

UTAH LAKE STUDY

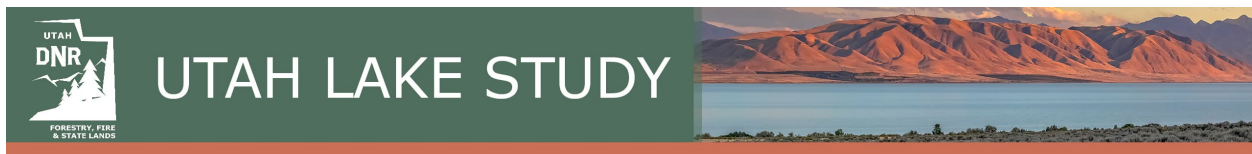
2025 Final Report

Prepared for



Prepared by

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Utah Lake Study

Final Report

October 31, 2025

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Charting a Path Towards an Enhanced Utah Lake

Executive Summary of the Utah Lake Study

Purpose and Context

Utah Lake is one of the largest freshwater lakes in the western United States and a vital ecological, recreational, and cultural resource. Despite decades of monitoring and management, the lake continues to face significant challenges, including poor water quality, invasive species, and degraded habitats.

In response to these challenges, the Utah Legislature passed Senate Bill (S.B.) 270, directing the Utah Division of Forestry, Fire and State Lands (FFSL) to develop actionable strategies to enhance the lake's condition (the S.B. 270 goals of the ULS are listed in Figure ES-1). A review of existing information was conducted to identify these information needs for further study. This Utah Lake Study (ULS) Report outlines a scientifically sound, legally defensible, and community-responsive path forward—one that enhances the lake's current state rather than attempting to restore a historical condition.

Current Condition versus Enhanced Condition

Today, Utah Lake is impacted by several stressors, including turbid water, invasive carp, limited native vegetation, and periodic harmful algal blooms (HABs). The future enhanced condition envisioned by the ULS (and illustrated on Figure ES-2) includes the following characteristics to counter the stressors:

- Clearer, cleaner water
- Reduced invasive species abundance
- Thriving native fish, vegetation, and bird populations
- Restored littoral zone and plant communities
- Expanded and improved recreational access and opportunities

Figure ES-2. Comparison of Utah Lake's Current (left) and Future Enhanced Conditions (right), the Utah Lake Study Goal

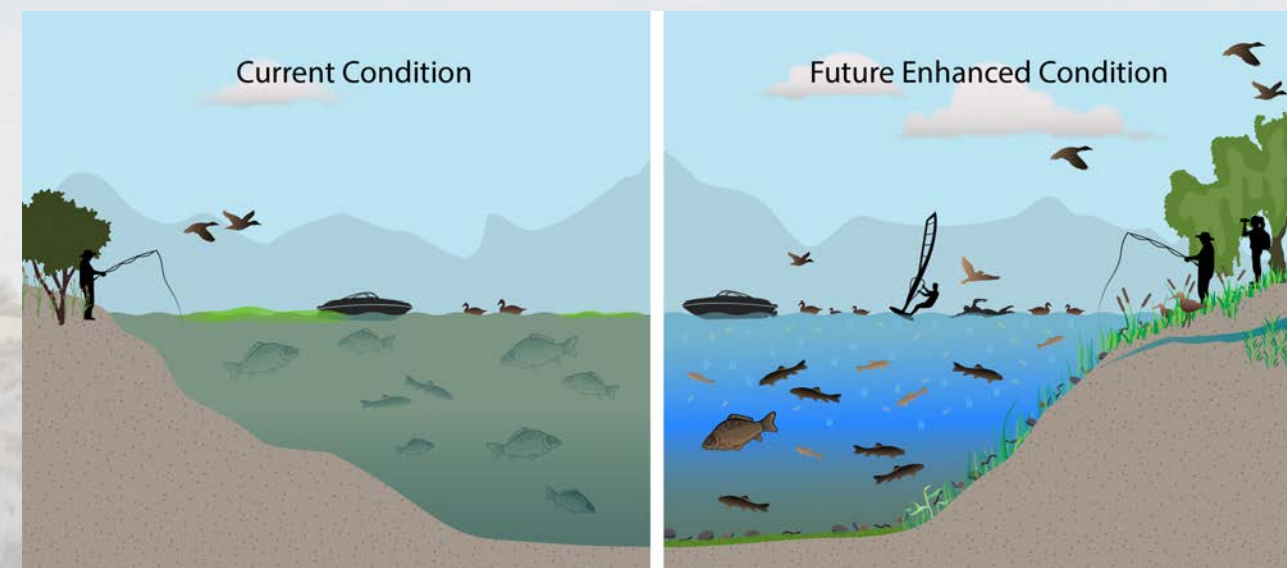


Figure ES-1. Utah Senate Bill 270 Benefit Area Goals for the Utah Lake Study

 a. Improving the clarity and quality of the water in Utah Lake	 b. Conserving water resources in and around Utah Lake
 c. Removing invasive plant and animal species, including phragmites and carp, from Utah Lake	 d. Restoring and improving littoral zone and other plant communities in and around Utah Lake
 e. Restoring and conserving native fish and other aquatic species in Utah Lake, including Bonneville cutthroat trout and June sucker	 f. Increasing the suitability of Utah Lake and its surrounding areas for shore birds, waterfowl, and other avian species
 g. Maximizing, enhancing, and ensuring recreational access and opportunities on Utah Lake	 h. Otherwise improving the use of Utah Lake for residents and visitors
 i. Substantially accommodating an existing use on land in or around Utah Lake	 j. Providing any other benefits identified by the division

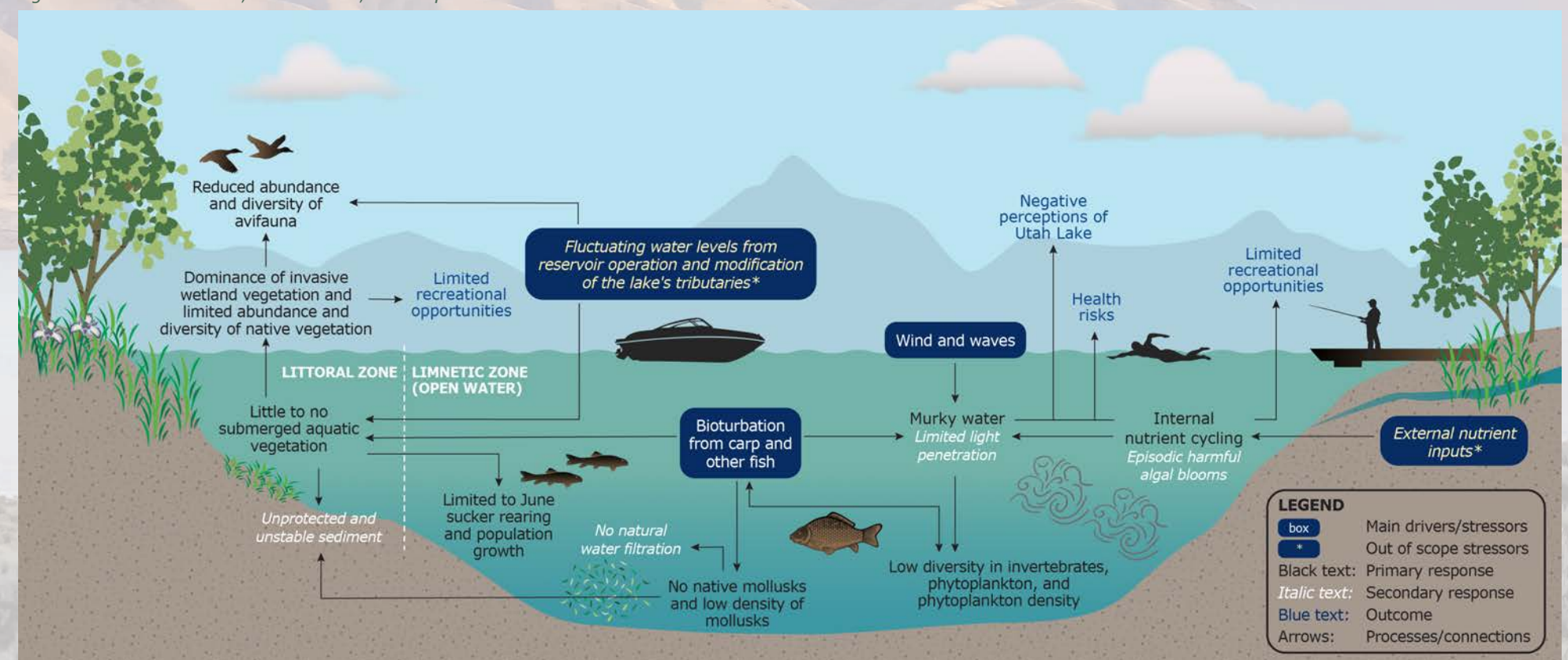
Key Findings

To improve the various interconnected benefits of the Utah Lake ecosystem as envisioned in S.B. 270, multiple stressors, including invasive carp, sediment resuspension and turbidity, elevated external nutrient inputs, and unnatural water level fluctuations, must be addressed in tandem through a coordinated, phased approach. No single solution can sufficiently meet the goal of the ULS, and successful recovery depends on managing all components in parallel.

The ULS addresses the stressors of invasive carp and sediment resuspension directly; nutrient inputs are addressed in the Utah Lake Water Quality Study (ULWQS; ULWQS Steering Committee and DEQ 2022). The ULS does not propose to modify existing water rights or interests related to water collection, storage, and delivery; instead the focus of the ULS is mitigating the effects of fluctuating water levels. Figure ES-3 provides a high-level overview of the ecological linkages between the various benefit areas and the following stressors that impact them, underscoring the need for enhancement efforts to address all ecosystem components. The benefit areas identified in S.B. 270 are influenced by the following primary stressors:

- **Invasive carp** bioturbation of sediments and subsequent degradation of aquatic habitats
- **Wind- and wave-driven sediment resuspension** resulting in elevated turbidity
- **Excessive nutrient inputs** (mainly nitrogen and phosphorus) from external sources
- **Significant and unnatural fluctuations in water levels** from lake management for water rights deliveries.

Figure ES-3. Main Stressors, Benefit Areas, and Responses of Utah Lake



The lake's ecosystem is complex, with interconnected processes affecting various S.B. 270 benefit areas.

Note: Utah Lake's ecosystem is complex, with interconnected processes affecting various S.B. 270 benefit areas. This illustration does not depict every detail of the lake's ecosystem or its complexity; rather, it shows the benefit areas to be enhanced under S.B. 270 and the main (high-level) processes that affect them.

Phased Enhancement Framework

The Phased Enhancement Framework (PEF) for Utah Lake (illustrated on Figure ES-4) is separated into two phases: Phase 1, short/mid-term (2026 through 2030), and Phase 2, mid/long-term (2030 through 2035). This PEF also uses four management tracks (detailed on Figure ES 5) to guide targeted actions by management agencies: invasive carp control, habitat enhancement and sediment management, nutrient management support, and human use enhancement.

This phased approach employing these four management tracks together provides a unified framework for lake recovery and management that allows managers to address the various stressors impacting Utah Lake simultaneously. This framework is flexible and can be adjusted based on changing conditions and results from completed and ongoing actions.

Phase 1: 2026 through 2030

Phase 1 is critical because it formalizes the long-term enhancement of Utah Lake by addressing key ecological stressors, especially invasive carp and habitat degradation, through targeted, science-based actions. This phase builds upon

existing knowledge, secures foundational funding, and establishes coordinated partnerships to ensure efficient implementation of enhancement strategies identified in this ULS Report. Figure ES-5 summarizes each of the four management tracks.

Phase 2: 2030 through 2035 Scaling Up

Phase 2 of the ULS PEF applies phased management principles, emphasizing learning through action. Rather than launching full-scale interventions immediately, enhancement strategies—such as carp removal, sediment stabilization, and habitat restoration—are first tested in pilot projects. These small-scale projects allow ecosystem responses to be closely monitored and techniques refined.

Once proven effective, these strategies are expanded into demonstration projects at a larger spatial scale and under more variable conditions. This step is critical for validating the scalability, cost-effectiveness, and ecological outcomes of Phase 1 actions. The iterative process minimizes risk, builds stakeholder confidence, and informs future decisions, ultimately guiding full-scale restoration across Utah Lake.

Figure ES-4. Overview of the Utah Lake Phased Enhancement Framework

Utah Lake Enhancement				Overall Goal
	Completed or Ongoing (2025)	Phase 1 (2026-2030)	Phase 2 (2030-2035)	
Invasive Carp Control 	- Carp aging analysis to update population model - Baited trap pilot project to increase efficiency of carp removal efforts and inform IPM strategy - Large seine trials to increase carp removal efficiency and inform IPM strategy - Carp movement monitoring to inform IPM strategy	- Develop decision matrix for carp management - Develop a lake-wide monitoring program to generate estimates of carp biomass - Expand the use of emerging carp removal technologies such as box trapping, poison bait, removal of winter and summer aggregations, and seasonal barriers at spawning locations - Develop a market for carp - Develop genetic tools to drive down the carp population	- Accelerate carp removal by scaling up gear and automation to implement IPM strategy lake-wide - Further invest in and deploy genetic control technologies	An enhanced Utah Lake with increased benthic primary production and less turbid water, which would result in the following benefits: - Reduced carp populations - Enhanced habitat for native species - Stabilized sediments - Improved water quality and clarity
Habitat Enhancement and Sediment Management 	- Characterization of lake elevation data to inform revegetation strategies - Development of a site suitability tool to inform revegetation efforts - Compiled species lists for revegetation - Development of an initial scope for the Goose Point pilot project - Description of the relationships between turbidity, light penetration, and SAV requirements to inform revegetation efforts - Numeric modeling of wind and wave action to confirm suitability of Goose Point	- Further develop Utah Lake Revegetation Handbook - Refine site suitability models - Launch Goose Point pilot project - Monitor avian populations and habitat use - Plan for scaling enhancement efforts using hydrodynamic modeling - Pilot engineering strategies to reduce sediment resuspension	- Implement successful strategies on a larger or lake-wide scale - Publish Utah Lake Revegetation Handbook - Demonstrate engineering to reduce sediment resuspension	
External Nutrient Management	Compilation of SAV habitat requirements to inform water clarity improvement needs	- Align restoration goals with nutrient reduction targets - Support DWQS numeric nutrient targets	Support the development of the ULWQS external nutrient management strategy	
Human Use Enhancement 	Supported the development of the ULA's Recreation Access Plan	- Collaborate with ULA and partners - Support efforts to upgrade recreational infrastructure, monitor visitation, and expand public safety programs	- Collaborate with ULA and partners on ULMP and ULRAP implementation - Support efforts to upgrade recreational infrastructure, monitor visitation, and expand public safety programs	

Figure ES-5. Management Tracks for the Phased Enhancement Framework



Invasive Carp Control

Goal:
Reduce carp density to improve habitat and water clarity.

Estimated cost:
Additional DWR staff, approximately \$2.6 million (excluding overhead).



Habitat Enhancement and Sediment Management

Goal:
Restore littoral vegetation and stabilize sediments to improve water clarity and aquatic habitat quality.

Estimated cost:
Estimated \$2.15 – \$3.5 million for Goose Point Pilot Project (not including overhead).



External Nutrient Management

Goal:
Support DWQ's development and implementation of nutrient targets to reduce nutrient pollution.

Estimated cost:
To be determined be based on the ULWQS implementation strategy.



Human Use Enhancement

Goal:
Improve recreational access, safety, and public engagement.

Estimated cost:
To be determined based on the number and scale of recreation and access amenity upgrades.

Critical Success Factors

Successful ULS implementation will hinge on several critical success factors:

- Interagency coordination:** Effective Utah Lake enhancement will hinge on strong collaboration. While FFSL is tasked with leading the ULS under S.B. 270, its jurisdiction is limited to sovereign lands within the lake's settlement boundary. Many factors influencing lake health—such as water levels, watershed restoration, and land use—fall under the authority of other state agencies. FFSL must work closely with these partners to align efforts, respect existing water rights, and ensure that enhancement strategies are legally sound and efficiently implemented.
- Dedicated team capacity:** Successfully implementing the ULS PEF will require a skilled, multidisciplinary team from multiple state agencies to lead coordination, monitoring, and execution across agencies and stakeholders.

- Building this capacity will require engaging the various agencies responsible for managing Utah Lake resources and hiring new staff to manage and execute the program's technical, operational, and collaborative components.
- Sustainable funding:** Long-term success will require a dedicated funding source. Without sustained investment, Phase 1 gains may stall, and the lake could regress to its current degraded state. The Utah Legislature's directive reflects a commitment to lasting stewardship—funding must match that ambition.
- Managing expectations:** Utah Lake enhancement will be a long-term, phased effort. Progress will be incremental, guided by pilot projects and phased, iterative management. Clear communication about timelines, milestones, and anticipated outcomes will be key to maintaining public and legislative support.

A Call to Action

The ULS Report presents a bold, science-driven roadmap for restoring one of Utah's most iconic waterbodies. This ambitious effort includes what could become the largest carp removal initiative in the country—positioning Utah as a national leader in innovative lake restoration. By addressing key stressors through phased, adaptive management and fostering collaboration across agencies and communities, the state has a unique opportunity to set a precedent in watershed enhancement. With sustained commitment, dedicated resources, and clear communication, Utah Lake can become a model for resilient, multibenefit restoration. The time to act is now—together, we can shape a healthier, more vibrant future for Utah Lake.

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Acronyms and Abbreviations

%	percent
\$	U.S. dollar(s)
>	greater than
CUPCA	Central Utah Project Completion Act
DEQ	Utah Department of Environmental Quality
DHHS	Utah Department of Health and Human Services
DNR	Utah Department of Natural Resources
DOR	Utah Division of Outdoor Recreation
DSP	Utah Division of State Parks
DWQ	Utah Division of Water Quality
DWR	Utah Division of Wildlife Resources
DWRe	Utah Division of Water Resources
DWRi	Utah Division of Water Rights
EA	Environmental Assessment
EPA	U.S. Environmental Protection Agency
EV	emergent vegetation
FFSL	Utah Division of Forestry, Fire and State Lands
FTE	full-time equivalent
ha	hectare
HAB	harmful algal bloom
HDPE	high-density polyethylene
IPM	integrated pest management
IWDP	Interim Water Distribution Plan
JSRIP	June Sucker Recovery Implementation Program
kg	kilogram
kg/ha	kilogram(s) per hectare
LHD	local health department
m	meter(s)

m/s	meter(s) per second
N/A	not applicable
N/m ²	Newton(s) per square meter
NTU	nephelometric turbidity unit
PAR	photosynthetic active radiation
PEF	Phased Enhancement Framework
POTW	publicly owned treatment work
PRWUA	Provo River Water Users Association
PTE	part-time equivalent
REIR	Review of Existing Information Report
RSS	relative shear stress
S.B.	Senate Bill
SAV	submerged aquatic vegetation
SSA	site suitability analysis
TBPEL	technology-based phosphorus effluent limit
TSS	total suspended solids
TSSD	Timpanogos Special Service District
ULA	Utah Lake Authority
ULFMP	Utah Lake Fisheries Management Plan
ULMP	Utah Lake Management Plan
ULRAP	Utah Lake Recreation Access Plan
ULS	Utah Lake Study
ULWP	Utah Lake Wetland Preserve
ULWQS	Utah Lake Water Quality Study
ULWUA	Utah Lake Water Users Association
URMCC	Utah Reclamation Mitigation and Conservation Commission
USFWS	U.S. Fish and Wildlife Service
USU	Utah State University
WM	wet meadow



1. Introduction

Utah Lake is one of the largest and most important waterbodies in the state of Utah and the western United States. The communities that surround Utah Lake are some of the largest and fastest-growing population centers in the state. Utah Lake is a prominent fixture of these communities and an important element of the region's economy and culture, providing a critical element of water infrastructure that sustains much of the population and growth along the Wasatch front (Fuller et al. 2016). Despite its vital role in providing significant ecological, recreational, and cultural benefits to the region, Utah Lake faces significant challenges that threaten its ecosystem and ability to support the communities and uses that depend upon it. To address these challenges, Utah Lake has been the subject of numerous research projects, management plans, and monitoring efforts over the last decade. Despite these efforts, a clear, actionable plan to enhance the condition of Utah Lake does not currently exist. With a broadening base of stakeholders, the call for action to resolve these challenges and enhance this fixture of the community became critically important.

In 2024, Senator Curtis Bramble and Representative Keven Stratton sponsored Senate Bill (S.B.) 270, Utah Lake and Great Salt Lake Amendments, that required the Utah Division of Forestry, Fire and State Lands (FFSL) to conduct a study (the Utah Lake Study [ULS]) to determine how to enhance several benefits associated with Utah Lake in a manner consistent with the division's management authority over sovereign lands under Utah Code Section 65A. S.B. 270 requires that the findings of the ULS, and a proposed plan to implement its findings, be completed by November 2025. FFSL used one-time funds appropriated from the legislature to hire a multidisciplinary team of consultants to conduct the ULS. The ULS team was led by Jacobs Engineering, and supported by Tetra Tech, The Langon Group, and Carp Solutions. FFSL and the ULS team were supported by a Steering Committee and a Planning Team.

The ULS Steering Committee comprised state agency directors or their designees and provided executive input on the ULS process and outcomes. The Steering Committee's job was to ensure that the findings of the ULS are scientifically sound, legally defensible, and do not interfere with water rights, projects, and interests related to water collection, storage, or delivery associated with Utah Lake. The Planning Team functioned as a technical working group to evaluate options for enhancing the ten Utah Lake benefits defined by S.B. 270. The Planning Team comprised representatives from state agencies, academia, nongovernmental organizations, and other groups. All project deliverables (including this one) were reviewed by the Steering Committee before they were finalized. Coordination and engagement with these key stakeholders were critical aspects of the ULS, because these stakeholders are most familiar with the lake's resources and will be essential in implementing the findings and recommendations of this ULS.

1.1 Purpose and Scope

This ULS report summarizes the work completed under the ULS from January to October 2025 and includes the following sections and appendices:

- Section 1 Introduction presents project background information and identifies ULS partner agencies.
- Section 2 Key Findings of the Review of Existing Information describes the lake's current condition and its stressors and identifies information needs.

- Section 3 Completed or Ongoing Actions Taken during the Utah Lake Study describes immediate actions taken to address key information needs.
- Section 4 Phased Enhancement Framework presents the two phases and four management tracks of the proposed Phased Enhancement Framework (PEF) for this ULS.
- Section 5 Discussion presents findings in relation to ULS goals, existing knowledge, and local context; outlines implications for stakeholders and future efforts; and identifies limitations in data and methods.
- Section 6 Conclusion provides a summary of the report.
- Section 7 References provides a comprehensive list of citations referenced in this ULS.
- Appendix A Review of Existing Information Report describes the review of existing information task completed as part of this ULS that identified the key information needs for developing Utah Lake enhancements.
- Appendix B Steering Committee and Planning Team lists individuals engaged as key stakeholders in the ULS on the Steering Committee and Planning Team.
- Appendix C Goose Point Pilot Project Details presents three conceptual design options for the Goose Point pilot-scale restoration project aimed at creating a carp-free enclosure to jump-start revegetation and improve water clarity and habitat conditions; evaluates costs, ecological trade-offs, and structural resilience; and recommends further modeling to support sediment mitigation and inform broader restoration strategies.
- Appendix D Utah Lake Revegetation Plant List lists suggested plant species for Utah Lake revegetation efforts.
- Appendix E Analysis of Water Clarity and Potential Impacts on Macrophyte Restoration in Utah Lake summarizes the water clarity (turbidity) analysis based on data collected on Utah Lake and vegetation (submerged aquatic vegetation [SAV]) requirements to identify the reductions in turbidity required to create conditions to enhance SAV populations in Utah Lake.
- Appendix F Wind and Shear Stress presents the analysis of wind and wave forces and their effects on sediment resuspension in Utah Lake.
- Appendix G Scope of Work: Numerical Model Development to Support Revegetation Efforts describes the approach for further modeling and analyzing Utah Lake hydrodynamics to support pilot project engineering design.
- Appendix H Utah Lake and Goose Point Conceptual Revegetation Information describes Utah Lake revegetation guidance (for example, species, planting techniques), monitoring, and management, specifically the Goose Point Pilot Project.
- Appendix I Proof of Concept for the Utah Lake Study Phased Enhancement Framework describes the existing framework referenced when developing this PEF and demonstrates its effectiveness in restoring complex ecosystems through a flexible, iterative approach. It provides global examples, like the Malheur Lake case study, and shows how the PEF aligns with the lake's ecological, stakeholder, and regulatory context.

The scope of this ULS is defined by S.B. 270, which identifies specific benefit areas for enhancement (Figure 1-1). Notably, S.B. 270 directs FFSL to determine how to enhance various benefit areas of Utah Lake, meaning the lake's condition should be improved in ways that are scientifically sound, legally feasible, and responsive to current and future community needs, rather than aiming to recreate a past ecological state.

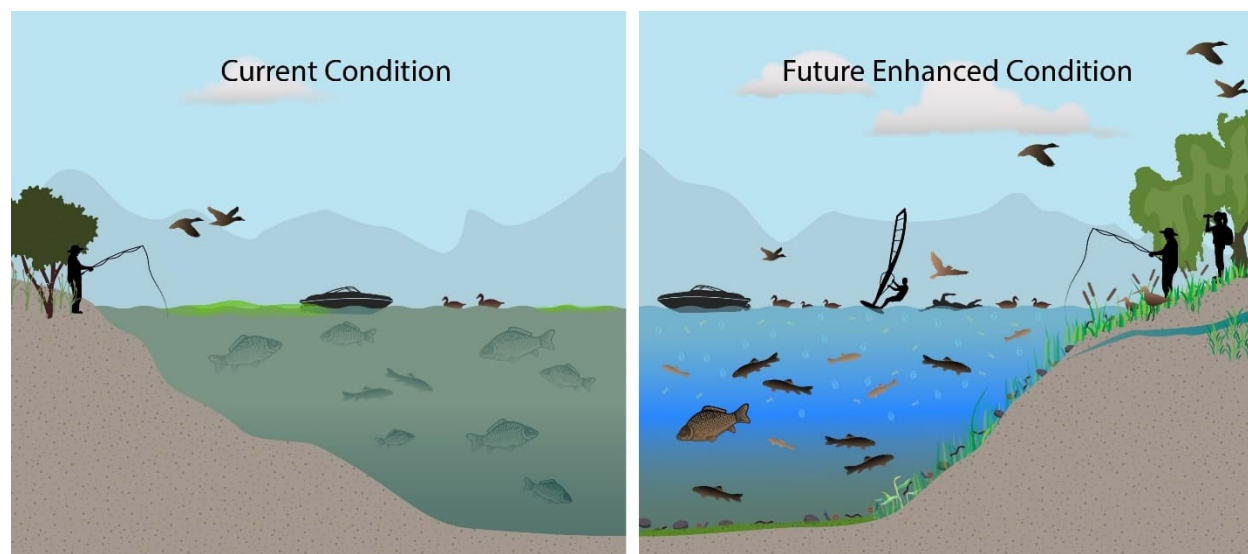
Figure 1-1. Utah Senate Bill 270 Benefit Area Strategies to Enhance Utah Lake

 a. Improving the clarity and quality of the water in Utah Lake	 b. Conserving water resources in and around Utah Lake
 c. Removing invasive plant and animal species, including phragmites and carp, from Utah Lake	 d. Restoring and improving littoral zone and other plant communities in and around Utah Lake
 e. Restoring and conserving native fish and other aquatic species in Utah Lake, including Bonneville cutthroat trout and June sucker	 f. Increasing the suitability of Utah Lake and its surrounding areas for shore birds, waterfowl, and other avian species
 g. Maximizing, enhancing, and ensuring recreational access and opportunities on Utah Lake	 h. Otherwise improving the use of Utah Lake for residents and visitors
 i. Substantially accommodating an existing use on land in or around Utah Lake	 j. Providing any other benefits identified by the division

Source: S.B. 270 (2024).

Figure 1-2 depicts Utah Lake’s future enhanced condition in contrast to its current condition. The current condition of the lake is turbid water and an aquatic ecosystem dominated by introduced common carp, with little to no SAV, high levels of suspended sediment, and periodic harmful algal blooms (HABs). An enhanced Utah Lake, as envisioned under S.B. 270, would feature clearer, cleaner water, thriving native fish and bird habitats, reduced invasive species, an improved shallow water ecosystem, and expanded recreational access, all while conserving water resources and supporting existing land uses around the lake.

Figure 1-2. Comparison of Utah Lake's Current and Future Enhanced Conditions



1.2 Intended Audience and Use

This ULS summarizes the ULS and focuses on the framework that was developed for managing Utah Lake towards an enhanced condition. Further, it is mainly meant to serve as a resource for Utah Lake managers and practitioners—those who are interested in and/or responsible for managing and enhancing Utah Lake. However, this ULS is accessible to a broad audience with much of the background information and more technical details included as appendices.

1.3 Previous and Ongoing Studies and Planning Efforts

Utah Lake has been the focus of many past investigations and planning efforts (Table 1-1). Rather than duplicating this work, this ULS builds upon those past efforts and integrates current studies and plans to create a coordinated enhancement framework. Of particular note is the Utah Lake Water Quality Study (ULWQS), an ongoing Utah Division of Water Quality (DWQ) planning effort to develop nitrogen and phosphorus numeric targets that protect the lake's recreational, aquatic life and agricultural-designated beneficial uses. The ULWQS has an extensive stakeholder engagement process, expansive bibliography, and comprehensive dataset spanning water chemistry, nutrient loading, algal blooms, and biological indicators, all of which provide a scientifically rigorous baseline that can inform and accelerate the ULS planning and implementation phases.

Additionally, FFSL is concurrently developing an updated version of the Utah Lake Comprehensive Management Plan, which outlines managing sovereign lands of Utah Lake under the Public Trust Doctrine. Where possible, efforts to develop the ULS and the updated Utah Lake Comprehensive Management Plan have been coordinated.

1.4 Partner Agencies

Implementing the PEF (described in Section 4) will be feasible only through coordination with and support from partner agencies that manage Utah Lake's resources (listed in Table 1-2 and shown on Figure 1-3). For example, the Utah Division of Wildlife Resources (DWR) has management authority over fish and wildlife that inhabit Utah Lake. Consequently, the numerous benefit areas specified in S.B. 270 (also illustrated on Figure 1-1) can be enhanced only through coordination with and support from DWR.

FFSL acknowledges its role as the lead agency with respect to the ULS; however, the ULS requires engagement and coordination with numerous management agencies involved in Utah Lake. Historically, FFSL managed lands under its control for the traditional public trust uses of fishing, navigation, and commerce. S.B. 270 directed the ULS to adopt a broader scope in items (a) through (f). The word "ecological" is used throughout this ULS to encapsulate the broad public interest that exists beyond FFSL's management obligations and is, instead, shared by other State of Utah agencies. The PEF presented in Section 4 was developed to consider both public interests in Utah Lake as well as public trust obligations of FFSL, specifically.

Table 1-1. Previous and Ongoing Studies and Planning Efforts Relevant to the Utah Lake Study

Study or Planning Effort/Authoring Agency	Status	Overview
1992 Interim Water Distribution Plan for the Utah Lake Drainage/DWRI	Complete	The 1992 IWDP sets forth criteria for distributing water in Utah Lake drainage basin and establishes a general framework within which the respective (water) rights can be administered. Distribution guidelines follow the priority doctrine of “first in time, first in right;” and where rights are equal in priority, each of those rights receives a proportional share of the total water available to divert under that priority. This IWDP is intended to be evaluated and modified as necessary into a final distribution order, which has yet to be issued.
June Sucker Recovery Implementation Program	Ongoing	The JSRIP, a multiagency effort, represents a successful working model, engaging local stakeholders—residents, business owners, policy makers, civic leaders, and scientists—in a multifaceted effort to balance water resource needs for humans with species recovery efforts in the lake.
Utah Lake Water Quality Study/DWQ	Ongoing	The goal of the ULWQS is to develop nitrogen and phosphorus targets that protect the lake’s designated beneficial uses. The ULWQS process has involved conducting extensive outreach and numerous research studies to provide new information relevant to the understanding of the lake and developing numeric nutrient targets. The ULWQS includes an implementation plan that identifies the sources of nutrients and the cost and feasibility of reducing nutrients to the lake.
Utah Lake Management Plan/ULA	Complete	The ULA was charged with developing and implementing the ULMP in <i>Utah Administrative Code</i> Section 11-65. The ULMP provides a road map for enhancing the ecological function of the lake and the value it provides to adjacent communities, Utah residents, and visitors to the region.
Development of Utah Lake Solutions/TSSD	Complete	This 4-year field experiment was implemented in partnership with DWQ and FFSL to augment the ULWQS and accelerate the development of realistic, comprehensive, and long-term solutions that reduce the intensity, duration, and frequency of future HABs in the lake. Final reports are in development.
Utah Lake Fisheries Management Plan/DWR	Ongoing	The ULFMP describes the future direction of fishery management at the lake and aims to be a comprehensive fisheries management plan for the lake that encompasses both sportfish management and June sucker (and other native species) recovery. The ULFMP also aims to develop specific goals and objectives to complement and coordinate with other planning efforts on and around the lake.
Utah Lake Recreation Access Plan/ULA	Ongoing	The ULRAP will provide the ULA and other stakeholders with a strategic guide for enhancing recreational access at the lake and evaluate 36 public access points (34 existing and 2 planned) to identify pain points and opportunities for improvement.

DWQ = Utah Division of Water Quality
 DWR = Utah Division of Wildlife Resources
 DWRI = Utah Division of Water Rights
 FFSL = Utah Division of Forestry, Fire, and State Lands
 HAB = harmful algal bloom
 IWDP = Interim Water Distribution Plan
 JSRIP = June Sucker Recovery Implementation Program

TSSD = Timpanogos Special Service District
 ULA = Utah Lake Authority
 ULFMP = Utah Lake Fisheries Management Plan
 ULMP = Utah Lake Management Plan
 ULRAP = Utah Lake Recreation Access Plan
 ULWQS = Utah Lake Water Quality Study



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Table 1-2. Summary of Partner Agency Roles and Responsibilities in Utah Lake Enhancement

Agency	Primary Responsibilities	Key Contributions to Utah Lake
FFSL	Manages sovereign lands and updates the Utah Lake Comprehensive Management Plan	Provides habitat restoration, invasive species control (for example, <i>Phragmites</i>), and lakebed management and stewardship
DOR	Supports recreation through grants and programs	Manages off-highway vehicle and boating programs and collaborates on lake projects
DSP	Operates Utah Lake State Park	Provides recreational infrastructure (for example, boat ramps and campgrounds)
DWR	Manages wildlife and waterfowl management areas	Provides habitat conservation, manages fish and wildlife, and regulates recreational access
DWRi	Administers measurement, appropriation, apportionment, and distribution of waters entering, being stored in, and leaving the lake	Verifies water rights associated with the lake are honored in priority in terms of receiving water from upstream sources and in regulating withdrawals of water from the lake
DWQ	Enforces water quality standards and monitors and reports on water quality conditions	Manages water quality to meet beneficial uses; addresses nutrient pollution and HABs; develops total maximum daily loads, issues permits for surface and stormwater discharges, and coordinates voluntary incentive based approaches to address nonpoint sources
JSRIP	Oversees multiagency fish recovery initiative	Works to restore the population of and reduce nonnative pressure on June sucker through large-scale carp removal and restores spawning habitats (for example, Hobble Creek and Provo River Delta)
DHHS and LHDs	Issue health advisories and monitor public health risks	Respond to HABs and provide EPA-based guidance based on EPA standards
PRWUA	Manages Provo River Project and participates as stakeholder in JSRIP	Delivers water for agriculture and municipal use and supports habitat restoration
ULA	Focuses on the lake's ecosystem, community, and recreation; manages the lake with its partners; and assists other involved parties involved by coordinating the efforts of all applicable state and local government entities, property owners, water rights owners, and other private parties, and other stakeholders, who together develop and implement a lake management plan that includes environmental sustainability, in conjunction with DEQ and DWR	Facilitates multiagency collaboration and assumes some management roles from FFSL
ULWUA	Operates lake outlet infrastructure and comprises major water districts and users	Manages water rights and flow
URMCC	Manages ULWP with DWR	Mitigates impacts from the Central Utah Project and supports recreation and conservation

DEQ = Utah Department of Environmental Quality
 DHHS = Utah Department of Health and Human Services
 DOR = Utah Division of Outdoor Recreation
 DSP = Utah Division of State Parks
 DWQ = Utah Division of Water Quality
 DWR = Utah Division of Wildlife Resources

DWRi = Utah Division of Water Rights
 EPA = U.S. Environmental Protection Agency
 FFSL = Utah Division of Forestry, Fire and State Land
 HAB = harmful algal bloom
 JSRIP = June Sucker Recovery Implementation Program
 LHD = local health department

PRWUA = Provo River Water Users Association
 ULA = Utah Lake Authority
 ULWP = Utah Lake Wetland Preserve
 ULWUA = Utah Lake Water Users Association
 URMCC = Utah Reclamation Mitigation and Conservation Commission

Figure 1-3. Partner Agency Roles and Responsibilities in Utah Lake Enhancement



DHHS = Utah Department of Health and Human Services
 DNR = Utah Department of Natural Resources
 DOR = Utah Division of Outdoor Recreation
 DWQ = Utah Division of Water Quality
 DWR = Utah Division of Wildlife Resources
 EPA = U.S. Environmental Protection Agency
 FFSL = Utah Division of Forestry, Fire and State Land
 HAB = harmful algal bloom
 JSRIP = June Sucker Recovery Implementation Program
 LHD = local health department
 PRWUA = Provo River Water Users Association
 ULA = Utah Lake Authority
 ULWUA = Utah Lake Water Users Association
 URMCC = Utah Reclamation Mitigation and Conservation Commission

2. Key Findings of the Review of Existing Information

The Review of Existing Information Report (REIR), provided in Appendix A, compiles and analyzes Utah Lake management plans, scientific studies, reports, and other relevant data. The REIR provides an overview of current knowledge related to each benefit area identified in S.B. 270, highlights key findings on existing conditions, and identifies critical information needs must be addressed to develop effective enhancements. This section summarizes REIR key findings to support developing opportunities for improving conditions at Utah Lake.

