomed places (see U.S. v. Washington, 384 F. Supp. 312, 365-367 [W.D. Wash. 1974], 459 F.Supp. 1020, 1049 [W.D. Wash. 1978]) (Urgenson et al. 2021).

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Summary

Salmon are an important source of food and essential to tribal culture and way of life for Native people since time immemorial. Salmon have also been integral to Washingtonians as a source of food, recreation, and provide significant economic value to the State of Washington. The Lake Washington Ship Canal (LWSC) is part of the Lake Washington/Cedar/Sammamish Watershed (Water Resource Inventory Area [WRIA] 8). In the LWSC, lethal and sublethal temperatures and dissolved oxygen (DO) conditions during salmon migration windows represent key obstacles to salmon recovery. There is a critical need to quickly identify and advance feasible and effective solutions to these water quality concerns which result in a barrier to fish migration. The LWSC is a heavily used, unique, and highly engineered system central to the most populous watershed in Washington State. Anadromous salmon in the watershed must pass through the LWSC twice in their life, as out-migrating juveniles and returning adults. Addressing this complex issue will require collaborative partnerships and innovative solutions grounded in comprehensive evaluation and technical, economic, and sociopolitical feasibility analysis. In addition to substantial ecological change and multiple intersecting interests and needs, major challenges include limited dedicated funding, jurisdictional complexity, and gaps in data and information to guide decision making.

In 2021, Long Live the Kings (LLTK)[1] and WRIA 8 Salmon Recovery Council[2] initiated a collaborative effort to bring together groups with management authority for or jurisdiction in, the LWSC. The **"Lake Washington Ship Canal Roundtable"** (hereafter "Roundtable") initially included over 13 public entities. The group defined a common goal to **"Act urgently to improve juvenile and adult salmon health and survival in the Lake Washington Ship Canal by lowering water temperatures, increasing dissolved oxygen, and reducing abrupt transitions in those conditions."** To achieve that goal, the Roundtable focused on identifying alternatives that could be implemented within the next 10 years. This report describes the approach and the prioritized alternatives identified during Phase 1 of the effort to achieve this goal.

Phase 1 goals included: (1) build and maintain consensus around the scope and priority of the problem, (2) pool expertise to identify solutions, and (3) prioritize solutions identified as most promising to meet the goal. Phase 1 was successful in identifying promising alternatives to address the impacts of high water temperatures and low DO for salmon in the LWSC. The Roundtable achieved broad consensus on the types of strategies considered, the challenges to address, and a process to move forward. Moreover, the group established a cooperative approach that will be foundational to the effective implementation of solutions. In Phase 2, we will (1) perform feasibility analyses of alternatives, (2) develop implementation and funding strategies, (3) establish necessary partnerships and authorizations, (4) support complementary efforts, and (5) build broad regional support.

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[1] Long Live the Kings is a 501(c)(3) nonprofit with a mission to restore wild salmon and steelhead and to support sustainable fishing in the Pacific Northwest.

[2] The Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Salmon Recovery Council is a regionally coordinated partnership among 29 local governments, community stakeholders, and scientists that oversees implementation of the science-based Chinook Salmon Conservation Plan.

Problem Statement

Salmon within the Lake Washington/Cedar/Sammamish Watershed (Water Resource Inventory Area [WRIA] 8) are experiencing unprecedented declines. Several anadromous salmon populations are exemplary of this decline. Lake Washington sockeye, which once represented the largest sockeye run in the lower 48, have not been able to support a fishery since 2006 and are vulnerable to population collapse. Endangered Species Act (ESA) listed Steelhead are now considered functionally extirpated within the watershed and ESA-listed Chinook populations remain far below recovery goals. Only coho populations still offer limited fishing opportunities, though these populations have also experienced substantial declines. These declines are occurring despite increased hatchery supplementation and significant investment in habitat restoration.

A primary challenge for anadromous salmon in this watershed is the impact of high and increasing water temperatures in freshwater migratory and rearing habitats which acts as a barrier to fish migration. Lethal and sublethal temperatures and DO levels within the Lake Washington Ship Canal (LWSC) during migration windows represent a key obstacle to salmon recovery (WRIA 8 SRC 2017). The WRIA 8 Salmon Recovery Council identifies the LWSC as one of the highest priority (Tier 1) areas to focus recovery actions in their 2017 Chinook Salmon Conservation Plan update (WRIA 8 SRC 2017). To better inform recovery strategies in the LWSC, WRIA 8 completed a recent synthesis of the best available science on impacts of temperature and DO conditions on salmon in the LWSC including a summary of management efforts to date (Urgenson et al. 2021).

All anadromous salmon in the WRIA 8 watershed must pass through the LWSC twice in their life, first as juveniles out-migrating to Puget Sound and again as adults returning to spawn. During the key May – September salmon migratory period (2009-2019), salmon passing through the relatively shallow LWSC encountered surface temperatures exceeding harmful sub-lethal thresholds (15 °C daily average) at least 87% of the time and exceeding lethal thresholds (22 °C daily average) at least 12% of the time (Urgenson et al. 2021). Unfortunately, this period also coincided with hypoxic conditions at the lower available depths in Lake Union where salmon could otherwise seek cold water refuge from higher temperatures (Urgenson et al. 2021). Low DO conditions in the hypolimnion are due to a combination of factors, including respiration and thermal stratification. Intrusion of dense marine water into Lake Union from lockages can result in a longer period of hypolimnetic anoxia. In the coming decades, the LWSC is predicted to experience both higher water temperatures and longer durations of harmful temperatures as air and surface water temperatures continue to warm with climate change (Urgenson et al. 2021).

Water temperature is a primary determinant of salmon health, development, migration, and survival. Heat-stressed salmon face increased risks from parasites, infection, predation, and migration blockages or delays which can result in increased mortality rates and reduced spawning success (Urgenson et al. 2021). Delayed migration due to high temperatures is a concern for adult Chinook and coho salmon, which can hold just upstream of the Hiram M. Chittenden Locks, as well as for juveniles which migrate through the LWSC. Prolonged holding delays migration and can result in greater thermal exposure, higher energetic costs, reduced reproductive success, and lower survival. Salmon holding for extended periods can also become stressed and crowded resulting in increased susceptibility to disease outbreak. Holding may also be associated with recycling through the Locks, increasing the threat of predation by pinnipeds. The direct impacts of high temperatures in the Ship Canal on juvenile salmon health, behavior, and outmigration is uncertain. Introduced warm water predatory fish species generally have higher metabolism at warmer temperatures, potentially allowing them to consume more prey, including juvenile salmon, and digest them more quickly.

History of the Issue

Historically, Lake Washington and the Cedar River drained separately south into the Black River, a tributary to the Duwamish River. In 1912, the Cedar River was partially diverted into the south end of Lake Washington. By 1916, a new connection between Lake Washington and Puget Sound, through the Ship Canal and Hiram M. Chittenden (a.k.a. Ballard) Locks (hereafter "the Locks"), was built. In the process of creating this new shipping corridor, the water level in Lake Washington dropped approximately nine feet and the Lake was disconnected from its southern outlet into the Black River, which ultimately dried up. The LWSC became the only connection between Lake Washington and Puget Sound (Urgenson et al. 2021).

The LWSC stretches 10.8 km (about 6.71 mi) - from Union Bay in Lake Washington west through the Montlake Cut, Portage Bay, Lake Union, Fremont Cut, Salmon Bay, the Locks and into Shilshole Bay in Puget Sound (Figure 1). This engineered waterway is critical to the region's economy, transportation, and flood control infrastructure. The Locks themselves are an iconic Seattle tourist attraction and a notable landmark listed on the National Register of Historic Places. With 45,000 vessels passing through each year, the Locks are the busiest in the country and support more than $1.2 billion in annual economic activity (McDowell Group 2017, WRIA 8 2019). The LWSC is also a critical migratory pathway for this watershed's anadromous salmon, including sockeye, coho, steelhead (functionally extinct), and ESA-listed Chinook.

Thermal and DO conditions at the Locks and in the LWSC have been identified as key constraints to salmon recovery in WRIA 8 (Urgenson et al. 2021). Most of the water in the LWSC comes from the surface of Lake Washington. High water temperatures in the LWSC are primarily driven by the solar heating of the surface of Lake Washington. Because the LWSC is relatively shallow (9-11 m on average and at its eastern connection to Lake Washington), the LWSC is cut off from the cooler waters below the Lake Washington thermocline (> 10 m depth; Urgenson et al. 2021). In 2014 parts of the LWSC were listed as Impaired (303(d) listed) for temperature under the Clean Water Act (Ecology, 2022). Since 1960 there has been an increasing trend in both the number of days surface waters in Lake Washington exceed critical thresholds for salmon health, as well as the seasonal extent of these temperature exceedances (Urgenson et al. 2021).

At its western end, the Locks are a barrier between freshwater in the Ship Canal and saltwater in Puget Sound. For migrating salmon, the Locks create an abrupt and stressful physiological transition between the cold saltwater of Puget Sound and the warm freshwater of the Ship Canal.

Physical and biological estuary functions are greatly limited. Freshwater flow to Puget Sound is minimal, and saltwater flows upstream only during large locks openings.