2.1 Current Conditions and Primary Stressors

Utah Lake's ecosystem is highly interconnected, meaning that changes or stressors in one benefit area often affect others. The benefit areas identified in S.B. 270, such as water quality, habitat, and recreation, do not function independently; they are linked through overlapping ecological processes. For example, bioturbation from carp impacts the abundance and health of SAV, which result in unstable lake sediments and increased water turbidity, impacting lake water clarity and quality, recreational opportunities, and public perceptions. Figure 2-1 provides a high-level overview of these ecological interconnections, underscoring the need for enhancements to address the system as a whole.

Table 2-1 organizes key findings from the REIR by the benefit areas defined in S.B. 270. For each area, current conditions are summarized and main stressors and impacts identified; this table serves as a central reference to help focus management and enhancement efforts where they are most needed. The benefit areas identified in S.B. 270 are influenced by the following primary stressors:

- Habitat degradation and bioturbation caused by invasive carp and other benthic fish species
- Sediment resuspension resulting from unstable sediments and wind-driven wave action
- High external nutrient inputs
- Significant and unnatural fluctuations in water levels

Because FFSL does not have the authority to manage lake levels, this ULS directly focuses on the first three stressors within FFSL's scope of influence and that align with the enhancement of benefit areas as defined in S.B. 270. With respect to water-level fluctuations, water management practices are not expected to change in the short term, and fluctuating water levels are expected to remain a stressor that will need to be mitigated. Water-level fluctuations, specifically the magnitude and rate of change, as well as the duration of dry and inundated periods along the shoreline, directly impact the restoration and ecological function of the littoral zone (the nearshore area of the lake where light penetration reaches the bottom of the lake to support benthic vegetation), a critical area for lake health. Therefore, the ULS focuses on mitigating the effects of fluctuating water levels.

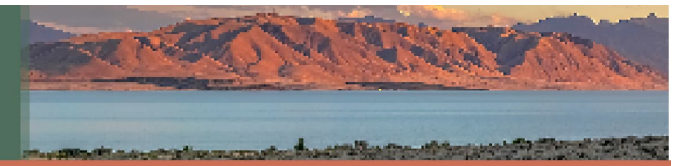
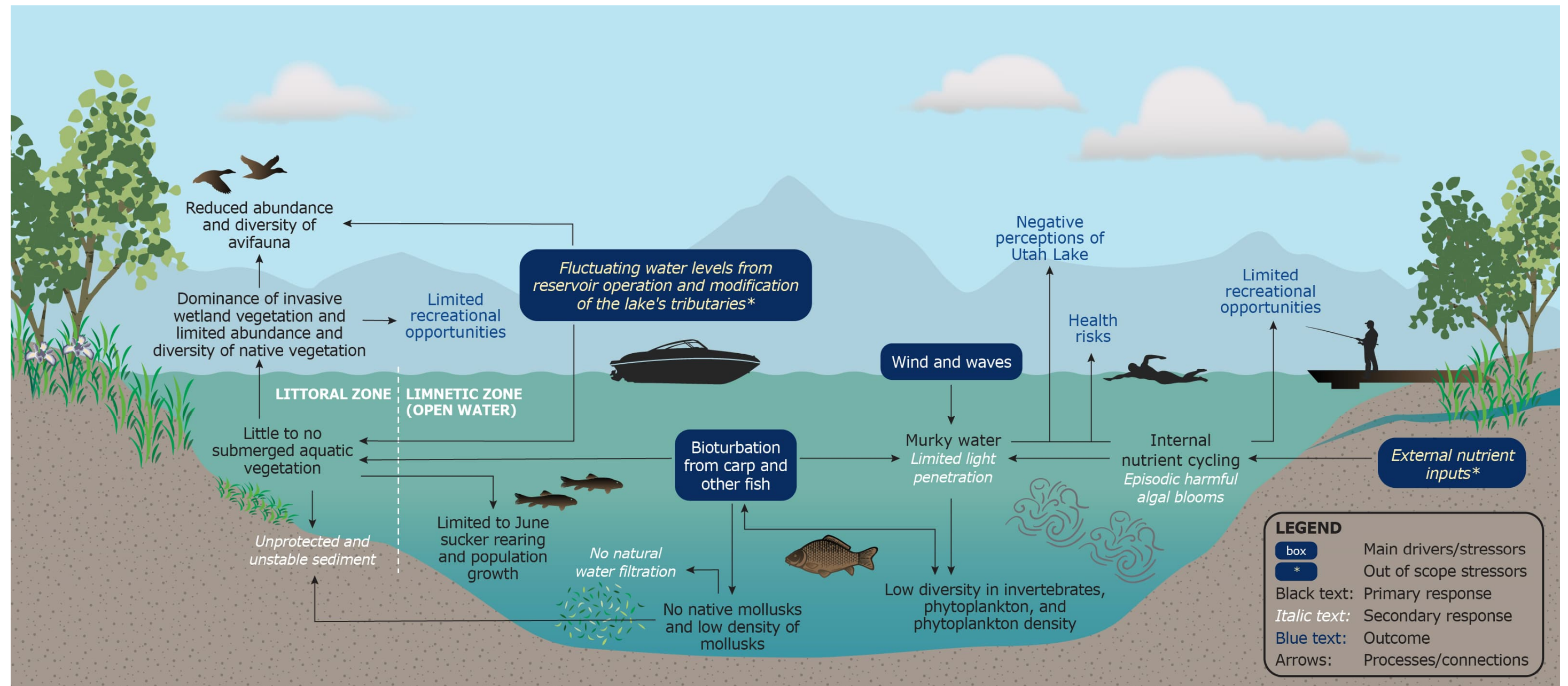


Figure 2-1. Utah Lake Main Stressors, Benefit Areas, and Responses



Note: Utah Lake's ecosystem is complex, with interconnected processes affecting various S.B. 270 benefit areas. This illustration does not depict every detail of the lake's ecosystem or its complexity; rather, it shows the benefit areas to be enhanced under S.B. 270 and the main (high-level) processes that affect them.



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Table 2-1. Key Findings and Current Conditions with Respect to the Main Stressors for Each Benefit Area

Senate Bill 270 Benefit Area	Key Findings Related to the Current Condition of Each Benefit Area	Current Condition of Each Benefit Area with Respect to Main Stressors
a. Improving the clarity and quality of the water in Utah Lake	▪ Today, Utah Lake has low water clarity, which is attributed to sediment resuspension and phytoplankton growth. Sediment resuspension makes up most of the turbidity (approximately 75 percent) and is driven mainly by wind and wave action and exacerbated by excessive disturbance of lake sediments by common carp. However, current algal growth is also sufficient to limit attainment of water clarity goals, and a reduction in mineral turbidity without a reduction in nutrients to reduce algal growth may not result in achieving water clarity goals. Phytoplankton growth is driven by excess nutrient loading, which is composed of external and internal nutrient loading. ▪ Empirical analysis of monitoring data and small-scale experiments in Utah Lake, as well as literature evidence from other lakes, indicate that nutrient reductions are needed to reduce algal growth in Utah Lake, but lag time associated with nutrient recovery is possible because of the time it will take for the sediments to reach a new equilibrium. However, in addition to nutrient reductions, rehabilitation of ecosystem structure (for example, restoration of benthic macrophytes, stabilization of benthic sediments) has been shown to be very important to improving water quality in other lakes. ▪ To achieve a clearer water state of a macrophyte-dominated system, several aspects of Utah Lake will need to be managed, including, but not limited to, nutrient loading, sediment resuspension, carp removal, and macrophyte recovery. ▪ Multiple forms of nutrient management are available, including external loading reductions, chemical treatments, dredging, ecosystem structure recovery, and top-down food web management. However, reduction of external loading is likely to be the most successful nutrient management activity over the long term in Utah Lake, and the ULWQS is planning for the implementation of external nutrient load management.	Poor water quality and water clarity due to external nutrient inputs , carp bioturbation, a lack of benthic vegetation (from lake-level fluctuations, turbidity, and carp bioturbation), and suspended sediments (from wind, waves, and unstable benthic sediments).
b. Conserving water resources in and around Utah Lake	▪ Utah Lake has been managed as a storage reservoir since the mid-1800s, with a complex system of water rights established over time. ▪ The lake's maximum elevation was initially set at 4,516 feet above sea level in 1885. However, because of flooding in the 1980s, the maximum elevation was revised to 4,489 feet above sea level (compromise elevation), with a storage capacity of about 870,000 acre-feet at this level. ▪ Over the past 30 years, Utah Lake's elevation has fluctuated by an average of 3.3 feet annually, with a maximum difference of about 7 feet recorded in 2004. The timing and the rate of change in water levels do not reflect typical natural patterns, and the decline through summer months is extremely fast. ▪ Providing strategies to support watershed management decisions, surface or groundwater inflow management decisions, water conservation or supply management decisions, or reservoir storage operations is not within FFSL's jurisdictional authority; these responsibilities belong to other local, state, and federal government entities. ▪ As part of the ULS, FFSL "shall respect the need to preserve water rights and interests related to water collection, storage, or delivery and projects for water collection, storage, or delivery associated with Utah Lake" (S.B. 270 lines 60 through 63). ▪ The lake has several operational challenges, including high evaporation rates, degraded water quality, and a nonnatural hydrograph because of upstream flow controls and reservoir operations.	Variable water levels of Utah Lake are a direct result of water storage management for water rights. Water rights distribution is a tool that could potentially be utilized in water resource conservation.



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Senate Bill 270 Benefit Area	Key Findings Related to the Current Condition of Each Benefit Area	Current Condition of Each Benefit Area with Respect to Main Stressors
c. Removing invasive plant and animal species	- Common carp make up 70 to 90 percent of fish biomass in Utah Lake, as suggested by net surveys conducted in the last 2 decades. - Carp biomass in Utah Lake appears to range between 400 and 600 kg/ha, as estimated by a carp population model (Walsworth et al. 2024), and exceeds the ecologically acceptable threshold of 100 kg/ha by four to six times (the 100 kg/ha threshold was identified in other lakes in North America but might also apply to Utah Lake). This abundance appears to be a major driver of water quality degradation in the lake. - Mechanical carp removal was tested from 2009 to 2023 using seine nets. Removal rates were relatively modest at 35 to 47 kg/ha per year (less than 10 percent of the estimated starting biomass). Nevertheless, model-predicted carp biomass declined from 550 kg/ha in 2009 to 200 kg/ha in 2019 as a result of systematic removal. However, the population then rebounded to 400 kg/ha by 2023 because of increased young carp production and reduced removal rates. - Production of young carp (recruitment) increases during high water years and following adult carp removal. Overall recruitment rates observed to date appear to be lower than in other systems, potentially because of the high abundance of small predatory fish in Utah Lake. - The current carp population model predicts that carp population is dominated by young individuals (ages 0 to 4), whereas empirical data suggest individuals age 5 and older dominate the population; this discrepancy suggests key data gaps in field data or model parameter estimates. Methods previously used to estimate the age of carp may have been underestimating the age of individual fish. - Using methods currently available, carp management would need to occur on an annual basis to continuously suppress the population. - Carp management efforts employed to date have been relatively constrained in scope and methodology in relation to the size and scale of Utah Lake. IPM strategies that employ multiple tools that target specific weaknesses in carp life history should be considered for Utah Lake (for example, telemetry-guided seines to target winter carp aggregations; automated box nets to target bait-induced summer aggregations; native fish biocontrol of carp eggs, larvae, and fry; and others). Management tools that can effectively target all year classes of carp in different types of habitats would likely accelerate carp management. <i>Phragmites australis</i> subspecies <i>australis</i> (common reed) became established at Utah Lake in or around the 1980s and has since expanded and colonized over 75 miles of Utah Lake shoreline, eliminating or significantly reducing diverse native vegetation, ecosystem function, and societal benefits. Impacts of <i>Phragmites</i> around Utah Lake include the following: - Reduced plant diversity - Reduced quantity and quality of bird, fish, and wildlife habitat - Increased evapotranspiration - Increased fire danger - Reduced recreational access - FFSL and other regional partners have been actively managing large-scale <i>Phragmites</i> infestations at Utah Lake since 2014, when a major collaborative effort to mitigate invasive vegetation along the shores of Utah Lake began. The methodology for controlling and removing <i>Phragmites</i> has been refined over the years, and <i>Phragmites</i> cover on Utah Lake has been reduced by approximately 70 percent. The goal is to maintain <i>Phragmites</i> cover at less than 20 percent across treated areas (FFSL n.d.). This involves regular monitoring and adaptive management, expanding treatment to adjacent upstream locations, and smaller-scale control methods (spot spraying and boat and boom application) to confirm the effectiveness of control measures. - Despite removal efforts, <i>Phragmites</i> remains relatively common around Utah Lake and continues to impact the ecosystem and recreation. - Native plant revegetation and management should be prioritized and expanded along with <i>Phragmites</i> treatments to restore vegetative communities and prevent reinvasion of invasives plants. - Ongoing collaboration with local communities, stakeholders, and volunteers is needed to support control efforts and promote awareness about the importance of managing invasive species (Farmonaut 2025).	Invasive species predominate Utah Lake (carp and <i>Phragmites</i>) due to habitat modification and disturbance from excessive nutrient inputs, and water-level fluctuations). A collaborative effort between FFSL, ULA, and Utah County has dramatically reduced the abundance of <i>Phragmites</i> around the lake. Invasive species will require long-term management.



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Senate Bill 270 Benefit Area	Key Findings Related to the Current Condition of Each Benefit Area	Current Condition of Each Benefit Area with Respect to Main Stressors
d. Restoring and improving littoral zone and other plant communities in and around Utah Lake	- Restoring native vegetation communities in and around Utah Lake is one of the cornerstones of returning the lake to a functioning ecosystem. Lakeshore vegetation (including wetlands [WM and EV], SAV, and riparian) supports many valuable aspects of lake ecosystems, including foraging areas for birds, rearing grounds for fish, nutrient cycling, carbon storage, and aesthetic and recreational aspects (clear water and reduced HABs). Yet, the native vegetation (including wetlands [WM and EV] and SAV) of Utah Lake has been lost or heavily impacted by invasive species (<i>Phragmites</i> and carp), human impacts, and land and water management objectives. - In the past 100 years, Utah Lake native emergent or lakeshore communities have been largely lost and replaced by invasive monocultures of <i>Phragmites</i>, and restoration of these emergent communities is greatly constrained or eliminated by Utah Lake fluctuating water levels. SAV communities are extremely reduced or eliminated due to the bioturbation from carp disturbance. Restoration of native plant communities can improve ecosystem function and diversity and provide a positive feedback loop for numerous ecosystem elements, including wildlife habitat and water quality conditions. - SAV growth is currently limited by poor water clarity in Utah Lake, driven by sediment resuspension (from wind and waves and carp bioturbation) and phytoplankton growth. - Reestablishing native plant communities in Utah Lake could provide opportunities to improve and support related ecosystem functions, including the following: - Wildlife habitat (that is, shorebird nesting and general habitat) - Native fish conservation (including Bonneville cutthroat trout and June sucker, which use native vegetation as nursery habitat) - Water quality (that is, sediment stabilization and transferring primary production from the water column to the benthos, nutrient reduction in the water column, suspended sediment reduction, and HAB reduction) - Littoral zone restoration (that is, sediment stabilization, reduced shear stress from wind and wave action and water circulation, and turbidity reduction)	Poor condition. Very little aquatic vegetation is present in the littoral zone due to carp , water-level fluctuations , and excessive turbidity (resulting from carp , nutrients , water-level fluctuations , and wind and waves).
e. Restoring and conserving native fish and other aquatic species in Utah Lake, including Bonneville cutthroat trout and June Sucker	- Utah Lake native fish species and other native aquatic organisms (for example, mollusks and amphibians) have drastically declined due to habitat loss, water diversion, pollution, and invasive species introduction. - Nonnative fish, especially common carp and piscivorous species like northern pike and white bass may impact June suckers and other native species (including zooplankton) through habitat degradation, predation, and possibly competition. - Conservation efforts have increased June sucker populations from hundreds to an estimated 30,000 to 50,000 individuals, which can be attributed to stocking programs, habitat restoration, and management programs like the JSRIP. Despite population increases, low juvenile June sucker recruitment is a critical bottleneck, primarily because of predation by nonnative piscivores and a lack of quality rearing habitat. Systemic improvements to spawning and rearing habitats, water quality, and lake stabilization will be critical for supporting native species recovery. The bottleneck in June sucker recovery is the successful recruitment of juveniles following spawning in the Provo River. - The restoration of the Bonneville cutthroat trout in Utah Lake is not a near-term priority because water quality and habitat conditions are not suitable for their survival. - Native unionid mussels, historically vital for water filtration and sediment stabilization, are extirpated from Utah Lake and replaced by invasive <i>Corbicula</i>, which present a major long-term threat to ecosystem. - Restoration and monitoring efforts, specifically additional tributary restoration projects (for example, Hobble Creek, Spanish Fork River, and American Fork River), must be prioritized for long-term species recovery.	Poor condition. The native species population is small. Few native aquatic species remain because of degraded water quality (from carp , nutrients , and water-level fluctuations); competition with, predation by, or displacement by invasive species; and habitat modification (from water-level fluctuations , invasive species, and degraded water quality).
f. Increasing the suitability of Utah Lake and its surrounding areas for shore birds, waterfowl, and other avian species	- Utah Lake historically supported a rich and diverse bird community, but recent declines in diversity and abundance are evident. - Fluctuating water levels, invasive species, pollution, and the effects of climate change have fragmented and degraded habitat. - Monitoring and scientific information of bird populations and habitat use in Utah Lake is limited. - A multifaceted approach, including increasing monitoring efforts, addressing stressors, improving habitat suitability, and incorporating monitoring and research, is needed to support and restore bird populations at Utah Lake. - More natural patterns in lake water levels, restoration of native vegetation, and improvements in water quality will benefit shorebirds, waterfowl, and other avian species at Utah Lake.	Monitoring data on avian abundance and diversity is lacking; habitat loss and degradation has occurred as a result of water-level management , degraded water quality (from carp , nutrients , and water-level fluctuations), and the dominance of invasive species and loss of native habitat communities and habitats.



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Senate Bill 270 Benefit Area	Key Findings Related to the Current Condition of Each Benefit Area	Current Condition of Each Benefit Area with Respect to Main Stressors
g. Maximizing, enhancing, and ensuring recreational access and opportunities on Utah Lake	- Current conditions: Detailed visitation data and recreation dynamics are currently limited, but efforts are underway to collect this information as part of the ULRAP (estimated completion date of 2025). - Management approach: Utah Lake recreation access points are managed by multiple stakeholders using a bottom-up (as opposed to top-down) approach, meaning various stakeholders and partners work together to make improvements at each access point. This approach has both advantages (alignment with local priorities and adaptability to site-specific challenges) and disadvantages (resource disparity and inconsistent standards). Lakeshore municipalities have diverse visions for recreational improvements, generally aligning with current land use patterns. - Challenges: Key challenges include jurisdictional confusion, lack of clarity on approval processes, unequal resource distribution, and lack of a dedicated funding source for recreational improvements. - Planning: The ULMP (ULA 2024) outlines the goals, objectives, and strategies that support ULA's vision of world-class recreation at Utah Lake. Since the ULMP's inception, ULA has demonstrated considerable progress, particularly in executing the short-term strategies. The ULA has been diligent in adhering to the implementation schedule set forth in the ULMP, indicating a strong commitment to realizing their vision for enhanced recreation at Utah Lake. - Opportunities: Successful implementation will depend on a delicate balance between respecting local autonomy, coordinating across jurisdictions, and aligning visions into a cohesive strategy for the lake's recreational future. ULA is dedicated to finding this balance by leading cooperative efforts to implement short-, mid-, and long-term strategies in the ULMP (ULA 2024).	Utah Lake is not fully meeting its potential as a recreational resource because of degraded water quality (due to carp , nutrients , a lack of benthic vegetation, and water-level fluctuations); invasive vegetation along the shoreline; and limited recreational access points, facilities, and opportunities.
h. Otherwise improving the use of Utah Lake for residents and visitor i. Substantially accommodating an existing use on land in or around Utah Lake	- A 2-mile buffer around the Utah Lake boundary reveals a complex mosaic of land ownership that includes state sovereign lands (within the lake boundary), state trust lands, wildlife management areas, Utah Department of Transportation lands, federal lands (managed by the Bureau of Land Management, the Bureau of Reclamation, and the U.S. Forest Service), and private lands. Some municipal boundaries extend into sovereign lands. - Zoning data collected from Utah County and individual municipalities show distinct patterns. The northern half of Utah Lake is zoned for higher-density urban development, whereas the southern half is primarily zoned for agricultural or mixed residential-agricultural use. - Land cover data from the National Land Cover Database closely mirror zoning patterns. The northern region of the lake is characterized by developed land, whereas the southern region remains largely open space and agricultural land. - Hydrologically connected wetlands surrounding Utah Lake play a critical role in maintaining the lake's ecological health by improving water quality, stabilizing shorelines, mitigating floods, supporting biodiversity, and sustaining groundwater levels. Agricultural lands near Utah Lake can, under certain conditions, function as hydrologically connected wetlands, contributing to the lake's ecological health.	Utah Lake faces challenges with respect to appreciation and utilization of the lake because of degraded water quality (due to carp , nutrients , wind and wave action and unprotected sediments, and water-level fluctuations). Adjacent land areas are negatively affected by fluctuating water levels and invasive vegetation.

EV = emergent vegetation
FFSL = Utah Division of Forestry, Fires and State Lands
HAB = harmful algal bloom
IPM = integrated pest management
JSRIP = June Sucker Recovery Implementation Program
kg/ha = kilograms per hectare
S.B. = Senate Bill
SAV = submerged aquatic vegetation
ULA = Utah Lake Authority
ULMP = Utah Lake Management Plan
ULRAP = Utah Lake Recreation Access Plan
ULS = Utah Lake Study
ULWQS = Utah Lake Water Quality Study
WM = wet meadow

2.2 Information Needs

The REIR (provided in Appendix A) summarizes current knowledge regarding Utah Lake and shallow lake restoration practices and identifies a set of critical information needs to guide the development of strategies aimed at enhancing the various benefit areas of Utah Lake (these needs are summarized in Table 2-2). The needs will be addressed through the various components of the PEF, as detailed in Section 4; addressing these needs is essential for achieving the improved lake conditions outlined in S.B. 270, as they directly support efforts to mitigate the lake's primary stressors.

The scope and complexity of these information needs range from straightforward tasks that can be completed during the ULS project timeline to more complex challenges that will require small-scale implementation to assess effectiveness and track progress. Regardless of complexity, all necessary data should be generated through the PEF over the next approximately 10 to 15 years.

2.3 Need for a Unified Lake Recovery and Management Framework

As identified in Section 2.1, Utah Lake has four primary stressors: invasive carp, wind- and wave-driven sediment resuspension, excessive nutrient inputs, and significant and unnatural fluctuations in lake water level (Figure 2-1). These stressors must be managed in parallel, because no single strategy can effectively address them alone. A successful recovery effort requires a comprehensive, phased, and multifaceted approach that reflects the complexity of the lake system that will support lasting improvements.

To guide targeted management actions by FFSL and its partners, this ULS introduces the concept of *management tracks*, which are distinct focus areas for implementing interventions that address these stressors and improve overall lake conditions. Following are the PEF's four management tracks and their objectives:

- Invasive carp control: Reduce carp populations to mitigate habitat degradation and sediment disturbance, improving overall ecosystem health.
- Habitat enhancement and sediment management: Stabilize sediments and reduce turbidity by restoring littoral zone vegetation, thereby enhancing aquatic habitat quality.
- External nutrient management: Reduce external nutrient inputs, support DWQ's development and implementation of nutrient targets to reduce nutrient pollution.
- Human use enhancement: Enhance the recreational and aesthetic value of Utah Lake and its surrounding land uses for residents and visitors through collaboration with partners and stakeholders (supporting benefit areas [g], [h], and [i], identified in S.B. 270).



Table 2-2. Information Needs Identified During the Review of Existing Information

Benefit Area	Information Need	Management Track	Complete?	Phase to Be Completed
a, d, e, f, g, h	Identification of potential treatments or methods for stabilizing benthic sediments.	Habitat enhancement and sediment management	No	2
a, d, e, f, g, h	Hydrodynamic modeling of Utah Lake to identify key areas where sediment resuspension and transport occur and identification of which locations should be prioritized for revegetation and habitat enhancement efforts.	Habitat enhancement and sediment management	Yes	1
a, d, e, f, g, h	Hydrodynamic modeling of Utah Lake to evaluate potential effects of innovative technologies or treatments that could effectively mitigate sediment resuspension and transport.	Habitat enhancement and sediment management	No	2
a, d, e, f, g, h	Development of nutrient targets and ecologically relevant nutrient loads for Utah Lake to support designated beneficial uses (currently under development through ULWQS). To what external nutrient load (and subsequent nutrient concentrations) will be required to revert Utah Lake to a clear-water state remains unclear.	External nutrient management	No	2
a, d, e, f, g, h	Identification of the threshold density of carp in Utah Lake at which impacts to the lake ecosystem (such as turbidity and benthic vegetation) are diminished.	Invasive carp control	No	1
c	Development of a lake-wide monitoring program to provide standardized and accurate estimates of carp biomass and abundance in Utah Lake.	Invasive carp control	No	1
c	Identification of key weaknesses in carp life history and development of tools to target them using an IPM strategy, as follows: - Assess the importance of carp biocontrol processes in Utah Lake. - Determine whether carp form winter, spawning, and summer aggregations. - Test removal of winter, spring, and summer aggregations, emphasizing scaled-up and automated technologies.	Invasive carp control	No	1
c	Identification of the main driver for the discrepancy between the observed carp population age structure (primarily older carp) and the structure predicted by the model (primarily young carp).	Invasive carp control	Yes	1
c	Exploration of the economic aspects of carp removal and biomass use.	Invasive carp control	No	1
c	Engagement with leaders on genetic technologies for invasive fish management.	Invasive carp control	No	1
c	Application of a carp IPM program on an increasing scale.	Invasive carp control	No	2



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Benefit Area	Information Need	Management Track	Complete?	Phase to Be Completed
c, d, f	Invasive vegetation mapping in and around Utah Lake, including higher up in the watershed to identify seed sources.	Habitat enhancement and sediment management	No	2
d, f	Identification of which active revegetation methods are most successful in reestablishing native plant communities following <i>Phragmites</i> treatments, planting, and/or seeding efforts.	Habitat enhancement and sediment management	No	2
c, d	Identification of the most efficient methods for breaking down mats of dead <i>Phragmites</i> that remain following treatments.	Habitat enhancement and sediment management	No	2
d	Identification (mapping) of areas with high potential for native plant community restoration.	Habitat enhancement and sediment management	Yes	1
a, d, e, f	A native vegetation restoration manual that provides a priority list of restoration species (WM, EV, and SAV) appropriate for different landscape positions, inundation depths, and durations given constraints of significant and unpredictable water-level changes.	Habitat enhancement and sediment management	Yes	1
a, d, e, f	Knowledge of environmental tolerances and methods for controlled propagation of SAV species.	Habitat enhancement and sediment management	No	2
a, d, e, f	Adaptive restoration efforts to restore SAV while controlling specific variables, such as carp exclusion.	Habitat enhancement and sediment management	No	2
a, d, e, f	Greater knowledge of the existing seedbank around Utah Lake, including an inventory of species that are present.	Habitat enhancement and sediment management	No	2
a, d, e, f	Improved seeding methods to improve the success of native vegetation seeding efforts.	Habitat enhancement and sediment management	No	2
e	Detailed knowledge of June sucker recruitment and knowledge of their movement throughout the lake at different life stages (juvenile and adult).	Habitat enhancement and sediment management	No	2
e	Improved knowledge of June sucker spawning and recruitment limitations to inform adaptive management of the Provo River Delta Restoration Project and other areas to increase recruitment.	Habitat enhancement and sediment management	No	2
a, c, e	Improved knowledge of the diets of the various fish species (who is eating what?) in the lake, which will inform fisheries management efforts, specifically the efforts to improve June sucker populations and to reduce carp.	Habitat enhancement and sediment management	No	2
e	Survey information for the presence of Columbia spotted frog and available habitat in and around Utah Lake.	Habitat enhancement and sediment management	No	2
a, d, e, f	Feasibility analysis of the potential to restore native unionid mussels to Utah Lake.	Habitat enhancement and sediment management	No	2



UTAH LAKE STUDY



Benefit Area	Information Need	Management Track	Complete?	Phase to Be Completed
f	Expanded bird monitoring programs to understand avian use of Utah Lake, including habitat use patterns, nesting sites, foraging areas, migratory stopovers, and food web dynamics. How changes in fish and invertebrate populations affect bird usage of Utah Lake is unclear.	Habitat enhancement and sediment management	No	2
f	Improved understanding of Utah Lake avian habitat needs, including water depth requirements and the effects of different stressors (such as invasive species, water quality degradation, and habitat alteration).	Habitat enhancement and sediment management	No	2
f	Understanding of the effects of restoration efforts (such as reintroduction of native plants and animals) on improving habitat quality for birds.	Habitat enhancement and sediment management	No	2
f	Understanding of contaminants' presence and effects on different bird species and the lake ecosystem (benthic sediments, plants, and other organisms).	Habitat enhancement and sediment management	No	2
g	An economic analysis of Utah Lake's recreational potential. By conducting a comprehensive economic analysis, stakeholders can make informed decisions about the future of Utah Lake so that enhancements improve recreational opportunities and also contribute significantly to the economic well-being of the state, visitors, and residents.	Human use enhancement	No	2
g, h, i	Understanding of the direct and indirect economic contributions to local and state economies from Utah Lake, as well as potential job creation and income generation from increased tourism.	Human use enhancement	Yes	N/A
a, g, h, i	Assessment of the economic value of improved water quality and ecosystem health.	Human use enhancement	No	2
g, h, i	Assessment of long-term economic benefits of environmental conservation efforts.	Human use enhancement	No	2
g, h, i	Understanding of how enhanced recreation at Utah Lake benefit broader regional economy.	Human use enhancement	No	2

EV = emergent vegetation

IPM = integrated pest management

N/A = not applicable

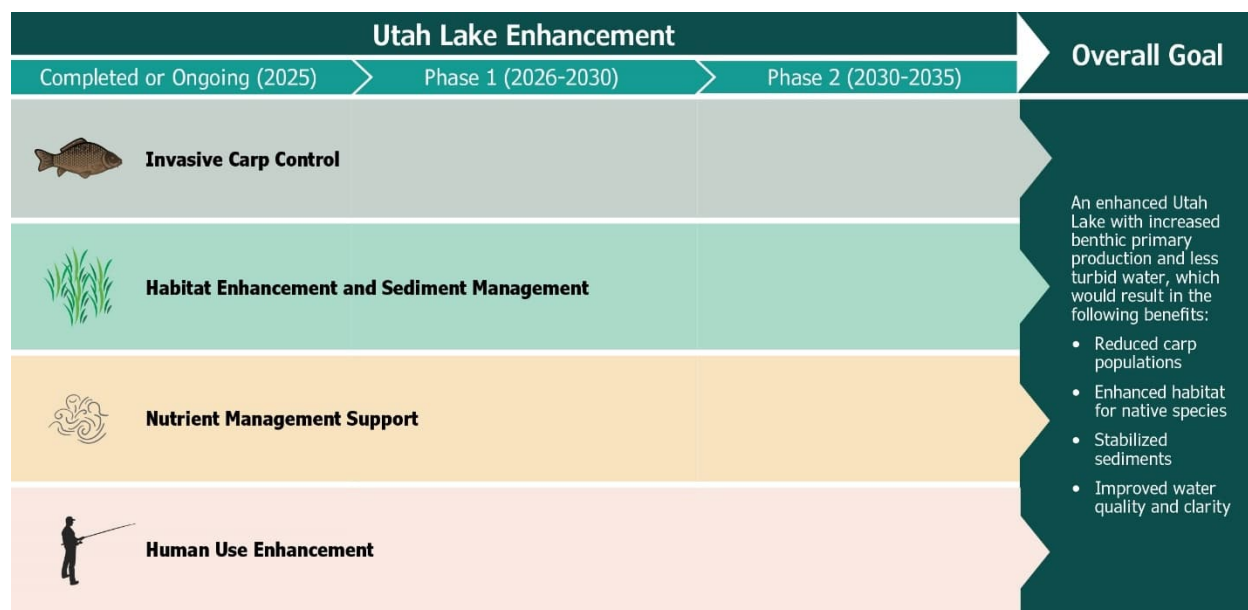
SAV = submerged aquatic vegetation

ULWQS = Utah Lake Water Quality Study

WM = wet meadow

These management tracks form the foundation of the PEF to improve lake conditions. By combining these tracks with a phased implementation strategy, this ULS presents a unified framework for lake recovery and management (Figure 2-2).

Figure 2-2. Phased Enhancement Framework: Four Parallel Management Tracks Supporting a Comprehensive Recovery of Utah Lake



In Sections 3 and 4, the information needs identified in Table 2-2 are discussed in terms of immediate actions (Section 3) and the framework of the PEF (Section 4). These needs range from straightforward tasks completed during the ULS timeline in 2025, to more complex challenges requiring pilot projects. Regardless of complexity, all necessary data should be generated through the PEF over the next 10 to 15 years. By using a phased approach, this framework helps optimize resources, increase the likelihood of success, and reduce unintended consequences. Lessons learned from monitoring Utah Lake’s response to enhancement actions will guide and refine future strategies.

3. Completed or Ongoing Actions Taken during the Utah Lake Study

During the review of existing information, the ULS team identified a series of immediate actions that could be initiated during ULS development and this ULS's preparation. These immediate actions address information needs identified in the REIR (Appendix A) and inform the PEF. Table 3-1 summarizes these actions, and this section discusses them in terms of the PEF's four management tracks. Some of these actions are being carried out by other management agencies but are included herein because they contribute to filling information needs identified by this ULS. Actions led directly by the ULS team are clearly distinguished from those implemented externally.

3.1 Invasive Carp Control

The main agencies working to manage the carp population in Utah Lake are the June Sucker Recovery Implementation Program (JSRIP), DWR, and Utah State University's (USU's) Walsworth Laboratory. Several current and ongoing efforts by these external partners as well as the ULS team will address specific information needs related to carp management.

3.1.1 Current Ongoing Actions by External Partners

The JSRIP and DWR are working with a consultant to experiment with carp removal methods that require less time and labor than methods that have been previously used on Utah Lake. Baited box trapping has been piloted during summer 2024 and summer 2025 to evaluate the effectiveness of the methodology in Utah Lake and explore opportunities for automation. Additionally, the JSRIP is working with USU to investigate the efficacy of large seines on carp catch rates as part of USU's annual ecosystem monitoring effort. A larger seine (similar to what was used historically in the carp removal program) will be tested and compared to catch rates with smaller seines that the USU ecosystem monitoring program has used in the past. The JSRIP has also been implanting passive integrated transmitter tags into carp during the summers of 2024 and 2025 to monitor and better understand their movements throughout Utah Lake, including spring migrations into the Provo River Delta. Preliminary analyses showed a large percentage of the carp tagged in the delta in 2024 returning in 2025 (Franklin, pers. comm. 2025; this work is ongoing).

3.1.2 Completed or Ongoing Actions by the Utah Lake Study Team

Accurate aging of Utah Lake's carp population is essential for developing and evaluating effective management strategies. Currently, age estimates rely on dorsal spines and pectoral fin rays, which have been shown to underestimate the age of older carp and other species (Phelps et al. 2007; Blackwell et al. 2019). To address this limitation, the ULS team proposed a new project to age carp using asterisci otoliths, an approach shown to be accurate across all age classes (Brown et al. 2004) despite potential variability between otolith readers (Yates et al. 2016).

Table 3-1. Summary of Actions Taken as Part of the Utah Lake Study

Management Track	Action	Description	Status
Invasive carp control	Carp Aging Analysis	Aging analysis of carp via both otoliths and dorsal fin spines	In progress, results may not be available until 2026
Habitat enhancement and sediment management	Utah Lake Water-Level Variability Analysis	Analysis of 35 years of elevation data to characterize seasonal patterns of lake elevations including rates of rise and fall	Complete
Habitat enhancement and sediment management	Site Suitability Analysis	Spatial model to identify areas around Utah Lake with the highest potential for successful native plant restoration by evaluating environmental factors and vegetation-specific criteria	Initial draft complete, but further refinement required
Habitat enhancement and sediment management	Compilation of Initial Information for the Revegetation Handbook	Initial compilation of information to guide revegetation efforts such site selection, recommended species, sources of vegetation, propagation techniques, and monitoring methods	Initial compilation complete and included in Appendix D and H
Habitat enhancement and sediment management	Initial Scoping of the Phase 1 Pilot Project at Goose Point	Description and scoping of the initial details for the development of a pilot project to initiate revegetation, turbidity reduction, and habitat enhancement in an approximately 100-acre site	Initial scoping complete (conceptual design in Appendix C)
Habitat enhancement and sediment management	Analysis of Water Clarity and Potential Impacts on Macrophyte Restoration in Utah Lake	Analysis of the relationship between water turbidity in Utah Lake, light availability for SAV, and light requirements for SAV	Complete (Appendix E)
Habitat enhancement and sediment management	Impacts of Wind and Wave Action on Sediment Resuspension	Analysis of wind, wave, and shear stress data to explore the relationship between these variables and identification of locations where shear stress may be modest enough to support SAV revegetation	Complete (Appendix F)

SAV = submerged aquatic vegetation

The new analysis may provide the following key benefits:

- More accurate mortality and recruitment estimates
- More accurate estimate of level of effort needed to manage Utah Lake carp population
- Better matching of annual recruitment spikes with lake history (such as water levels, physical removal) (for example, Bajer and Sorensen 2010)

Potential reconciliation of the apparent discrepancy between model-predicted population data (Utah Lake dominated by young carp) and observed population data (Utah Lake dominated by older carp) (for example, Walsworth et al. 2020, 2024)

During the experimental box trapping efforts from June to September 2025, the ULS team measured, sexed, and aged approximately 200 carp using both asterisci otoliths¹ and dorsal spines to determine the accuracy of age estimates. The objective is to provide the results of the aging analysis to JSRIP/the Walsworth Lab to update the current model parameter estimates and redo key model runs, analyze the results of updated model runs, and examine whether the predicted effectiveness of management scenarios have changed.

While the fish have been collected for analysis, the analyses are not yet complete, and the results may not become available until after the termination of the ULS. Accurate aging analyses have been fundamental in deciphering the histories of carp populations in the Midwest and identifying processes that control carp recruitment spikes and population growth (Bajer and Sorensen 2010). A key immediate action is assigning a project lead(s) who would plan and coordinate various short-term and long-term efforts related to invasive carp control. This would include an assessment of the annual investment needed to achieve biomass targets to give partners an accurate estimate of the level of effort (personnel hours and funding) needed to control carp.

3.2 Habitat Enhancement and Sediment Management

The habitat enhancement and sediment management track focuses on stabilizing sediments and reducing turbidity, primarily through the restoration of littoral zone vegetation. Native plant communities, such as emergent vegetation (EV) and SAV, are essential to Utah Lake's ecological health. They improve water clarity, stabilize sediments, support wildlife, and resist invasive species. However, their recovery is challenged by invasive *Phragmites*, carp disturbance, fluctuating water levels, high turbidity, unstable sediments, and nutrient-driven phytoplankton growth.

Reestablishing these vegetation communities will help reduce sediment resuspension, enhance recreational opportunities, and improve habitat for native species. To guide these efforts, several key questions remain (see Table 2-2). The following questions, derived from that table, inform immediate actions taken by the ULS team and external partners:

- Where are the key areas in Utah Lake where sediment resuspension and transport occur, and which locations should be prioritized for revegetation and habitat enhancement?

¹ Asterisci otoliths are one of three pairs of otoliths (fish ear bones) found in the head of fish. Thin sections of an otolith reveal a detailed microstructure consisting of bands of opaque and translucent material, sort of like the rings of a tree trunk, that can provide useful information on age, growth rate, and other characteristics.

- Which areas around Utah Lake have the highest potential for successful native plant community restoration?
- What native plant species are best suited for different landscape positions, water depths, and inundation durations, given Utah Lake's variable water levels?

3.2.1 Completed or Ongoing Actions by External Partners

Numerous external partners are researching and testing methods to enhance native plant communities and control invasive species establishment at Utah Lake. Research and land management efforts at Utah Lake have been actively underway for over a decade. Current initiatives lead by partner agencies include the following:

- Management and control of invasive *Phragmites*, completed as a partnership between FFSL, Utah County, Utah Lake Authority (ULA), and others
- Revegetation techniques and guiding principles at Utah Lake, with research and methodology development led by USU, FFSL, and others
- Utah Lake SAV and invasive species interactions, with research and methodology development conducted by USU, PRDRP, and others
- Vegetation response to invasive carp species and wave action, including JSRIP, Timpanogos Special Service District (TSSD), ULA, and others
- Selection of appropriate species for revegetation, species diversity, and planting density, led by USU, FFSL, ULA, and others
- Other critical ecological research areas, including Utah Native Plant Society, Utah Natural Heritage Program, USGS Wetland Program (Utah State's wetland resources), and others
- Utah Lake Wetland Restoration Demonstration Project, led by USU and FFSL to improve lakeshore wetland restoration under hydrologic extremes, with core objectives of assessing native seed bank resilience, monitoring natural plant recolonization, and evaluating active seeding approaches using low- (five species) and high-diversity (approximately 35 species) mixes, and produce tools and data to support restoration under variable water levels and enhance climate resilience, with findings shared through field tours, publications, and stakeholder outreach

While the collective research efforts at Utah Lake are robust and growing, the information generated—ranging from restoration techniques and best management practices to monitoring data, ecological insights, and cost analyses—remains dispersed across agencies, projects, and formats. This fragmentation poses challenges for synthesizing lessons learned, coordinating strategies, and applying findings consistently across restoration initiatives. Establishing mechanisms to consolidate, share, and integrate this knowledge will be critical to maximizing the impact of current and future habitat enhancement efforts under the PEF.

3.2.2 Completed Actions by the Utah Lake Study Team

The following immediate activities were initiated and/or completed as part of the ULS:

- Utah Lake water-level variability analysis: Used Utah Lake water surface elevation data from 1990 to 2025 to quantify, characterize, and visualize patterns and timing of elevation variability to support restoration planning and habitat design.

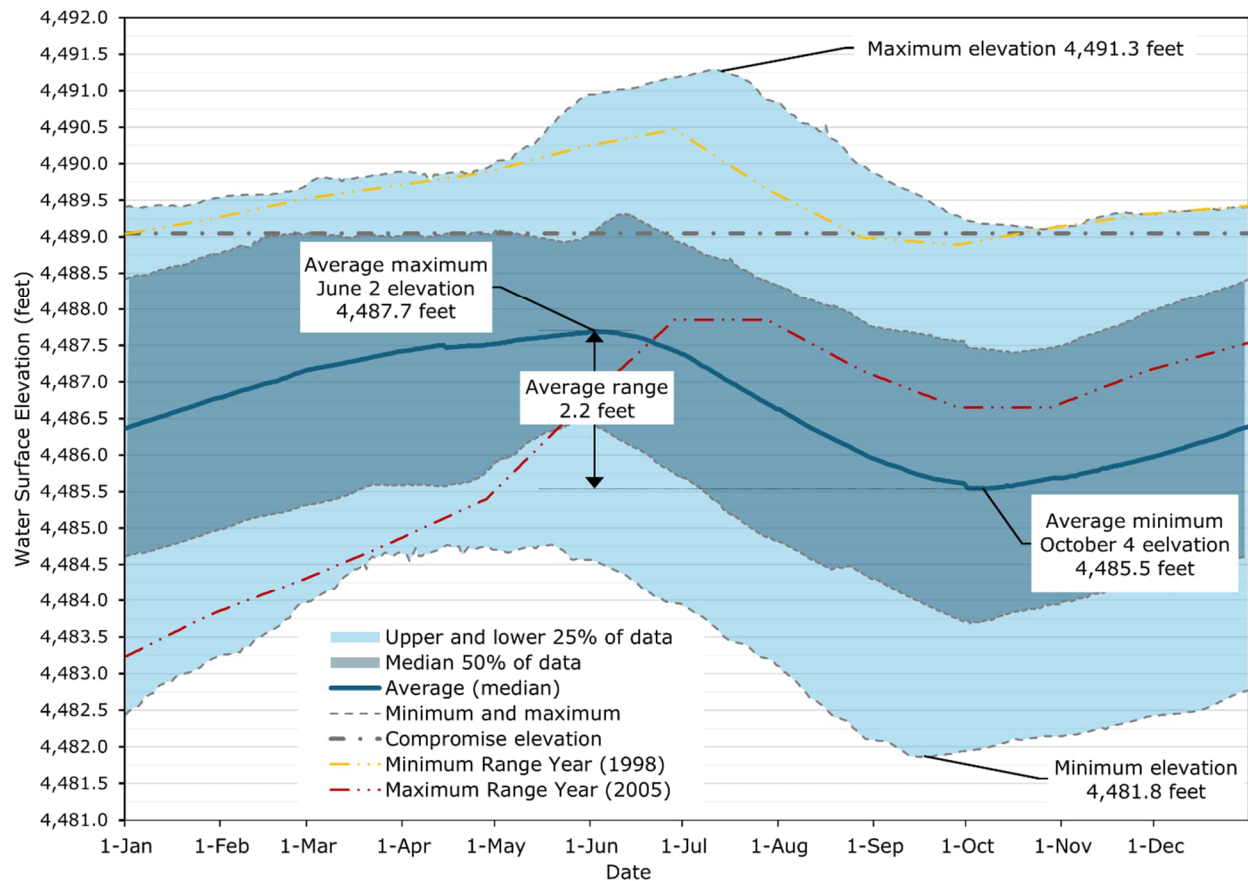
- Hydrodynamic Modeling (Appendix F): Identified key areas of sediment resuspension and transport and determine priority locations for revegetation and habitat enhancement.
- Revegetation site suitability analysis (SSA): Analyzed historical Utah Lake water surface data to select elevations and corresponding areas within Utah Lake that are most likely to meet the preferred depth criteria for the vegetation types included in revegetation efforts.
- Data compilation for proposed Utah Lake Revegetation Handbook: As envisioned in this ULS, a consolidated resource is recommended to address the lack of a comprehensive resource guiding revegetation at Utah Lake. A compilation would consolidate proven approaches, lessons learned, and best practices to support future restoration efforts.

3.2.2.1 Water-Level Variability Analysis

Having more predictable water levels, or even seasonal forecasts, would greatly improve restoration success by allowing managers to select appropriate plant species, time planting efforts effectively, and reduce the risk of vegetation loss due to flooding or drying. This foresight would support better site design, more efficient resource use, and stronger ecological outcomes. Without Utah Lake predictive models, the ULS team conducted a retrospective analysis of water levels for the 1990 to 2024 period of record to inform restoration planning; this period was selected because it reflects the current management regime, including establishment of compromise elevation, and includes the most recent complete water year (2024).

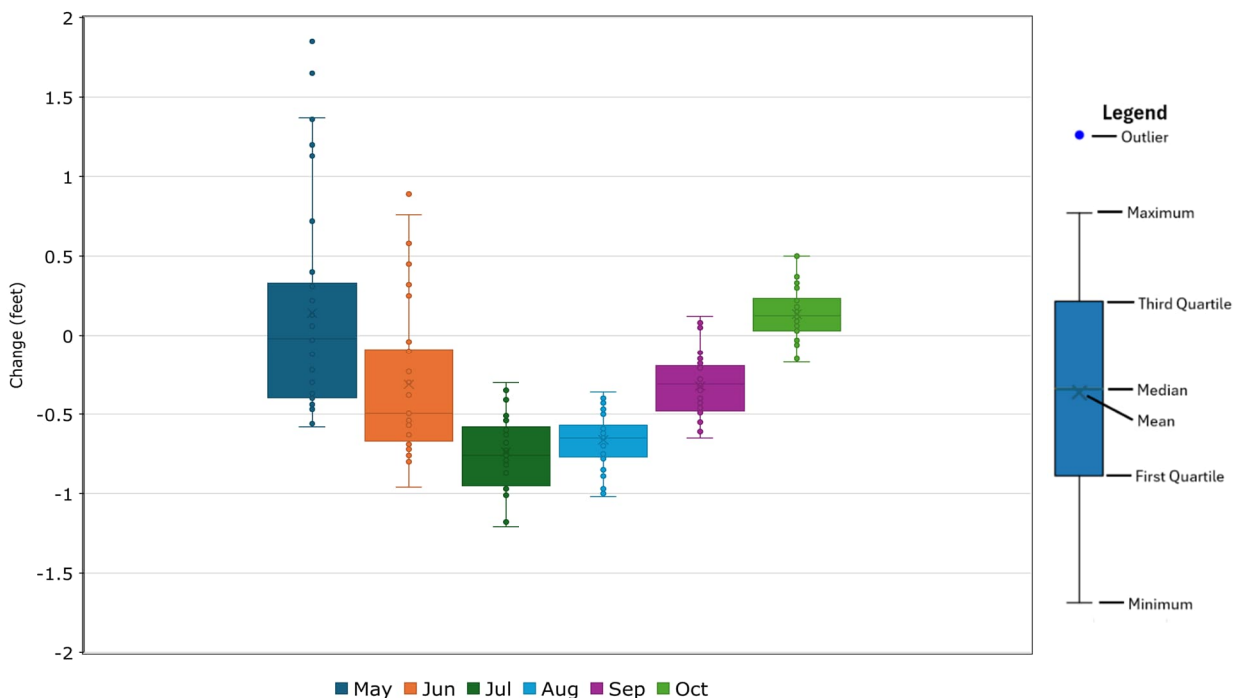
Historical daily water surface elevations were obtained from the Utah Division of Water Resources (DWRe) using records available publicly on their website (DWRe n.d.). The recorded surface elevations during this period ranged from minimum elevation of 4,481.0 feet to a maximum elevation of 4,491.3 feet, with an average elevation of approximately 4,486.5 feet (Figure 3-1). Notably, about 15 percent of the recorded elevations exceeded the compromise elevation of 4,489.0 feet.

Figure 3-1. Annual Average Hydrograph for 1990 to 2024 Period of Record



Seasonal (growing season) trends in lake elevation follow a consistent annual pattern (illustrated on Figure 3-2). May has widest range of elevation changes, whereas July and August exhibit consistently negative trends with narrower ranges, reflecting more predictable hydrologic behavior during those months. Elevations typically reach lowest point in early October, following irrigation season, and peak in late May after spring runoff. The seasonal drawdown—driven by sustained outflows for agricultural and municipal use and reduced summer inflows—ranged from 1.3 to 6.8 feet, with average decline of 2 to 3 feet.

Figure 3-2. Box Plots of Monthly Average Water Surface Elevation during the Growing Season for 1990 to 2024 Period of Record



Note: Positive values indicate an increase in water surface elevation and negative values indicate a decrease in water surface elevation.

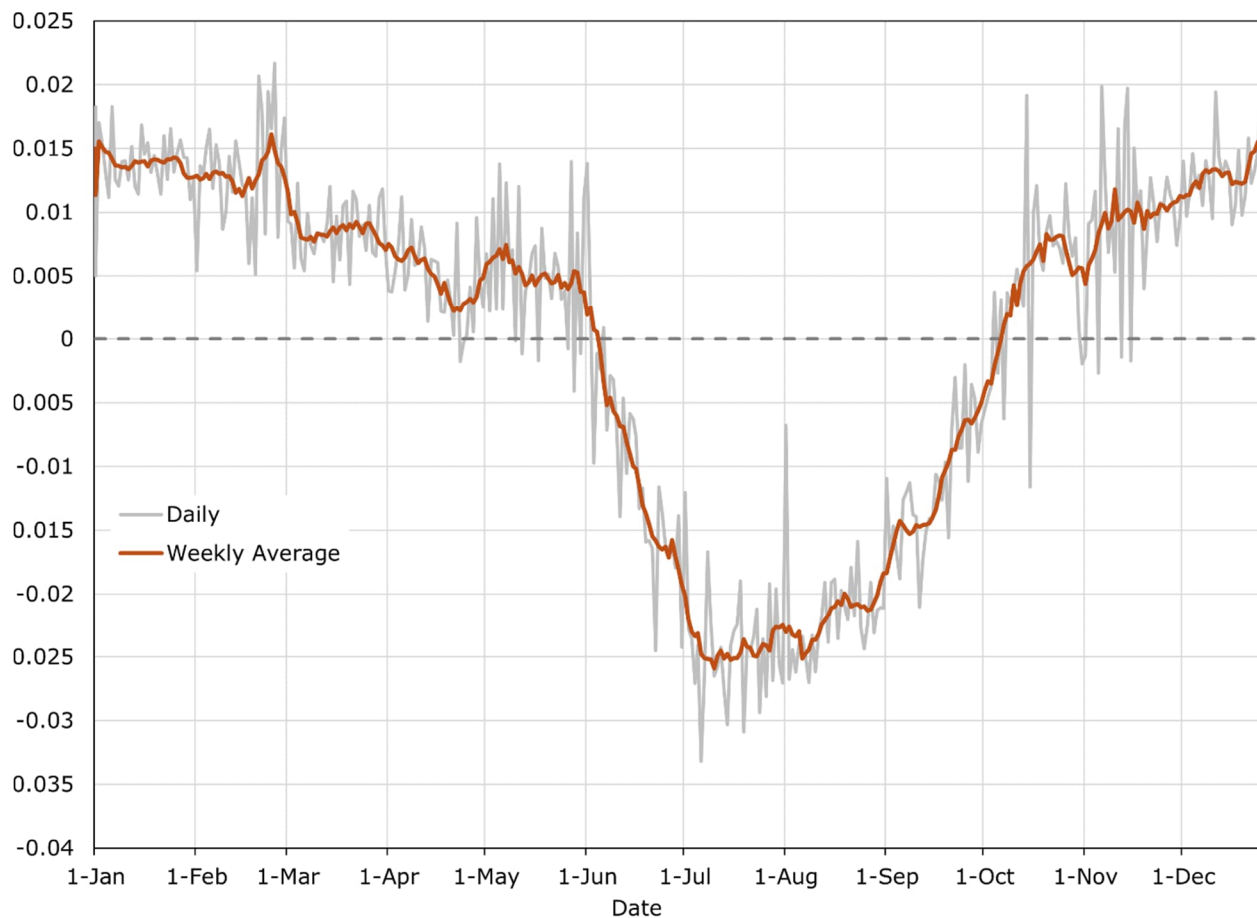
Elevations generally rise gradually until May, followed by transitional period and more rapid declines in July and August (shown on Figure 3-3). May exhibits the greatest variability, with equal likelihoods of increases or decreases ranging from gains of up to 2 feet to early-season declines. June shows decreases in approximately 75% of years, although minor increases are also observed. July consistently marks the steepest decline, with all years from 1990 to 2024 showing drops between 0.25 and 1.25 feet. August shows consistent but smaller decreases. September typically experiences minor reductions, while October often shows slight rebound, likely due to reduced outflows and early-season precipitation.

3.2.2.2 Site Suitability Analysis

As part of its immediate actions, the ULS team used ArcGIS Pro's Suitability Modeler to conduct an SSA around Utah Lake, aiming to identify areas with the highest potential for native plant restoration. The process involved standardizing input data, ranking criteria by suitability, and combining them to produce a map highlighting priority zones for habitat enhancement. Key criteria included historic lake inundation levels, lake bathymetry, species-specific water depth tolerances and light requirements, sovereign land classifications, light availability, wind exposure, and historical *Phragmites* treatment.

A key finding from the literature review revealed that Utah Lake's terrain elevations rarely meet the depth criteria needed for persistent SAV growth. While some areas fall within the SAV depth range during parts of the growing season, the probability of these conditions persisting throughout the season is low. This suggests that, under current hydrologic conditions, sustainable SAV habitat is unlikely without significant improvements in water clarity to allow growth at greater depths.

Figure 3-3. Rate of Change in Average Water Surface Elevation, 1990 to 2024



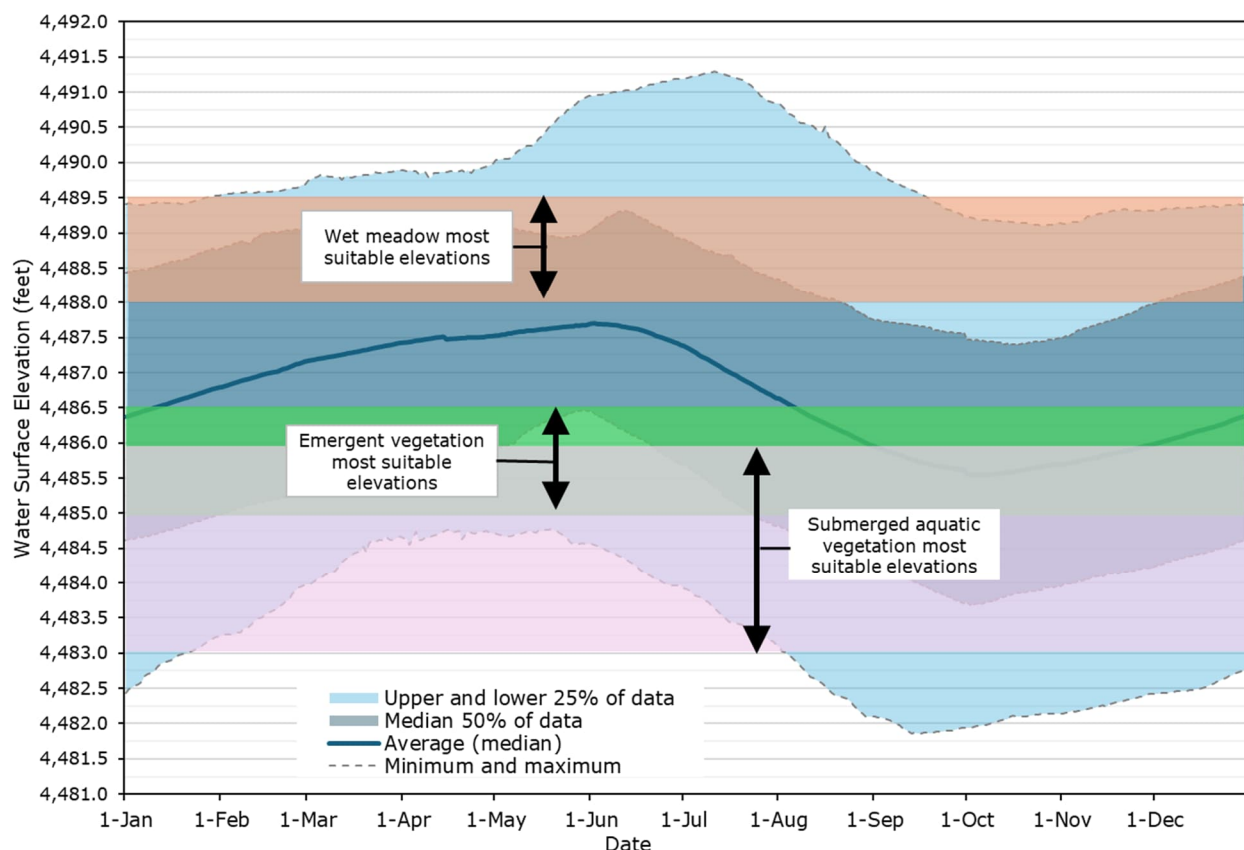
Note: Water levels are increasing when the values on the Y-axis are greater than 1 and decreasing when they are less than 1. The transition zone refers to the period from May to June, during which the lake's water surface elevation may either rise or fall in any given year; however, on average, this period marks the change from increasing to decreasing lake water surface elevations.

Preliminary results from the SSA further underscored this limitation, showing that the model alone could not reliably identify high-potential areas for SAV, EV, and wet meadow (WM) habitats without additional data, such as field surveys and detailed habitat parameters. Due to lake-level variability, even the most favorable SAV elevations experience periods outside species-specific depth range. No areas met SAV criteria consistently from 1990 to 2024, but an elevation band between 4,483.0 and 4,486.0 feet offers the highest probability of meeting SAV depth and light requirements (illustrated on Figure 3-4). For EV, which depends on seasonal inundation, no elevation meets both inundation and depth constraints year-round. The most promising elevation band lies between 4,485.0 and 4,486.5 feet, where the ground is typically inundated but remains shallower than 3 feet—conditions generally favorable for EV growth. Compromise elevation of 4,489.05 feet is referenced on Figure 3-5.

WM conditions—defined as lake levels within ± 1 foot of the ground surface—are never continuously maintained at any elevation. The highest probability occurs between 4,488.0 and 4,489.5 feet, where this condition is met approximately 30–35% of the time. Again,

4,489.05 feet serves as the compromise elevation (Figure 3-5). Although intermittent, this band offers the best chance for supporting WM vegetation.

Figure 3-4. Most Suitable Elevation Ranges for Submerged Aquatic Vegetation, Emergent Vegetation, and Wet Meadow Communities



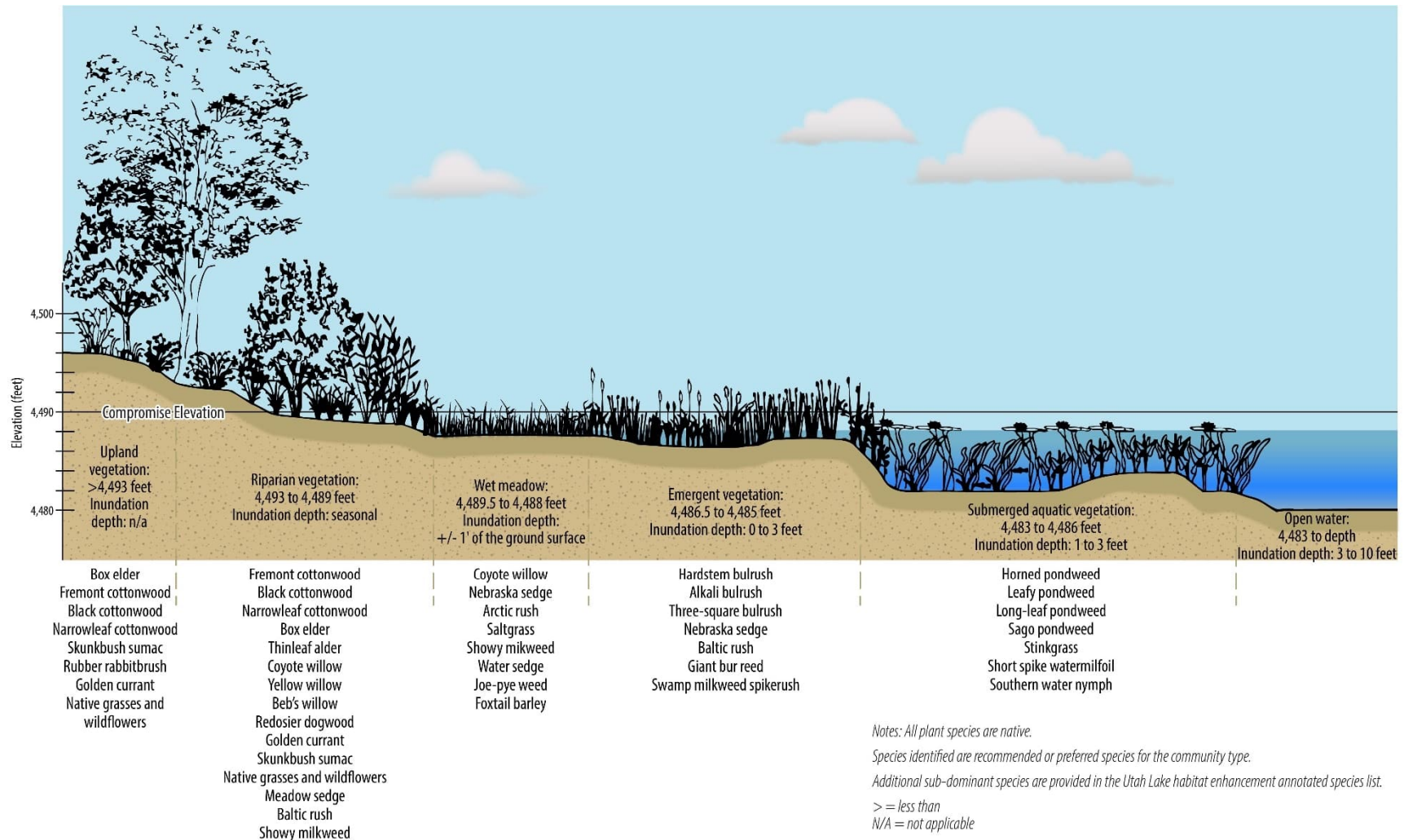
Overall, vegetation establishment around Utah Lake is strongly constrained by water-level fluctuations. Restoration efforts should focus on the identified elevation bands for EV and WM to maximize success. However, SAV establishment will likely require additional interventions, particularly to improve water clarity and light penetration. Ultimately, the SSA was not advanced further due to several limitations:

- Hydrologic variability: Large annual and interannual fluctuations in lake elevation hindered the definition of consistent depth zones for vegetation types.
- Limited differentiation: The SSA showed minimal variation in habitat suitability across shoreline vegetation types, with water elevation emerging as the dominant factor.
- Insufficient resolution: Current SSA lacked granularity needed to identify high-potential areas for SAV, EV, and WM without additional field data and refined habitat parameters.

Future development of the screening tool should incorporate field validation of reference areas to support more targeted revegetation efforts around Utah Lake.



Figure 3-5. Recommended Plant Species For Utah Lake Revegetation



3.2.2.3 Development of Utah Lake-Specific Plant Species List

While the collective research efforts at Utah Lake are robust and growing, the information generated—ranging from restoration techniques and best management practices to monitoring data, ecological insights, and cost analyses—remains dispersed across agencies, projects, and formats. This fragmentation poses challenges for synthesizing lessons learned, coordinating strategies, and applying findings consistently across restoration initiatives. Establishing mechanisms to consolidate, share, and integrate this knowledge will be critical to maximizing the impact of current and future habitat enhancement efforts under the PEF.

The ULS team compiled technical information to support habitat enhancement at Utah Lake, focusing on a key question: *Which native plant species are best suited to different landscape positions, water depths, and inundation durations, given the lake's variable water levels?* This effort lays the foundation for a future Utah Lake Revegetation Handbook, which could include guidance on restoration practices, prioritization of restoration areas, species lists for EV and SAV, sources for SAV, propagation techniques, water fluctuations effect on EV or WM community establishment, and growth and monitoring best practices.

A first step toward this handbook was the development of a curated list of recommended species organized by community type and planting elevation range (summarized on Figure 3-5 and listed in Appendix D). These recommended species, WM, EV, and SAV, are expected to perform well under Utah Lake's environmental and fluctuating lake-level conditions. The effect of fluctuating water levels on EV and WM community types can limit seedling and plant establishment. Typical water-level changes during the heat of the growing season that expose EV and WM planting elevations cause an increase the risk of drought stress for unestablished seedlings.

While EV and WM community are tolerant of habitats that are characterized by fluctuating and variable hydrologic conditions; however, these habitats can be stressful to certain plants at specific life stages. WM and EV communities are most sensitive to fluctuating water levels when they are seedlings, as such tracking and forecasting water-level changes can significantly affect where and when to install WM and EV vegetation, in addition to what species are most appropriate. Priority species were selected for their competitiveness and likelihood of successful establishment and spread.

The recommended mix emphasizes high species diversity within and across community types, with some overlap between them. This diversity is intended to increase resilience and improve the likelihood of successful establishment across a range of environmental conditions that may vary from year to year. The list also includes historically dominant species (as identified by Brotherson 1981) in Utah Lake, ensuring that restoration efforts are grounded in the lake's ecological history, including the following:

- *Distichlis spicata*, saltgrass
- *Schoenoplectus americanus* (*Scirpus americanus*), three-square or chairmaker bulrush
- *Eleocharis palustris*, spike rush
- *Juncus arcticus*, Baltic rush
- *Carex nebraskensis*, Nebraska sedge
- *Schoenoplectus acutus*, harstem bulrush

The Utah Lake SAV species list and recommendations are less developed compared to shoreline WM and EV species. However, several SAV species, including the following, have

been noted as recommended by members of the Planning Team, Steering Committee, or project stakeholder for Utah Lake habitat enhancement:

- *Potamogeton nodosus*, longleaf pondweed
- *Potamogeton foliosus*, leafy pondweed
- *Stuckenia pectinata* (*Potamogeton pectinatus*), sago pondweed
- *Zannichellia palustris*, horned pondweed

3.2.2.4 Analysis of Water Clarity and Potential Impacts on Macrophyte Restoration in Utah Lake

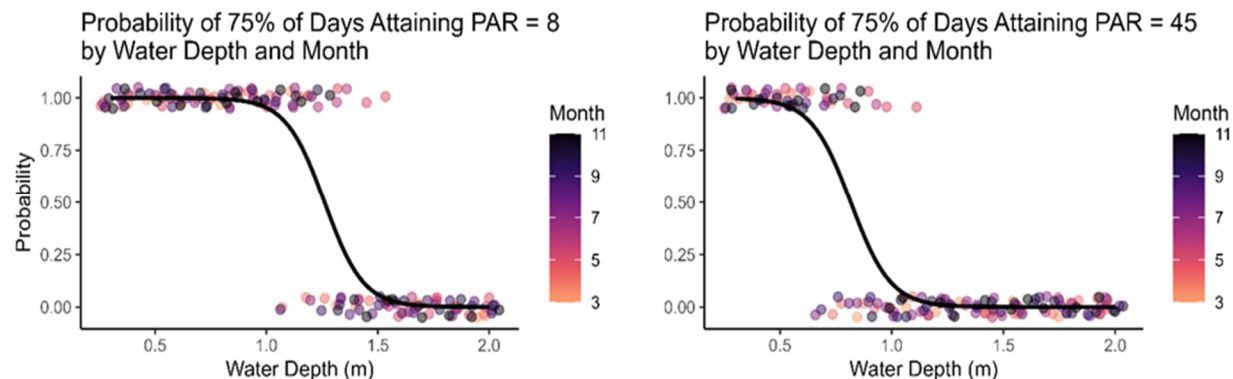
The ULS team conducted an analysis of sunlight penetration through the water column in Utah Lake and framed around how this potentially impacts SAV restoration (memorandum summarizing this analysis and its results is presented in Appendix E). Highly turbid conditions resulting from suspended sediment and algae inhibit the restoration of SAV by limiting the amount of sunlight reaching the sediment surface. The shallow nature and large surface area of Utah Lake results in conditions that frequently entrain sediments into the water column. Suspended sediments inhibit light penetration through the water column. Additionally, the eutrophic conditions in Utah Lake result in frequent algal blooms that block sunlight from penetrating deeper into the water column. Highly turbid conditions mixed with high concentrations of suspended algae (that is, algal blooms) both could inhibit the restoration of SAV by limiting sunlight and the sediment surface. This analysis evaluated the following:

- Light requirements for the establishment of common SAV by species, including coontail (*Ceratophyllum demersum*), stonewort (*Chara* spp.), American waterweed (*Elodea canadensis*), sago pondweed (*Stuckenia pectinata*), and whitestem pondweed (*Potamogeton praelongus*)
- Rate of light extinction through water column in Utah Lake (that is, light attenuation coefficient)
- Spatial and temporal variation in the light attenuation coefficient
- Relative contributions of algal and nonalgal turbidity to reduced water clarity
- Turbidity and algal conditions for sunlight to reach different water depths in Utah Lake

Light requirements for SAV growth historically observed in Utah Lake were sourced from the literature. These light requirements, specifically the minimum light requirement, called the *light compensation point* (that is, the photosynthetic active radiation [PAR] level at which photosynthesis matches respiration and net growth is zero) were cross-referenced to light profiles from monitoring data in Utah Lake to determine areas of suitability for SAV restoration. These PAR thresholds for light-tolerant SAV (PAR of approximately 45 micromoles per square meter per second) and light-sensitive SAV (PAR of approximately 8 micromoles per square meter per second) were used to guide the rest of the analyses in this section (Figure 3-6).