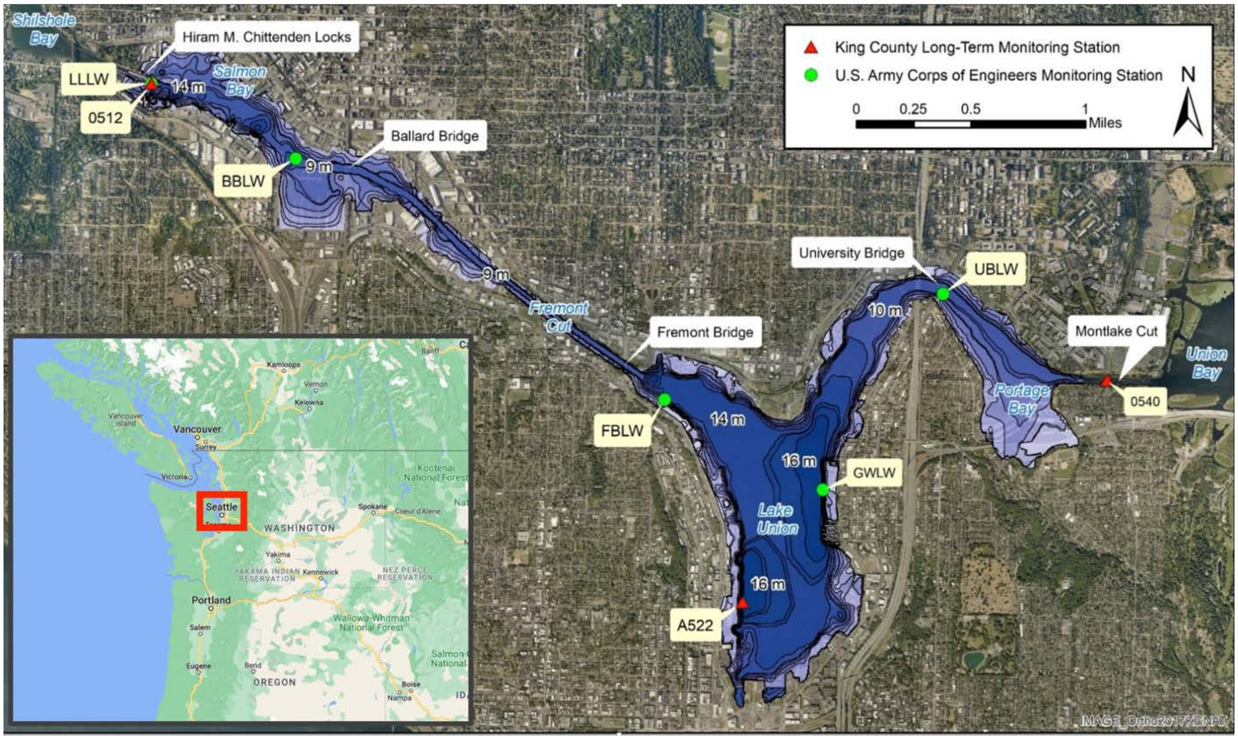

Figure 1. Areal extent and bathymetric profile of the Lake Washington Ship Canal showing locations of existing water quality monitoring stations (excerpted from Urgenson et al. 2021, Figure 4; inset from Google).

Chinook salmon are particularly impacted by the water quality challenges in the LWSC. Most adult Chinook salmon enter the LWSC during the warmest periods in late July–August and coincide with the lowest flow rates. Deeper areas with cooler water can be found in Lake Union (mean depth 10.5 m and maximum depth 16 m), however critically low DO levels make these areas unsuitable as thermal refuge for salmon. The saltwater drain area immediately upstream of the Locks (maximum depth 14-16 m) provides a small pocket of cool water refuge where adult Chinook exhibit holding behavior to mitigate the abrupt physiological transitions at the Locks. However, this area is small, and its persistence relies on frequent lockages. In addition to holding at the saltwater drain, many adult Chinook will recycle through the Locks at least once before continuing their migration through the LWSC (Urgenson et al. 2021). This behavior exposes them to increased risk of predation or injury from large populations of pinnipeds at the Locks, attracted by the high concentration of salmon congregated below the Locks.

Salmon face additional challenges along this corridor that are difficult to address. Most notably, the Locks have eliminated the gradient of estuarine habitats that juvenile salmon use to acclimate along their transition between fresh and saltwater. Further, heavy shoreline development (96% armored shorelines; Urgenson et al. 2021) has left little natural riparian and shoreline habitat and few opportunities for habitat restoration. The lack of natural vegetation and shoreline features has limited the availability of refuge and rearing habitat. Contaminated sediments, a legacy of the industrial history of this waterway, and stormwater pollution present additional challenges. Lakeshore development also introduces problems such as overwater structures and light pollution that can facilitate predation.

Previous Efforts to Address Issues

Several previous studies and management efforts led by governments and agencies have focused on improving thermal conditions for salmon in the LWSC (Urgenson et al. 2021). Some management strategies originating from these efforts have been tested and implemented (primarily operational adjustments at the Locks), with relatively limited geographic scope. Primary hurdles for advancing more comprehensive solutions include: 1) limited funding, 2) jurisdictional complexity, and 3) ongoing data needs and critical information gaps. Ensuring a future for salmon in this unique system will require collaborative and innovative solutions grounded in comprehensive evaluation of technical, economic, and sociopolitical feasibility. The following is a summary of previous efforts. For a more thorough overview, see Urgenson et al. 2021.

In 1997 the U.S. Army Corps of Engineers (USACE) initiated the Lake Washington Basin Ecosystem Restoration General Investigation Study (LWGI) with King County and the City of Seattle as local sponsors. The goal was to inform planning of ecosystem improvements for salmon and other wildlife, and to ensure efficient water use and adequate fish passage at the Locks (SPU & USACE 2008). Two of the six study objectives focused on decreasing water temperatures and salinity gradients associated with the Locks (between Shilshole Bay and the east end of the LWSC for adult salmon, and Salmon Bay and the east end of the LWSC for juveniles). Proposed management actions included operational adjustments at the Locks, habitat restoration, and active cooling of the Ship Canal. Information gaps were identified in the study and recommended all proposed actions undergo further study and be evaluated for benefits and consequences.

In 2010, WRIA 8 commissioned an analysis of potential restoration projects in the Salmon Bay estuary (the estuarine area downstream of the Locks) including an assessment of daylighting Wolfe Creek, a historical tributary to Salmon Bay. The Salmon Bay Estuary Synthesis Report identified specific recommendations for future research and restoration actions to improve growth and survival of juvenile Chinook (Taylor and Associates 2010). However, the report concluded that habitat restoration efforts in this area would have minimal measurable benefits for juvenile Chinook. To improve survival of adult salmon, the authors recommended projects that lower water temperature above the Locks and minimize the delay of fish passage.

In 2010-2011 the U.S. Army Corps of Engineers (USACE), Seattle District, convened the Lake Washington Ship Canal (LWSC) Water Quality Science Panel (Panel) to fulfill regulatory requirements that emerged from a 2007 US Fish and Wildlife Service Biological Opinion (BiOp), Incidental Take Statement, Reasonable and Prudent Measure; requiring USACE to minimize the incidental take associated with the degraded water quality in the LWSC. The Panel recommended nine potential solutions for improving water quality (specifically temperature and DO) related to salmon passage through the LWSC (USACE 2012). Four solutions focused on improved operations and/or fish passage at the Locks, four focused on improving water quality in the LWSC, and the last recommendation was for a more centralized data repository.

These recommended solutions were preliminary and required further proof of concept and feasibility analysis. To date, the USACE has investigated and implemented some of the recommendations regarding operations of the Locks (e.g., false lockages, USACE 2015). Although these operational adjustments may provide some localized improvements, thermal stress continues to be a significant problem in the LWSC. In 2021 USACE began updating hydrodynamic water quality models for the LWSC to study potential changes from operational scenarios at the Ballard Locks.

In 2011 the Washington State Department of Transportation (WSDOT) conducted a study to identify mitigation options associated with the SR-520 floating bridge replacement project (I-5 to Medina). The study identified six options (5 dredging, 1 pumping) to improve cold water refugia for salmon in the Montlake Cut area of the LWSC (WSDOT 2011). Two of these options received additional technical analysis. The first (Option A) involved dredging a navigation channel through the LWSC to entrain cold water from below the Lake Washington thermocline. The second (Option F) proposed constructing a pumping system to transport cold water from below the Lake Washington thermocline into the Montlake Cut. While a technical analysis showed the limited scale of these options would only provide slight and localized reductions in water temperature, the strategies showed promise. Given appropriate modifications (e.g., expanding the scale, etc.) and combined with additional efforts (e.g., modified Locks operations, etc.), the study concluded these strategies have potential to improve water quality conditions for salmon in the LWSC (WSDOT 2011).

The Roundtable

LLTK/WRIA 8 Partnership

LLTK and the WRIA 8 Salmon Recovery Council have a history of working together on salmon restoration in the region. In 2019 the organizations partnered on coordinating solutions to the problem of high temperatures and low DO in the LWSC. At the time, WRIA 8 was completing a synthesis on the best available science and management responses to high temperature and low DO in the LWSC (Urgenson et al. 2021). The purpose of this report was to support a common understanding of the problem, inform decision-making around management goals and priorities, and inform the development of innovative solutions. This synthesis was instrumental in guiding LLTK and WRIA 8's collaborative approach to identify and advance solutions.

Formation of the Roundtable

The LWSC Roundtable was formed to build a group who could: 1) apply the latest science to inform prioritization of solutions, 2) cultivate broad support and political will needed to secure the considerable funding required to test and implement solutions, and 3) act and/or engage entities with the authority to implement solutions and tackle jurisdictional challenges. Central to this effort was ensuring that there was representation from among the many entities with overlapping mandates, authority, and priorities along the LWSC (**Table 1**).

Table 1. Roles of some of the entities interacting in the LWSC. Information is limited to the project scope. Not all entities are necessarily members of the Roundtable.

Entity	Role in the LWSC
City of Seattle/Seattle Public Utilities (SPU)	Utility supporting improved water quality, habitat, and salmon recovery
WA Department of Ecology (Ecology)	Regulator, adopts and administers State water quality standards
WA Department of Natural Resources (DNR)	Land manager with a focus on restoration and enhancement projects
Environmental Protection Agency (EPA)	Regulator focused on water quality
King County	Utility and watershed jurisdiction with salmon recovery and water quality focus
National Oceanographic and Atmospheric Administration (NOAA)	Regulator (administers Endangered Species Act for listed salmonids), Salmon recovery focus
Port of Seattle	Supports salmon recovery efforts: habitat enhancement, water quality
Puget Sound Partnership	Coordinates regional salmon recovery
U.S. Army Corps of Engineers (USACE)	Navigation and Operations; Needs local sponsor to consider work beyond the LWSC operations and maintenance
U.S. Fish and Wildlife Service (USFWS)	Scientific research with salmon recovery focus
U.S. Geological Survey (USGS)	Scientific research with salmon recovery focus
WA Department of Fish and Wildlife (WDFW)	Natural resources co-manager, Salmon recovery focus
Water Resource Inventory Area 8 (WRIA 8)	Responsible for Chinook Recovery Plan

Process

Phase 1 of the process to address temperature and DO in the LWSC was intended to produce a small number of alternative solutions that would then advance through additional feasibility assessment and implementation phases (Phases 2+, Figure 2).