While sediment is usually the main factor reducing water clarity, algal blooms can temporarily become the dominant cause of poor water clarity in Utah Lake. Periodic algal blooms further inhibit light penetration for SAV growth, compounding the effects of sediment-driven turbidity. Improving water clarity and light conditions for SAV establishment will require reductions in sediment turbidity in addition to reducing the frequency and severity of algal blooms suggesting management actions to reduce sediment resuspension and nutrient reductions are necessary to improve water clarity.

Figure 3-6. Probability of Attaining Target Photosynthetic Active Radiation Levels in Utah Lake by Lake Depth and Month



Source: Tetra Tech 2025b.

Note: Probability of attaining target PAR concentrations decreases quickly with water depth.

m = meter(s)

PAR = photosynthetic active radiation

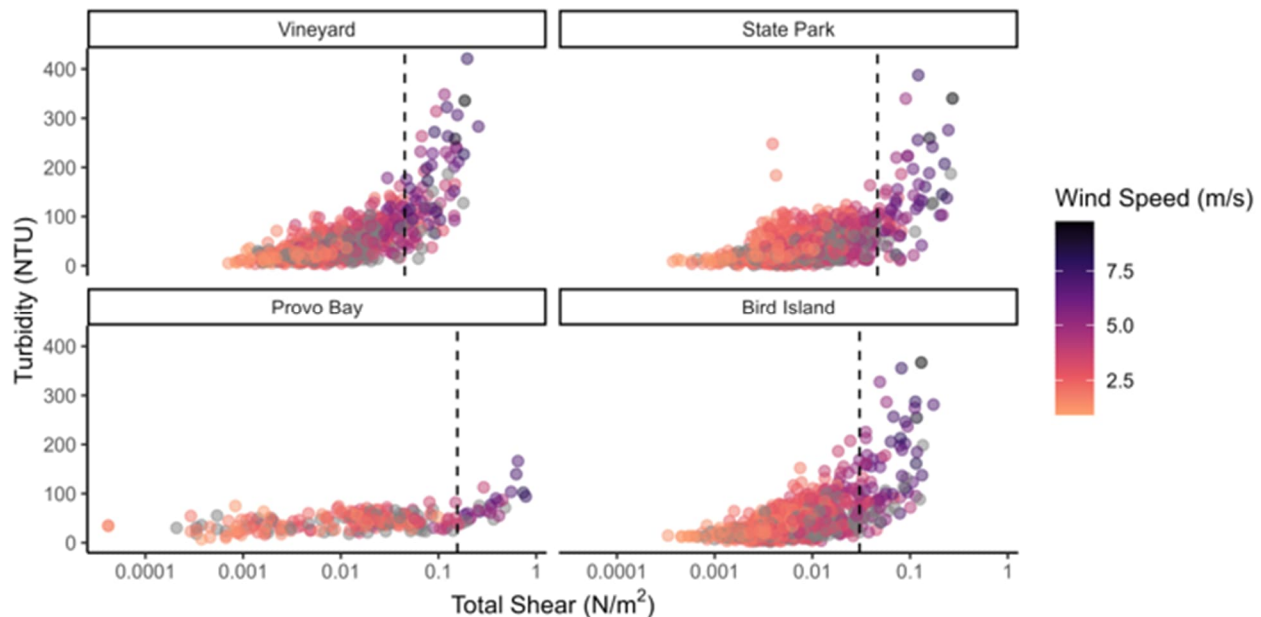
3.2.2.5 Impacts of Wind and Wave Action on Sediment Resuspension

As part of the ULS immediate actions, the ULS team investigated this question: *Where are the key areas in Utah Lake where sediment resuspension and transport occur, and which locations should be prioritized for revegetation and habitat enhancement?* To answer this question, this section and the memorandum presented in Appendix F address wind and wave action and their effects on sediment resuspension, specific to restoring and improving the littoral zone and other project area plant communities. Utah Lake's shallow nature encourages conditions that frequently entrain sediments into the water column, which creates highly turbid conditions that inhibit light penetration and instable substrate conditions, both of which could inhibit SAV restoration.

This also section also summarizes the findings from a technical analysis, including the following:

- Relationship between wind, wave action, and shear stress on benthic sediment resuspension (Figure 3-7)
- Critical shear stress value above which sediments are resuspended into the water column
- Conditions under which critical shear stress is exceeded over time and space in Utah Lake
- Whether any locations in the lake have shear stress modest enough to support macrophyte and mollusk communities

Figure 3-7. Utah Lake Wave Shear and Turbidity Relationships as They Relate to Wind Speed



Source: Tetra Tech 2025a.

Dashed vertical line = mean critical shear value

m/s = meter(s) per second

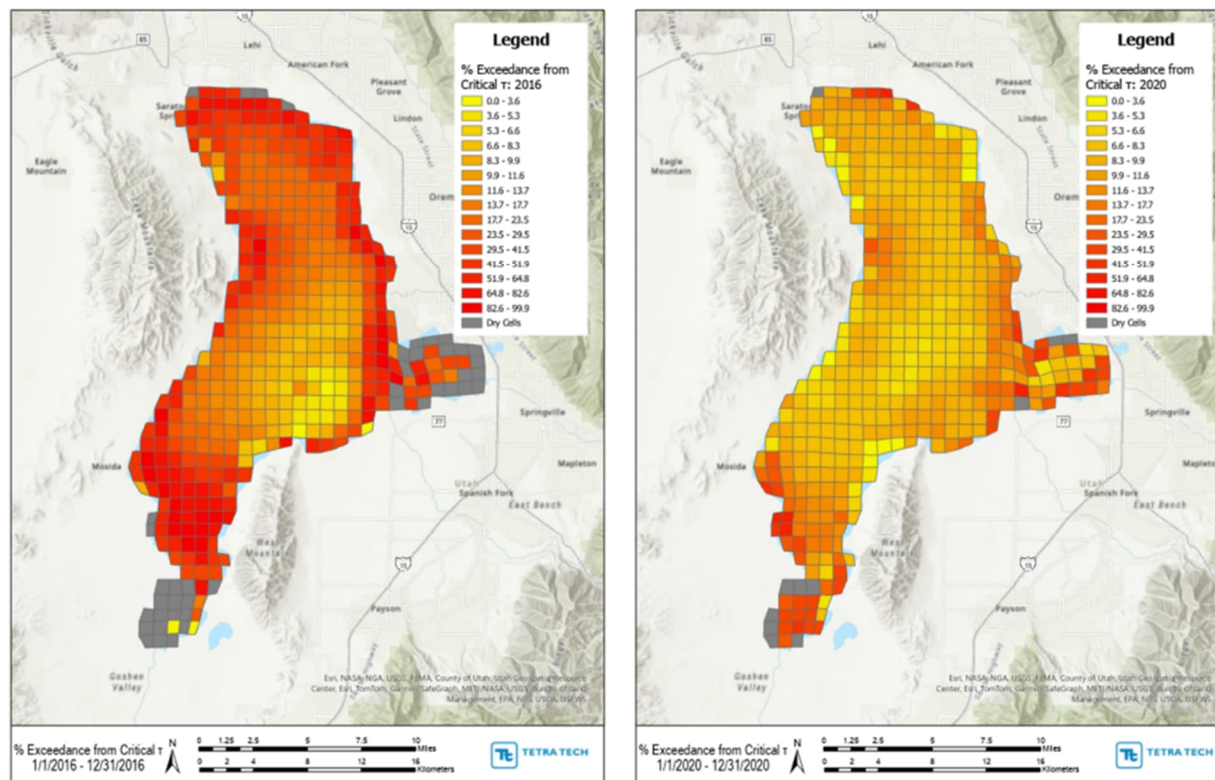
N/m^2 = Newton(s) per square meter

NTU = nephelometric turbidity unit

The Environmental Fluid Dynamics Code model was used to calculate shear stress in Utah Lake. Additional analyses were supplemented with statistical analysis of monitoring data. Shear stress was largely driven by wind/wave action, with a small component also affected by lake currents. Major drivers of shear stress in Utah Lake are wind speed, direction, and water depth. On average, low water years tended to have greater shear stress in shallow, nearshore areas than high water years, whereas deeper open water locations tended to have fairly consistent shear stress across years (Figure 3-8). Turbidity was significantly correlated with shear stress, supporting the idea that wind-driven sediment resuspension is a major driver of reduced water clarity in the lake.

Critical shear, the shear stress value that would be sufficient to resuspend sediments into the water column, was typically exceeded by approximately 10 percent of modeled days. This indicates that wind conditions in the lake are sometimes, but not usually, sufficient to entrain sediments into the water column. High levels of turbidity on days when critical shear is not exceeded are likely driven by fine-grained particles slowly sinking from previous sediment resuspension events, carp bioturbation, and/or phytoplankton-driven turbidity. Furthermore, critical shear was greater in Provo Bay than in the main basin, likely because of the wind sheltering effect and low fetch of the bay. Sediment resuspension is less likely to occur in Provo Bay than in the main basin at equivalent wind velocities; this is also supported by observations of lower levels of nonalgal turbidity in Provo Bay.

Figure 3-8. Environmental Fluid Dynamics Code Model Output of Time (in percent) Critical Shear is Exceeded for Water Years 2016 (low, left) and 2020 (high, right)



Source: Tetra Tech 2025a.

To minimize stirring fine-grained, suspended sediment in the lake's water column, particularly along shoreline, structural mitigation alternatives should be considered. Options such as nearshore reef structures or shore-perpendicular groins can help reduce the energy caused by waves and currents. However, making effective recommendations for these structures requires a comprehensive understanding of the annual fluctuations in local wave and current conditions during both low and high lake levels, as well as consideration for mixed uses (for example, lake navigation). Therefore, additional coupled wave and current modeling is recommended to explore these concepts further across varying lake levels. However, sediment resuspension improvements and nutrient reduction efforts should proceed concurrently. Improving water clarity without reducing external nutrient loading may result in increased benthic or epiphytic (growing on plants) algal growth, essentially trading one form of algae issues for another. This should not be a reason to avoid water clarity improvements, but rather a reason to implement water clarity and external nutrient loading reductions in tandem. To support this effort, an internal scope of work document has been prepared to outline the necessary numerical modeling (Appendix G).

3.3 External Nutrient Management

Completed or ongoing actions in the external nutrient management track of the PEF are exclusively being carried out by external partners, specifically DWQ, through implementation of the ULWQS. Current ULWQS activities include the development of

numeric nutrient targets protective of the designated beneficial uses of Utah Lake, as well as an implementation strategy to determine a pathway to achieving nutrient reduction. Utah Lake's designated beneficial uses are recreational, aquatic life, and agricultural. These efforts are being undertaken currently and will continue into the time frame laid out for Phase 1 of the ULS (refer to Section 4.1.3 for more information). Publicly owned treatment works (POTWs), which are one of the largest point-source nutrient inputs to Utah Lake, in the Utah Lake watershed currently are in the process of implementing a technology-based phosphorus effluent limit (TBPEL), which requires effluent phosphorus concentrations to be reduced to 1 milligram per liter and is set to be completed by January 1, 2026 (Utah Administrative Code R317-1-3 (3.3)), TBPEL. The TBPEL is a minimum feasible treatment target based on available and affordable treatment technologies and may only be one step along a multifaceted pathway to meeting future numeric nutrient targets. The TBPEL rule sets requirements for phosphorus concentrations in wastewater effluent but not nitrogen concentrations, and the concentration-based limit does not address potential nutrient load increases that could arise from increased effluent volumes driven by population increase. Three POTWs have already achieved the TBPEL, with the remaining facilities still working to achieve the TBPEL as of the writing of this ULS. The specific impacts of the TBPEL implementation and their effects on nutrient loading reductions will be realized during Phase 1 and will be evaluated as part of the ULWQS implementation strategy. Reducing external loading from POTWs by implementing the TBPEL may not be entirely sufficient in reducing nutrient concentrations in Utah Lake. Concurrently, nutrient reduction activities should be pursued to reduce external loading (for example, nonpoint source, stormwater) and internal loading (sediment stabilization through SAV and carp management), which is also discussed in the *ULWQS Numeric Nutrient Criteria Implementation Framework* (ULWQS Steering Committee and DEQ 2022). The ULS team recommends that nutrient reduction progress be periodically assessed within the PEF.

3.4 Human Use Enhancement

The ULS team did not undertake immediate actions within the human use enhancement management track, recognizing that external partners are already making substantial progress in this area. Many collaborators, including the ULA, lakeshore municipalities, and various state agencies, are actively working to enhance recreation opportunities at Utah Lake. The following subsections summarize these ongoing initiatives, highlighting how they align with the ULS framework and, in some cases, directly address information needs identified in the REIR (Appendix A).

3.4.1 Economic Impacts Study

The ULA is undertaking several key initiatives that support the human use enhancement management track. In 2025, the ULA commissioned an economic impacts study (Ernst & Young 2025) to quantify Utah Lake's economic value. The study found that in 2024, visitors spent \$74.3 million on trip-related expenses, generating \$9.2 million in state and local tax revenue and supporting 823 jobs in Utah County. These benefits stemmed from spending at restaurants, hotels, campsites, recreation facilities, and other local businesses. Taxes were collected through mechanisms such as the transient room tax and the tourism, recreation, cultural, convention, and airport facilities tax. The study focused on spending by visitors from outside Utah County, using an online survey to estimate expenditures.

The economic impacts study (Ernst & Young 2025) not only highlights the lake's economic significance but also fills a key information need identified in the review of existing data

related to S.B. 270 elements (g) and (h). Specifically, this study provides the needed economic analysis of Utah Lake's recreational potential, which is critical for understanding and quantifying the benefits of enhanced recreation for the state, residents, and visitors.

3.4.2 Utah Lake Recreation Access Plan

In addition to commissioning the economic impacts study, the ULA is furthering its vision of world-class recreational opportunities and thriving communities at Utah Lake by preparing a Utah Lake Recreation Access Plan (ULRAP; ULA 2025, in progress). The ULRAP evaluates 39 access points—34 existing public sites, 2 sites under construction, and 3 private sites—to identify challenges and opportunities associated with each site. During the planning process, 6 previously undocumented public access points were identified, increasing the total from 30 to 36. The ULRAP has four main objectives:

- Assess current conditions, amenities, and challenges at public access points.
- Identify recreation improvements and potential new access sites.
- Provide implementation strategies, including project prioritization and feasibility.
- Develop management strategies to expand recreational use.

Each access point was categorized by type and evaluated using a framework of three categories: pain points, planned improvements, and strategic improvements. Pain point resolutions were prioritized because of their immediate impact, whereas strategic improvements were considered lower priority because they require additional planning and stakeholder input.

Common pain points include lack of signage, litter or inadequate trash bins, limited parking, overgrown vegetation, rough roads, and lack of shade. Planned improvements reflect ongoing efforts by municipalities or the ULA, as well as frequently suggested enhancements from stakeholders. Strategic improvements involve new features that enhance specific sites based on anticipated use. Potential new access points were evaluated based on geographic gaps and projected demand.

Beyond recreation access planning and economic analysis, the ULA is involved in several other initiatives to improve recreation and infrastructure around Utah Lake. These include upgrading state park infrastructure, developing trail amenities in Vineyard, installing eco-counters to monitor visitation, and supporting water safety and search and rescue operations.

By supporting the collaborator-led initiatives, FFSL can help advance the following specific benefit areas defined by S.B. 270: (g) maximizing, enhancing, and ensuring recreational access and opportunities on Utah Lake; (h) otherwise improving the use of Utah Lake for residents and visitors; and (i) substantially accommodating existing uses on land in or around Utah Lake.

3.4.3 Substantially Accommodating Existing Uses on Land in or around Utah Lake

In alignment with S.B. 270 benefit (i), which emphasizes substantially accommodating existing land uses in and around Utah Lake, the ULS has prioritized understanding how current land uses interact with and support broader ecological and human use and enjoyment goals outlined in S.B. 270. A key focus area associated with this benefit area has been evaluating the role of hydrologically connected wetlands, which are prevalent in the



surrounding landscape and serve as critical components of the lake's ecological infrastructure.

These wetlands are vital to the health and functionality of the Utah Lake system. They naturally filter water by trapping sediments and retaining excess nutrients and pollutants from the watershed, thereby improving water quality and helping to prevent HABs and oxygen depletion. In some cases, constructed wetlands, also known as natural treatment systems, have been successfully integrated with conventional wastewater treatment to enhance these benefits.

Beyond water quality, wetlands contribute to shoreline stabilization and erosion control. The dense root systems of wetland vegetation absorb wave energy and anchor soil, reducing erosion along lake margins and riverbanks. Wetlands also play a crucial role in flood mitigation by absorbing and slowly releasing excess water from precipitation, snowmelt, and flood events, which helps reduce downstream flood risks. Ecologically, they provide essential habitat for a wide range of species, including migratory birds, threatened and endangered wildlife, and fish that rely on these areas for spawning and nursery grounds. Additionally, wetlands support groundwater recharge and help maintain stream and lake levels during dry periods through slow infiltration into aquifers.

A prominent example of these ecological functions in practice is the Utah Lake Wetland Preserve (ULWP), located southwest of Provo in Utah County. Established under the 1992 Central Utah Project Completion Act (CUPCA), the ULWP was designed to mitigate environmental impacts from the Central Utah Project. CUPCA authorized the Utah Reclamation Mitigation and Conservation Commission (URMCC), in collaboration with the DWR and the U.S. Fish and Wildlife Service (USFWS), to acquire private lands and water rights from willing sellers within the preserve boundary.

Land acquisition began in 1996, followed by interim management agreements with DWR for federally owned parcels. Today, the ULWP spans approximately 21,750 acres across two primary units, Goshen Bay and Benjamin Slough.

The following project partners actively manage approximately 15,870 acres of the ULWP:

- URMCC (7,200 acres)
- Bureau of Land Management (4,150 acres)
- State of Utah (4,500 acres, primarily the lake bed and banks administered by FFSL)
- Utah County (19 acres)

To ensure long-term stewardship, the URMCC and the Department of the Interior, acting as Joint Lead Agencies, prepared an Environmental Assessment (EA) (URMCC 2022) in compliance with CUPCA and the National Environmental Policy Act. This EA evaluated the transfer of federally acquired ULWP lands to the State of Utah and proposed a Comprehensive Management Plan for the ULWP. As required by CUPCA, the state entered into an agreement for DWR to manage the preserve in accordance with the National Wildlife Refuge System Administration Act of 1966. The resulting 15-year comprehensive management plan outlines strategies for habitat conservation, vegetation management, restoration, and wildlife-dependent recreation, while ensuring compliance with state regulations. Following public review and interagency coordination, the EA concluded that the proposed actions would not significantly affect the natural or human environment, and a Finding of No Significant Impact was issued in July 2022 (URMCC 2022).

In addition to designated preserves, agricultural lands surrounding Utah Lake can also contribute to the lake's ecological health when they function as hydrologically connected

wetlands. Many irrigated agricultural areas in Utah are located in valley bottoms near surface water sources, where seasonal flooding, high water tables, and irrigation practices can create wetland-like conditions. Under the right circumstances—such as appropriate hydrology, soils, and vegetation—these lands can act as buffers, filtering sediments and nutrients before they reach the lake. Even when not formally classified as wetlands, agricultural lands managed to support these features can perform similar ecological functions and enhance the resilience of the Utah Lake watershed (Mushet and Effland 2020). However, agricultural lands can also represent sources of nonpoint source pollution to the lake and may require best management practices to minimize such loading.

Together, these land uses—natural wetlands, managed preserves, and ecologically functional agricultural lands—demonstrate how existing uses around Utah Lake can be substantially accommodated while advancing the environmental and policy goals of S.B. 270.

4. Phased Enhancement Framework

The PEF is organized into two phases: Phase 1 (2026 through 2030) focuses on short- to mid-term efforts, while Phase 2 (2030 through 2035) addresses mid- to long-term efforts (refer to Figure 4-1). Phase 1 builds on insights from previous studies and immediate actions (discussed in Section 3), aiming to address key information needs and advance the goals of the ULS. Although construction-level details are not included for Phase 1, the PEF offers extensive conceptual strategies, management guidance, and discussion to support future resource managers and decision-makers in adapting and implementing actions across both phases to improve lake conditions. In alignment with a phased management approach (Appendix I), the full scope and specific strategies for Phase 2 will be developed based on monitoring and evaluation of Phase 1 outcomes.

This section summarizes planned actions across both phases within the four primary management tracks:

- Invasive carp control: Reducing carp populations to minimize habitat degradation and sediment disturbance.
- Habitat enhancement and sediment management: Stabilizing sediments and reducing turbidity, mainly through the restoration of littoral zone vegetation.
- External nutrient management: Reduce external nutrient inputs, which are being addressed through the ULWQS, led by the DWQ.
- Human use enhancement: Enhancing the recreational and aesthetic value of Utah Lake and surrounding land uses for residents and visitors through collaboration with partners and stakeholders.

While specific details about how the ULS may be implemented have yet to be determined, implementation will require strong leadership, organization, and coordination among all agencies and stakeholders. A project lead or leadership team comprising representatives from several agencies who can lead the project and spearhead coordination and collaboration efforts is recommended.

4.1 Phase 1

Phase 1 of the PEF will build upon knowledge gained from previous investigations, ongoing projects, and the immediate actions of the ULS. The PEF is organized into the four management tracks listed previously.

4.1.1 Invasive Carp Control

The goal of this management track is to enhance existing carp control efforts and reduce carp density to minimize ecological impacts on Utah Lake. Although a lake-specific density threshold has not yet been established, 100 kilograms per hectare (kg/ha; approximately 100 pounds per acre) is recognized as a benchmark for ecological damage in other lake systems (Bajer et al. 2009; Vilizzi et al. 2015; Bajer et al. 2016). Phase 1 of the ULS aims to address key information needs identified in the REIR (Appendix A), improve the understanding of carp life history in Utah Lake, and develop a Utah Lake-specific threshold and a robust integrated pest management (IPM) approach.



Figure 4-1. Overview of the Utah Lake Phased Enhancement Framework

Utah Lake Enhancement			Overall Goal
	Completed or Ongoing (2025)	Phase 1 (2026-2030)	Phase 2 (2030-2035)
Invasive Carp Control 	- Carp aging analysis to update population model - Baited trap pilot project to increase efficiency of carp removal efforts and inform IPM strategy - Large seine trials to increase carp removal efficiency and inform IPM strategy - Carp movement monitoring to inform IPM strategy	- Develop decision matrix for carp management - Develop a lake-wide monitoring program to generate estimates of carp biomass - Expand the use of emerging carp removal technologies such as box trapping, poison bait, removal of winter and summer aggregations, and seasonal barriers at spawning locations - Develop a market for carp - Develop genetic tools to drive down the carp population	- Accelerate carp removal by scaling up gear and automation to implement IPM strategy lake-wide - Further invest in and deploy genetic control technologies
Habitat Enhancement and Sediment Management 	- Characterization of lake elevation data to inform revegetation strategies - Development of a site suitability tool to inform revegetation efforts - Compiled species lists for revegetation - Development of an initial scope for the Goose Point pilot project - Description of the relationships between turbidity, light penetration, and SAV requirements to inform revegetation efforts - Numeric modeling of wind and wave action to confirm suitability of Goose Point	- Further develop Utah Lake Revegetation Handbook - Refine site suitability models - Launch Goose Point pilot project - Monitor avian populations and habitat use - Plan for scaling enhancement efforts using hydrodynamic modeling - Pilot engineering strategies to reduce sediment resuspension	- Implement successful strategies on a larger or lake-wide scale - Publish Utah Lake Revegetation Handbook - Demonstrate engineering to reduce sediment resuspension
External Nutrient Management	Compilation of SAV habitat requirements to inform water clarity improvement needs	- Align restoration goals with nutrient reduction targets - Support DWQS numeric nutrient targets	Support the development of the ULWQS external nutrient management strategy
Human Use Enhancement 	Supported the development of the ULA's Recreation Access Plan	- Collaborate with ULA and partners - Support efforts to upgrade recreational infrastructure, monitor visitation, and expand public safety programs	- Collaborate with ULA and partners on ULMP and ULRAP implementation - Support efforts to upgrade recreational infrastructure, monitor visitation, and expand public safety programs
			An enhanced Utah Lake with increased benthic primary production and less turbid water, which would result in the following benefits: - Reduced carp populations - Enhanced habitat for native species - Stabilized sediments - Improved water quality and clarity

This effort is intended to complement and add value to ongoing initiatives led by the JSRIP and DWR, rather than duplicate them. Notably, there is significant alignment with the draft Utah Lake Fisheries Management Plan (ULFMP; DWR 2024), and opportunities to coordinate across plans are being explored.

Stakeholders from DWR and JSRIP involved in developing the PEF emphasized the need for a dedicated project lead and support team to coordinate carp management, foster collaboration, and ensure strategic investment and follow-through.

To support Phase 1 implementation of the invasive carp control management track, Table 4-1 presents a high-level summary of the core strategy areas, associated actions, and intended outcomes. These strategies are designed to be scalable, and complementary to existing efforts led by partner agencies. The approach focuses more on the development of the IPM strategy, the level of effort dedicated to carp removal could be increased if desired. Detailed descriptions, technical guidance, and implementation considerations for each strategy are provided in the subsequent sections.

Table 4-1. High-Level Summary of Phase 1 Strategies for Invasive Carp Control

Strategy Area	Actions	Purpose
Monitoring and Assessment	- Develop decision matrix - Launch lake-wide biomass monitoring - Refine biomass estimates using sonar, gillnets, and mark-recapture	Establish baseline data and guide adaptive management decisions
Biocontrol and Recruitment Suppression	- Conduct egg predation trials - Analyze fish diets - Survey age-0 carp	Evaluate natural recruitment suppression and inform future control strategies
Seasonal Aggregation Removal	- Winter telemetry-guided seining - Summer commercial seining	Target carp during vulnerable periods to maximize removal efficiency
Spawning Run Management	Install seasonal barriers and traps at tributaries	Intercept spawning carp and reduce reproduction in key areas
Feeding Aggregation Removal	- Expand bait-induced summer removal - Automate box net systems	Selectively remove carp in habitats unsuitable for seining
Technology Testing and Optimization	- Pilot various removal technologies - Evaluate cost-effectiveness	Identify scalable, efficient solutions tailored to Utah Lake conditions
Economic and Genetic Innovations	- Explore carp biomass utilization - Engage with genetic control managers and researchers	Offset costs and assess long-term genetic management potential

4.1.1.1 Integrated Pest Management Framework

The approach to common carp management in Utah Lake is driven primarily by IPM. Although generally implemented in agricultural contexts, IPM has been shown to be critically important in recent successful common carp management efforts in North America (Bajer and Sorensen 2010; Bajer 2017; Dauphinais et al. 2018; Sorensen and Bajer 2021). IPM

focuses on identifying key weaknesses in the life history of carp and synergistically developing multiple technologies and approaches to target them. For example, in the Midwest, the following information helped facilitate successful carp management programs:

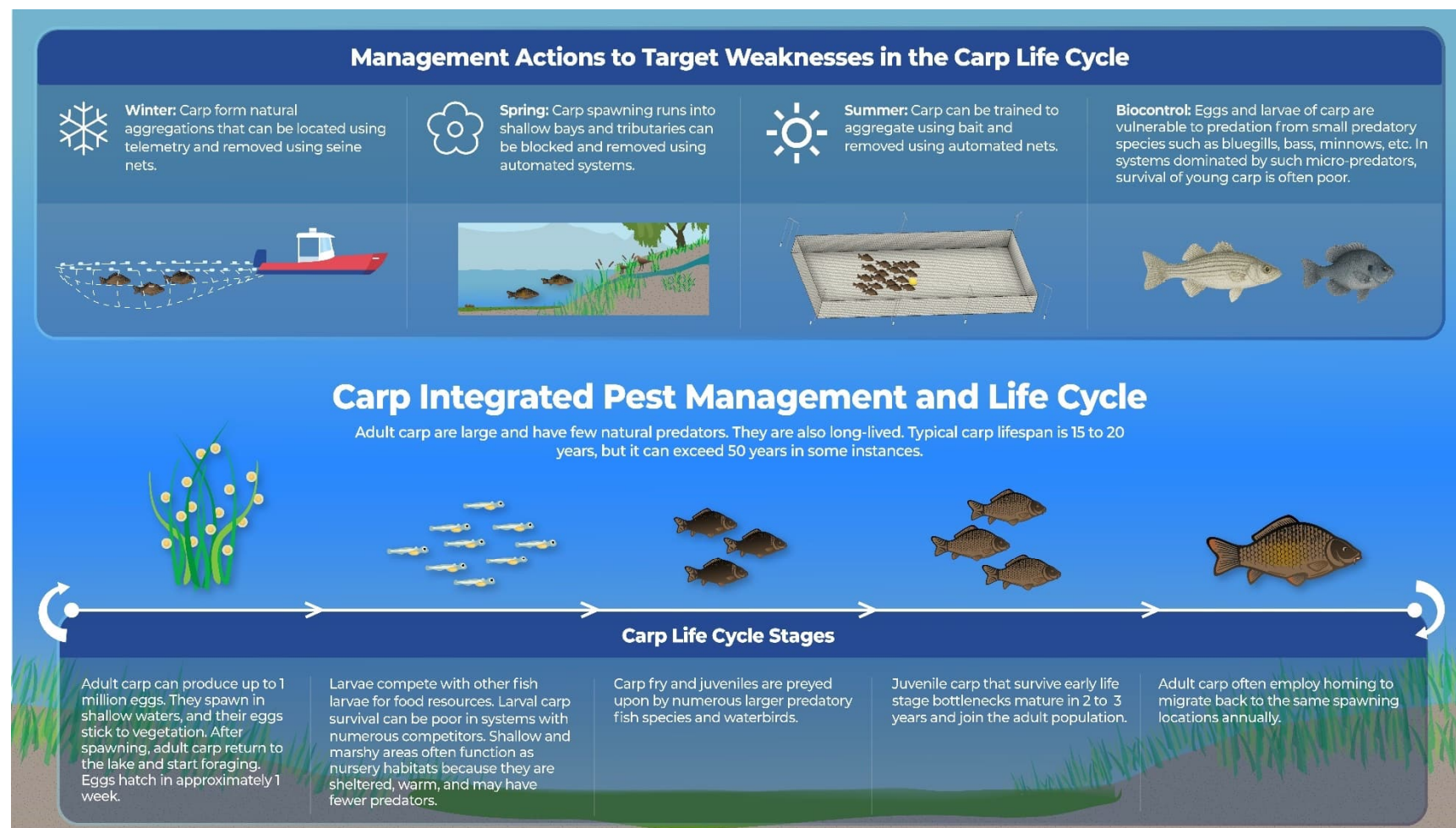
- Small, native, predatory fish (micropredators such as bluegill sunfish) that consume carp eggs and larvae are more important in controlling carp than large predators (Bajer and Sorensen 2010; Bajer et al. 2012; Silbernagel and Sorensen 2013; Bajer et al. 2015b).
- Carp form extensive spawning runs to predator-free habitats, and those runs can be blocked and removed with automated technologies (Bajer and Sorensen 2010; Bajer et al. 2015a; Chizinski et al. 2016; Bajer et al. 2022, 2024).
- Carp form winter aggregations that can be targeted with telemetry and seine nets (Johnsen and Hasler 1977; Bajer et al. 2011).
- Carp can be trained to form large feeding aggregations in the summer that can be targeted with automated baited traps (Bajer et al. 2010; Hirt 2021; Hundt et al. 2022).
- Increased automation is important in successful carp management to reduce cost and level of effort (Hirt 2021; Bajer et al. 2024).

Despite a long history of mechanical carp removal, the life history of carp in Utah Lake is still relatively poorly documented. The life history of carp in Utah Lake is likely different from carp in Midwestern systems. Midwestern systems where carp have been successfully controlled consist of interconnected lakes and marshes (Lechelt and Bajer 2016b; Sorensen and Bajer 2021). Although the carp overwinter in lakes, they migrate in large numbers to the peripheral marshes to spawn (Bajer and Sorensen 2010; Chizinski et al. 2016). These spawning migrations are driven by the fact that overwintering in the marshes often causes winter kill (because of the lack of oxygen under the ice) and marshes lack native micropredators that would normally control the survival of carp eggs and larvae (Bajer et al. 2012; Silbernagel and Sorensen 2013). The survival of juvenile carp is high in the predator-free marshes, from where they subsequently disperse to the adjacent lakes, completing their life cycle (Lechelt et al. 2017). The carp are typically unable to produce successful year classes in lakes or marshes with high abundance of micropredators, despite intensive spawning (Bajer et al. 2012, 2015b).

This lake-marsh life history is quite different from the conditions in Utah Lake (one large lake with a limited number of bays and tributary streams). However, following the IPM roadmap likely still offers the greatest chance of success, as, for example, carp recruitment hot spots may be limited to bays and areas with fewer local predators, carp may still employ spawning runs into bays and tributaries, or carp may form natural (winter) or bait-induced (summer) aggregations that can be targeted for removal (Figure 4-2).



Figure 4-2. Carp and Integrated Pest Management Life Cycle

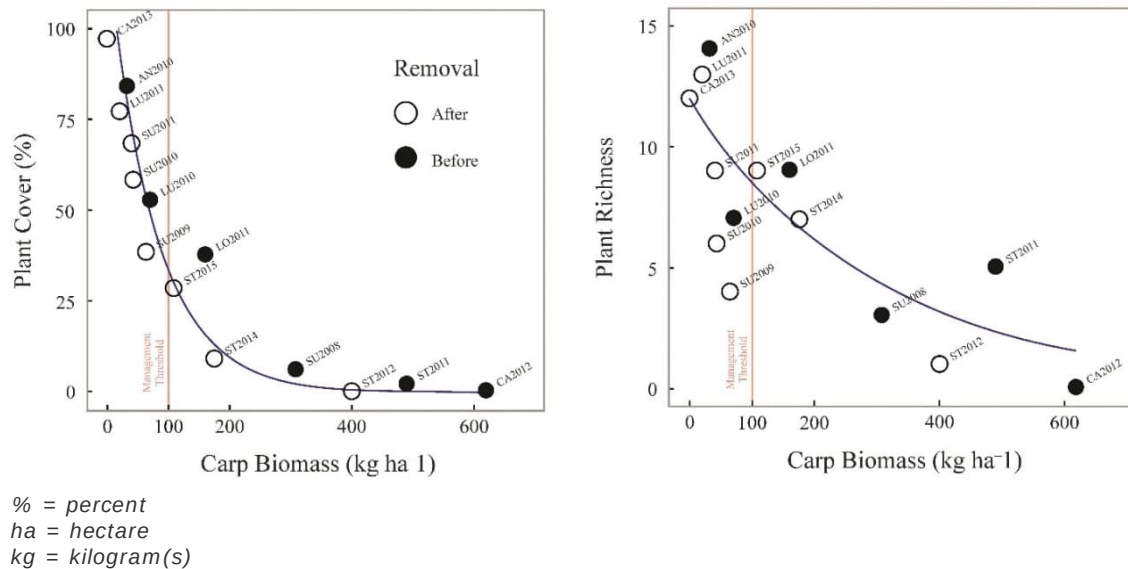


4.1.1.2 Implementation Strategies

To effectively reduce carp populations and improve ecological conditions in Utah Lake, Phase 1 of the PEF outlines a suite of targeted implementation strategies to be refined. These actions are grounded in an IPM framework and informed by both regional expertise and lessons learned from other successful invasive carp control programs. The following strategies are designed to be adaptive, scalable, and complementary to existing efforts led by partner agencies:

- **Monitoring and assessment**
 - Develop a decision matrix that identifies key metrics and performance targets based on the existing understanding of carp population dynamics (for example, the existing biomass model) and the management goal (for example, reducing carp biomass to less than 100 kg/ha or a more specific local target). The decision matrix should support the goal of improving ecological conditions in Utah Lake via carp reduction and should coordinate with other aspects of Utah Lake management and goals related to water quality improvements and vegetation reestablishment targets.
 - Develop a lake-wide monitoring program that will refine quantitative methodology for effectively capturing large quantities of carp to generate standardized and accurate estimates of carp biomass and abundance in Utah Lake. This monitoring program will provide important information to ground truth the USU carp model and will help guide management efforts on the lake.
 - Estimate current carp abundance and biomass in Utah Lake to guide management decisions. Carp impacts are density-dependent, with significant ecological damage typically occurring above 200 kg/ha (Figure 4-3; Bajer et al. 2009, 2016; Vilizzi et al. 2015). As a precautionary benchmark, 100 kg/ha is often used as a management target. Current biomass estimates rely on a population model informed by commercial seining and standardized surveys (for example, Walsworth et al. 2024), but these methods assume all catchable carp are captured—an assumption that may underestimate true biomass due to gear avoidance and variable catch efficiency.
 - Implement a lake-wide monitoring program using methods less influenced by gear type or crew expertise to improve accuracy: Methods could include modern sonar technologies paired with netting to validate species and size distributions (Munnelly et al. 2024); standardized gillnet surveys targeting all size classes, with consideration for June sucker bycatch risks (Weber and Brown 2011; Colvin et al. 2012; Bajer et al. 2016); and localized mark-recapture studies using tagged carp to estimate escapement and refine biomass estimates.