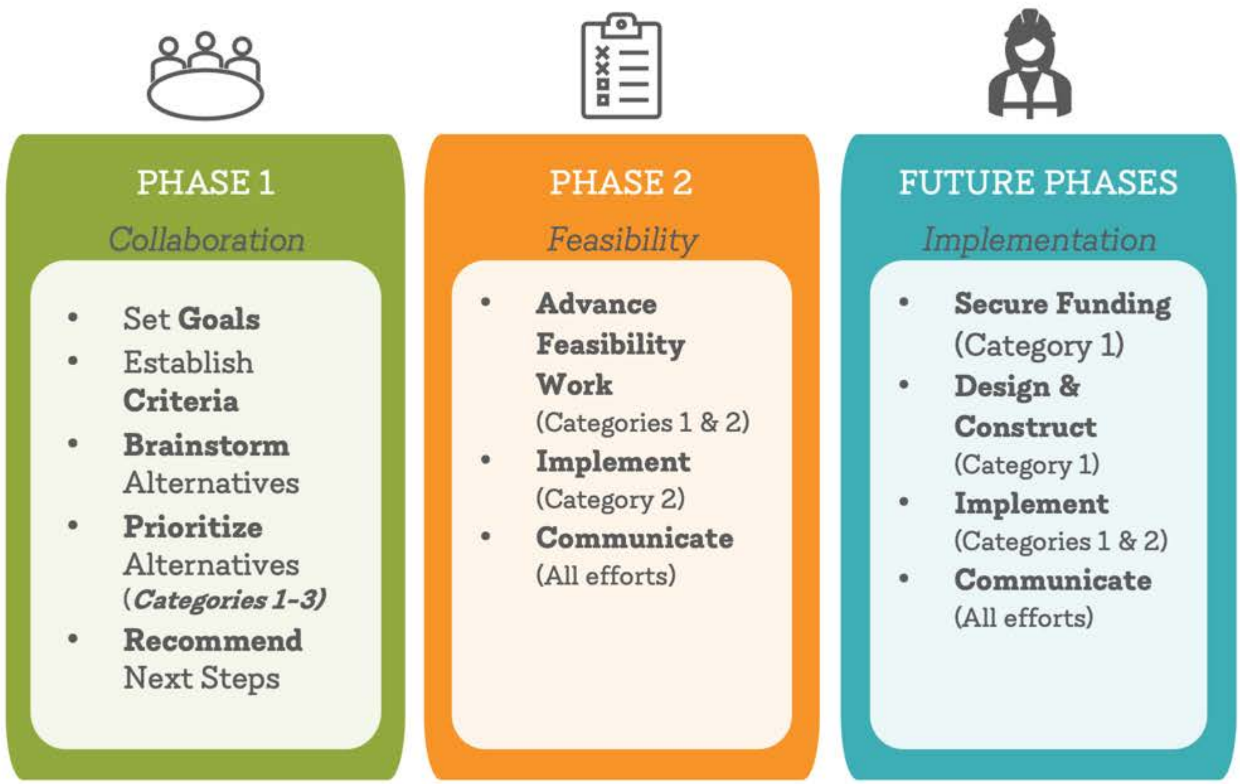

Figure 2. Phases of the Lake Washington Ship Canal (LWSC) project aimed at identifying and implementing solutions to alleviate warm water impacts to salmon in the LWSC. This report addresses Phase 1.

Phase 1 began with two Roundtable discussions. The objectives of the initial meeting were to share relevant information on temperature and DO levels in the Lake Washington Ship Canal (LWSC) in relationship to salmon health and recovery, and to discuss how to advance solutions. Almost 40 people representing 14 entities attended and demonstrated a strong willingness to work together to make progress on the long-standing problem. One month later, most of the initial attendees reconvened for a follow-up discussion. The objectives were to review key comments from the first meeting and discuss roles and considerations for evaluating potential solutions moving forward.

In the initial meetings, the Roundtable identified the following common priorities and values:

> **Species** – Prioritize strategies that address all Pacific salmon species impacted by high temperatures and low DO over more targeted species-specific strategies.

Scope – Temperature and DO conditions in the LWSC are the focus of this effort but consider how solutions link with a watershed-based approach to salmon recovery. Quantify and/or model benefits to salmon directly, in addition to changes in biophysical conditions that would result from alternative actions. Consider a range of alternatives across the LWSC to assess feasibility and effectiveness, rather than predetermine or prioritize any specific approach. The LWSC is conventionally defined as the waters between Webster Point in Union Bay (eastern extent) and Salmon Bay and Shilshole Bay (western extent). The Roundtable chose to focus on the waters between the Montlake Cut and the fish ladder at the Locks, as these areas are most problematic for temperature and DO.

Timeframe – Immediate action is critical. Consider both near-term strategies with potential to immediately mitigate impacts to salmon and illustrate progress/build momentum/prevent further decline, while also assessing longer-term, more comprehensive solutions. Alternatives that were unlikely to be implemented within 10 years should not be considered. Consider current and future conditions (e.g., climate change) in vetting alternatives.

Value Drivers – High value placed on multi-benefit solutions (economic, social, equity/human-wellbeing, ESA listed species, environmental quality/protection, Locks maintenance, stormwater) that touch on a variety of interests and funding resources. It is important to evaluate public cost/benefit, potential regulatory barriers, and sociopolitical feasibility of alternatives in addition to assessment of technical feasibility and effectiveness.

After the initial Roundtable meeting, participants had the option of joining one of three voluntary work groups based on their expertise and desired commitment level. The three work groups included: 1) **Information, Input, and Advocacy** Work Group (IIAWG), 2) **Steering and Strategy** Work Group (SSWG), and 3) **Technical** Work Group (TWG). This organizational structure was developed and approved by Roundtable participants. Together the three groups worked towards the project goal. Overall, Phase 1 included two Roundtable meetings, one workshop, five smaller WG meetings, and numerous phone and email communications (Table 2).

Table 2. *Lake Washington Ship Canal Roundtable Timeline.*

Date	Meeting	Purpose	Attendees
June 7, 2021	Roundtable Discussion: 1 of 2	Share information & build collaborative partnership	Public (40 people, 16 entities)
July 3, 2021	Roundtable Discussion: 2 of 2	Establish process and next steps (Phase 1)	Public (32 people, 13 entities)
August 26, 2021	Work Group (WG) meeting	Refine and approve next steps	Steering & Strategy WG
September 17, 2021	WG meeting	Review Phase 1 goal, timeline, ranking alternatives	Technical WG

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Date	Meeting	Purpose	Attendees
September 27, 2021	WG meeting	Refine Phase 1 goal and criteria for ranking alternatives	Steering & Strategy WG
September 30, 2021	WG meeting	Finalize criteria, plan Workshop	Technical WG
December 9, 2021	Roundtable Workshop	Brainstorm alternatives	Information, Input, and Advocacy WG (35 people, 16 entities)
March 8, 2022	WG meeting	Prioritize alternatives	Technical WG

The IIAWG included all attendees of the original LWSC Roundtable meetings and additional interested parties. This group included a diverse array of representatives from agency, private, non-profit, and community representatives who wanted to stay involved and advocate for the project's goals and objectives. The SSWG included senior management level representatives from organizations invested in this issue who could contribute time and expertise to strategic planning. The TWG included individuals with expertise in water quality, fish biology, engineering, or a close working knowledge of the LWSC. The general process involved the TWG preparing recommendations, the SSWG vetting these recommendations and helping define next steps, and the IIAWG reviewing the recommendations to help identify red flags and provide additional feedback.

Roundtable Goal

One of the first actions of the work groups was to articulate and approve a project goal. Guided by input from all groups, their goal was to "**Act urgently to improve juvenile and adult salmon health and survival in the Lake Washington Ship Canal by lowering water temperatures, increasing dissolved oxygen, and reducing abrupt transitions in those conditions**." The Roundtable specifically chose to focus on environmental metrics as they relate to salmon health (i.e., water temperature, etc.) as they are easier to quantify and link to management actions than salmon population measures which are more complex and subject to a suite of factors. Adding a sense of urgency to the goal was important to the group as it matched the severity and time-sensitive nature of the problem. It also helped focus the prioritization of alternatives to ones that have the potential to be **implemented within the next 10 years**.

Criteria Development

The Roundtable developed criteria through TWG and SSWG discussions to help evaluate potential alternatives. The criteria were intended to highlight specific characteristics important to meeting the Roundtable's goal and that reflected mutual values. The criteria (Table 3) provided WG members with a consistent framework to use when discussing alternatives during the workshop and through the prioritization process. In future phases of the project, more rigorous methods, such as modeling, may be applied to better describe how alternatives address criteria. In the criteria, 'feasibility' refers to the technical ability to practically implement the proposed alternative and the likelihood of the alternative to substantially improve water quality, depending on the context.

Table 3. Criteria used to evaluate potential alternatives for addressing high water temperatures and low DO in the Lake Washington Ship Canal. These criteria were developed by the LWSC Roundtable during Phase 1, 2021-2022.