Figure 4-3. Relationship between Carp Biomass and Plant Cover in North American Lakes



■ Biocontrol and recruitment suppression

- Assess the importance of biocontrol processes in Utah Lake by completing a carp egg survival field trial and evaluating fish diets. Predation on carp eggs by other fish species (including native fish species) can play a key role in carp population control, as has been documented in Midwestern lakes (Bajer et al. 2012; Silbernagel and Sorensen 2013; Poole and Bajer 2019). Utah Lake has several species of small and medium predatory fish species that may have significant effects on carp recruitment. This may explain the generally lower carp recruitment rates in Utah Lake than those documented in Midwestern systems (refer to REIR [Appendix A] for more details); however, the diets of the various fish species in Utah Lake are not well understood (Landom et al. 2023). Simple field experiments that determine predation on carp eggs by local fish species (for example, placing protected and unprotected carp eggs on artificial substrate within carp-spawning habitat and retrieving them 24 hours later to quantify mortality; Bajer et al. 2012) may shed important light on carp biocontrol in Utah Lake. Additionally, understanding the diets of the fish community in Utah Lake is critical for managing the threatened June sucker and various sport fish species in the lake and for potential bioenergetic analyses of system response following carp management and decline in abundance (for example, *what responses can be anticipated once carp densities are reduced dramatically? Will local fish species that forage on carp eggs, larvae, and fry switch to alternative prey? What effect might that have?*). Such a diet study is also recommended by the JSRIP's Draft Recovery and Delisting Strategy. Such a diet study has been identified in the draft ULFMP (DWR 2025). The goal of this diet study is not to suggest new stocking strategies with predatory fish, which would be impractical and likely ill-advised, as the abundance of these fish is determined by local conditions; rather, the goal is to determine if biocontrol plays a significant role in curbing carp recruitment in Utah Lake. Strong evidence for local biocontrol would also greatly increase the likelihood for successful applications of mechanical removal and genetic control strategies in the future.

- Assess the abundance of age 0 carp (3 to 4 months) shortly after spawning in littoral habitats (for example, as described in Fadlovich 2024). These surveys could also leverage the already occurring sampling effort for juvenile June suckers. Age 0 carp can typically be sampled using a variety of gear (for example, trapnets and small mesh gillnets although June sucker mortality would be a concern with potentially using gill nets). Conducting such surveys approximately 3 to 4 months after the peak of spawning season in areas where carp are known to spawn could shed important light on biocontrol. Low catches of age 0 carp in such areas in late summer would be indicative of recruitment failure, potentially as a result of biocontrol.
- Seasonal aggregation removal
 - Initiate winter aggregation removal operations using telemetry-guided seining to reduce carp biomass during peak vulnerability periods. Manual or automated carp removal will likely be an important part of future carp management efforts. Carp removal will be much more efficient and effective if it is targeted at seasonal large aggregations of individuals. Cold-season aggregations of carp (November through March) have been well documented in North America and have been successfully targeted using commercial seines guided by telemetry and sonars (Johnsen and Hasler 1977; Penne and Pierce 2008; Bajer et al. 2011). Such aggregations are also believed to occur in Utah Lake and have been targeted in the past during periods with solid ice cover (Landom et al. 2006; Franklin, pers. comm. 2025). However, telemetry studies of carp aggregations in Utah Lake have involved relatively small sample sizes and limited number of acoustic receivers, thus not fully portraying when and where these aggregations form and how they move around (Landom et al. 2006). The efficacy of their removal with seine nets has also not been addressed, potentially using larger nets and boats than in the past. Notably, these aggregations are likely to form as early as November (Bajer et al. 2011) and are not only restricted to ice-cover periods, which may facilitate removal and extend the removal period beyond periods of solid ice cover. Telemetry-guided operations would also identify important limitations of this method (for example, areas where carp aggregate but cannot be targeted with seine nets because of habitat conditions) or the need for alternative removal strategies at aggregation sites (for example, the modified unified method).
 - Perform summer removal with large commercial seines. Large seine nets can be used in lakes with flat bottoms, such as Utah Lake, to cover extensive areas. To date, relatively small seine nets have been used in Utah Lake for standardized surveys (approximately 600 feet long; 2,000 to 3,000-foot-long nets are often used by commercial carp fishermen in other states), although commercial fisherman historically used larger seines (1,800 feet) for carp removal. Much larger seine nets can potentially be deployed, increasing the catch. Although this method is not expected to be species specific (bycatch will likely be significant), its efficacy should be evaluated. The advantage of using seine nets in the summer is a considerable extension of the fishing season. Local observations suggest that this method might be more successful in late summer and early fall (Franklin, pers. comm. 2025).
- Spawning run management
 - Deploy seasonal barriers and removal systems at known spawning run locations to intercept and reduce carp reproduction. In some ecosystems,

carp employ extensive spawning runs into tributary streams (Bajer and Sorensen 2010; Chizinski et al. 2016). In some cases, these runs can be removed using automated traps, low-voltage guidance systems, and conveyers, which facilitates automation and reduces labor cost (Bajer et al. 2024). Although most carp inhabiting Utah Lake likely do not employ spawning runs into tributaries, this behavior may be of local importance (for example, in Provo River Delta or Provo Bay). A passive integrated transmitter study in the Provo River Delta in 2024 and 2025 and acoustic telemetry in Provo Bay have suggested that carp migrate into the delta and the bay in the spring (Landom et al. 2006; Franklin, pers. comm. 2025). However, these studies were limited in scope and did not attempt to test if the migrating carp could be removed. In the delta, seasonal carp barriers could be considered for blocking and removing the migrating carp. Further, whether carp-spawning runs overlap with spawning runs of native fish species, especially the June sucker, should be determined. Carp have a prolonged spawning season in Utah Lake and spawn over extensive areas of the shoreline, bays, and marinas, especially during high water years. This spatially extensive spawning behavior is unlikely to be controlled, other than by local fish biocontrol or potential genetic methods in the future. Nevertheless, significant numbers of carp may still exhibit spawning runs into bays and tributaries, and those carp could be targeted for removal.

- Summer feeding aggregation removal
 - Scale up bait-induced summer aggregation carp removal using automated box nets and remote feeding systems. The removal of all size classes of carp in various habitats, including vegetated areas in the bays or flooded areas with brush where seine nets cannot be used, is likely to play a significant role in carp management. Common carp employ social feeding behaviors and can be trained to aggregate using bait (Zion et al. 2007; Bajer et al. 2010; Hirt 2021; Hundt et al. 2022). These aggregations can be induced during late spring, summer, and fall, offering a relatively long removal season. The bait (cracked corn) does not typically attract local fish (other than channel catfish), allowing for highly selective removal of carp (Hirt 2021). Further, the process of baiting and catching the carp can be largely automated using remotely controlled feeders, box nets, passive integrated transmitter systems, and edge computing. This can potentially reduce labor and increase efficacy. Nets of various lengths and mesh sizes can be deployed to match local habitats and carp size to target all year classes. The feasibility of baited box nets for removing carp in Utah Lake has been piloted in the summers of 2024 and 2025. Tests of automated box nets should continue, focusing on increasing automation, testing larger net sizes, and scaling up the removal gear (larger boats and cranes).
- Technology testing and optimization
 - Launch operational trials of carp removal technologies to identify scalable, cost-effective solutions for Utah Lake. The ultimate mix of removal strategies that offers the greatest removal and efficiency may depend on initial testing of technologies and critical information about the life history of carp in Utah Lake, such as seasonal aggregations and spawning runs. A broader array of feasible technologies, including poison bait and emerging genetic technologies, should also be explored. For the short- and mid-term objectives, this ULS focuses primarily on methods that are currently feasible, permissible, likely to accelerate the overall carp management effort most significantly.

- Economic and genetic innovations

- Facilitate industry partnerships to pilot carp biomass utilization and offset management costs. Although unsubsidized carp management would unlikely be economically viable, because as there are no examples of sustained success in North America, developing commercial products from harvested carp biomass could partially offset the costs of management. Exploring commercial options could be addressed through a series of onsite workshops with industries that use animal and fish biomass for various commercial products, both in the United States and abroad. This could be modeled after similar efforts in Australia that have been well documented and published (Tilley et al. 2019) and by collaborating with other centers that focus on developing commercial products from invasive species (for example, [BioMADE](#)). Howieson et al. (2019) provides a comprehensive review of the use of common carp biomass for various potential commercial products in Australia.
- Engage with leaders on genetic technologies for invasive fish management. Genetic technologies may offer the most cost-effective invasive carp control options in the future (Badger et al. 2025). The release of Trojan males (YY chromosome males) has already been theoretically explored for Utah Lake using the population model (for example, Walsworth et al. 2024). This relatively simple approach has shown promise for controlling short-lived species of invasive fish, such as brook trout, in small streams of the western United States (Miller et al. 2024). However, this method may be less effective for longer-lived and highly fecund species such as the common carp inhabiting large ecosystems (Erickson et al. 2023). Genetic incompatibility or gene-drive methods would be more potent for controlling common carp populations because in these scenarios, the genetic construct responsible for controlling the population (for example, female lethality) is inherited by all offspring of the genetically modified parents and all their offspring for multiple generations. In such cases, the genetic control mechanism spreads rapidly through the population and persists for generations. By contrast, the potency of chromosomal manipulation techniques, such as release of YY males, disappears after the first generation. Although no gene-drive techniques have been fully developed (or permitted) at this point, several are at various developmental stages in the United States and Australia (Thresher et al. 2014a, 2014b; Badger et al. 2025). A workshop could be hosted with research groups currently working on carp genetic control technologies to determine whether and when applications of such technologies might be possible in Utah Lake. This should also include modeling scenarios that compare the efficacy of YY male versus gene-drive technologies. Notably, gene-drive control would likely face significant regulatory hurdles, even if developed under laboratory conditions.

4.1.1.3 Implementation Resources for Phase 1 of Invasive Carp Control: Staffing, Budget, and Level of Effort

Effective implementation of ULS, particularly the carp management component, will require a dedicated team and sustained funding. Agencies should collaborate with the legislature and other partners to establish a robust management structure, secure necessary resources, and ensure long-term program continuity. Examples of successful common carp management globally typically include a team of professionals dedicated to designing and executing carp management programs, often including collaborations between local

governments and private industries, in addition to sustained, long-term funding (Yick et al. 2021; www.maisrc.umn.edu).

A combination of low-effort gillnet surveys and labor-intensive mark-recapture studies is recommended to develop a reliable index of carp abundance (for example, catch per unit effort) and estimate biomass (kg/ha) and density (individuals/ha). These data will inform the PEF management decisions and track progress toward ecological targets.

This staffing and budget framework summarized in Table 4-2 is designed to support a scalable and adaptive carp management program. Additional seasonal technicians may be required if box net and seining operations are conducted in-house and/or if efforts to remove carp from the lake in the short term are to be expanded. Agencies should prioritize securing long-term funding and staffing commitments to ensure continuity and effectiveness of Phase 1 efforts and set the stage for effective implementation of Phase 2.

Table 4-2. Proposed Utah Division of Wildlife Resources Staffing for Phase I Carp Management

Component	Staffing (FTE)	Estimated Cost	Purpose
Program director	1	1 FTE at DWR pay rate	Lead coordination and oversight
Biologists	2	2 FTEs at DWR pay rate	Manage implementation and monitoring
Seasonal technicians	8 or more	8 or more at DWR pay rate	Conduct field operations and box net deployment
Biocontrol		\$500,000	Conduct egg predation and diet analysis
Telemetry		\$300,000	Conduct seasonal movement and aggregation mapping
Contractor services		\$1,500,000	Conduct winter and summer seining and baited box net testing
Equipment and supplies		\$235,000	Manage nets, telemetry gear, and baiting systems
Miscellaneous		\$50,000	Explore carp biomass utilization and engage with genetic control managers and researchers
Total^[a]	11	\$2,585,000	

^[a] Excludes overhead costs

\$ = 2025 U.S. dollars

DWR = Utah Division of Wildlife Resources

FTE = full-time equivalent

4.1.2 Habitat Enhancement and Sediment Management

Phase 1 of habitat enhancement and sediment management consists of further refining the understanding of revegetation techniques for Utah Lake. This will involve continued implementation and monitoring of revegetation projects such as FFSL/USU North Shore project, ULA revegetation efforts, the TSSD wetland mitigation project, and more. Further development and refinement of the habitat suitability analyses and the Utah Lake Revegetation Handbook will be informed by these monitoring efforts and will be pushed closer to completion. Finally, an enhancement pilot project will be planned and implemented

to jump-start revegetation efforts and understanding while other efforts to mitigate the effects of the main stressors to Utah Lake are underway. Additional details related to the various components of Phase 1 of habitat enhancement and sediment management are provided in this section.

4.1.2.1 Implementation Strategies

The various implementation strategies for the Phase 1 habitat enhancement and sediment management track are described in greater detail in the following subsections.

Technical Guidance Development

To advance habitat enhancement efforts at Utah Lake, Phase 1 should prioritize strengthening the technical foundation for revegetation established in the immediate actions of the Utah Lake Strategy (Appendix D provides a revegetation plant list). This will be achieved through the development of a draft Utah Lake Revegetation Handbook, envisioned as a cornerstone resource for the habitat enhancement and sediment management track. The handbook will serve as a centralized guide for practitioners and managers, offering best practices for species selection, site suitability, and monitoring protocols. Key components will include the following:

- Propagation methods for Utah Lake plant species
- Updates to the site suitability model for identifying restoration sites
- Curated list of EV and SAV species list
- SAV sources
- Recommended monitoring methodologies

Revegetation efforts must involve close coordination with FFSL, ULA, and Utah County who have successfully decreased the abundance of *Phragmites* through annual treatments.

Updated Site Suitability Analysis

Effective habitat enhancement at Utah Lake requires a refined understanding of where restoration efforts are most likely to succeed. Building on the initial SSA, Phase 1 will focus on improving the accuracy and utility of this tool by incorporating field-based vegetation surveys, spatial imagery, and additional environmental variables. These refinements will help validate depth tolerance ranges for SAV, EV, and WM species under actual lake conditions.

While the initial SSA identified elevation bands with restoration potential, its reliance on historical lake elevations and generalized vegetation assumptions limited its precision. To improve accuracy and usefulness for restoration planning, future efforts could incorporate field-based data collection and additional environmental variables that may influence vegetation establishment and long-term growth.

A possible next step is to conduct field surveys of existing non-invasive vegetation communities around Utah Lake; however, analytical tools using spatial imagery are in development and could replace the need for on ground surveys. These surveys should document species composition, spatial distribution, and associated ground elevations, as well as corresponding water depths during the growing season. This information will serve two purposes: (1) validating the current suitability model and (2) refining depth tolerance ranges for SAV, EV, and WM species under actual lake conditions. Given the variability in

water levels, these observations will help bridge the gap between theoretical suitability and real, in-lake habitat suitability.

In addition to hydrologic and bathymetric considerations, future analyses should incorporate site-specific physical and logistical factors to further identify priority areas within the identified elevation bands. These factors could include ice shove exposure, soil type and stability, site accessibility, shoreline ownership, and land management constraints. Considering these elements will help confirm that selected sites are both ecologically suitable and logistically feasible for restoration activities. Integrating these variables into the SSA will support a multicriteria decision-making approach, moving beyond hydrology-driven screening toward a more specific site identification tool.

Pilot-Testing Sediment Resuspension Reduction Strategies

While the primary approach to reducing sediment resuspension in Utah Lake involves reducing the carp population and revegetating the littoral zone, alternative strategies should also be pursued. Such strategies could focus on blocking wind patterns and disrupting the currents that resuspend sediments. After potential impacts on Utah Lake navigation are carefully considered, promising strategies should be piloted and monitored for effectiveness.

Avian Population Monitoring

Monitoring bird populations and their use of habitat is needed for evaluating the ecological outcomes of enhancement actions at Utah Lake. The REIR identified information needs in both historical and baseline avian data. To address these needs, this PEF includes a dedicated avian monitoring component to ensure that enhancement activities are aligned with ecological objectives in S.B. 270.

PEF Phase 1 will initiate baseline monitoring of avian populations and habitat use at both enhancement sites and reference areas. This monitoring effort will focus on key indicator species and seasonal patterns, including breeding, migration, and overwintering periods. The monitoring design will align with the spatial scales and management tracks outlined in the PEF to ensure consistency across other Phase 1 components. Additionally, coordination with existing regional efforts such as the Intermountain West Shorebird Survey will ensure data compatibility and continuity.

Pilot projects will incorporate avian monitoring to evaluate initial habitat responses and refine site enhancement protocols. Data collected from these early efforts will inform future enhancement phases, support phased enhancement, and contribute to long-term ecological assessments. Protocol development will be guided by stakeholder input, including contributions from Audubon and Sageland Collaborative, to ensure relevance to project priorities and enhancement goals.

This monitoring framework will establish a robust baseline for avian use, enable pre- and post-implementation comparisons, and ensure that bird habitat considerations are integrated into the broader restoration and enhancement strategy for Utah Lake.

4.1.2.2 Goose Point Pilot Project

The Goose Point Pilot Project is a strategic Phase 1 action designed to test habitat enhancement methods under controlled conditions by mitigating key stressors such as carp bioturbation and sediment resuspension from wind and wave energy. By establishing a carp-free enclosure, the project enables targeted revegetation and monitoring of ecological

responses, including improvements in water clarity and vegetation recovery. This pilot supports a phased approach by generating actionable data to refine restoration techniques and validate carp removal efforts in Phase 1 and inform scalable enhancements across Utah Lake in Phase 2. Its visible outcomes will also help build public support and demonstrate the feasibility of restoring ecological function in high-value shoreline areas.

Insights gained from the Goose Point Pilot Project—such as ecosystem responses, system variability, and effective recovery methods—inform the broader, phased implementation of lake-wide enhancements. This approach minimizes the risk of costly failures and supports adaptive management. The following summarizes the main justifications for the pilot project:

- Accelerates learning and implementation. Waiting for full carp removal before initiating revegetation would delay revegetation progress. The pilot allows for immediate action and provides critical data on whether passive recovery is sufficient or active interventions (for example, planting or seeding) are required. This knowledge will guide future planning and funding decisions.
- Supports and validates carp removal efforts. Demonstrating habitat recovery at scale will help justify the carp removal program. If revegetation fails despite carp exclusion, strategies can be adjusted accordingly. Conversely, visible success will reinforce stakeholder support.
- Enables scalable enhancements. Goose Point offers a valuable opportunity to test revegetation methods that can be applied to larger areas, such as Goshen Bay (2,000 or more acres), Provo Bay, and other high-value shoreline zones.
- Determines the role of wetlands in turbidity remediation. Wetlands stabilize sediments, which prevents waves from creating turbidity plumes that constantly cover the entire lake. Large wetlands still water and trap sediments. A large-scale pilot provides actionable data for how to use wetland restoration to enhance water quality. Approximately 75 percent of turbidity is inorganic; thus, water clarity enhancements must include a strategy for reducing this portion of turbidity.
- Builds public support. Unlike carp, which are largely invisible, restored wetlands are tangible and accessible. Visible success stories can help build public and political momentum for broader lake enhancement efforts, particularly those that the public can observe themselves. Wetlands also immediately benefit public recreation, such as bird watching and hunting.

Site Selection and Characteristics

Goose Point is a strategically favorable location for the first pilot project. Situated within the Utah Lake settlement boundary and managed as sovereign lands of the State of Utah under the public trust, it offers both logistical and ecological advantages. Modeling and field observations indicate that Goose Point lies in a low-energy zone in the lee of Pelican Point, where natural sediment barriers (bars) provide protection from ice scour and wave energy. These sand and gravel bars partially isolate the site from the lake, allowing approximately 100 acres of carp-free wetland to be enclosed with the addition of about 2,250 feet of fencing—an efficient layout that presents substantial cost savings compared to other potential sites. The area's size supports meaningful interior zones, which are critical for reducing edge effects and enhancing ecological resilience. These characteristics may enable Goose Point to achieve turbidity reductions comparable to much larger wetland areas, making it an ideal candidate for testing scalable restoration strategies.

Pilot Design and Size Considerations

Effective enhancement of Utah Lake requires addressing both biological and physical stressors. A sustained reduction in carp biomass—targeting less than 100 kg/ha—is essential. Carp disturb sediments and uproot vegetation, which is a base cause of poor water clarity not only in Utah Lake but also wherever carp populations are excessive. Even after carp removal, turbidity may remain a persistent legacy issue. To improve water clarity, large-scale revegetation is necessary to stabilize sediments and dampen wave energy, while also trapping suspended solids in plant-sheltered zones deep within wetlands. The pilot must be large enough to assess how revegetated wetlands respond to varying water levels, which was identified as a major constraining stressor. Designing effective pilot projects for Utah Lake also requires addressing several scale-dependent factors that influence ecological outcomes. These include hydrology, turbidity, ice scour, restoration strategy, edge effects, natural variability, and site selection. Each factor plays a critical role in determining the success and applicability of pilot project results to lake-wide restoration efforts. Wildlife habitat is also scale dependent. The pilot must be large enough to assess habitat use at scales relevant to lake-wide revegetation. Methods such as natural colonization, planting, and seeding will be tested to determine the most effective approaches for different habitat types.

The generic design includes fencing on three sides, with the fourth side open landward above the high water mark. Three innovative conceptual design options have been developed to establish a robust carp-free zone while fostering a clearer, healthier aquatic environment for natural protection. Additional conceptual construction details of the Goose Point Pilot Project are provided in Appendix C. Exclosures are widely used in ecological restoration, particularly in overgrazed forest systems (Sarr 2002; Tanentzap et al. 2009). A key lesson from such efforts is that scale matters, as small plots often yield inconclusive or misleading results. For Utah Lake, meaningful ecological insights require pilot projects of sufficient size to reflect lake-wide dynamics.

Historically, at least 10 percent of Utah Lake (roughly 15 square miles) supported wetland and aquatic vegetation. A pilot project covering 100 acres—about 1 percent of that area—would provide a representative scale for testing revegetation strategies. Smaller plots (for example, 1 to 10 acres) are more vulnerable to edge effects and site-specific failures and may not adequately capture broader ecological processes. Larger plots reduce these risks and better reflect the habitat continuity needed for successful restoration.

Utah Lake's shorelines are high-energy zones subject to wave and ice scour. Small plots are more vulnerable to ice shove events, which can destroy vegetation and fencing. A 1-acre to 10-acre wetland could be bulldozed by ice once every few years, whereas larger plots are more resilient. Designing larger pilot projects increases realism and durability against natural disturbances such as storms and ice shove.

The concept of “ecological pixels” helps frame this need. From the perspective of ecological reclamation, a pixel is the smallest area that provides results directly applicable to larger scales. In Utah Lake (96,000 acres, or 150 square miles), habitat enhancement is best suited on the shallower lake edges (estimate 9,600 acres, or 15 square miles) or littoral zone. This equates to ninety-six 100-acre habitat enhancement pixels from which the larger revegetation picture emerges. A 100-acre pilot site, such as Goose Point, offers a feasible and ecologically relevant scale for testing revegetation methods and understanding system-wide impacts.

Turbidity and the concept of interior area provide a quantitative basis for defining the Utah Lake “revegetation pixel.” In Utah Lake, wetland plants (for example, *Schoenoplectus acutus*) will grow from approximately the high water elevation into the lake to a water depth of about 5 feet. To simplify geometry, wetlands are assumed to grow approximately as a rectangle, with one side, the length, being the distance into the lake that the wetlands colonize. The width is along the shore. For a given area, the length sets the width, which then allows a simple calculation of the interior area (Table 4-3).

Table 4-3. Interior Area by Area of Wetland

Distance (length) into Utah Lake (feet)	Interior Area (percent)			
	1 Acre	10 Acres	100 Acres	1,000 Acres
500	0	46	59	60
1,000		43	76	80
2,000		7	82	89
3,000		0	80	92

Implementation Strategy

Three innovative conceptual design options have been developed to establish a robust carp-free zone while fostering a clearer, healthier aquatic environment. All three options take advantage of the natural elevated gravel berms present along the area. Additionally, they create barriers that carp would not be able to pass through and that would be resilient to wind, wave, and ice shove forces.

The first option (Figure 4-4) proposes the strategic use of gravel-filled rock bags to effectively seal off Goose Point at the northern boundary, just below Pelican Point. To the east of this entrance, a half-circle barrier net will be introduced, creating an additional area of 414,400 square feet that will remain unaffected even during low water season, as depicted on Figure 4-4. The half-circle barrier, approximately 1,444 feet long, will consist of a series of high-density polyethylene floating booms connected by stainless steel chains. High-tension netting, made from high-modulus polyethylene fiber, will be attached to the bottom of the floating boom to prevent carp, algae, and floating debris from entering the enclosed area. Option 1 also includes rock bags along the northern and eastern perimeter of the Goose Point enclosure, including a section of floating boom system with high-modulus polyethylene fiber netting. The estimated rough cost for construction of this pilot project is \$2,150,000 (based on 2025 costs).

Appendix C presents two additional options for the construction of the Goose Point Pilot Project. The other options utilize different materials to create the enclosure and vary in both their resistance to wave action and ice shove forces, in addition to construction cost. Table 4-4 summarizes the three conceptual design options (described in Appendix C), highlighting the materials used, estimated costs, and relative resilience to environmental stressors.

Figure 4-4. Goose Point Pilot Project Concept (Option 1) with Temporary Barriers Preventing Carp Passage Along Northern and Eastern Edges

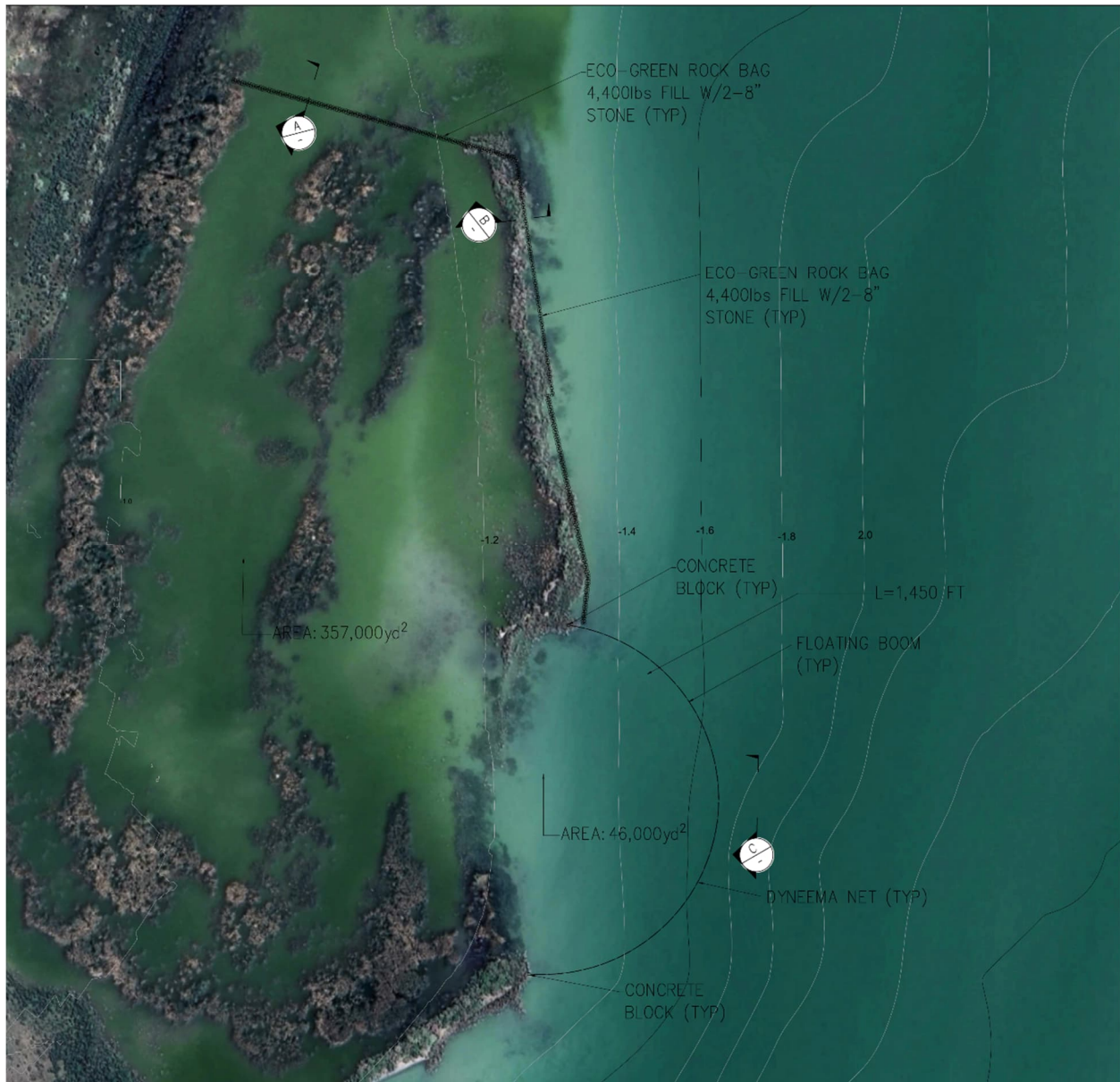


Table 4-4. Comparison of Conceptual Design Options for Goose Point Pilot Project

Design Option	Materials Used	Estimated Cost	Resilience to Wind, Wave, and Ice Shove	Notes
1	- Gravel-filled rock bags - Floating booms (HDPE) - Stainless steel chains - High-modulus polyethylene fiber netting	\$2,150,000	High resilience due to robust materials and flexible boom system	Designed to seal off northern boundary and create a half-circle barrier; effective in low water conditions
2	- Geotextile fabrics - Anchored mesh barriers - Modular fencing systems (details in Appendix C)	\$3,500,000	Varies depending on material choice; potentially moderate to high	Offers different resistance profiles and cost structures; may be more adaptable or cost-effective
3	- Reinforced concrete elements - Permanent berms - Ice-resistant structural components (details in Appendix C)	\$2,250,000	Designed for maximum durability against ice shove and wave action	May be more expensive but suitable for long-term installations

\$ = 2025 U.S. dollars

HDPE = high-density polyethylene

Integration with Phase 1 Monitoring

Baseline monitoring of the pilot project could be done with aerial imagery and drones to capture imagery on a daily or weekly basis. Aerial imagery from drones can provide high-quality, high-resolution images that could allow managers to assess water turbidity conditions, vegetation coverage, vegetation species (although this may require some ground truthing), and potentially additional environmental conditions. Additional ground-based monitoring will be required, and a dedicated team of biologists will need to be available to the project. Approximately two to four biologists would be needed for monthly and annual monitoring (one to two full-time equivalents plus two to four seasonal technicians). Project engineers and/or technicians would need to complete regular monitoring and maintenance of the enclosure structure.

Scaling and Future Adaptations

Utah Lake's water levels fluctuate significantly as a result of reservoir operations—up to 8 feet over a decade and 2 to 4 feet annually. These fluctuations affect plant survival, especially for species with narrow depth tolerances, although some species are able to tolerate periodic drying. Pilot projects must span a sufficient elevation gradient to include both high and low water zones and provide interior areas unaffected by edge conditions. Small plots risk being entirely submerged or desiccated, while larger plots offer resilience and better represent ecosystem dynamics under current hydrologic regimes.

The 100-acre area within the bars and fencing dries out every few years, meaning Goose Point is not a suitable place to investigate SAV. An extension of fencing into the lake would explore SAV recovery. The scale (10 to 15 acres) is small and does not fulfill the scaling

criteria used in the EV. However, it does offer the opportunity to study SAV recovery with carp removal in a large area that is subject to edge effects.

A key question is whether wetland and aquatic plants will return spontaneously once stressors like carp bioturbation and wave energy are reduced or whether active planting and seeding will be required. This is a scale-dependent issue. For example, the Olentangy Experimental Wetland Project (Mitsch et al. 2023) planted one 2.5-acre cell and left another unplanted. After 5 years, both were ecologically similar, and after 15 years, they were indistinguishable. Utah Lake pilot projects can test whether similar passive restoration is feasible. Rather than creating separate control plots, establishing a small area (1 to 2 acres) that is planted and seeded within a larger pilot site can reveal colonization dynamics and inform future restoration strategies. Appendix H provides further information about Goose Point Pilot Project revegetation. To inform potential strategies for piloting enhancement projects, higher-resolution hydrodynamic modeling should be completed to develop a comprehensive understanding of wind, wave, and current dynamics. Therefore, additional coupled wave and current modeling should be conducted to explore these concepts further across varying lake levels. To support this effort, an internal scope of work document has been prepared to outline the necessary numerical modeling (Appendix G).

4.1.2.3 Resource Needs Summary

To support effective planning and implementation of Phase 1 activities under the habitat enhancement and sediment management track, Table 4-5 summarizes the anticipated resource needs across key components. This includes staffing requirements, estimated budget ranges, and the relative level of effort for each activity. Staffing would be expected to involve a mix of existing and new state agency staff but depend on funding for and implementation of the ULS. The table provides a high-level overview to guide coordination, funding allocation, and scheduling, ensuring that technical development, monitoring, and pilot implementation are adequately supported throughout the initial phase of the Utah Lake Strategy.

4.1.3 External Nutrient Management

Phase 1 of the external nutrient management track for the ULS focuses on developing science-based strategies to improve water quality and support ecological restoration in Utah Lake. Central to this effort is DWQ's ULWQS, which is working toward establishing numeric targets for chlorophyll, nitrogen, and phosphorus. Additionally, Phase 1 aims to identify water quality and clarity targets that facilitate the restoration of benthic vegetation, which may require distinct management approaches.

The ULWQS is currently in the process of developing a Technical Support Document, which will lead to a recommendation of numeric nutrient targets (for nitrogen and phosphorus) for Utah Lake. This effort is being conducted using an approach with multiple lines of evidence, wherein the designated uses of Utah Lake are mapped to specific management end points that represent support of those designated uses. Then, a series of reference, stressor response, and literature analyses are conducted to establish the levels of chlorophyll, nitrogen, and phosphorus that are protective of the management end points. Analyses will include information from mechanistic modeling, monitoring data, and scientific studies conducted in Utah Lake.

Table 4-5. Phase 1 Implementation of Habitat Enhancement and Sediment Management Track

Component	Staffing Needs	Estimated Budget	Activities
Technical guidance development	2 PTEs (botanists, plant ecologists, or restoration ecologists)	Staff salaries	Information gathering, writing, species list curation, coordination with agencies
SSA	1 PTE 2 to 3 seasonal technicians	Staff salaries	Field and drone surveys, information gathering, model refinement, spatial analysis
Avian monitoring	1 FTE biologist 2 seasonal technicians	Staff salaries	Baseline data collection, protocol development, coordination
Goose Point Pilot Project	1 FTE project manager 1 PTE engineer and construction crew (for design and construction) 2 PTE biologists 4 seasonal technicians 1 PTE drone operator	Staff salaries, \$2,150,000 (Option 1)	Engineering design, construction, monitoring, data analysis, reporting
Monitoring and maintenance	1 to 2 FTE biologists, drone imagery analysts, or maintenance technicians	Staff salaries	Seasonal monitoring, structure upkeep and maintenance
Scaling and adaptation planning	1 FTE program lead 1 FTE technician or hydrodynamic modeler	Staff salaries, \$18,000 (modeling)	Elevation gradient analysis, hydrodynamic modeling, SAV strategy development

\$ = 2025 U.S. dollars
 FTE = full-time equivalent
 PTE = part-time equivalent
 SAV = submerged aquatic vegetation
 SSA = site suitability analysis

The process for developing numeric nutrient targets is laid out in the *ULWQS Numeric Nutrient Criteria Implementation Framework* (ULWQS Steering Committee and DEQ 2022). The ULWQS will result in nutrient targets to protect the designated uses of Utah Lake (Phase 1). Once adopted, these water quality criteria will be used to determine appropriate point-source nutrient effluent limits and non-point-source nutrient reduction goals and strategies to further reduce nutrient loading (Phase 2).

Concurrently with numeric nutrient targets development, the ULWQS is developing an implementation plan that lays out the path toward achieving numeric nutrient targets in Utah Lake (ULWQS Steering Committee and DEQ 2022). The following are the overall objectives of the implementation plan:

- Develop practical, feasible, effective nutrient reduction program to achieve numeric nitrogen and phosphorus water quality targets developed during ULWQS Phase 2.