#	Criterion	Type	Notes
1	How well does the alternative reduce the exposure of juvenile and adult salmon to high water temperatures and low DO?	Technical (biology, limnology)	Consider measuring by the reduction in average number of days during the salmon migration window that water temperature was: • > 15° C (thermal stress threshold) • > 21.5° C (mortality threshold) Incorporate climate change projections, how temperature changes across depths, and the anoxic conditions at depth.
2	How well will the alternative create or enhance areas with desirable water quality to support salmon migrating through the Lake Washington Ship Canal?	Technical (biology, limnology)	Desirable areas are defined by areas closer to these standards, but it may not be realistic to reach all standards: • Water temperature ≤ 15°C • DO ≥ 6mg/L • Minimal exposure to toxins and other negative habitat features, such as heavy boat traffic or overwater structures.
3	How well will the alternative connect discrete areas of desirable water quality to support salmon migrating through the LWSC?	Technical (biology, limnology, hydrology)	Connectedness in the context of thermal barriers is still being researched and likely varies across salmon species and habitats. • The TWG concluded that a continuous pathway of desirable water quality is preferable but acknowledged that it may be more challenging to implement. • The size and location of areas of desirable water quality may need to be adaptively managed.
4	How well will the alternative reduce the abrupt transitions in water quality conditions (temperature, DO, salinity) at the Locks?	Technical (biology, limnology, hydrology)	Focus on adult migration at the fish ladder, especially the transition from relatively cold saltwater to warmer freshwater from the LWSC that occurs halfway up the fish ladder.

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#	Criterion	Type	Notes
5	Will the alternative reduce the exposure of Chinook and/or sockeye populations to high water temperatures and low DO?	Technical (biology, limnology)	Consider species-specific differences in migration timing and behavior. • The TWG recommended focusing on Sockeye and ESA-listed Chinook. • Alternatives that benefit Chinook and Sockeye will likely benefit coho as well assuming benefits extend into September.
6	Will the alternative reduce the exposure of returning adults and/or juvenile salmon to high water temperatures and low DO?	Technical (biology, limnology)	Consider life-stages present in the LWSC when evaluating alternatives. • Adult and juvenile salmon exhibit differences in migration timing, behavior, and physiological constraints.
7	What are potential negative consequences associated with the alternative?	Technical (science, politics, $)	Note potential negative aspects of alternatives so they may be considered in a cost/benefit framework in more intensive feasibility work.
8	What data gaps could be addressed to better understand the feasibility of the alternative?	Technical (science, politics, $)	Addressing data gaps (e.g., through empirical evidence, modeling, etc.) will be costly and should be prioritized by utility for evaluating alternatives. • Hydrodynamic modeling was identified as a priority data gap needed for a rigorous technical feasibility analysis of most alternatives.
9	What factors affect the technical and political feasibility of the alternative?	Feasibility (political, technical)	Consider factors during more in-depth design/planning work, but also when deciding which alternative merits additional research.
10	How well does this alternative leverage or advance other regional priorities?	Feasibility (regional alignment)	Alternatives with multiple benefits on top of salmon recovery often deliver greater public value and these factors should be considered.
11	What is the expected implementation cost for this alternative?	Feasibility ($)	Cost estimates will be refined with further analysis, but it's important to generally understand the costs involved.
12	What is the expected annual maintenance cost for this alternative?	Feasibility ($)	Should be considered outside of implementation cost because it may inform overall operating cost and ongoing funding need.

Workshop: Brainstorming Alternatives

In December 2021, LLTK and WRIA 8 held a Roundtable Workshop to brainstorm management alternatives to improve conditions for salmon in the Lake Washington Ship Canal (LWSC). Thirty-five people representing sixteen entities and all three WGs participated in this workshop. The goal of the workshop was to encourage innovative thinking and out-of-the-box solutions to supplement, adapt, and expand upon the recommendations that had been made in previous efforts. Because achieving the LWSC Roundtable's goal will require a massive environmental investment, it was prudent to consider solutions that captured both previous efforts as well as the latest science and technology. Experts on novel techniques like district energy and green infrastructure presented potential approaches to address our goal and to inspire creative thinking.

Attendees explored alternatives in four different themes: 1) Engineered water quality improvements, 2) Operational changes to the locks or LWSC, 3) Natural process restoration, and 4) Methods for salmon to bypass the LWSC. Attendees had the chance to brainstorm and discuss alternatives in each category during breakout group sessions. The outcome of this workshop was a broad list of 45 alternatives and additional notes regarding their potential feasibility.

Alternatives Prioritization Process

The Roundtable workshop's alternatives ranged from expansions of existing programs to massive restoration projects. To compare the merit of these alternatives effectively, the list needed to be narrowed. LLTK and WRIA 8 collated the list of alternatives and prioritized them based on input from relevant workshop participants and members of the TWG and SSWG. This initial prioritization was revised by the TWG and further vetted by the SSWG. The goal of this prioritization was to focus the group's efforts on alternatives that met the Criteria and had the most chance of meeting the project's goal. While alternatives were evaluated individually, it was recognized that a combination of alternatives may ultimately be needed.

During the prioritization, alternatives were placed into three categories based on feasibility and how well they met the LWSC Roundtable goal. Category 1 included large-scale and comprehensive strategies to achieve the goal. Category 2 included alternatives related to Locks infrastructure or operation. Category 3 included alternatives that did not merit additional consideration during this process. While some alternatives may be beneficial, they were considered infeasible currently for technical or political reasons or were highly unlikely to meet the LWSC Roundtable goal. The alternatives, in their respective categories, are listed below.

Category 1 Alternatives

Large-scale alternatives that merit additional consideration. These are strategies that would require large investments but would fundamentally improve water quality through the system. It is worth investing in pre-feasibility to better understand challenges, benefits, and any fatal flaws to select an alternative to pursue further. These alternatives are primarily focused on supplementing cold water to lower the LWSC temperature as there are readily available approaches to oxygenate water which could be combined with any of these alternatives. The alternatives are only concepts that are expected to be refined and may be combined.

1. **Hypolimnetic Withdrawal:** During juvenile and adult salmon migration periods, when daily average water temperature exceeds 15° C, pump enough cold water from an appropriate depth and location below the thermocline in Lake Washington (≥ 10 m deep) and disperse it into the LWSC to create connected areas or a continuous pathway of cool water. Lake Washington's hypolimnion is > 40 m deep in some locations with temperatures < 10° C through summer.

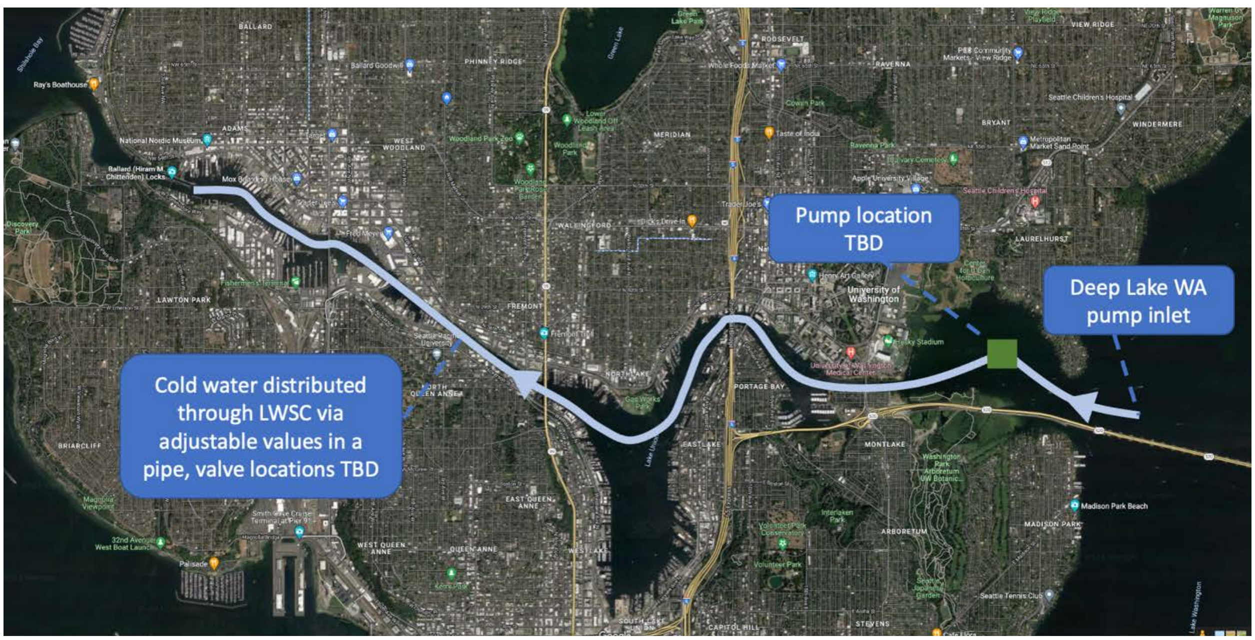

Figure 3. Conceptual diagram illustrating the path of cold water into the LWSC from deep Lake Washington. The light blue line represents piping that would distribute cold water through the LWSC, and the green box represents the pump. All infrastructure is not to scale or located accurately.

2. **Pump from Aquifer:** During juvenile and adult salmon migration periods, when daily average water temperatures exceed 15°C, pump enough cold water from a nearby aquifer and disperse it through the length of the LWSC to create connected areas or a continuous pathway of cool water refuge.

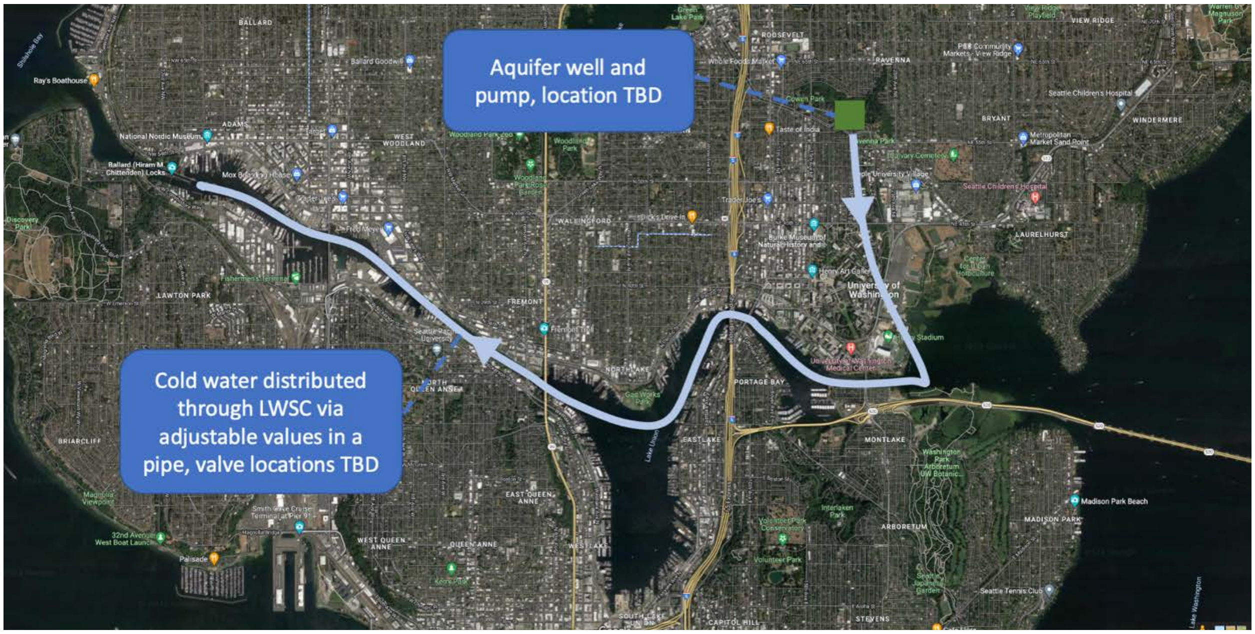

Figure 4. Figure 3. Conceptual diagram illustrating the path of cold water into the LWSC. The light blue line represents piping that would distribute cold water through the LWSC, and the green box represents the pump from aquifer. All infrastructure is not to scale or located accurately.

3. **Heat Exchanger**: During juvenile and adult salmon migration periods, when daily average water temperature exceeds 15°C, pump marine water and LWSC water to a large heat exchanger. To avoid introducing saltwater into the LWSC, the salt and fresh water would be pumped separately in two independent systems. The heat exchanger would transfer heat from the warmer LWSC to the colder saltwater to lower LWSC water to below 15° C. Cooled LWSC water would be dispersed through the LWSC by an unspecified method and warm marine water would be returned to Puget Sound/Shilshole Bay. It's assumed the heat exchanger would be located on the west end of the LWSC. A heat pump used to dispose heat in the sewer, ground, or air may be another device to create closed-loop cooling of LWSC water.

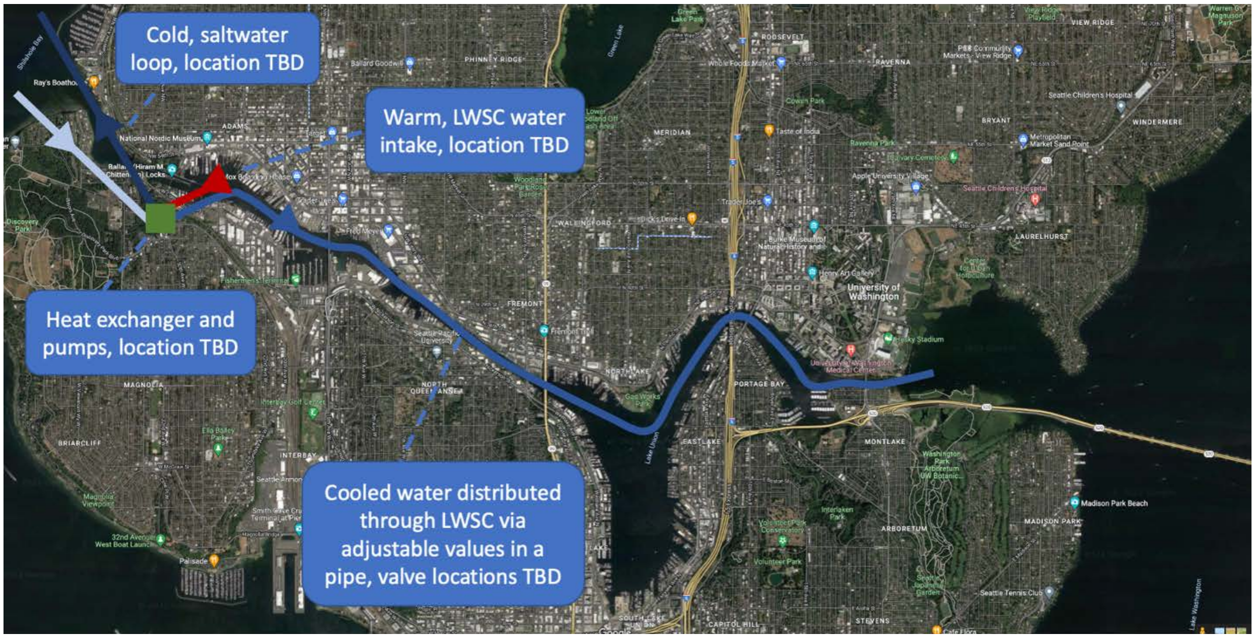

Figure 5. Conceptual diagram illustrating how cold salt water could be used to cool LWSC water using a heat exchanger. The lightest blue line represents piping directing the coldest saltwater entering the heat exchanger and the darkest blue line represents piping directing the warmed saltwater back to the bay. The red line represents the piping directing the hot LWSC water to the heat exchanger and the medium-dark blue line represents piping returning cooled LWSC water through the canal. All infrastructure is not to scale or located accurately.

4. **District Energy Project**: District Energy is a well-established approach used for central thermal energy generation and distribution to serve the aggregated heating and/or cooling load of connected customers in a cluster, campus, or community. District energy projects have been considered in this area, including a project in South Lake Union which concluded some systems have the potential to supply cooler, oxygenated water to Lake Union, Lake Washington and the Montlake Cut (FVB and WSU, 2004). The alternative considered here would integrate a deep-lake-water cooling system with a large, existing district energy network using thermal energy in the lake to indirectly cool buildings then subsequently outflow cool water into the LWSC. The cold water in the intake would be pumped from below the thermocline near Webster Point and return in an outfall through Union Bay directed westward into the Montlake Cut. The water pumped from Lake Washington would be warmed (or cooled) by the cooling (or heating) application needed from the building. In the case that the building required cooling, which is likely during the salmon migration period, the water from Lake Washington would be warmed by an undetermined amount (flow and thermal loads would need to be defined) but would still be relatively cooler than the water in the LWSC. Collaborating with the University of Washington to improve their existing system by integrating deep-lake-water cooling is a specific approach under discussion that is likely to provide some cooling benefit to the LWSC. This alternative is very similar to hypolimnetic withdrawal, but the water from the outfall would be relatively warmer and the system costs could be distributed across multiple users.

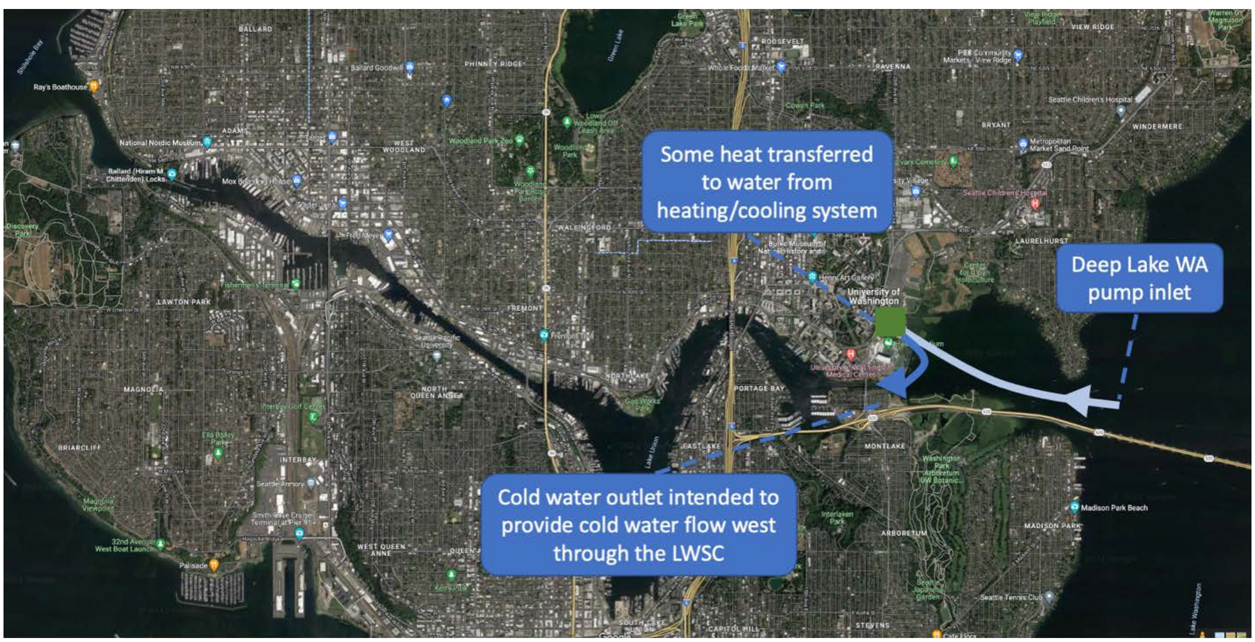

Figure 6. Conceptual diagram illustrating the flow of water through a district energy system. The light blue line represents cold water entering the district energy system from Lake Washington. The darker blue line represents piping directing warmer, but still relatively cool water into the LWSC. All infrastructure is not to scale or located accurately.