- Incorporate all significant nutrient sources to Utah Lake, including nonpoint, point, and atmospheric sources.
- Evaluate the most cost-effective in-lake and watershed strategies to improve water quality in Utah Lake to achieve measurable improvements as quickly as feasible.
- Develop an adaptive management approach to address changing watershed conditions and respond to the effectiveness of the implementation program.
- Use flexible regulatory tools to implement point-source discharge permits (for example, water quality trading and/or watershed-based permits).
- Engage all management partners.
- Leverage federal, state, and local funding.

To achieve these objectives consistent with the time frame of Phase 1, the *ULSWQS Numeric Nutrient Criteria Implementation Framework* (ULWQS Steering Committee and DEQ 2022) details a series of activities, including the following:

- Engaging stakeholders on the watershed planning process
- Quantifying and prioritizing nutrient sources in the watershed
- Identifying implementation planning scenarios for point sources, nonpoint sources, stormwater, atmospheric deposition, and ecological restoration with respect to their cost, feasibility, and effectiveness
- Quantifying expected load reductions and in-lake responses for nutrient implementation planning scenarios
- Exploring implementation options, including watershed-based permitting, a water quality trading program, compliance schedules, a monitoring program, an education and outreach program, and an adaptive management program
- Developing a comprehensive watershed plan

An additional objective of the external nutrient management efforts in Phase 1 will be to identify water quality and clarity targets that support restoration of benthic vegetation. This could be completed as part of the ULWQS implementation or as part of the regular Utah Lake monitoring by USU. In some cases, these targets may be consistent with the targets identified as part of the ULWQS to support designated beneficial uses (for example, reducing the magnitude, frequency, and duration of HABs), but in other cases, the water quality and clarity targets to support benthic vegetation could be distinct from the targets identified for the ULWQS (for example, reductions in suspended sediment). Water quality conditions for benthic vegetation are explored in the analyses of water clarity, depth, and turbidity in Appendix E and in King et al. (2023). Additional field trials, paired with the habitat suitability analysis presented in Section 4.2, will help to inform management actions that can improve macrophyte restoration efforts.

4.1.4 Human Use Enhancement

Phase 1 of the human use enhancement management track under the PEF will implement a coordinated set of strategies to enhance recreation, access, safety, and public engagement around Utah Lake. Guided by the ULMP (ULA 2024) and the ULRAP (ULA 2025, in progress) and led by ULA in collaboration with FFSL, URMCC, DWR, Utah Division of State Parks, lakeshore municipalities, and other state agencies, planned initiatives will include park

infrastructure upgrades, trail development, visitation monitoring, and integration of emergency response systems. Public safety and outreach efforts, such as the Life Jacket Loaner Program, seasonal safety messaging, and education on HABs and *Phragmites*, will support a more informed and responsible public.

A central focus of Phase 1 of the human use enhancement management track is the implementation of strategies outlined in both the ULMP (ULA 2024) and the ULRAP (ULA 2025, in progress). The ULA plays a key role in advancing these strategies, not only through access planning and economic analysis but also by leading and supporting a range of initiatives aimed at enhancing recreational infrastructure and visitor experience. These initiatives include the following:

- Upgrading state park infrastructure
- Developing trail amenities in Vineyard
- Installing eco-counters to monitor visitation
- Supporting water safety and search and rescue operations

As access points around the lake are improved, a critical opportunity is available to integrate public safety and emergency response infrastructure. Coordinated planning among law enforcement, emergency services, and local agencies ensures that safety measures—such as signage, emergency access routes, communication systems, and water safety equipment—are embedded into recreation upgrades. The ULA also leads public education and outreach efforts to promote lake safety, including the following:

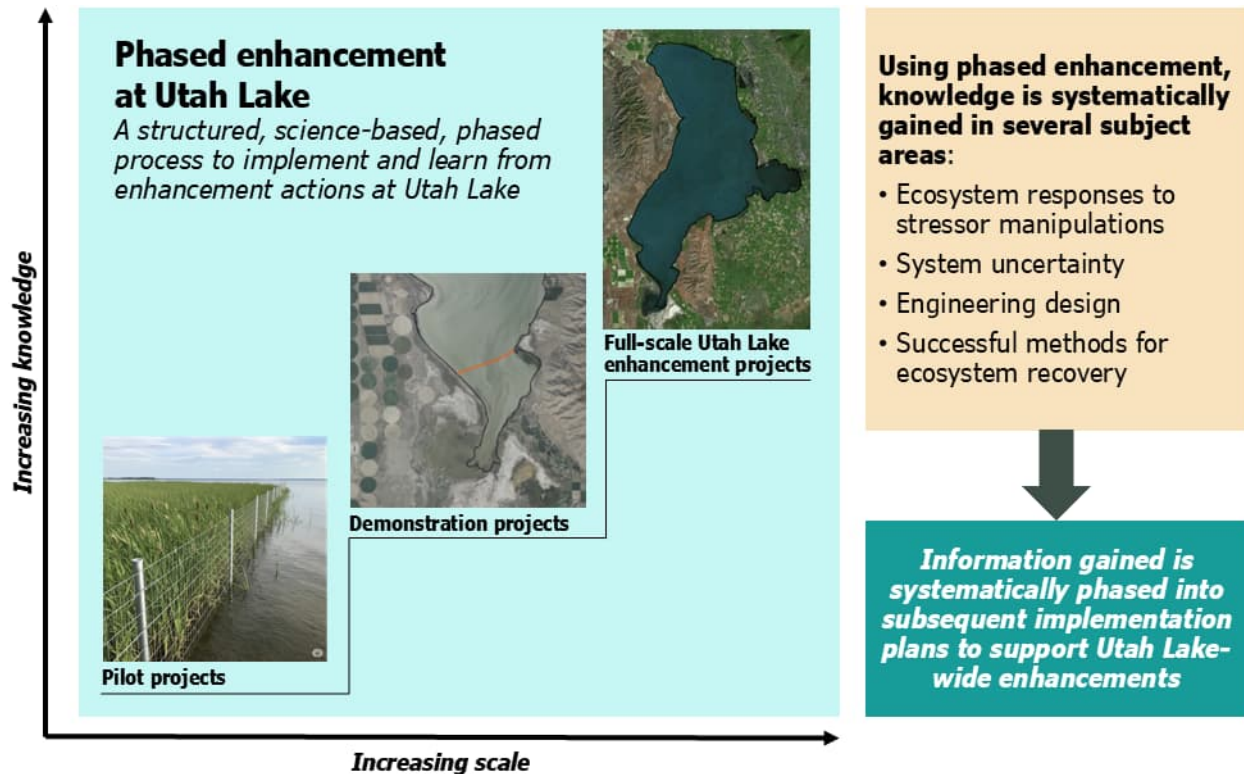
- The Life Jacket Loaner Program
- Dissemination of water safety guidelines through social media and blogs
- Seasonal messaging on winter and ice safety
- Updates on HAB advisories
- Information on *Phragmites* management

Together, these initiatives form a comprehensive and coordinated response to the S.B. 270 directives, demonstrating how human use enhancement under PEF Phase 1 supports the long-term vision for Utah Lake as a vital recreational, ecological, and economic asset. These efforts also connect to the concurrent update of the Utah Lake Comprehensive Management Plan, which involves engagement with municipal partners to include their input on the management of Utah Lake's sovereign lands.

4.2 Phase 2

The PEF for enhancing Utah Lake is based on phased and iterative management principles, wherein enhancement actions that primarily target the manipulation (reduction and removal) of key stressors impacting Utah Lake are implemented in an experimental setting and ecosystem responses to stressor manipulations are tracked over time. Rather than commencing directly with large-scale implementation throughout the lake, the process is inherently iterative, with enhancement actions initially tested in pilot or demonstration-scale areas and ecosystem responses to enhancement actions tracked over time. Armed with an improved understanding of ecosystem responses to stressor manipulations, system uncertainty, engineering design, and successful methods for ecosystem recovery, this information provides the basis for phased implementation of enhancements on an increasing scale with minimized risks of costly failures (Figure 4-5).

Figure 4-5. Phased Enhancement Framework Recommended for Utah Lake



Note: The Demonstration projects image is an artificial intelligence-generated image (created with Google Gemini on June 18, 2025) for illustrative purposes and does not indicate proposed design.

Two central priorities will define Phase 2:

- Further securing a dedicated funding source for Utah Lake. Without sustained financial support, the enhancements initiated in Phase 1 risk stagnation, and the lake may revert to the status quo—a condition the Utah State Legislature deemed inadequate. The legislature's directive in S.B. 270 to enhance conditions at Utah Lake reflects a clear mandate for improvement and long-term stewardship.
- Scaling up from a pilot project to a demonstration project. This is a critical step in the PEF, allowing for the transition from small-scale, controlled testing to broader, more representative implementation. Pilot projects serve as experimental platforms to test specific enhancement actions—such as carp exclusion, sediment control, or revegetation—under manageable conditions, enabling close monitoring and refinement of methods. Once these actions demonstrate effectiveness and feasibility, they can be expanded into demonstration projects, which operate at a larger spatial scale and under more variable environmental conditions. This scaling process helps validate the applicability of pilot-tested strategies across diverse lake settings, reduces the risk of large-scale implementation failures, and builds confidence among stakeholders. Demonstration projects also provide opportunities to test the scalability, cost-effectiveness, and ecological outcomes of enhancement actions, ultimately informing adaptive management decisions and guiding full-scale restoration efforts.

This section outlines potential Phase 2 activities across the four management tracks of the PEF that may help achieve the overall goals of the ULS. Specific details are not yet defined,

as they will be shaped by the outcomes of Phase 1. As enhancement efforts progress, monitoring will capture changes in and around the lake, along with the successes, challenges, and any unintended consequences of Phase 1 activities.

Due to significant uncertainty around timing, scope, and cost, no staffing or budget estimates have been developed for Phase 2. Its success will depend on the establishment of a Utah Lake management program during Phase 1, along with dedicated project staff and consistent funding to support ongoing monitoring, analysis, and planning under the PEF.

4.2.1 Invasive Carp Control

The long-term objective is to reduce carp densities to minimize impacts to the lake. Phase 2 is centered around full implementation of an IPM strategy developed as part of Phase 1, driving down the population of carp in the lake and implanting technologies to reduce the effectiveness of carp reproduction and recruitment. The strategies are as follows:

- Design and implement carp IPM in Provo Bay and Provo River Delta to reduce carp biomass below a threshold density to be determined (potentially approximately 100 kg/ha) wherein carp impacts to Utah Lake are minimized within 5 to 10 years. Once the short- and mid-term objectives have been achieved and the components of an IPM management strategy have been developed, a full-scale IPM can be developed, focusing first on Provo Bay and Provo River Delta. Even if Provo Bay remains open to the main lake (unless it could be temporarily isolated for carp migrations, which at this point seems unlikely), aggressive management effort focused on Provo Bay is more likely to succeed than effort that encompasses the entire system.

Carp movement in and out of Provo Bay should be monitored using, for example, stationary acoustic telemetry receivers. The Provo River Delta could be blocked off from carp movement (at least during drier years) using seasonal carp barriers that would minimize impacts to the June sucker spawning run. The Provo River Delta and Provo Bay IPM would focus on a synchronized rollout of several of the removal and management technologies (for example, seines, baited traps, spawning run removals, and biocontrol by local fish) while monitoring the response of the carp population, habitat conditions, and overall management success. Local success in Provo Bay and Provo River Delta would create momentum to expand to the entire Utah Lake in the following phase. Fisheries and (ideally) ecosystem monitoring should be done to specifically evaluate the response of the ecosystem to carp removal.

- Implement full-scale IPM for the entire Utah Lake to reduce carp biomass significantly (to below a threshold to be determined wherein their impacts are minimized) in 10 to 15 years. Learning from the Provo Bay IPM, a similar effort would be designed and implemented in the entire lake. This would follow the PEF wherein specific removal rates and methods are adjusted to target specific components of carp population as needed (for example, focusing more on juveniles versus adults). Notably, two of the proposed methods (baited traps and seine nets) should be able to target all size classes of carp, including young of the year, although thus far both methods have caught primarily older carp in Utah Lake (Walsworth et al. 2025).
- Invest in developing long-term genetic control technologies and establish collaborations with research groups that are already working on these technologies in the United States and Australia. Genetic technologies are currently in development and the specific technology and/or cost associated with implementation are unknown at this time. Implementation may require the production of large numbers of genetically modified carp in a hatchery for stocking into Utah Lake.

4.2.2 Habitat Enhancement and Sediment Management

Phase 2 of the habitat enhancement and sediment management track will apply lessons learned from five or more years of revegetation and monitoring at the Goose Point Pilot Project. These insights will guide the design and implementation of a demonstration project, ideally located in Goshen Bay. Practical experience from Phase 1 will shape best practices for planting locations, techniques, and species selection. To support this transition, the development of the Utah Lake Revegetation Handbook is recommended as a key Phase 2 deliverable. This handbook is intended to fill a critical gap: no comprehensive resource currently exists to guide revegetation efforts in Utah Lake. It will compile proven approaches, lessons learned, and best practices from Phase 1, and will be reviewed by key collaborators and stakeholders prior to publication at the onset of Phase 2.

Scaling up from pilot to demonstration projects is a critical step in the PEF. While pilot projects allow for controlled testing of specific strategies under limited conditions, demonstration projects expand these efforts to broader, more variable lake environments. This transition enables validation of pilot-tested methods under real-world conditions, supports continuous refinement of techniques, and builds confidence in their broader applicability. Demonstration projects also provide opportunities to evaluate the scalability, cost-effectiveness, and ecological outcomes of enhancement actions, ultimately informing management decisions and guiding full-scale restoration efforts.

4.2.2.1 Site Selection and Design

Goose Point Pilot Project focuses on reducing turbidity and establishing SAV with a primary emphasis on restoring EV communities. Achieving meaningful turbidity reduction across Utah Lake will require revegetation at a much larger scale, particularly in turbidity-generating zones. This underscores the importance of planning a follow-up demonstration project.

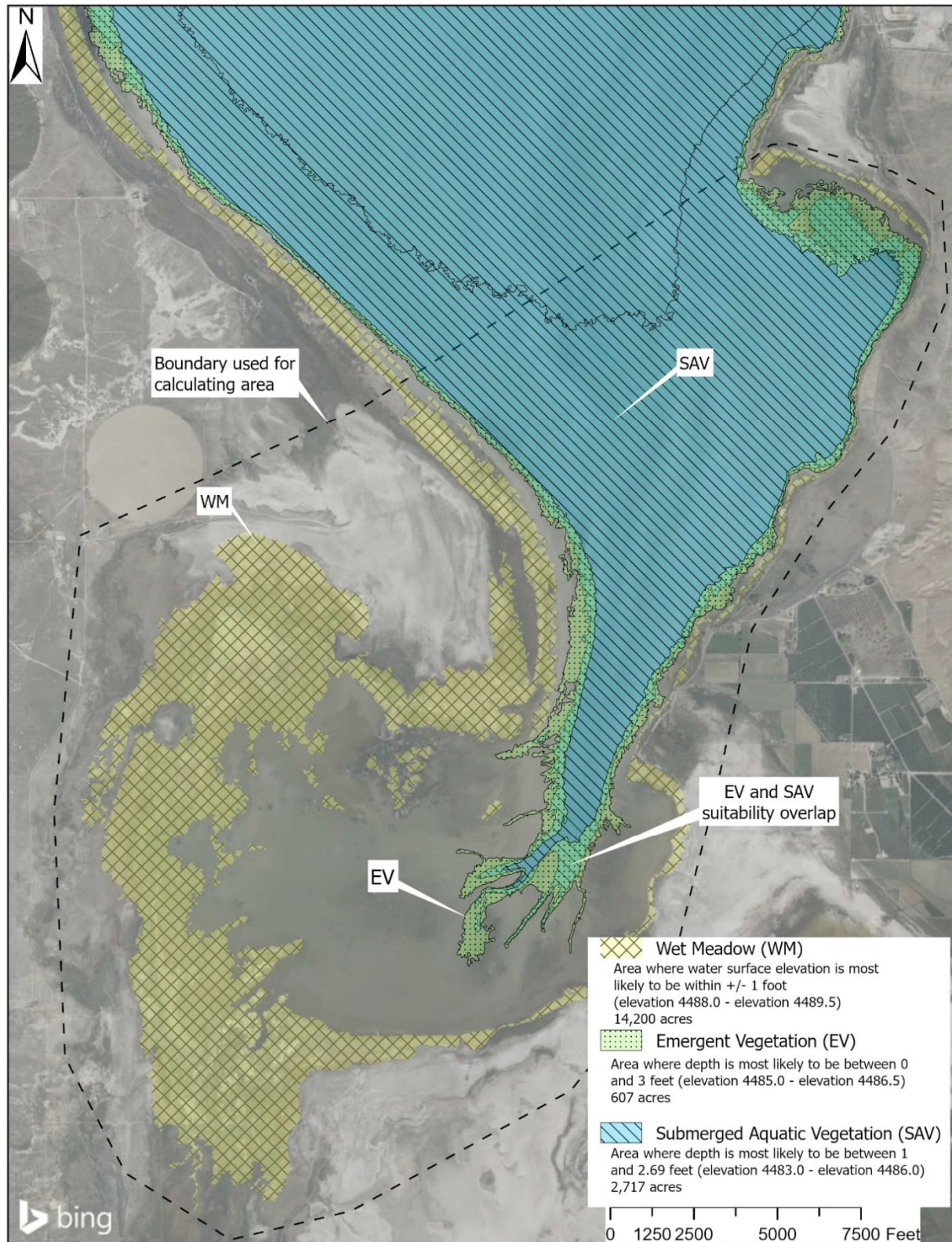
In accordance with the scaling criteria developed in this document, a 100-acre pilot study would be more functionally similar to 1,000 acres of wetland than it would be to 10 acres of wetland. A 10-acre plot has a large proportion of its area subject to edge effects in relation to turbidity abatement and habitat suitability for many bird species. Moreover, a 10-acre plot is vulnerable to disturbances that force the entire area into edge zone. In contrast, both 100-acre and 1,000-acre plots are mostly interior area with little vulnerability to disturbances.

The design philosophy at Goose Point—enclosing large areas with minimal carp barrier fencing—can be directly applied to potential demonstration sites in Goshen Bay and Provo Bay. While Provo Bay remains of interest, Goshen Bay presents fewer complications related to June sucker migration and land use.

A 4,000-foot fence in Goshen Bay could exclude carp from approximately 2,500 acres of wetland (Figure 4-6). Technically, Goshen Bay is as suitable as Goose Point, and the unit cost of revegetation would be lower. Because many project costs are fixed, the marginal cost of a longer fence is only slightly higher than that of a shorter one.

Although some areas in outer Goshen Bay may be more consistently suitable for SAV than the proposed inner demonstration site, deferring SAV-focused projects in these areas is recommended until experience is gained from Goose Point and inner Goshen Bay.

Figure 4-6. Goshen Bay Demonstration Project



Note: The dashed line represents a potential site for carp exclusion fencing.

Most of the proposed Goshen Bay demonstration project area is best suited to EV revegetation (Figure 4-6). Water depths are shallow, and the bay frequently dries out. Ecologically, the hydrology of WM to EV habitat predominates. Nevertheless, at this scale, an opportunity for SAV restoration is available, as well. In the mouth of Goshen Bay, roughly 200 acres of the proposed area are consistently inundated with about a foot of water about 80 percent of the time. At this scale, SAV communities likely can be established in this area.

EV are reasonably likely to outcompete SAV in this environment once the carp stressor is gone. However, at a larger scale, SAV may thrive in small patches amongst the EV. Hydrological conditions at the mouth of Goshen Bay more closely reflect lake-wide hydrology at a larger scale than at Goose Point. At Goose Point, the larger parcel protected by the sand and gravel berms has substantially less (one half to two thirds) of SAV suitability compared to the mouth of Goshen Bay. These differences can be decisive ecologically. Thus, Goshen Bay is likely to substantially add to the knowledge base gained by the Goose Point Pilot Project, which would be needed to plan lake-wide revegetation.

4.2.2.2 Implementation Logistics

While small-scale engineering structures may assist with localized revegetation, they are not a substitute for large-scale restoration. SAV restoration is unlikely to succeed outside of highly sheltered areas due to persistent inorganic turbidity. In demonstration-scale projects, these sheltered conditions will not be engineered but created through extensive revegetation of EV.

Lessons learned from Goshen Bay would apply directly to other potential revegetation parcels at large scale elsewhere in the lake. Carp is expected to be under control by the time a Goshen Bay demonstration project is mature, meaning large-scale exclosures would no longer be needed. Both Goose Point and Goshen Bay fencing would be removed in Phase 2. If carp removal requires more time, other areas in the lake could be suitable for similar scale follow-up projects.

Some areas in outer Goshen Bay are more consistently suitable for SAV than the proposed inner Goshen Bay demonstration project. A parcel in greater Goshen Bay could be fenced off for SAV revegetation; however, development of such a demonstration project would best await experience gained at Goose Point or inner Goshen Bay. However, several site-specific challenges may delay implementation in Goshen Bay:

- Permitting may be more difficult
- Coordination with landowners for construction access (at minimum) would need to be worked out
- Potential recreational access issues would need to be resolved. The current concept is that an electric carp barrier could protect a gap in the fencing while allowing boat access.

These planning-level issues for a Goshen Bay demonstration project could be investigated soon after the Goose Point Pilot Project is underway. Lessons learned from Goshen Bay would apply directly to other potential revegetation parcels at a large scale elsewhere in the Utah Lake area. Carp likely will be under control by the time a Goshen Bay demonstration project is mature, meaning large-scale exclosures would no longer be needed. Both Goose Point and Goshen Bay fencing would be removed. If carp removal requires more time, then other Utah Lake areas could be suitable for similar scale follow-up projects.

The Goose Point Pilot Project aims to reduce turbidity and establish SAV communities, with a primary emphasis on restoring EV communities. Meaningful reduction in Utah Lake turbidity will require thousands of acres of revegetation in turbidity-generating zones, which is why conceptualizing the follow-up demonstration project is important.

Phase 2 is not free of ecological uncertainties, but the nature of the uncertainties leads to answers at the scale of understanding needed for the revegetation of Utah Lake. From an engineering perspective, the fencing design requirements are uncertain, because the fencing would be exposed to strong wave forces when wind blows from the north. Unlike the Goose Point Pilot Project, sand and gravel bars would not offer protection from wave energy, and fencing will be more vulnerable to storm damage.

Each of these zones in Goshen Bay is larger than the entire Goose Point Pilot Project, some by over an order of magnitude. This scaling difference introduces some uncertainty. Although 100 acres and 1,000 acres have similar scale-dependent functions, there are differences. For example, the pilot project area likely will not have more than 10 to 20 acres of SAV, but Phase 2 will involve 10 times that amount of SAV, except during extremely low water years. If the SAV community experiences important scale-dependent effects, then Phase 2 will likely uncover them. Also, notably, most revegetation in Utah Lake will have to occur in open shore areas. Apart from the mouth of Goshen Bay, most of these areas are exposed to much stronger wave energy than lower Goshen Bay. Importantly, Goshen Bay encompasses the full range of littoral conditions found throughout Utah Lake, including riparian vegetation, WM, EV, and SAV. This diversity of habitat types, along with the scale, make Goshen Bay an ideal location for the Phase 2 demonstration project.

The greatest concern for fencing damage is ice shove. Preliminary engineering concepts for storm-vulnerable fencing indicate that proven design methods in harbors could be applied to the fencing. A comprehensive engineering study would need to be part of the design for Phase 2 to adequately address this uncertainty.

4.2.3 External Nutrient Management

With respect to the external nutrient management track, Phase 2 will largely involve tracking the nutrient implementation approach for the ULWQS and conducting phased, iterative management to evaluate the impacts of applying the numeric nutrient targets and the watershed implementation plan. Although numeric nutrient targets and watershed nutrient reduction strategies are currently unknown, ULWQS outcomes will involve navigating Utah's regulatory context and engaging in permitting, reduction strategies, monitoring, and outreach. This process should be conducted within the PEF framework, wherein strategies will be implemented based on an updated understanding of current conditions and changes from previous strategy implementation informed by monitoring data.

4.2.4 Human Use Enhancement

Phase 2 of the human use enhancement management track of the PEF builds on the foundational work of Phase 1. As the ULA and its partners implement the short-, mid-, and long-term strategies outlined in the ULMP (ULA 2024) and the ULRAP (ULA 2025, in progress), Phase 2 will emphasize the importance of tracking key performance indicators, reporting progress transparently, and adjusting course as needed to meet evolving recreational, ecological, and community needs.

5. Discussion

The ULS represents a significant opportunity to complete one of the largest ecological enhancement projects of its kind. The PEF will be key to the success of the project; however, extensive coordination will be required to implement it successfully. Additionally, it is important to attempt to anticipate potential unanticipated responses to some of the strategies to be implemented as part of the PEF.

5.1 Critical Success Factors

FFSL plays a pivotal role in coordinating the ULS PEF. FFSL is responsible for managing state sovereign lands—including the bed of Utah Lake—in public trust, which includes ensuring public access, supporting economic development, and preserving recreation on the lake. In addition, FFSL acts as the convening agency that encourages coordination among state agencies to conserve the ecological integrity of Utah Lake.

FFSL's leadership will be critical to the following:

- Coordinating interagency efforts to align recreation, conservation, and infrastructure goals
- Coordinating with other jurisdictional agencies on regulatory compliance of Utah Lake enhancement projects
- Facilitating funding mechanisms and legislative support for long-term lake enhancement
- Upholding and managing sovereign land resources in the public trust under multiple-use, sustained-yield management principles

5.2 Addressing Uncertainty: Surprising Ecological Outcomes

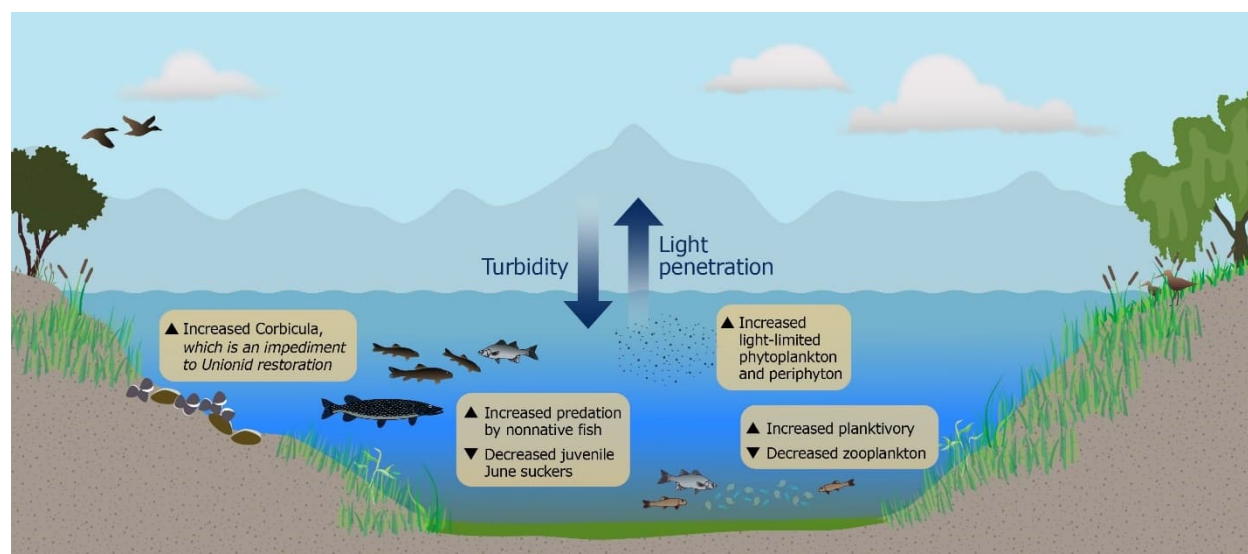
Utah Lake is an altered ecosystem, having shifted from a clear-water, macrophyte-dominated state to a turbid, phytoplankton-dominated one. The lake's trophic structure and function has shifted from one dominated by native species to one currently dominated by nonnative and pollution-tolerant species. Manipulating stressor pressures in the lake through management actions can potentially trigger cascading effects throughout the lake's food web that, through complex interactions and feedback loops, can impact species and processes in ways that are generally expected to be beneficial to the ecosystem but in some cases may not be immediately apparent (Sondergaard et al. 2007; Bernes et al. 2015; Meerhoff and Beklioglu 2024). For example, although the implementation of management actions to reduce the impacts of primary stressors, such as carp, wind/wave-driven sediment resuspension, and nutrients, are expected to contribute toward improving the overall health of the Utah Lake ecosystem, surprising or unexpected ecological outcomes are possible. The proposed pilot and demonstration projects are of sufficient scale to potentially reveal some ecological surprises. Recognizing and anticipating these ecological outcomes, however, will contribute to the overall understanding of the lake's ecology and provide the basis for a comprehensive and well-informed approach to managing enhancement strategies and actions at Utah Lake.

The PEF described in this ULS is particularly well-suited for advancing understanding of ecological outcomes as stressor pressures are gradually reduced. Actions that mitigate key stressors within each of the four management tracks of the PEF create valuable

opportunities to monitor and evaluate ecosystem responses. These efforts may also help uncover underlying uncertainties, as unexpected outcomes emerge over time.

For example, a shared goal across several Phase 1 implementation strategies, such as invasive carp control, reduction of wind- and wave-induced sediment resuspension, reduction of external nutrient loading, and establishment of native aquatic vegetation, is to reduce algal and inorganic turbidity in the lake. This would increase light penetration to the benthic zone, thereby promoting the establishment of benthic primary productivity (SAV and periphyton). The establishment of benthic primary productivity throughout Utah Lake is likely a critical factor in ultimately improving its water quality by stabilizing clear-water regimes (King et al. 2023). However, the potential also exists for some surprising outcomes as enhancement actions improve turbidity and light availability in Utah Lake. A few examples of such outcomes are conceptually presented on Figure 5-1.

Figure 5-1. Potential Unintended Outcomes of Reduced Turbidity in Utah Lake



5.2.1 Potential Increases in Invasive Clams (*Corbicula*) and Implications for Native Mussel Reintroduction

Native bivalve mollusks (mussels and clams) were historically abundant in Utah Lake and its associated tributaries but are now largely extinct or nearly extinct within the lake (Richards 2022). The likely causes for their extinctions from Utah Lake include, among other factors, high levels of inorganic turbidity, variable water levels, loss of aquatic vegetation and habitat, direct and indirect impacts from invasive fish species such as carp, and, in the case of unionid mussels, the loss of host fish species that are necessary to complete their unique reproductive cycle (Richards 2017; Goldsmith et al. 2021; Luck and Ackerman 2022). These filter-feeding benthic mollusks were historically present in large numbers in Utah Lake (Richards 2017) and were likely largely responsible for maintaining the integrity and stability of the lake's substrate through their burrowing activities and metabolic processes and for maintaining water quality and clarity through their filtration activities. Native bivalve mollusks likely also played an important role in nutrient cycling within the lake by filtering organic matter and detritus and by processing and releasing bioavailable nutrients into the water column to promote primary productivity (Richards 2022; Verma et al. 2025).

The ecological niche once occupied by native bivalves in Utah Lake has now been largely replaced by a highly invasive and relatively pollution-tolerant bivalve, the Asian clam, *Corbicula fluminea* (Richards 2022). Although *Corbicula* are currently present in Utah Lake, they occur in relatively lower densities (Richards 2022) than observed in lake systems with more suitable habitats. Some of the same stressors that caused the demise of native bivalves in Utah Lake likely also affect *Corbicula*. *Corbicula* are relatively more tolerant of degraded conditions than native bivalves (Tuttle-Raycraft et al. 2017; Zhang et al. 2023), but their populations can still be limited once their tolerance thresholds for specific stressors are exceeded.

High levels of turbidity caused by wind/wave-driven resuspension of primarily inorganic sediment in Utah Lake (Randall et al. 2019) likely play a key role in controlling *Corbicula* densities. Avelar et al. (2014) reported that *Corbicula* are increasingly intolerant of turbidity levels exceeding 150 nephelometric turbidity units (NTUs) and suffer high levels of mortality above this threshold. Turbidity levels measured at four locations (Vineyard, State Park, Provo Bay and Bird Island) in Utah Lake exceed this threshold (Tetra Tech 2025a). Turbidity data measured with sondes deployed at buoys from April to November at these four sites indicate that turbidity exceeded 150 NTUs 12 percent of days at Vineyard, 6 to 7 percent of days at Provo Bay, and 2 to 3 percent of days at State Park and Bird Island (Tetra Tech 2025a). Such exceedances in turbidities could conceivably be responsible for maintaining *Corbicula* densities at the current low levels observed in the lake.

High levels of turbidity are also known to exert a metabolic cost on filter-feeding bivalves that need to process and sort unpalatable inorganic particles (sediment) from food particles (algae); inorganic particles are subsequently bound up and discarded as pseudofeces. The lower clearance rate of food particles and increased energetic cost associated with processing suspended sediment can thus negatively affect the growth and condition of filter-feeding bivalves living in waters with high turbidities (Madon et al. 1998; Avelar et al. 2014). The high energetic cost of processing inorganic sediment could conceivably be manifested sub-lethally as poor growth and poor condition of *Corbicula* even below 150 NTUs turbidity in Utah Lake.

Decreasing levels of turbidity in Utah Lake following enhancement actions may create conditions that could trigger significant increases in *Corbicula* populations within the lake (Figure 5-1). As a widely successful invasive species that is tolerant of a broad range of environmental conditions, *Corbicula* can quickly capitalize on improving turbidity within the lake and outcompete and prevent other desirable but far less tolerant native species from establishing. For example, unlike native mussels, *Corbicula* are hermaphroditic, capable of very high reproductive potentials, and do not have specialized reproductive cycles that are dependent on specific host fish species (Modesto et al. 2025; Haag et al. 2021). Further, *Corbicula* are relatively less sensitive to high levels of total suspended solids (TSS) than native mussels, especially when the TSS has relatively high organic content (Tuttle-Raycraft et al. 2017; Zhang et al. 2023). *Corbicula* is thus likely to be one of the first bivalve species to take advantage of reduced turbidity in the lake.

The turbid environment of Utah Lake currently poses an immense challenge for reintroducing native unionid mussels to the lake. Goldsmith et al. (2021) report that significant declines in native mussel biodiversity occur in environments where relative shear stress (RSS) exceeds a value of 1.0. RSS is a measure of substrate stability in response to wind/wave-related scour and entrainment. RSS estimated at the Vineyard, State Park, Provo Bay, and Bird Island sites in Utah Lake all frequently exceed this threshold of 1.0 (Tetra Tech 2025a), and, on average, these exceedances occur at turbidities exceeding

80 NTUs to 100 NTUs. Data from other studies suggest that such conditions create inhospitable environments for native mussels (Goldsmith et al. 2021; Tuttle-Raycraft et al. 2017). Even when water clarity improves as a result of enhancement actions, increasing populations of *Corbicula* can still pose a significant impediment to efforts aimed at restoring populations of native unionid mussels in Utah Lake. Studies have shown that *Corbicula* can have multiple negative effects on native mussel populations and are directly linked to widespread declines of native freshwater mussels elsewhere (Haag et al. 2021).

The potential increase in populations of *Corbicula* in Utah Lake could provide inadvertent benefits in some respects. *Corbicula* are prodigious filter feeders, capable of clearing TSS from large volumes of water in relatively short periods of time (Li et al. 2023). Gu et al. (2020) provided empirical evidence that, as highly efficient filter feeders, *Corbicula* alleviated the harmful effects of small crucian carp on submerged macrophyte and benthic algae growth by promoting a clear-water state that increased benthic primary productivity. As such, *Corbicula* substantially lowered TSS loads and chlorophyll-a concentrations in the water column within a week, promoting better light conditions that spurred the growth of submerged macrophytes and benthic algae. Increased benthic algae and plants stabilized the sediment layer, thereby reducing carp-driven resuspension of sediment and, through positive feedback mechanisms, also removed nutrients from the water column. In addition, *Corbicula* enriched the sediment total nitrogen and total phosphorus content by binding particles from the water column and depositing them in the sediment as feces and pseudofeces, further favoring macrophyte growth. *Corbicula* could thus potentially act as freshwater mussel surrogates in Utah Lake, taking over the roles of promoting and maintaining sediment stability, submerged macrophytes, and benthic primary productivity within the lake.