Category 2 Alternatives

Alternatives related to the operations or infrastructure at the Locks that merit additional consideration. These alternatives include operational adjustments and infrastructure changes to reduce water quality impacts and improve passage conditions in the vicinity of the Locks. It is worth investing to better understand costs, benefits, feasibility, and begin design and implementation as appropriate. These solutions would likely be pursued as a part of a larger strategy.

Operational Changes

1. **Lockages:** Conduct more/longer/adjust timing of lockages (with or without boat traffic) to introduce saltwater upstream from the Locks. This will move colder salt water upstream and prevent anoxic conditions. Lockages would be coordinated with saltwater drain and saltwater barrier operations. The use of finer scale measurements or modeling could also maximize saltwater introduction without exceeding the saltwater standard at the University Bridge. USACE may be employing a similar strategy, but there may be more room for refinement. In the past, USACE exceeded the saltwater standard during these operations, but this was related to saltwater drain operations. When the saltwater drain is open, saltwater can flow back to the westside of the locks and minimizes the chances that water east of Lake Union exceeds salinity standards.

    a. ***Relax the Saltwater Standard:*** *Washington State administrative code prohibits actions that would cause salinity to exceed one part per thousand (1.0 ppt) at any depth east of the University Bridge (WAC 173-201A-602). This standard is a factor limiting more frequent lockages. Increasing this standard by a small amount could provide more latitude for USACE to conduct lockages for the benefit of salmon. More analysis would be needed to determine the ecological impact of higher salinity water entering Lake Washington and Lake Union, and an adjustment to the saltwater standard may not be possible from a regulatory perspective.*

    b. ***Lake Washington Draw Down:*** *Adjust Lake Washington draw down operations to increase freshwater flow. Manage lake levels to maximize capacity prior to the salmon migration season and increase flow through the Locks to lower the lake to the minimum lake level through the migration season. The impacts to lakeside users and property owners would need to be investigated further.*

Infrastructure Changes

2. **Redesign Fish Passage at the Locks and associated infrastructure:** *Redesign and replace upstream and downstream fish passage facilities at the Locks. This may also include altering the saltwater drain size or location. The saltwater drain is important to cooling the water in the fish ladder. Complete an analysis of potential facilities to replace the existing fish ladder and smolt flumes with a facility that would better facilitate juvenile and adult fish passage. Facilities that provide a more gradual and longer water quality transition would be preferable. Implement the most preferable modification(s).*

3. **Update Instrumentation and Alert Systems:** Update monitoring instrumentation at the Locks to gauge equipment status, performance, and to alert operators of failures in real-time. Install remote, real-time monitoring devices for key Locks systems that influence fish passage and water quality. Pair this data with additional real-time, finer scale monitoring of temperature and dissolved oxygen in the fish ladder, surrounding the Locks, and in the LWSC. Make this data available to USACE, co-managers, and other parties as appropriate. Consider using this data to create an automated management system with parameters defined by USACE, co-managers, and other parties as appropriate. Parameters would be set to create optimal water quality for salmon and fulfill USACE's management mandate.

Category 3 Alternatives

Lower-ranked alternatives not selected for additional consideration. These strategies are considered currently infeasible, highly uncertain, or unlikely to meet the Roundtable goal. Below each alternative, there is an explanation in *italics* that explains some of the reasoning for including it in this category.

1. Increase freshwater flow by diverting freshwater sources to the Lake Washington Basin and Ship Canal.
   There are no known readily available sources of cool, uncontaminated fresh water which could increase flow to an extent that would benefit salmon.

2. Bubble curtains to create mixing near the Locks.
   It is not clear how bubble curtains would create mixing or how that would be beneficial to salmon given that there is already a cold-water refuge for Chinook. In fact, this approach may make the existing cold-water refuge less effective.

3. Plan for end of usable life of Locks with new, fish friendly design.
   While there are improvements to the Locks that would benefit salmon, many of those improvements are included in Category 2 and could be implemented before the end of the Locks' usable life. Furthermore, a new locks facility is unlikely to change the flow of warm water coming from Lake Washington.

4. Daylight the section of Wolfe Creek flowing through Commodore Park to improve freshwater inputs and estuary habitat.
   This is outside of the scope of the project as it does not address the LWSC.

5. Use green stormwater infrastructure to maximize groundwater recharge around LWSC.
   There is not strong evidence to suggest that additional groundwater could enter the LWSC during peak migration season (summer) at quantities or locations which would be enough to cool the LWSC.

6. Isolated corridor (naturally augmented) for salmon migration inside the LWSC.

While this has the potential to bring better habitat to salmon, it is unlikely to improve water quality to the extent needed to improve salmon health or survival. Also, it's not clear that salmon would use the corridor.

7. New restoration within Union Bay based on lessons learned from prior actions.
   This is outside the scope of the project as it does not address the goal of the Roundtable.

8. Dredge a channel in the LWSC to allow cold water from Lake Washington thermocline to enter the LWSC.
   There are several feasibility concerns (toxic sediments, existing infrastructure, slope of channel in narrower parts of the LWSC, saltwater intrusion into Lake Washington, etc.) related to the depth of channel that would be necessary to allow cold water from Lake Washington to naturally flow into the canal. See WSDOT 2011 for more information.

9. Pump saltwater from downstream to upstream of the Locks to create a larger area of cold water.
   This is different than alternative 3 in Category 1 because it is not using a heat exchanger to introduce cold water. False lockages introduce enough saltwater upstream of the Locks. More saltwater could risk exceeding the salinity standard of 1 ppt at the University Bridge intended to protect against increased saltwater intrusion and prolonged hypoxia in Lake Union and, ultimately, ecological damage to Lake Washington.

10. Use solar panels to cover all or portions of the LWSC to reduce solar energy entering the water (lower temperature) and harness energy.
    The LWSC requires high vertical clearance for passing vessels and the solar panels would need to be placed at a height which would significantly reduce the effectiveness of the shading benefits. It's also not clear whether shading alone would reduce temperatures to a large enough extent.

11. Suspend sediment to tint water.
    This is likely to have significant unintended consequences compared to the relatively low potential benefit.

12. Use "Soil Freeze" dewatering refrigerant technology to cool the Ship Canal.
    This is a relatively new technology that is usually used for dewatering purposes and there are no known examples of it being used for this application. It would also be energy intensive.

13. Construct a new system (glass tub or tunnel) adjacent to the LWSC.
    The solution doesn't have any mechanism to reduce water temperatures to the extent needed to improve salmon health or survival. Also, it's not clear that salmon would use the corridor.

14. Mobile cooling unit (e.g., boat or submarine) that creates cool, high DO flow conditions, attracts fish along a migration corridor.
    The alternative has a low degree of technical feasibility.

15. Reconnect the Black River to allow another outlet.
    The cost associated with land acquisition is high and political feasibility is low. This would require raising the elevation of Lake Washington several feet. The reconnected Black River is also likely to experience warm water inputs from Lake Washington, although the reconnection of the Cedar would ameliorate that to a large degree. This may also reduce the flow through the LWSC enough that the Locks could not be operated.

16. Establish a new salmon stream from Elliott Bay (Terminal 91) to Ballard Bridge / Fisherman's Terminal with riparian areas and a substantial salt/freshwater transition zone.
    The cost associated with land acquisition is high and political feasibility is low. This new waterway is also likely to experience warm water inputs from Lake Washington. There would likely not be enough water in many years to run both this and the Locks.

17. Riparian cover (or any other shading options presented) to increase shading which decreases solar radiation.
    Shading from riparian cover may provide minimal benefits on a site-specific scale and the feasibility of acquiring land for riparian shading is low, so it was not further considered for this process.

18. Small site restoration in Salmon Bay (e.g., Ray's Boathouse, West Sheridan Street End) to improve estuary habitat.
    Small site restoration could be beneficial to salmon on a site-specific scale and this categorization isn't meant to devalue the potential of this work. However, this alternative does not align with the magnitude of the problem.

19. Cedar River aquifer storage.
    This alternative has low political feasibility due to the interests invested in these water resources and it may only provide some additional flow to the watershed in summer months.

Matrix

The matrices below apply the Criteria to alternatives in Category 1 and 2 through qualitative explanations under each criterion. This tool methodically summarizes and compares information highlighted during Phase 1 of the Roundtable. There is one matrix for Category 1 alternatives and another for Category 2. Category 3 alternatives do not merit additional consideration and were not summarized in a matrix format as discussions had already ruled them out as viable options to meet our goal.

Matrix for Category 1 Alternatives

Category 1 Alternative	1. Hypolimnetic Withdrawal	2. Pump from Aquifer	3. Heat Exchanger	4. District Energy Project
Description (See Category 1 descriptions above for more detail)	Withdraw cold water from below Lake Washington thermocline and discharge through the LWSC during critical periods. **Potential discharge options include a "trunk line" with multiple adjustable outlets, an underwater canal designed to direct denser cold water toward Ballard locks, or passive discharge to fill the depths of the LWSC and Lake Union.*	Pump water from nearby aquifer and discharge through the LWSC. (See *Potential discharge options to the left)	Pump marine water and LWSC water into a large heat exchange system at the west end of the LWSC and discharge cool LWSC water through the LWSC. (See *Potential discharge options to the left)	Develop a lake water district energy system that discharges cold lake water into the LWSC to meet the heating and/or cooling needs of the University of Washington (UW) and other potential partners surrounding the LWSC. Outfall would direct the cool water westward at location(s) near the campus or institution requiring heating/cooling.
Reduction in salmon thermal stress	Reliable and abundant source of cool water below Lake WA thermocline could be pumped into Ship Canal at outfall locations or into a channel. Temperature effects depend on mixing. Potential to reduce Chinook holding if cooler temperatures detected farther upstream from the Locks. Assumes salmon would seek out and use this water if it were available.	Need to identify availability, amount, temperature, and DO levels in aquifer(s). Temperature effects depend on mixing. Potential to reduce Chinook holding if cooler temperatures detected farther upstream from the Locks.	Need to evaluate water temperature and quantity. Water temperature may vary with temperatures in LWSC. Opportunity to utilize cool marine water without risk of exceeding salinity standard.	Quantity and location of outfall depends on facility's heating/cooling system needs but can be dispatched with greater flow once installed. Potential for cold storage effect from winter operations. Need to identify if it may still provide benefits depending on the quantity of water. UW concept may provide almost 20% of LWSC summer flow. *Continued next page.*

Category 1 Alternative	1. Hypolimnetic Withdrawal	2. Pump from Aquifer	3. Heat Exchanger	4. District Energy Project
Connects Areas with Desirable Water Quality	Depends on water quantity, dispersal method, and LWSC bathymetry. A continuous pathway of cold water may be preferable but connected areas of cold water may be adequate. DO impacts are unclear and may require a separate approach to oxygenate input water.	See the description for alternative 1 under this criterion.	Depends on design features including water quantity, dispersal method, and LWSC bathymetry. Need for pressurized "trunk line" to move water upstream and discharge at multiple adjustable outlets. A continuous pathway of cold water is preferable but connected areas of cold water may also be adequate.	In addition to the factors described under this criterion for alternative 1, outfall directs flow westward into the Montlake Cut. For UW concept, cold mixed flow is likely to carry downstream which may help connect areas of cold water but may need to identify strategy to convey water past Lake Union and/or block flow from returning directly to Lake Washington.
Creates Areas of Cold Water	Need to evaluate effects of temperature, quantity, heat transfer, mixing characteristics, and location of discharge.	See the description for alternative 1 under this criterion.	See the description for alternative 1 under this criterion.	In addition to the factors described under this criterion for alternative 1 and depending on outfall locations, cold water may collect in Lake Union and/or flow back to Lake Washington without a method to convey water past Lake Union. The cold water may also flow west over denser water in Lake Union.
Improves Locks Water Quality Transition	Unlikely to substantially improve unless design moves cold water into the top of the ladder while limiting mixing with warm surface water.	See the description for alternative 1 under this criterion.	See the description for alternative 1 under this criterion.	See the description for alternative 1 under this criterion.
Species Impacted	All	All	All	All *Continued next page.*

Category 1 Alternative	1. Hypolimnetic Withdrawal	2. Pump from Aquifer	3. Heat Exchanger	4. District Energy Project
Returning Adults and Out-Migrating Juveniles Impacted	Both	Both	Both	Both
Potential Negative Consequences [Need Evaluation]	> Impacts on Lake WA ecosystem due to cold water withdrawals. >Changes in the flow at the east end of the LWSC may confuse migrants. > Water quality impacts to the LWSC or Lake Union from additions of Lake WA water. > Prolonged disturbance of contaminated sediments.	> Impacts on competing water uses. > Impacts from mixing water sources. > Prolonged disturbance of contaminated sediments. > Effects on groundwater availability.	> Discharging warm water into Puget Sound, near the Locks. > Prolonged disturbance of contaminated sediments.	> Impacts on Lake WA ecosystem due to water withdrawals. > Water quality impacts to the LWSC or Lake Union from additions of Lake WA water. > Prolonged disturbance of contaminated sediments. > Effects on olfactory cues used by salmon during migrations.
Data Gaps	> Lake Washington water quality suitability - likely suitable but needs verification. > Hydrodynamic needs (temp./quantity/outfall locations) to create cold water corridor. > How dispersal method may be impacted by LWSC bathymetry. > Mixing characteristics of cold water introduced to the LWSC. > Need for a continuous pathway vs. connected pockets of cold water to expedite migration through areas of poor water quality.	> Depth, location, and size of nearby aquifers. > Aquifer water quality suitability > Hydrodynamic needs (temp./quantity) to create cold water corridor > Impacts of LWSC bathymetry and its impact on dispersal methods. > Mixing characteristics of cold water introduced to the LWSC > Need for a continuous pathway vs. connected pocket of cold water to expedite migration through areas of poor water quality. > Relative benefit of different	> Hydrodynamic needs (temp./quantity) to create cold water corridor. > Capabilities and energy demand of heat exchanger. > Impacts on proximate Puget Sound water temps. > Net change in heat considering impacts of LWSC bathymetry on dispersal methods. > Mixing characteristics of cold water introduced to the LWSC. > Need for a continuous pathway vs. connected pocket of cold water to expedite migration through areas of poor water quality.	> Estimate outfall temperature and volume during salmon migration and extent to which the flow rates can be maximized for habitat once infrastructure is installed. > How dispersal method may be impacted by LWSC bathymetry. > Mixing characteristics of cold water introduced to the LWSC. > Need for a continuous pathway vs. connected pocket of cold water to expedite migration through areas of poor water quality. > Impact on salmon olfactory cues.

Continued next page.

	>Changes to attraction flow at east end of the LWSC. > Relative benefit of different approaches to dispersing cold water. > Impact on salmon olfactory cues. > Should water be discharged near the channel bottom or above ordinary high-water line? > Changes to DO.	approaches to dispersing cold water. > Impact on salmon olfactory cues. > Should water be discharged near the channel bottom or above ordinary high-water line? > Changes to DO.	> Assess the relative benefit of different approaches to dispersing cold water. > Should water be discharged near the channel bottom or above ordinary high-water line? > Changes to DO.	> Should water be discharged near the channel bottom or above ordinary high-water line? > Changes to DO. *Continued next page.*

Category 1 Alternative	1. Hypolimnetic Withdrawal	2. Pump from Aquifer	3. Heat Exchanger	4. District Energy Project
Feasibility	Generally feasible. Additional considerations: > USACE 408 permitting. > Inlet/outlet permitting. > Need for complementary monitoring system to adaptively manage pumping quantities or other factors. > Defining need for consumptive or non-consumptive water rights. >Broadly justifying the significant expense in relation to opportunity costs. > Identifying a party that would own and operate the system.	Generally feasible. Additional considerations: > USACE 408 permitting. > Inlet/outlet permitting. > Need for complementary. monitoring system to adaptively manage pumping quantities or other factors. > Aquifer water availability over time. > Water rights may be difficult to secure.	Generally feasible, but relatively more complex than other alternatives. Additional considerations: > USACE 408 permitting. > Inlet and outlet permitting for saltwater and freshwater systems. > Need for complementary monitoring system to adaptively manage pumping quantities or other factors. > Identifying a conveyance system to move cold water east. > Relatively more permitting for additional inlets/outlets in fresh and saltwater environment. > Defining need for consumptive or non-consumptive water rights consider the use for heating/cooling. > Identifying a party that would own and operate the system. >Depending on design. would need to be robust to withstand high flows in the dam tailrace and anchors farther out.	Generally feasible. Additional considerations: > Outlet permitting after introducing heat to the cold-water source. > Inlet permitting. > Need for complementary monitoring system to adaptively manage pumping quantities or other factors. > Identifying a conveyance system to move cold water west. > Defining need for consumptive or non-consumptive water rights consider the use for heating/cooling. > Identifying a party that would own and operate the system. In this case, the heating/cooling benefactor may be an owner or anchor customer. > The heating/cooling benefactor may assume some costs. *Continued next page.*

Category 1 Alternative	1. Hypolimnetic Withdrawal	2. Pump from Aquifer	3. Heat Exchanger	4. District Energy Project
Leverages other Regional Priorities	This would generally align with community goals to improve water quality in this area and feasibility and monitoring work could help inform other actions in the system or in other geographic locations.	See the description for alternative 1 under this criterion.	See the description for alternative 1 under this criterion.	This would have the clear benefit of adding economic value in the form of potential heating/cooling energy reduction, decarbonization, reduction in electric capacity constraints. It may come with University academic and research alignment as well.
Implementation Cost	There are high costs associated with designing, modeling, and constructing this system. It may need to be adapted after 2-5 years of operation based on performance.	See the description for alternative 1 under this criterion.	This is potentially the highest cost option because of the need to pump approximately twice as much water (salt and fresh) over the same or greater distance, and the added equipment (heat exchanger). It may also need to be adapted after 2-5 years of operation based on performance.	There are high costs associated with designing, modeling, and contracting this system, but these costs may be shouldered by the heating/cooling benefactor(s). *Continued next page.*

Category 1 Alternative	1. Hypolimnetic Withdrawal	2. Pump from Aquifer	3. Heat Exchanger	4. District Energy Project
Operation and Maintenance	Operational costs are high and it's likely to require at least 1 FTE to monitor and manage operations in addition to additional expense for ongoing maintenance needs.	Operational costs are high and it's likely to require at least 1 FTE to monitor and manage operations in addition to additional expense for ongoing maintenance needs.	Operational costs would likely be highest for this option considering the addition of the heat exchanger and it's likely to require at least 1 FTE to monitor and manage operations in addition to expense associated with ongoing maintenance needs.	Operational costs would be high, but they may be incurred mostly by the heating/cooling benefactor(s).
Notes	> Cold water areas/outlets should generally target relatively better salmon habitat (low boat traffic, lower presence of toxics, away from predator hotspots, etc.).	> Depending on the depth of the aquifer, it may be more cost effective to pump from the aquifer compared to deep Lake Washington. > Cold water areas/outlets should generally target relatively better salmon habitat (low boat traffic, lower presence of toxics, away from predator hotspots, etc.).	> Cold water areas/outlets should generally target relatively better salmon habitat (low boat traffic, lower presence of toxics, away from predator hotspots, etc.).	> The University District is a suitable location for this approach given the existing and large-scale district energy network serving the University of Washington, potential cost reductions associated with shared infrastructure using this approach, and their need to eliminate existing discharges into the LWSC.