Despite the potential benefits of *Corbicula* to water clarity and benthic primary productivity, it is a highly successful and prolific invasive species that is widely known for its multiple negative impacts on lacustrine and riverine ecosystems. These negative impacts include the following, among others (Modesto et al. 2025):

- Competition with and suppression and displacement of native mollusks and other benthic macroinvertebrates
- Alterations in biogeochemical cycles, primarily through nutrient excretion
- Addition of potentially toxic levels of ammonia caused by periodic massive *Corbicula* die offs (for example, winter die offs due to severe cold temperatures)
- Alterations in biotic interactions in planktonic and benthic communities mediated by its multimodal filter-feeding, suspension-feeding, and pedal-feeding activities
- Bioconcentration of viable blue-green algae and its subsequent deposition in pseudofeces, which may locally promote blue-green algae blooms

In conclusion, both how existing populations of *Corbicula* in Utah Lake are likely to respond to improving water clarity following specific enhancement actions and the specific effects that increases in *Corbicula* populations may have on the lake's ecology remain uncertain. Other factors (for example, water temperature, substrate type, and other water quality parameters) may also be responsible for exerting controls over *Corbicula* populations in Utah Lake (USFWS 2024), but turbidity appears to be the dominating factor (Avelar et al. 2014). *Corbicula* populations need to be monitored in Utah Lake to facilitate management actions in case this species increases with improving conditions from enhancement actions.

5.2.2 Increased Predation by Nonnative Fish on June Suckers

High levels of turbidity in aquatic systems provide a form of refuge from predation, because they can influence predator–prey interactions by reducing the foraging efficiency of visual predators (Snow et al. 2018). Utah Lake has several species of nonnative fish, including white bass, channel catfish, largemouth bass, northern pike, and walleye, that rely heavily on vision to locate and capture prey (USFWS 1999). These species are voracious predators of juvenile fish, and some, such as walleye and white bass, have been linked to the decline in June suckers observed within the Utah Lake system (USFWS 1999; Belk et al. 2001). A decline in turbidity (increased water clarity) could conceivably further exacerbate predatory pressures on June sucker populations by allowing nonnative fish predators to detect prey from greater distances, thus facilitating their capture.

Conversely, June suckers are also visual planktivores, with preferences for relatively small-bodied zooplankton species, such as *Bosmina* and *Ceriodaphnia* (USFWS 1999). The current high levels of turbidity in Utah Lake likely interfere to some degree with prey detection and capture of small-bodied zooplankton by June suckers. Improved water clarity in the future could thus increase feeding efficiency in June suckers.

The critical role of native EV and SAV as areas of refuge for June suckers cannot be understated in this case. Native aquatic macrophytes provide refuge for larval and juvenile June suckers from nonnative fish predators (Andersen et al. 2007); this form of refuge will become even more critical once the protective effects of turbidity are reduced with improving water clarity. Such vegetated areas of refuge are relatively sparse within Utah Lake, and enhancement actions that include passive and active revegetation efforts, if successfully implemented, will support overall conservation efforts for June suckers, as well (Andersen et al. 2007).

Declining turbidity also could mediate shoaling behavior in June suckers. Shoaling has been reported in all ages of June sucker, but the benefits of this behavior appear to differ with fish size or age (Billman 2008). Juvenile June suckers in shoals are likely to benefit from reduced risk of predation due to the increased collective ability to spot predators and the safety conferred by large numbers of fish in a shoal (predator confusion in targeting prey). Conversely, large adult fish with fewer predators than juveniles likely benefit primarily from increased foraging efficiency conferred by shoaling, which collectively increases the probability of detecting suitable patches of plankton (Billman 2008). The effects of turbidity on shoaling (schooling) behavior appear to be species specific. Some studies report stronger and tighter shoal formations with increasing or higher turbidity, likely because of perceived danger from reduced visibility (Horka and Vlachova 2024; Lekanda et al. 2025). Although how June suckers will respond to declining turbidity in Utah Lake is unknown, improving water clarity nonetheless has the potential to mediate their shoaling behavior, with associated implications for their predation risk and foraging efficiency.

5.2.3 Zooplankton and Size-Selective Planktivory by Visual Predators

Zooplankton occupy a key ecological niche within lakes. As primary consumers, zooplankton are a critical link between the lake's primary producers (phytoplankton) and its higher trophic levels (planktivorous fish). Zooplankton provide multiple ecosystem services through their filtering and feeding activities, consuming and regulating the structure and abundance of phytoplankton communities within lakes, helping control cyanobacterial blooms, and regulating water quality. Zooplankton, in turn, are a food source for a wide variety of

planktivorous fish, including the larval and juvenile stages of piscivorous fish and other macroinvertebrates. The metabolic activities of zooplankton, including the consumption and excretion of nutrients, contribute to nutrient cycling within lakes, in turn regulating phytoplankton growth and lake productivity (Declerck and Domis 2023).

Utah Lake supports a zooplankton assemblage of approximately 17 taxa represented by various species of cladocerans, copepods, and rotifers (Richards and Miller 2017); however, the effective number of species, a standardized measure of species diversity, is about 3 to 4. This diversity is quite low in comparison to other lakes in North America (Richards 2022). Predation on zooplankton by the large number of nonnative planktivorous fish in Utah Lake likely contributes to the low diversity observed in its zooplankton assemblage. Moreover, size-selective planktivory is indicated in Utah Lake, where preference for large-bodied zooplankton (for example, *Daphnia* sp.) by planktivorous fish has likely shifted the zooplankton assemblage to small-bodied individuals (Richards and Miller 2017; Richards 2022). Landon and Walsworth (2004) and Landon et al. (2025) demonstrated a shift towards larger-bodied zooplankton taxa following the decline in carp biomass in Utah Lake. Such size-selective planktivory and its effects on zooplankton community structure has been widely observed in other shallow lake systems (Jeppesen et al. 2001; Iglesias et al. 2007).

Wind/wave-induced turbulence and turbidity are likely other factors regulating the composition and size structure of the zooplankton assemblage in Utah Lake. The frequently turbulent and turbid conditions in shallow lakes that lack macrophytes are known to have detrimental effects on the feeding, growth, and reproduction of various species of zooplankton (reviewed in Zhou et al. 2018). High levels of inorganic suspended solids could mechanically interfere with food collection or dilute gut contents, resulting in less food being assimilated. Food limitation can lead to reduced reproductive output. Wind/wave-driven turbulence can also result in injury from abrasion and turbulent shear forces (Zhou et al. 2018). Empirical evidence indicates that large-bodied cladocerans and copepods are disproportionately affected in a negative manner by turbulent and turbid conditions than small-bodied rotifers and that such conditions can shift the zooplankton community size structure to one dominated by small-bodied species (Zhou et al. 2018). Wind/wave-driven turbulence and turbidity likely play a similar role in structuring the zooplankton community in Utah Lake.

Large-bodied zooplankton, such as *Daphnia*, are considered keystone species in the pelagic food web. As nonselective feeders with high grazing rates, *Daphnia* are capable of markedly reducing phytoplankton biomass, even reducing cyanobacteria and suspended sediments in the water column and are key to maintaining water clarity in shallow lakes (Jeppesen et al. 1999). The relatively low abundance of large-bodied zooplankton is likely at least partially responsible for maintaining the current phytoplankton-dominated turbid state in Utah Lake (Richards 2022).

Enhancement actions that reduce turbidity and improve water clarity will likely have an overall positive effect on the zooplankton community and size structure in Utah Lake, provided such enhancement actions also promote the establishment of native macrophytes, especially SAV. Stands of native macrophytes provide daytime refuge to large-bodied zooplankton such as *Daphnia* and other cladocerans from size-selective planktivory by visual predators such as zooplanktivorous fish (Meerhoff and Beklioglu 2024). The larvae and juveniles of even piscivorous sportfish in Utah Lake all go through a zooplanktivorous stage. As such, all fish species present in Utah Lake consume zooplankton at some stage in their life cycle. Clearer water would allow these fish to detect and target larger zooplankton more effectively. Without the refugia provided by native macrophytes, planktivorous fish can

exert even stronger selective pressures on large-bodied zooplankton than under turbid conditions, maintaining the dominance of small-bodied zooplankton that are less vulnerable to visual predation but also far less efficient at clearing phytoplankton and other suspended solids from the water (Meerhoff and Beklioglu 2024).

5.2.4 Shading Effects by Light-Limited Phytoplankton and Periphyton

Utah Lake is a highly turbid and phytoplankton-dominated system. The lake lacks extensive stands of native macrophytes, which serve as physical barriers against wind and waves and stabilize the lake's sediment layer to reduce turbulence and sediment resuspension. This lack of native EV and SAV in Utah Lake is in large part responsible for maintaining the lake in its current turbid, phytoplankton-dominated state via sediment resuspension and internal nutrient loading from the sediment that promotes phytoplankton growth (Jacobs 2025).

Inorganic and algal turbidity markedly reduce light penetration in Utah Lake, limiting the establishment and growth of SAV (Jacobs 2025; King et al. 2023). Limited light availability mediated by inorganic and algal turbidity can also significantly restructure phytoplankton communities in shallow lakes by limiting photosynthesis, thereby restricting the growth and abundance of phytoplankton species that are less tolerant of low light conditions and promoting the proliferation of shade-tolerant species; the latter includes several species of cyanobacteria (Meerhoff and Beklioglu 2024; Scheffer et al. 1997; Scheffer and van Nes 2007). Positive feedback mechanisms further reinforce the dominance of shade-tolerant phytoplankton, that is, the increasing biomass of shade-tolerant phytoplankton contributes to turbidity by self-shading, limiting light penetration and creating low light conditions that further promote their growth (Scheffer et al. 1997); there is evidence that these mechanisms are at play in Utah Lake, as indicated by the presence of shade-tolerant phytoplankton, including certain cyanobacteria that are known to cause HABs (Richards 2018; 2019). Light limitations in Utah Lake also limit the growth of periphyton, which contributes to benthic primary productivity and is responsible for stabilizing and protecting sediments from wind/wave-induced resuspension (King et al. 2023).

Reducing abiotic and biogenic turbidity through the implementation of enhancement actions in Utah Lake will likely increase light penetration, benefiting light-limited phytoplankton, periphyton, and SAV. Reduced turbidity can likely induce shifts in phytoplankton community composition toward light-limited species and shift the balance between phytoplankton and periphyton, potentially leading to increased periphyton biomass due to greater light availability (King et al. 2023). However, specific responses will also be mediated by nutrient availability, among other factors (Phillips et al. 2016; Li et al. 2025).

Excessive growth of periphyton due to greater light availability, however, has the potential to also significantly limit the growth of SAV by reducing light availability and through competition for nutrients (Phillips et al. 2016; Li et al. 2025). Periphyton (epiphytes) growing on the shoots and leaves of SAV can impact SAV growth by intercepting light before it reaches the photosynthetic structures of SAV (for example, chloroplasts within mesophyll cells), thereby inhibiting SAV photosynthesis. Periphyton and SAV also compete for nutrients like nitrogen and phosphorous; the rooted forms of SAV can access such nutrients from the sediment, whereas periphyton are superior in nutrient uptake from the water column (Phillips et al. 2016; Li et al. 2025).

Macroinvertebrate grazers, most importantly gastropods (snails), play a key role in grazing and controlling periphyton growing on the SAV surfaces (Cheng et al. 2023). Snail grazing

prevents shading of SAV by periphyton while facilitating the cycling of nutrients and mediating nutrient uptake from the water column by regulating periphyton growth (Koleszar et al. 2022; Cheng et al. 2023). Utah Lake has lost much of its species-rich native gastropod assemblage, which is now dominated by just two pollution-tolerant species, *Physella* and *Stagnicola* (Richards 2022). Whether these remnant gastropod species can fulfill the functional role of grazing and controlling periphyton growth on SAV is uncertain. Other studies have reported that grazing by *Physella* and *Stagnicola* (reported as *Lymnaea*) can effectively control periphyton biomass and promote the maintenance of healthy macrophytes (Pinowska 2002; Munoz et al. 2001; Swamikannu and Hoagland 1989). Whether *Physella* and *Stagnicola* can fill this essential ecological niche to maintain SAV once improved conditions allow SAV establishment in Utah Lake is uncertain, yet conceivable.

The scenarios of potential ecological outcomes presented in this section are not meant to exhaustively cover the ecological interactions and dynamics that can be expected to occur with the implementation of enhancement actions in Utah Lake. Rather, these scenarios are presented as a few examples of some expected and some potentially surprising outcomes as turbidity is reduced and light availability improves in Utah Lake to highlight the complex ecological interactions, feedback loops, and uncertainty inherent in the system.

Stands of native EV in the shallow littoral zone provide a natural barrier against wind/wave-generated turbulence and turbidity, which can be particularly intense in the shallow littoral zones of Utah Lake. Shallower water allows wind-generated waves to interact more directly with the lakebed, increasing bed shear stress. This shear stress can resuspend sediments, especially fine particles, contributing to higher turbidity (Tetra Tech 2025a). If littoral sediments are coarser or already scoured (for example, gravel or sand), they may be less prone to resuspension. Conversely, if fine sediments are present, they can be easily mobilized, increasing turbidity in shallower areas.

Native EV plays an important role in improving water clarity by stabilizing lakebed sediments; through nutrient uptake; and by providing habitat for fish, invertebrates, birds and other wildlife (van Leeuwen et al. 2023). Enhancement actions aimed at establishing native EV plants at Utah Lake would contribute to reducing suspended sediment loads through wave energy attenuation and trapping and depositing of sediment particles while providing other ecological services. This process would also set the stage for improved water clarity conditions in adjacent deeper littoral zones, priming those areas for SAV establishment through passive and active means.

The establishment of SAV in the deeper littoral zone is also of importance to Utah Lake due to the roles that SAV plays in stabilizing the sediment, retaining and cycling nutrients, promoting and maintaining water clarity, providing food and habitat for many aquatic organisms, and supporting aquatic biodiversity (King et al. 2023; Bakker et al. 2013; Hilt et al. 2006; Hilt et al. 2018).

Importantly, the scenarios presented previously (Figure 5-1) highlight the central role that native macrophytes are expected to play in their interactions with other components of Utah Lake's ecology and in improving the overall ecological condition of Utah Lake, summarized as follows:

- ***Corbicula* and SAV:** *Corbicula* is an invasive species known to exist in Utah Lake, although populations appear to remain low, likely due to high concentrations of suspended sediment above the ideal range for the species. A decrease in suspended sediment concentrations could allow *Corbicula* populations to expand in the lake. Increased filtration of suspended solids by *Corbicula* in Utah Lake and subsequent

transfer of nutrients from the water column to the sediment could further facilitate clear-water conditions and support the establishment and growth of SAV and benthic algae, thereby stabilizing sediments and making them less prone to bioturbation and wind/wave-related resuspension. In this respect, *Corbicula* could unexpectedly fill the ecological role previously fulfilled by native mollusks in Utah Lake. However, *Corbicula* should be managed as a threat to the Utah Lake ecosystem and will need to be controlled if populations begin to expand.

- June suckers and native macrophytes: Native EV and SAV provide important areas of refuge for larval and juvenile June suckers. Macrophyte refugia becomes even more critical for June sucker conservation efforts once the protective effects of turbidity (through deterrence of visual predation) are diminished by improving water clarity.
- Zooplankton and native macrophytes: Native macrophytes provide refugia and protection from size-selective planktivory to large-bodied keystone zooplankton species such as *Daphnia* and other cladocerans. Large-bodied zooplankton are far more efficient than small-bodied species at removing biogenic and abiogenic suspended solids from the water and play an important role in promoting and maintaining water clarity. Once turbidity begins to decline, predation on large-bodied zooplankton by size-selective planktivorous fish is likely to increase because visual predators can detect prey from greater distances with improved water clarity. Once turbidity declines in Utah Lake, predation refugia provided by native macrophytes will be critical to maintaining populations of keystone zooplankton species and their important filter-feeding functions that benefit water quality.
- Phytoplankton, periphyton, and SAV: Shifts in the phytoplankton community structure from shade-tolerant to light-limited species can be expected with reduced turbidity and improved light penetration in Utah Lake, including a shift in the balance between phytoplankton and periphyton, mediated by greater light availability at the bottom of the lake and by competition for nutrients. Periphyton growth is beneficial to Utah Lake because of its role in supporting sediment stability and maintaining water clarity. However, excessive growth of periphyton on SAV can potentially limit SAV growth by reducing light availability and through competition for nutrients. Grazing activities by remnant gastropods in Utah Lake, such as *Physella* and *Stagnicola*, will be critical to maintaining periphyton cover at levels that are not detrimental to SAV.

5.3 Legislative Mandate, Jurisdictional Boundaries, and Ecological Considerations

S.B. 270 directs FFSL to conduct a study identifying strategies to enhance conditions at Utah Lake. However, FFSL's jurisdiction is limited to the lake's sovereign lands, as defined by the negotiated settlement boundary. All activities undertaken as part of the ULS must align with FFSL's statutory authority over these lands. In fulfilling this directive, FFSL is also required to respect and preserve existing water rights and interests related to water collection, storage, and delivery.

While FFSL's scope is confined to the lake itself, many factors influencing Utah Lake's health originate outside this boundary, within the broader watershed. These include land use planning, water quality protection, watershed restoration, regulation of surface and groundwater inflows, water supply and conservation planning, and reservoir operations—particularly the management of lake water levels. These responsibilities fall under the jurisdiction of other state agencies with the appropriate regulatory mandates (see Table 1-2).

This dual mandate presents a complex challenge. FFSL must evaluate and support opportunities for water conservation, ecological restoration, and enhanced human use while remaining within its legal boundaries and avoiding encroaching on the responsibilities of other agencies. Successfully navigating this challenge requires close coordination with partner management agencies who have direct management authority over the various resources of Utah Lake. FFSL, partner agencies, and stakeholders should continue to coordinate, seeking opportunities for increased coordination and collaboration with greater efficiency.

5.3.1 Conserving Water Resources in and Around Utah Lake

As part of the review of existing information for the ULS (Appendix A), fluctuations in lake levels have been identified as a significant ecological stressor. The magnitude and rate of water-level change, along with the duration of dry and inundated periods along the shoreline, affect the restoration and functionality of the littoral zone—an area critical to the lake’s ecological health. However, FFSL does not have the authority to directly manage lake levels or mitigate this stressor.

Beyond lake-level variability, altered tributary flows and channel modifications have further stressed the Utah Lake system. Diversions, channelization, and dredging have reduced the functionality of tributaries, with some no longer reaching the lake in some years. These changes have also impacted hydrologically connected wetlands, which serve as natural filtration systems by capturing sediments and retaining excess nutrients and pollutants before they enter the lake. Hydrologically connected wetlands impact water quality, native species abundance, and invasive vegetation.

To address these issues, Utah Lake may benefit from formal programs that restore tributary flows in alignment with the hydrologic needs of connected wetlands—such as the Provo River Delta Restoration Project—and/or establish mechanisms to dedicate conserved water to the lake in support of ecological and water quality goals. The Spanish Fork River could be a good candidate for stream flow and delta restoration. Currently, no programmatic mechanism exists to dedicate conserved water to Utah Lake, as is available for the Great Salt Lake.

Although developing such programs would be beneficial, doing so would present challenges in the context of broader water scarcity concerns across northern Utah and the state as a whole. Any such initiatives would need to be pursued in coordination with partner agencies and with financial support from the legislature.

5.3.2 Coordination

Enhancing Utah Lake requires a holistic, multiagency approach grounded in a shared vision. Despite its jurisdictional limitations, FFSL plays a critical role in supporting water resource outcomes through its stewardship of sovereign lands, habitat restoration efforts, and ecological enhancement initiatives. Its continued leadership in these areas will be essential to advancing the goals of the ULS in a collaborative and legally responsible manner.

5.3.3 Challenges and Limitations of the Current Utah Lake Management Framework

PEF implementation faces several significant challenges and limitations that must be addressed to promote its success, including the following:

- **Governance structure:** Utah Lake's management is distributed across multiple state agencies, each with distinct statutory mandates. No single entity holds overarching authority for implementation, necessitating a coordinated, multiagency approach grounded in a shared vision. Strong leadership and a continuation of effective collaboration and coordination are essential to successful enhancement of Utah Lake.
- **Water-level variability:** Fluctuations in lake water level, driven by reservoir operations, upstream storage, downstream demands, and drought condition, pose a major ecological challenge. These variations affect the littoral zone, a critical habitat for native aquatic species and vegetation. Periodic exposure and inundation of sediments disrupt restoration efforts, sediment stabilization, and nutrient cycling. Large-scale littoral zone restoration efforts are hindered by inconsistent water levels that do not follow natural hydrologic cycles.
- **Staffing constraints:** Additional resources will be needed to successfully coordinate and implement the PEF, including dedicated personnel across multiple agencies. Without additional staffing resources, the capacity to plan, coordinate, and execute enhancement activities will remain constrained.
- **Funding limitations:** To date, federal funding has supported many of the lake's enhancement initiatives. However, this funding has significantly declined in recent years. For Utah to make meaningful progress, a dedicated and sustainable state-level funding source is needed, one that supports both staffing and long-term project implementation.
- **Jurisdictional boundaries and scope limitations:** Many of Utah Lake's ecological stressors, such as nutrient loading, watershed-scale land use, and upstream water management, originate beyond the sovereign lands' negotiated settlement boundary of Utah Lake. Addressing these broader issues requires strategic partnerships and coordinated planning efforts between lake managers and other agencies and entities beyond the meander line.
- **Anticipating population growth and policy impacts:** Future planning must account for demographic shifts and evolving land use policies that may influence lake health. A robust communication strategy will be essential to disseminate enhancement program information to land use planners, lakeshore municipalities, and other regional policy makers in a timely and accessible manner.
- **Climate change and drought:** The ongoing drought and continually changing climate are variables that cannot be controlled but have a large impact on Utah Lake. The uncertainty associated with drought and climate reinforce the importance of the phased approach to Utah Lake enhancement, as conditions will change over time due to the impacts of drought and climate.
- **Centralized data management:** A centralized data repository will be essential for the successful implementation of the PEF. Serving as the backbone of the program's phased approach, this repository will enable transparent decision-making, efficient resource allocation, and consistent monitoring across agencies and stakeholders. By consolidating ecological, hydrological, and management data into a single, accessible platform, the repository will reduce duplication of data collection and analysis efforts among agencies. This will lead to more efficient use of public resources and foster interagency collaboration. Furthermore, the repository will support standardized data formats and protocols, allowing for consistent tracking of restoration outcomes and adaptive management over time. The repository also will facilitate integration with GIS platforms, remote sensing technologies, and academic research, enhancing the program's capacity for long-term planning and innovation. Ultimately, the centralized data repository will

allow all entities involved in the enhancement of Utah Lake to work from a shared, comprehensive, and transparent foundation, which is critical for the program's success.

5.3.4 Additional Considerations

The following additional considerations related to PEF implementation pertain to changing stressors, urban expansion, water scarcity, and infrastructure proposals:

- Changing stressor profiles: As development expands southward, agricultural nutrient inputs may decline, and wastewater and stormwater discharges could increase. This is one specific example of changing stressor profiles; however, other unanticipated factors may come become relevant in the future.
- Wetland loss: Urban expansion may result in the loss of hydrologically connected wetlands, which play a critical role in supporting the lake's ecological integrity.
- Water scarcity: Utah Lake's water resource management must be considered within the broader context of regional water scarcity, particularly in relation to the Great Salt Lake. Reduced upstream inflows could impact restoration efforts.
- Infrastructure proposals: Future development proposals, including bridges, shoreline modifications, and other infrastructure, will require thorough ecological and hydrological evaluation to confirm compatibility with Utah Lake enhancement goals identified in S.B. 270.

5.4 Key Messaging for the Utah Lake Study

This section provides FFSL with a communication resource to support outreach and engagement with external stakeholders about the ULS. The purpose of this communication resource is to ensure consistency and clarity in conveying ULS findings and future actions, fostering a shared understanding across diverse audiences. For the ULS, external stakeholders include the general public; media representatives; elected officials; lakeshore municipalities; nongovernmental organizations; and state, local, and federal agencies.

Following are potential discussion topics; however, FFSL is expected to exercise discretion in selecting and tailoring key messages to suit the context and needs of individual stakeholder interactions.

Utah Lake Study versus Phased Enhancement Framework? What is the difference?

- ULS is the study commissioned by the 2024 legislature through S.B. 270 that tasks FFSL with conducting a comprehensive study to identify strategies for enhancing ecological function and promoting public use and enjoyment of the lake. This ULS is that document.
- PEF is the framework to implement the findings of the ULS. S.B. 270 tasks FFSL with reporting the findings of the ULS and a proposed plan to implement the findings. The PEF is that plan.

Yet another study? Really?

Acknowledge that stakeholders want action, not another study. FFSL shares that perspective developed the PEF specifically to respond to it. The PEF is designed to implement targeted enhancement strategies within small, controlled, and low-risk environments. Rather than continuing to reassess known challenges, the program focuses on evaluating the

effectiveness of specific solutions. This marks a shift from theoretical analysis to practical, actionable enhancement efforts.

What were the key findings of the Utah Lake Study?

- Key takeaways: Enhancement of Utah Lake cannot be achieved overnight or through a single large-scale intervention. Also, addressing one single stressor alone will not resolve the lake's challenges, and no single agency can solve the lake's challenges. The PEF acknowledges this and employs a multipronged approach to address key stressors simultaneously.
- Primary environmental and logistical stressors: Utah Lake has several environmental stressors and mitigating them will require a coordinated response. The key environmental stressors affecting the lake are invasive carp populations; excess nutrient loading; sediment instability caused by wind, wave action, and bioturbation; and water-level fluctuations. Lack of benthic macrophytes (underwater plants) and functional shoreline wetlands exacerbate the turbidity and sediment instability issues.
- Water-level fluctuations: Utah Lake operates as a water storage reservoir, supplying water to downstream users and the Great Salt Lake. While fluctuations in water levels are natural, the magnitude and speed of changes within a single growing season—often ± 3 feet and up to 7 feet—along with extended dry or inundated periods, significantly affect the littoral zone, an area critical to the lake's ecological health. These rapid changes make it difficult for native plants to establish along shorelines and create conditions that favor *Phragmites* growth on exposed lakebed areas. As a result, water-level variability poses a major challenge for restoration efforts and represents a critical constraint the ULS PEF seeks to mitigate. FFSL does not have authority to directly manage lake levels or eliminate this stressor, making dynamic management strategies essential for success.
- Logistical stressors: Although FFSL is charged with enhancing conditions at Utah Lake, its jurisdiction is limited to the negotiated settlement boundary of the lake. Many of the factors influencing the lake's health originate outside this boundary, within the broader watershed. These include land use planning, water quality protection, watershed restoration, regulation of surface and groundwater inflows, water supply and conservation planning, and reservoir operations—particularly the management of Utah Lake water levels. These responsibilities fall under the purview of other state agencies with the appropriate regulatory mandates. This dual mandate presents a complex challenge. FFSL must evaluate and support opportunities for water conservation, ecological restoration, and enhanced human use while remaining within its legal boundaries and avoiding encroaching on the responsibilities of other agencies. Successfully navigating this challenge will require close coordination with relevant agencies and stakeholders and a clearly defined role for FFSL in contributing to the enhancement of Utah Lake through water conservation, land management, habitat restoration, and stewardship of sovereign lands.

What does the Phased Enhancement Framework include?

The PEF includes activities under the following four management tracks coinciding with the key stressors identified:

- Invasive carp control: The Phase 1 objective is to fill other critical data needs required to improve the understanding of carp life history in Utah Lake and inform a robust IPM approach to carp management in Utah Lake.

- **Habitat enhancement and sediment management:** The Phase 1 objective is to implement a habitat enhancement pilot project at Goose Point. This would be a fenced off area where carp would not have access. Within this pilot project area, enhancement actions that primarily target the manipulation (reduction and removal) of key stressors impacting Utah Lake will be implemented in a controlled setting, and ecosystem responses to stressor manipulations will be tracked over time. Rather than commencing directly with large-scale implementation throughout the lake, the process is inherently iterative, with enhancement actions initially tested in select pilot/pilot-scale areas and ecosystem responses to enhancement actions tracked over time. Armed with an improved understanding of ecosystem responses to stressor manipulations, system uncertainty, engineering design, and successful methods for ecosystem recovery, this information will provide the basis for phased implementation of enhancements on an increasing scale with minimized risks of costly failures.
- **External nutrient management:** The process for developing numeric nutrient targets is laid out in the *ULWQS Numeric Nutrient Criteria Implementation Framework* (ULWQS Steering Committee and DEQ 2022) and will be completed within the time frame laid out for Phase 1. The ULWQS will result in nutrient targets to protect the designated uses of Utah Lake (Phase 1). The implementation of the *ULWQS Numeric Nutrient Criteria Implementation Framework* may focus upon identifying and prioritizing critical nutrient source areas.
- **Human use enhancement:** This management track considers two main themes:
 - **Recreation:** ULA is currently developing a ULRAP (ULA 2025, in progress) to provide ULA and other stakeholders with a plan for enhancing recreation access at Utah Lake.
 - **Outside land uses:** Although FFSL is charged with enhancing conditions at Utah Lake, its jurisdiction is limited to the lake's negotiated settlement boundary. Many of the factors influencing the lake's health originate outside this boundary, within the broader watershed. These include land use planning, water quality protection, watershed restoration, regulation of surface and groundwater inflows, water supply and conservation planning, and reservoir operations—particularly the management of Utah Lake water levels. These responsibilities fall under the purview of other state agencies with the appropriate regulatory mandates. Engagement and collaboration from local governments in land use planning and management will be critical.
- **Why pilot projects matter:** Pilot projects, such as the proposed fenced area at Goose Point, are critical to the PEF's success because they provide a practical, low-risk way to test restoration strategies before scaling up. These small-scale efforts allow managers to identify effective methods, learn from challenges, and avoid unintended consequences that could occur with lake-wide implementation. They offer a cost-effective approach to gaining valuable insights while respecting agency mandates, water rights, and jurisdictional responsibilities. Pilot projects also build public awareness and support by demonstrating tangible progress, balancing ecological improvements with recreational access. Ultimately, they serve as proof of concept, complement existing agency efforts, and ensure that future restoration aligns with broader watershed management goals.
- **Respect for agency mandates and jurisdiction:** FFSL fully acknowledges and respects the statutory authority and management responsibilities of all participating entities.

- **Water resource management:** The PEF does not include activities to interfere with water management, and FFSL respects the need to preserve water rights and interests related to water collection, storage, or delivery and projects for water collection, storage, or delivery associated with Utah Lake.
- **Complementary, not redundant:** The Utah Lake PEF is designed to complement, not duplicate or compete with, existing agency efforts. Messaging should emphasize that the program is additive and integrative, aligning with broader watershed management goals to fill critical gaps.

What are the key messages to the Utah Legislature?

- **Positioning Utah as a national leader:** This plan represents an ambitious and aspirational effort. It includes what could become the largest carp removal initiative in the country (or the world), positioning Utah as a leader in innovative lake restoration. The state has a unique opportunity to set a national precedent in watershed enhancement.
- **Establishing a dedicated funding mechanism:** Although federal funding has historically supported enhancement efforts, these resources have significantly declined. To ensure continued progress, the creation of a dedicated Utah Lake Enhancement Fund is critical. Potential funding sources may include state appropriations, competitive grants, public-private partnerships, recreation access fees, and conservation easements.
- **Setting realistic expectations:** Legislators should be informed that ecological restoration is a long-term, phased process. The program is designed to deliver incremental improvements through pilot projects and adaptive management, not immediate, large-scale transformation. Clear communication about timelines and milestones will help manage expectations and build sustained legislative confidence.

What are the connections to Great Salt Lake

Utah Lake may benefit from formal programs that restore tributary flows in alignment with the hydrologic needs of connected wetlands, such as the Provo River Delta Restoration Project or the ULWP and/or establish mechanisms to dedicate conserved water to the lake in support of ecological and water quality goals. Currently, no programmatic mechanism exists to dedicate conserved water to Utah Lake, as is available for the Great Salt Lake.

Although the development of such programs would be beneficial, they present challenges in the context of broader water scarcity concerns across northern Utah and the state as a whole. Any such initiatives would need to be pursued in coordination with partner agencies that hold the relevant jurisdiction and expertise.

6. Conclusion

Utah Lake is an incredible resource for the state of Utah, and interest in enhancing its condition for the nine benefit areas described in S.B. 270 is significant. Scoping efforts during the beginning of the project confirmed broad support for S.B. 270. The ULS establishes a framework and PEF for achieving this future enhanced condition for the lake (as described in S.B. 270).

Although the path toward achieving the enhanced condition is not simple or quick, it is achievable through a phased approach involving numerous strategies to address the multiple stressors that impact the lake. The phased approach to achieving the enhanced condition for Utah Lake includes several different management tracks (that is, invasive carp control, habitat enhancement and sediment management, external nutrient management, and human use enhancement) and numerous interrelated strategies that overlap in the objectives that they aim to achieve.

The PEF includes two phases and will require allocating new resources (funding and staff) to be successful; it will also require strong leadership that can coordinate amongst management agencies to ensure communication and coordination, data management, and sharing.

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UTAH LAKE STUDY



Appendix A

Review of Existing Information Report



Review of Existing Information Report

Version: Final

Utah Division of Forestry, Fire and State Lands
Utah Lake Study
October 31, 2025





Review of Existing Information Report

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Project name: Utah Lake Study
Project no: D3936700 **Document no:** 251013215453_50e8c954
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Executive Summary

Sponsored by Senator Curtis Bramble and Representative Keven Stratton, the 2024 Utah Legislature passed Senate Bill (S.B.) 270, Utah Lake and Great Salt Lake Study Amendments. The bill appropriated funds for the 2024 fiscal year to the Utah Department of Natural Resources, Division of Forestry, Fire and State Lands (FFSL) to conduct the Utah Lake Study (ULS) to determine how to enhance several benefit areas of Utah Lake in a manner consistent with the division's management authority over sovereign lands. In accordance with S.B. 270, FFSL is studying the scientific, technical, measurement, and other information needed to inform and improve discussions about Utah Lake and its enhancement. As a first step, FFSL is reviewing and assessing the available information, literature, and data about improving Utah Lake.

The purpose of this report is to summarize the state of existing science and knowledge that informs the enhancement of the Utah Lake benefit areas from S.B. 270. The Review of Existing Information task completed as part of the project scope is not an exhaustive comprehensive literature review. Rather, it focuses on the most relevant existing information to determine what information is missing to help determine methods for enhancing Utah Lake. Using the objectives established for elements of S.B. 270 as a guide, the consultant team conducted a review of relevant research, studies, plans, data, and other information developed for Utah Lake and its resources. Key findings and critical information needs (to inform methods to enhance the various benefit areas of Utah Lake) were identified for each of the benefit areas and are described in the following sections.

Conserving Water Resources in and Around Utah Lake

Key Findings

- Utah Lake has been managed as a storage reservoir since the mid-1800s, with a complex system of water rights established over time.
- The lake's maximum elevation was initially set at 4,516 feet above sea level (based on the Salt Lake City datum) in 1885. However, because of flooding in the 1980s, the maximum elevation was revised to 4,489 feet above sea level (compromise elevation), with a storage capacity of about 870,000 acre-feet at this level.
- Over the past 30 years, Utah Lake's elevation has fluctuated by an average of 3.3 feet annually, with a maximum difference of about 7 feet recorded in 2004.
- Providing strategies to support watershed management decisions, surface or groundwater inflow management decisions, water conservation or supply management decisions, or reservoir storage operations is not within FFSL's jurisdictional authority; these responsibilities belong to other local, state, and federal government entities.
- As part of the ULS, FFSL "shall respect the need to preserve water rights and interests related to water collection, storage, or delivery and projects for water collection, storage, or delivery associated with Utah Lake" (S.B. 270 lines 60 through 63).
- The lake has several operational challenges, including high evaporation rates, degraded water quality, and a nonnatural hydrograph because of upstream flow controls and reservoir operations.

Information Needs

- The development of seasonal lake level predictions could significantly improve resource managers' capabilities in overseeing Utah Lake's diverse assets. This advanced forecasting would enable more

effective management of recreational access points, native plant restoration initiatives, fishery and upland habitat improvement projects, and more.

- Improved coordination between water managers and natural (and recreational) resource managers.

Improving the Clarity and Quality of the Water in Utah Lake

Key Findings

- The Utah Lake Water Quality Study (ULWQS) is working to identify water quality targets for nutrients necessary to meet Utah Lake's designated beneficial uses and develop a water quality improvement strategy.
- Paleolimnological (paleo) indicators and historical accounts indicate Utah Lake was historically a clear-water, low-nutrient system with primary production dominated by macrophytes.
- In response to human disturbances since the turn of the 20th century, Utah Lake has shifted to a phytoplankton-dominated, high-nutrient system. These disturbances include the introduction of invasive species, including carp; wastewater and other point and nonpoint pollutant loading; and land use change in the watershed.
- Today, Utah Lake has low water clarity, which is attributed to sediment resuspension and phytoplankton growth. Sediment resuspension makes up most of the turbidity and is driven mainly by wind and wave action. Phytoplankton growth is driven by excess nutrient loading to the lake, which is exacerbated by sediment nutrient recycling.
- Empirical analysis of monitoring data and small-scale experiments in Utah Lake, as well as literature evidence from other lakes, indicate that nutrient reductions are needed to reduce algal growth in Utah Lake, but lag time associated with nutrient recovery is possible because of the time it will take for the sediments to reach a new equilibrium. However, in addition to nutrient reductions, rehabilitation of ecosystem structure (for example, restoration of benthic macrophytes and stabilization of benthic sediments) has been shown to be very important to improving water quality in other lakes.
- To restore a clear-water state of a macrophyte-dominated system, several aspects of Utah Lake will need to be managed, including but not limited to nutrient loading, sediment resuspension, carp removal, and macrophyte recovery.
- Multiple forms of nutrient management are available, including external loading reductions, chemical treatments, dredging, and top-down food web management. External loading reduction is likely to be the most successful management activity long term in Utah Lake, and ULWQS is planning for the implementation of external nutrient load reductions.