Matrix for Category 2 Alternatives

Category 2 Alternative	1a. Lockages ± changes to saltwater standard	1b. Lake Washington Draw Down	2. Redesign Fish Passage at Locks	3. Update Instrumentation and Alert Systems
Description	Fine scale measurement/modeling to maximize benefits of cool, oxygenated saltwater inflow using lockages. Changing the saltwater standard at the University Bridge may increase cooling effects.	Manage lake levels to increase flow through the migration season and offer greater operational flexibility at the Locks (e.g., lockages, smolt flumes).	Analyze potential facilities to replace fish ladder to better facilitate adult fish passage. This may include modifying the saltwater drain and smolt flumes. Implement the most preferable modification(s).	Remote, real-time monitoring devices for locks systems associated with fish passage and water quality.
Reduces Exposure to High Temp. or Low DO	Temporary reduction in total exposure to high temperatures and low DO with diminishing effect east of the locks.	Greatest benefit is likely operational flexibility with lockages, smolt flumes, and salinity management. Increased flow during migration may decrease travel times, limiting exposure to the LWSC WQ issues.	Reductions in temperature limited to the top weirs of the fish ladder. DO may be improved immediately upstream of the locks.	May result in reduced temperature and improved DO in some instances, assuming data changes locks operation. Will help minimize disasters (ladder turned off, wrong valves opened, saltwater barrier broken). Currently these problems may exist for days or weeks before anyone notices. Will help ensure the fish ladder is working correctly.
Connects Areas with Desirable Water Quality	Benefits are limited to waters just east of the locks.	Unlikely to connect cold water refugia.	Improves transition in ladder, better connects downstream with upstream refugia. It may also improve water quality immediately upstream of the locks.	Could improve the transition in fish ladder and in the LWSC west of the University Bridge, assuming operations are not currently maximized for suitable water quality.
Creates Areas of Cold Water	Already does but may expand the size or duration of these colder areas.	Unlikely to create cold water refugia but may lead to operational adjustments that reduce water temperature and improve migration.	May reduce temperature in top half of the fish ladder and expand the size or duration of cold area immediately upstream of the locks.	Could lower temperature in the fish ladder and in the LWSC west of the University Bridge, assuming operations are not currently maximized for suitable water quality. *Continued next page.*

Category 2 Alternative	1a. Lockages ± changes to saltwater standard	1b. Lake Washington Draw Down	2. Redesign Fish Passage at Locks	3. Update Instrumentation and Alert Systems
Improves Locks Water Quality Transition	Proven to already have some positive impact and it may be improved.	More water though the LWSC means a slightly greater lens of freshwater below the Locks than would have occurred otherwise.	Likely to improve transition at Locks, but fish would still face a relatively abrupt transition compared to nature estuary conditions.	May improve transition if this will reduce the likelihood of operational failure and would refine lock operations to improve water quality, at least during some times.
Species Impacted	all	all	all	all
Returning Adults and Out-Migrating Juveniles Impacted	Both	Both	Both	Both
Potential Negative Consequences	> Exceed saltwater standards at University Bridge resulting in saltwater harming Lake Washington (meromixis). > Additional saltwater in Lake Union	> Not having enough water to operate the fish ladder.	> To be determined through assessment. > Impacts to salmon migration during construction.	> None.
Data Gaps	> Updated modeling tools to run appropriate scenarios. > Additional monitoring tools. > Biological response to increasing cold-water refuge just upstream of the locks. > Publicly available DO data.	> Updated modeling tools to run appropriate scenarios. >Biological response? Shouldn't this be true for any scenario?	> Extensive design work (including modeling) to identify feasible solutions.	> Monitoring device scope and placement.
Feasibility	> Currently implemented. > Unclear whether further refinement to operations will improve water quality. > May not be feasible to changes Saltwater standard.	> Technically feasible, but significant political barriers.	>Feasibility will be dependent on design idea. > Requires a partnership or new USACE authority	> Feasible. Requires a partnership or new USACE authority. *Continued next page.*

Category 2 Alternative	1a. Lockages ± changes to saltwater standard	1b. Lake Washington Draw Down	2. Redesign Fish Passage at Locks	3. Update Instrumentation and Alert Systems
Leverages other Regional Priorities			Could be coordinated with other necessary Locks improvements and may help with pinniped predation (telescoping weir, increasing attraction flow by shutting off the small ladder opening, Dispersing attraction water into upper weirs).	May improve overall Locks operations and long-term viability of the Locks.
Implementation Cost	Low - would only require staff time for analysis and operations.	Low - would only require staff time for analysis and operations.	This would be a costly longer-term project.	This would still have substantial cost, but relatively inexpensive compared to the scope of the problem.
Annual Maintenance Cost	Small amount of staff time for refining analysis and operations.	Small amount of staff time for refining analysis and operations.	May increase or decrease annual costs compared to current operations.	New components would require additional maintenance costs.
Notes	Effectiveness may be increased by: > Repositioning or changing the size of the saltwater drain. > Installing an underwater barrier to limit the flow of saltwater into Lake Union. This may harm fish migration.	> Explore combining this with other alternatives (i.e., additional false lockages) to achieve benefits. >USACE has existing authority to manage lake levels at lower levels in some years. By lowering lake levels in hot years, the USACE may be able to do this with their existing authority.	> The ladder was updated in the 1970's and better designs exist. > The ladder could also be replaced with a separate route around the Locks. >Could increase the size/longevity of cool water refuge upstream of locks, but not necessarily reduce Chinook holding times.	> Relatively easy compared to all solutions and would have immediate practical benefit. > Pair data with additional real-time, finer scale monitoring of temperature and dissolve oxygen in the fish ladder, surrounding the locks, and in the Ship Canal. >Make data available to USACE, co-managers, and others as appropriate. >Consider automated management system with parameters defined to improve/maintain water quality for salmon. > This is a known problem and has directly resulted in salmon mortality.

Recommended Next Steps

Phase 2 of the effort to address the Roundtable goal will focus on feasibility assessments and implementation for alternatives in Categories 1 and 2. Category 1 alternatives are large-scale potential solutions that need significant feasibility work, while Category 2 alternatives mainly concern Locks operations and may be less resource intensive but are unlikely to achieve the entire goal of the LWSC Roundtable. Due to the urgency of the problem, Category 1 and 2 alternatives must be advanced in parallel. The following recommendations outline the next steps to work towards the goal of the LWSC Roundtable.

1. **Investigate the feasibility of and develop implementation strategies for Category 1 alternatives.**
   a. **Complete feasibility assessment** – All Category 1 alternatives introduce cold water into the LWSC with the intention of creating a continuous pathway or connected pockets of water with temperature and DO for healthy and uninhibited salmon migration. To select one of these alternatives and advance it into a design phase, a feasibility assessment must establish initial estimates of the water temperature, quantity, and DO concentrations needed to create these areas of cold water. The assessment also needs to identify the best source of cold water and method to convey and distribute the cold water in the LWSC.
   b. **Pursue modeling of Lake Washington, Lake Union, and the Ship Canal** – Given the magnitude of investment required to implement Category 1 alternatives and the complicated nature of hydrodynamics and salmon behavior, computer-based models will be important to determine if the alternative will produce expected outcomes. There are existing hydrodynamic models that may provide initial insights into this question and could be pursued immediately. In addition, it may be important to invest in more detailed models that can estimate other important water quality parameters, such as nutrients, prop wash, and the impacts of shading.

2. **Pursue implementation and feasibility as appropriate for Category 2 alternatives. This may include a combination of actions.**
   a. **Investigate and establish the necessary partnership and authorities** – Category 2 alternatives involve modifications to Locks infrastructure and/or operation. Partners will need to define a shared approach and mutual objectives to advance Category 2 alternatives. USACE participation will be essential and may require partners acting as "local sponsors" through existing USACE programs or a congressional act empowering USACE to devote resources to a specific project.
   b. **Support USACE modeling efforts –** The explanation above discusses these efforts, and they are likely to be helpful to understand the feasibility of alternatives 1-3 under Category 2. – The USACE developed a CE-QUAL-W2 temperature and salinity model in 2016 and is refining that model and running new scenarios in 2022. This two-dimensional (longitudinal/vertical) hydrodynamic model covers the LWSC from Union Bay/Montlake to the Ballard Locks/Shilshole area. The model uses data on water flow, temperature, salinity, bathymetry, and weather data to calibrate the model and estimate

temperature and salinity conditions through the area when temperature or flow inputs are altered. Regardless of any limitations of the model, the results from this work are likely to provide valuable information which will add to our understanding of the feasibility of alternatives. Simpler models may also be used to test additional scenarios in a relatively cost-effective manner.

3. **Communicate the problem, potential solutions, and build support.**
   Multiple organizations and governments have significant interests in the LWSC, and the magnitude of potential solutions are likely to require partnerships and significant public investment. Phase 1 of this work has helped to define the problem and mutual interests for organizations and government entities with interests in the LWSC, but there is a much wider audience of businesses and residents around the LWSC that need to learn about the problem, potential solutions, and the process to arrive at these solutions. Creating videos, written summary documents, website content, and presentations are important tools to facilitate proactive community involvement.

4. **Develop implementation/funding strategies.**
   Alternatives in Categories 1 and 2 require specific strategies to establish authority, mandate, and funding mechanisms. Traditional avenues to secure public funding, such as grants and appropriations, will be essential. Given anticipated costs, we will also need to explore non-traditional funding sources. Private institutions may be willing to invest in the health of salmon traveling through the heart of Seattle.

   Innovative public-private partnerships may provide a mechanism to implement alternatives in Category 1. For instance, District Energy is a widely used approach of centralizing heating and cooling infrastructure for large building clusters, campuses, and communities. These large-scale systems present the opportunity for significant resource efficiency, capacity, and environmental improvements by using existing thermal sources to remove or add heat to the system. Enwave in Toronto, Canada is one of the largest and most innovative systems, using cold water pumped from the depth of Lake Ontario intended for drinking water to cool buildings and campuses around the city. Users receive a benefit from this service and pay rates accordingly. In this way, they have created revenue from a massive investment in drinking water infrastructure without burdening drinking water users with the entire cost. A similar system could be used with water from the depths of Lake Washington to remove heat from nearby buildings (e.g., University of Washington campus) while still introducing cooler water to the LWSC.

5. **Address critical data gaps.**
   Work with partners to identify key information needs that arise through the feasibility process and ways to address them.

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