Information Needs

- The following information associated with completion of the ULWQS: (1) finalization of the ULWQS numeric nutrient targets for protection of beneficial uses and (2) completion of the ULWQS nutrient management plan, which will include point-source reductions and nonpoint-source best management practices.
- Identification of nutrient ranges characteristic of oligo-mesotrophic lakes that would support transition to a clear water, stable state to achieve the objectives of this ULS.
- Improved understanding of sediment nutrient cycling and its potential impact on lake recovery time.
- Strategies that can reduce sediment resuspension and transport.

- Environmental requirements of submerged aquatic vegetation (SAV) for restoration (native plant restoration toolbox).
- Information about how benthic macrophytes can be restored with stressors like common carp and variable water levels.

Removing Invasive Plant and Animal Species from Utah Lake

Common Carp Key Findings

- Common carp make up 70 to 90 percent of fish biomass in Utah Lake, as suggested by net surveys conducted in last two decades.
- Carp biomass in Utah Lake appears to range between 400 and 600 kilograms per hectare (kg/ha), as estimated by the carp population model (Walsworth et al. 2024), and exceeds the ecologically acceptable threshold of 100 kg/ha by four to six times; the 100 kg/ha threshold was identified in other lakes in North America but might also apply to Utah Lake. This abundance appears to be sufficiently high to be a major driver of water quality degradation in the lake.
- Mechanical carp removal was tested from 2009 to 2023 using seine nets. Removal rates were relatively modest at 35 to 47 kg/ha per year (less than 10 percent of estimated starting biomass). Nevertheless, model-predicted carp biomass declined from 550 kg/ha in 2009 to 200 kg/ha in 2019 as a result of systematic removal. However, the population then rebounded to 400 kg/ha by 2023 as a result of increased young carp production and reduced removal rates.
- Production of young carp (recruitment) increases during high water years and following adult carp removal. Overall recruitment rates observed to date appear to be lower than in other systems, potentially because of the high abundance of small predatory fish in Utah Lake.
- The current carp population model predicts that the carp population is dominated by young individuals (ages 0 to 4), whereas empirical data suggest individuals age 5 and older dominate the population; this discrepancy suggests key data gaps in field data or model parameter estimates. Methods previously used to estimate the age of carp may have been underestimating the age of individual fish.
- Using methods currently available, carp management would need to occur on an annual basis to continuously suppress the population.
- Carp management efforts employed to date have been relatively constrained in scope and methodology in relation to size and scale of Utah Lake. Integrated pest management strategies that employ multiple tools that target specific weaknesses in carp life history should be considered for Utah Lake (for example, telemetry-guided seines to target winter carp aggregations; automated box nets to target bait-induced summer aggregations; native fish biocontrol of carp eggs, larvae, and fry; and others). Management tools that can effectively target all year classes of carp in different types of habitats would likely accelerate carp management.

Common Carp Information Needs

- Additional data, particularly on the abundance of juvenile carp, carp age, and carp mortality, to solidify model parameters and address the apparent discrepancy between observed data and model predictions. A robust carp population model is key for guiding management efforts.
- The carp density threshold in Utah Lake where impacts to ecosystem are minimized.
- Updated and improved population age estimates to improve population modeling.
- Identification of a main driver for the discrepancy between the observed carp population age structure (primarily older carp) and the one predicted by model (primarily younger carp).

- Determination of whether carp form seasonal aggregations, including winter aggregations in the lake and spring spawning runs into tributaries or wetland areas.

***Phragmites* Key Findings**

- *Phragmites australis* subspecies *australis* (common reed) became established at Utah Lake in or around the 1980s and has since expanded and colonized over 75 miles of Utah Lake shorelines, eliminating or significantly reducing ecosystem function and societal benefits. Impacts of *Phragmites* around Utah Lake include the following:
 - Reduced plant diversity
 - Reduced quantity and quality of bird, fish, and wildlife habitat
 - Increased evapotranspiration
 - Increased fire danger
 - Reduced recreational access
- FFSL and other regional partners have been actively managing large-scale *Phragmites* infestations at Utah Lake since 2014, when a major collaborative effort to mitigate invasive vegetation along the shores of Utah Lake began. The methodology for controlling and removing *Phragmites* has been refined over the years, and *Phragmites* cover on Utah Lake has been reduced by approximately 70 percent. The goal is to maintain *Phragmites* cover at less than 20 percent across treated areas (Duncan 2023). This involves regular monitoring and adaptive management, expanding treatment to adjacent upstream locations, and smaller-scale control methods (spot spraying and boat and boom application) to confirm the effectiveness of control measures. Grazing is also used as a *Phragmites* management tool.
- Ongoing collaboration with local communities, stakeholders, and volunteers is needed to support control efforts and promote awareness about the importance of managing invasive species (Farmonaut 2025).
- Despite removal efforts, *Phragmites* remains relatively common around Utah Lake and continues to impact the ecosystem and recreation.
- Native plant revegetation needs to be prioritized and expanded in conjunction with *Phragmites* treatments to restore vegetative communities and prevent reinvasion of invasives plants.

***Phragmites* Information Needs**

- Long-term monitoring and control of *Phragmites* is required to maintain and extend management success at Utah Lake. Comprehensive mapping of *Phragmites* communities adjacent to Utah Lake and within the watershed will be critical to planning and controlling *Phragmites* in the long term, in part to identify seed sources.
- Methods and infrastructure for native plant revegetation on the lake scale need to be fine-tuned and scaled up. Supporting native plant revegetation is critical to long-term stabilization and protection against invasive species invasion or re-establishment.

Restoring and Improving Littoral Zone and Other Plant Communities in and Around Utah Lake

Key Findings

- Restoring native vegetation communities in and around Utah Lake is one of the cornerstones of returning the lake to a functioning ecosystem. Lakeshore vegetation (including wetlands) supports many valuable aspects of lake ecosystems, including foraging areas for birds, rearing grounds for fish,

nutrient cycling, carbon storage, and aesthetic and recreation aspects. Yet, the native vegetation (including wetlands) of Utah Lake has been lost or heavily impacted by humans and land management objectives.

- In the past 100 years, Utah Lake native emergent or lakeshore communities have been largely lost and replaced by invasive monocultures of *Phragmites*, and SAV has been reduced or eliminated by fluctuating water levels and bioturbation. Restoration of native plant communities can improve ecosystem function and diversity and provide a positive feedback loop for numerous ecosystem elements, including wildlife habitat and water quality conditions.
- SAV growth is currently limited by reduced clarity in Utah Lake, driven by sediment resuspension and phytoplankton growth.
- Re-establishing native plant communities in Utah Lake could provide opportunities to improve and support related ecosystem functions, including the following:
 - Wildlife habitat (that is, shorebird nesting and general habitat)
 - Native fish conservation (including Bonneville cutthroat trout and June sucker, which use native vegetation as nursery habitat)
 - Water quality (that is, sediment stabilization and transferring primary production from the water column to the benthos, nutrient reduction in the water column, suspended sediment reduction, and harmful algal bloom reduction)
 - Littoral zone restoration (that is, sediment stabilization, reduced shear stress from wind and wave action and water circulation, and turbidity reduction)

Information Needs

- Native vegetation restoration toolbox:
 - Prioritization of species for restoration in different landscape positions and hydrologic conditions that will help guide adaptive management of succession of different species over time, given the constraints of fluctuating water levels.
 - Mapping of areas with high potential for native plant community restoration.
 - Methods to support establishing emergent plant communities from water-level dynamics that create extreme drought and flood conditions
 - Water quality targets (clarity) and corresponding optimal water depths (and rates of water-level changes) to support SAV community establishment
 - Methods to support and protect SAV establishment from carp disturbance, wave action, and sheer stress
 - Establishment and expansion of large-scale native emergent and SAV plant nurseries to grow and support large-scale restoration activities.
 - Establishment of a comprehensive management strategy for native vegetation restoration.

Restoring and Conserving Native Aquatic Organisms

Key Findings

- Utah Lake native fish species and other native aquatic organisms (for example, mollusks and amphibians) have drastically declined as a result of habitat loss, water diversion, pollution, and invasive species introduction.

- Nonnative fish, especially common carp and piscivorous species like northern pike and white bass, may impact June suckers and other native species through habitat degradation, predation, and possibly competition.
- Conservation efforts have increased June sucker populations from hundreds to an estimated 30,000 to 50,000 individuals, which can be attributed to stocking programs, habitat restoration, and management programs like the June Sucker Recovery Implementation Program. Despite population increases, low juvenile June sucker recruitment is a critical bottleneck, primarily because of predation by nonnative piscivores and a lack of quality rearing habitat. Systemic improvements to spawning and rearing habitats, water quality, and lake stabilization will be critical for supporting native species recovery. The bottleneck in June sucker recovery is the successful recruitment of juveniles following spawning in the Provo River.
- Native unionid mussels, historically vital for water filtration and sediment stabilization, are extirpated from Utah Lake, replaced by invasive *Corbicula*, which may offer ecosystem benefits initially but present major threat to ecosystem.
- Restoration and monitoring efforts, specifically additional tributary restoration projects (for example, Hobble Creek, Spanish Fork River and American Fork River), must be prioritized for long-term species recovery.

Information Needs

- Detailed knowledge of June sucker recruitment (that is, where juvenile June suckers are ending up).
- Improved knowledge of June sucker spawning and recruitment limitations to inform adaptive management of Provo River Delta Restoration Project and other areas to increase recruitment.
- Improved understanding of how lake levels, river hydrology, and other physical variables affect June sucker recruitment in the Provo River Delta and Hobble Creek.
- Improved understanding of the role various native and nonnative aquatic plant species in June sucker habitat use and recruitment success.
- Improved understanding of which nonnative fish species pose the greatest threat to June sucker recruitment through predation or other effects.
- Improved knowledge of the diets of various fish species in the lake to inform fisheries management and improve carp and June sucker management.

Increasing the Suitability of Utah Lake and Its Surrounding Areas for Shorebirds, Waterfowl, and Other Avian Species

Key Findings

- Utah Lake historically supported a rich and diverse bird community, but recent declines in diversity and abundance are evident.
- Fluctuating water levels, invasive species, pollution, and the effects climate change have fragmented and degraded habitat.
- Monitoring and scientific information of bird populations and habitat use in Utah Lake is limited.
- A multifaceted approach, including implementing more monitoring efforts, addressing stressors, improving habitat suitability, and incorporating monitoring and research, is needed to support and restore bird populations at Utah Lake.

- More natural patterns in lake water levels, restoration of native vegetation, and improvements in water quality will benefit shorebirds, waterfowl, and other avian species at Utah Lake.

Information Needs

- Expanded monitoring is needed to understand avian use of Utah Lake, including habitat use patterns, nesting sites, foraging areas, migratory stopovers, and food web dynamics (*what do different birds eat in Utah Lake, and how are changes in fish and invertebrate populations affecting birds?*).

Maximizing, Enhancing, and Ensuring Recreational Access and Opportunities on Utah Lake

Key Findings

- Detailed visitation data and recreation dynamics are currently limited, but efforts are underway to collect this information as part of the Utah Lake Authority's (ULA's) Recreation Access Plan (estimated completion date of 2025). Water quality conditions are likely a deterrent to some recreational users.
- Managing Utah Lake's recreational resources is complex, involving multiple stakeholders and a bottom-up approach. This approach allows for local expertise and community engagement, but it also has coordination and consistency challenges.
- Utah Lake recreation access points are managed by multiple stakeholders using a bottom-up (as opposed to top-down) approach, meaning various stakeholders and partners work together to make improvements at each access point. This approach has both advantages (alignment with local priorities and adaptability to site-specific challenges) and disadvantages (resource disparity and inconsistent standards). Lakeshore municipalities have diverse visions for recreational improvements, generally aligning with current land use patterns.
- Key challenges include jurisdictional confusion, lack of clarity on approval processes, unequal resource distribution, and lack of a dedicated funding source for recreational improvements.
- The *Utah Lake Management Plan* (ULMP; ULA 2024) outlines goals, objectives, and strategies that support ULA's vision of world-class recreation at Utah Lake. Since the plan's inception, ULA has demonstrated considerable progress, particularly in executing the short-term strategies. The ULA has been diligent in adhering to the implementation schedule set forth in the management plan, indicating a strong commitment to realizing their vision for enhanced recreation at Utah Lake.
- Successful implementation will depend on a delicate balance between respecting local autonomy, coordinating across jurisdictions, and aligning visions into cohesive strategy for the lake's recreational future. ULA is dedicated to finding this balance by leading cooperative efforts to implement short-, mid-, and long-term strategies in the ULMP (ULA 2024).

Information Needs

- Streamlined, clear approval processes and improved resource allocation are needed to effectively enhance recreational opportunities.
- A Utah Lake economic analysis of recreational potential holds significant value for understanding and quantifying the benefits of enhanced opportunities for the state, visitors, and residents.
- Informational needs for determining methods to enhance recreational access and opportunities at Utah Lake are consistent with those documented in ULMP.

Otherwise Improving the Use of Utah Lake for Residents and Visitors

Key Findings

- The analysis completed for this report covers a 2-mile buffer around the Utah Lake settlement boundary. Ownership within this buffer is a mix of state, federal, and private lands. State lands include sovereign land, trust land, wildlife management areas, and Utah Department of Transportation land. Federal lands are owned by the U.S. Bureau of Land Management, U.S. Bureau of Reclamation, and U.S. Forest Service. Some municipal boundaries extend into sovereign lands below the lake boundary. Landownership disputes are ongoing around the shoreline. Federal landownership is largely related to the Central Utah Project Completion Act of 1992.
- Zoning data were collected from Utah County and individual municipalities. The northern side of Utah Lake has higher-density urban development. The southern half is predominantly zoned for agricultural activities or a mix of residential and agricultural use.
- Land cover data were examined using the U.S. Geological Survey National Land Cover Database (USGS 2024b). The land cover pattern mirrors the zoning around Utah Lake. The northern half shows higher-density development. The southern half has more open space and agricultural areas.
- The mosaic of land ownership and zoning around a shared resource like Utah Lake presents several challenges, including coordination complexity, environmental impact management, and resource allocation.

Information Needs

- Land ownership disputes around Utah Lake need to be resolved to provide a clear, stable foundation for planning and management. Establishing landownership can significantly streamline planning efforts, leading to more efficient and effective stewardship of shared resources.

The information needs summarized for each benefit area will help to inform future research and management efforts aimed at enhancing the various benefit areas specified in S.B. 270. The next phase of the ULS will focus on further exploring these information needs and the path forward to enhance Utah Lake.

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Acronyms and Abbreviations

°C	degree(s) Celsius
µg/g	microgram(s) per gram
µg/L	microgram(s) per liter
alum	aluminum sulfate
BLM	U.S. Bureau of Land Management
CaCO ₃	calcite
CFW	constructed floating wetland
Chl <i>a</i>	chlorophyll <i>a</i>
CI	confidence interval
cm	centimeter(s)
CPUE	catch per unit effort
CUPCA	Central Utah Project Completion Act
CUWCD	Central Utah Water Conservancy District
CWA	Clean Water Act
CyHV-3	Cyprinid herpesvirus 3
DEQ	Utah Department of Environmental Quality
DHHS	Utah Department of Health and Human Services
DNR	Utah Department of Natural Resources
DOR	Utah Division of Outdoor Recreation
DSP	Utah Division of State Parks
DWQ	Utah Division of Water Quality
DWR	Utah Division of Wildlife Resources
DWRe	Utah Division of Water Resources
DWRi	Utah Division of Water Rights
EPA	U.S. Environmental Protection Agency
FAC	facultative wetland species (equally likely to occur in wetlands and uplands)
FACU	facultative upland species (usually occur in uplands)
FACW	facultative wetland species (usually occurs in wetlands)
FFSL	Utah Division of Forestry, Fire and State Lands

GIS	geographic information system
GSLBIP	Great Salt Lake Basin Integrated Plan
H.B.	House Bill
ha	hectare(s)
HAB	harmful algal bloom
IPM	integrated pest management
JSRIP	June Sucker Recovery Implementation Program
kg	kilogram(s)
kg/ha	kilogram(s) per hectare
km	kilometer(s)
LHD	local health department
m/s	meter(s) per second
MCMC	Markov chain Monte Carlo simulation
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
mm	millimeter(s)
nmol g ⁻¹ OM	nanomole(s) per gram of organic matter
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit(s)
OBL	obligate wetland species (almost always occurs in wetlands)
paleo	paleolimnological
PCB	polychlorinated biphenyl
PDF	portable document format
Pheo <i>a</i>	pheophytin <i>a</i>
PLS/m ²	pure live seed per square meter
POTW	publicly owned treatment works
PRDRP	Provo River Delta Restoration Project
PRWUA	Provo River Water Users Association
Reclamation	U.S. Bureau of Reclamation
RFU	relative fluorescence unit(s)

S.B.	Senate Bill
SAV	submerged aquatic vegetation
sedDNA	sediment deoxyribonucleic acid
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
UDAF	Utah Department of Agriculture and Food
UGS	Utah Geological Survey
ULA	Utah Lake Authority
ULMP	<i>Utah Lake Management Plan</i>
ULS	Utah Lake Study
ULWP	Utah Lake Wetland Preserve
ULWQS	Utah Lake Water Quality Study
ULWUA	Utah Lake Water Users Association
UPDES	Utah Pollutant Discharge Elimination System
URMCC	Utah Reclamation Mitigation and Conservation Commission
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USU	Utah State University
WRI	Utah's Watershed Restoration Initiative
WMA	wildlife/waterfowl management area

1. Introduction

Utah Lake is one of the largest and most important waterbodies in the state of Utah and the western United States. It serves as the source of one of the main tributaries to Great Salt Lake and as a reservoir for water that sustains much of the populations along the Wasatch Front (Fuller et al. 2016). The surrounding communities (within Utah County) are becoming the largest and fastest-growing population centers in the state. Because of these large and growing communities' proximity to the lake, improving the condition of the lake is of significant interest, particularly because of the lake's well-documented ecological issues and residents' and visitors' lack of appreciation for and underutilization of the lake.

1.1 Overview of Senate Bill 270

Sponsored by Senator Curtis Bramble and Representative Keven Stratton, the 2024 Utah Legislature passed Senate Bill (S.B.) 270, Utah Lake and Great Salt Lake Study Amendments. The bill appropriated funds for the 2024 fiscal year to the Utah Department of Natural Resources' (DNR's) Division of Forestry, Fire and State Lands (FFSL) to conduct the Utah Lake Study (ULS) as follows:

"... to determine how to enhance the following benefits associated with Utah Lake in a manner consistent with the division's management authority over sovereign lands under Section 65A-10-1:

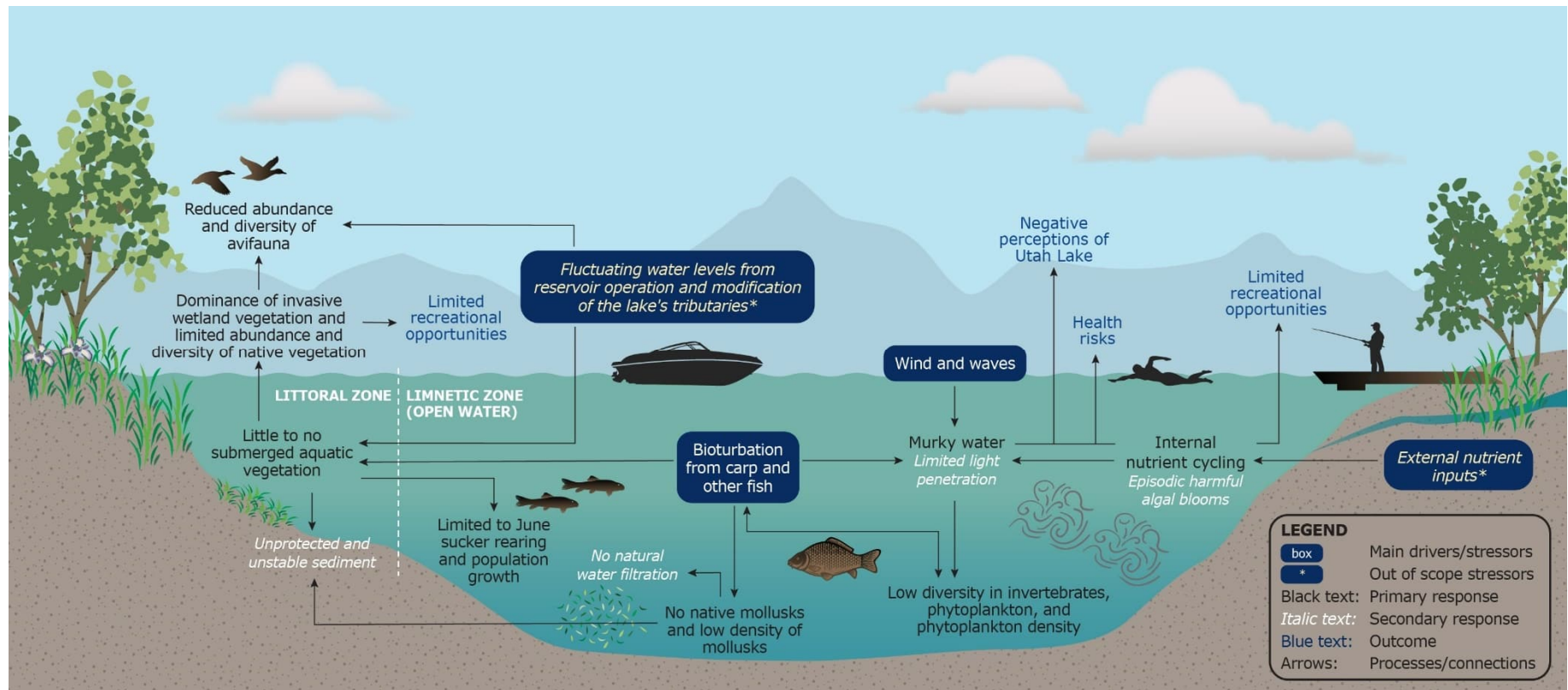
- a) improving the clarity and quality of the water in Utah Lake;*
- b) conserving water resources in and around Utah Lake;*
- c) removing invasive plant and animal species, including phragmites and carp, from Utah Lake;*
- d) restoring and improving littoral zone and other plant communities in and around Utah Lake;*
- e) restoring and conserving native fish and other aquatic species in Utah Lake, including Bonneville cutthroat trout and June Sucker;*
- f) increasing the suitability of Utah Lake and its surrounding areas for shorebirds, waterfowl, and other avian species;*
- g) maximizing, enhancing, and ensuring recreational access and opportunities on Utah Lake;*
- h) otherwise improving the use of Utah Lake for residents and visitors;*
- i) substantially accommodating an existing use on land in or around Utah Lake; and*
- j) providing any other benefits identified by the division."*

In accordance with S.B. 270, FFSL is studying the scientific, technical, measurement, and other information needed to inform and improve discussions about Utah Lake and its enhancement. As a first step, FFSL is reviewing and assessing available information, literature, and data about improving Utah Lake. This *Review of Existing Information Report* summarizes the existing information review, specifically the main findings about information needed to determine methods for enhancing Utah Lake.

1.2 Overview of Utah Lake Ecosystem

The 10 benefit areas specified for enhancement in S.B. 270 can be divided into ecological ([a] through [f]) and human-oriented ([g] through [i]) groups. Although S.B. 270 specifies 10 different benefit areas, some enhancements may benefit most, if not all, of the benefit areas. Figure 1-1 depicts the various benefit areas described in S.B. 270, the main stressors that affect them, and the resulting impacts. Figure 1-1 does not depict or describe every detail of the Utah Lake ecosystem; rather, it focuses on the benefit areas to be enhanced under S.B. 270 and the main (high-level) processes that affect them.

Figure 1-1. Utah Lake Main Stressors, Benefit Areas, and Effects



Note: Utah Lake's ecosystem is complex, with interconnected processes affecting various S.B. 270 benefit areas. This illustration does not depict every detail of the lake's ecosystem or its complexity; rather, it shows the benefit areas to be enhanced under S.B. 270 and the main (high-level) processes that affect them.

The lake's ecosystem is complex, with interconnected processes affecting various benefit areas. Many stressors affect multiple benefit areas, and the structural elements the stressors affect in the lake are interconnected between benefit areas. For example, bioturbation from carp impacts the abundance and health of benthic vegetation, which results in unstable lake sediments and increased water turbidity, which then impacts water quality, recreational opportunities, and public perceptions of the lake. The lack of benthic vegetation affects many benefit areas, including water quality and clarity, restoration of native fish (such as the June sucker, which is endemic to Utah Lake), restoration of native bird populations, recreational opportunities, and others.

A central goal of enhancing the lake ecosystem is to facilitate an increase in recreation and other human uses of the lake. A stronger and healthier Utah Lake ecosystem will result in improved public perception of the lake, interest in recreation, and interest in other uses of the lake by residents and visitors. Without enhancing water clarity and quality, in addition to other aspects of the lake ecology, greatly enhancing recreation or improving the use of the lake for residents and visitors will be difficult.

1.3 Utah Lake Governance

The governance and management of Utah Lake is complex, and many state, local, and federal government agencies, along with other partners, need to work together to manage Utah Lake and its resources. Several councils and committees also contribute resources and information toward advancing their common goals. This section outlines the various agencies and stakeholders involved in enhancing Utah Lake, as defined by S.B. 270. This section aims to clarify the roles, responsibilities, and collaborative efforts of these entities in managing and improving the lake's ecological, recreational, and economical value.

1.3.1 Utah Division of Forestry, Fire and State Lands

FFSL, which is part of DNR, is responsible for forest health, wildland fire response, and state sovereign land management.

Sovereign lands are defined as areas below the ordinary high water mark of navigable waters at the time of statehood that are owned by the state (*Utah Administrative Code* 65A-1-1[6]). For Utah Lake, this includes the lakebed below the established boundary settlement line, which FFSL manages.

FFSL is tasked with developing and implementing a comprehensive management plan for Utah Lake's sovereign lands. This plan ensures that natural and cultural resources are managed according to multiple-use, sustained-yield principles. Currently, FFSL is updating the *Utah Lake Comprehensive Management Plan* (FFSL, forthcoming) to reflect sustained-yield practices and the public trust doctrine. The update considers factors such as best use, future use, suitability, impact, compatibility, and uniqueness of resources.

Since 2014, FFSL has led a coordinated effort to control invasive *Phragmites* along the lake's shoreline. This initiative involves collaboration with Utah County, the Utah Lake Authority (ULA), the Utah Department of Agriculture and Food (UDAF), and Utah's Watershed Restoration Initiative (WRI), resulting in significant progress in managing shoreline vegetation.

1.3.2 June Sucker Recovery Implementation Program

The June Sucker Recovery Implementation Program (JSRIP) is a multiagency initiative focused on recovering the June sucker, a fish species native to Utah Lake and its tributaries, especially the lower Provo River. Partners include federal, state, and local agencies, such as the U.S. Fish and Wildlife Service (USFWS), DNR, Central Utah Water Conservancy District (CUWCD), URMCC, Provo River Water Users Association (PRWUA), and various environmental organizations.

Key projects include the following:

- **Hobble Creek Restoration Project:** JSRIP acquired property along lower Hobble Creek and restored a functioning wetland and delta to provide additional spawning habitat for the June sucker.
- **Provo River Delta Restoration Project (PRDRP):** The PRDRP is a large-scale ecological restoration effort aimed at improving habitat for the June sucker while enhancing public recreational opportunities near Utah Lake.

1.3.3 Provo River Water Users Association

PRWUA manages the Provo River Project, a U.S. Bureau of Reclamation (Reclamation) initiative that delivers water to users in Utah, Salt Lake, Summit, and Wasatch counties. This water supports agricultural irrigation and municipal drinking water needs for nearly one million people. PRWUA is also a stakeholder in JSRIP, contributing to habitat restoration and flow management efforts that benefit Utah Lake's ecosystem. The association works closely with federal, state, and local agencies to promote sustainable water use and ensure environmental compliance.

1.3.4 Utah Department of Health and Human Services and Local Health Departments

Local health departments (LHDs) are responsible for protecting public health at Utah Lake by issuing advisories and closing waterbodies when HABs pose a risk. These decisions are based on thresholds established by the Utah Department of Health and Human Services (DHHS). The DWQ supports this process by monitoring and sampling high-use or high-risk waterbodies, including those used for recreation and drinking water. DWQ analyzes the results and, in collaboration with DHHS, provides technical recommendations to LHDs. Utah's recreational health advisory guidance for HABs, last updated in 2023 (DEQ and HHS 2023), follows U.S. Environmental Protection Agency (EPA) recommendations and incorporates current research on cyanotoxins, such as microcystin, cylindrospermopsin, and anatoxin-a, as well as toxigenic cyanobacteria cell densities.

1.3.5 Utah Division of Outdoor Recreation

The Utah Division of Outdoor Recreation (DOR) works to enhance outdoor experiences across the state and provides planning and technical support for projects at Utah Lake. DOR oversees the state's Off-highway Vehicle and Boating Programs and administers a variety of grant programs that fund the development, restoration, and maintenance of outdoor recreation infrastructure. These grants support projects ranging from trail construction and public space improvements to youth-focused educational programs. DOR also maintains the Recreation Asset Database (Smith 2024), which provides statewide data on recreational resources. At Utah Lake, DOR serves as a partner to local communities, offering funding and expertise for specific initiatives. DOR staff participated in initial stakeholder engagement for the ULS.

1.3.6 Utah Division of Water Quality

The Utah Division of Water Quality (DWQ), operating under the Utah Department of Environmental Quality (DEQ), plays a central role in implementing the federal Clean Water Act (CWA) within the state. Acting under delegated authority from the EPA, DWQ is responsible for establishing and enforcing water quality standards for Utah's surface waters.

A key component of DWQ's work is the administration of the Utah Pollutant Discharge Elimination System (UPDES), which mirrors the federal National Pollutant Discharge Elimination System (NPDES). This

program regulates point-source discharges from facilities such as wastewater treatment plants and industrial operations.

DWQ also meets CWA requirements by conducting statewide water quality monitoring and producing integrated reports under Sections 305(b) and 303(d). These reports assess the condition of Utah's waters and identify impaired waterbodies. For waters that fail to meet designated standards, DWQ develops total maximum daily loads (TMDLs) to guide restoration efforts.

In addition, DWQ facilitates public participation in water quality rulemaking and planning, promoting transparency and stakeholder engagement. These responsibilities are particularly important for Utah Lake, where DWQ applies its regulatory and scientific expertise to address challenges such as nutrient pollution and harmful algal blooms (HABs), in alignment with the goals of the CWA.

1.3.7 Utah Division of Wildlife Resources

The Utah Division of Wildlife Resources (DWR) plays an important role in managing public access to Utah Lake through its oversight of wildlife/waterfowl management areas (WMAs). These areas are designed to conserve critical wildlife habitats, support recreational activities such as hunting and fishing, and reduce wildlife-related impacts on surrounding lands. Several WMAs around the lake include designated access points, which are regulated to protect ecological integrity and public safety.

Access to WMAs may require a valid Utah hunting, fishing, or combination license, especially in densely populated areas like Utah County. DWR maintains infrastructure, enforces seasonal closures, and implements habitat restoration projects to ensure these areas remain safe, functional, and ecologically sound.

To support coordinated planning and effective public communication, WMAs should be clearly identified and included in any comprehensive inventory of lake access points. Clarifying what qualifies as an official access point—whether for recreation, education, or wildlife management—is essential for aligning conservation and public use goals.

1.3.8 Utah Lake Authority

The ULA is an independent public entity established by the state to manage and enhance Utah Lake. Its mission is to support the comprehensive management of the lake by working collaboratively with federal, state, and local agencies; property owners; water rights holders; private organizations; and other stakeholders. ULA's role includes coordinating and facilitating improvements that promote the lake's long-term health and viability while also delivering economic, recreational, environmental, and aesthetic benefits to the state.

ULA has assumed certain management responsibilities previously held by the FFSL. Specifically, as written in *Utah Administrative Code* 11-65-205, the ULA has taken over the management of Utah Lake in place of the FFSL. However, FFSL continues to serve as the trustee of Utah's sovereign lands, maintaining authority over permits, leases, rights of entry, easements, and land disposal.

Although ULA does not have jurisdiction over the political subdivisions surrounding Utah Lake, it has been granted land use authority over publicly owned lands within its defined boundary. This boundary was established through legal settlements or litigation between the State of Utah and adjacent upland property owners. Within ULA's planning area, multiple entities retain jurisdictional authority, requiring ongoing coordination.

1.3.9 Utah Lake Water Users Association

Utah Lake Water Users Association (ULWUA) owns and operates the pump station and control gates at the outlet of Utah Lake. Its nine members include water districts, industrial users, and irrigation and canal companies that rely on the lake for water storage. Entities with significant water rights in Utah Lake include the following:

- Utah and Salt Lake Canal Company
- Jordan Valley Water Conservancy District
- South Jordan Canal Company
- East Jordan Irrigation Company
- North Jordan Irrigation Company
- Salt Lake City Corporation
- CUWCD
- Kennecott Utah Copper Corporation
- Utah Lake Distributing Company
- Draper Irrigation Company
- Successors to Sandy Canal Company
- Welby Jacob Water Users Company
- USFWS

1.3.10 Utah Reclamation Mitigation and Conservation Commission

Utah Reclamation Mitigation and Conservation Commission (URMCC), in partnership with the DWR, manages federally acquired lands within the Utah Lake Wetland Preserve (ULWP), which spans approximately 21,750 acres across Goshen Bay and Benjamin Slough. These lands were established to mitigate environmental impacts from the Central Utah Project and are managed under a comprehensive plan that allows compatible recreational activities, such as birdwatching, hunting, and nature study. Despite their importance, many access points within the preserve are not currently included in broader lake access inventories, underscoring the need for clearer definitions and inclusion of these sites in planning efforts.

1.4 Utah Lake Study Objectives and Scope

The purpose of this *Review of Existing Information Report* is to summarize the state of existing science and knowledge that informs the enhancement of Utah Lake's 10 benefit areas from S.B. 270. This task completed as part of the project scope is not an exhaustive comprehensive literature review. Rather, it focuses on the most relevant existing information to determine what information is missing to help determine methods for enhancing Utah Lake. Therefore, not all literature, data, reports, and studies pertaining to Utah Lake were reviewed, and the references cited within this report should not be considered a complete bibliography for Utah Lake.

S.B. 270 directs FFSL to determine how to “enhance” several benefit areas in Utah Lake but does not mandate that they be “restored” or “fixed.” Although this project is not focused on restoring the lake to a specific historical condition, this report does provide some historical context for the lake and various benefit areas specified in S.B. 270. Understanding both the historical context and the current condition for each benefit area can help clarify what has changed over time and what may be possible for a future enhanced condition of the lake.

To support ULS development, FFSL has formed an interdisciplinary Planning Team that will function as a technical working group to evaluate options for enhancing the 10 aforementioned benefits defined by S.B. 270; the team comprises representatives from state agencies, academia, nongovernmental

organizations, and others. In addition, a Steering Committee comprising state agency directors or their designees will provide executive input on the ULS process and outcomes. The Steering Committee will ensure that the ULS findings are scientifically sound and legally defensible. The committee will preserve water rights and interests related to water collection, storage, or delivery and projects for water collection, storage, or delivery associated with Utah Lake. The outcomes of the existing information review will be used to develop enhancement strategies for Utah Lake and pathways for implementing them. Following reviews by the Planning Team and Steering Committee, the report will be finalized and incorporated into the final ULS deliverable to the Natural Resources, Agriculture, and Environment Interim Committee of the Utah Legislature in November 2025.

1.5 Report Organization

This report is mostly organized to follow the organization of benefit areas listed in S.B. 270. Section 2 describes the methods used in the Review of Existing Information task for both written information and stakeholder engagement and outreach conducted as part of the effort. Because of the lake's important role as a storage reservoir, Section 3 next describes Utah Lake hydrology and management, and Sections 4 through 8 summarize existing information for the ecological ([a] through [f]) benefit areas specified in S.B. 270. Sections 9 and 10 summarize existing information and current conditions for human interactions with Utah Lake. The general structure of each section includes some historical information about the resource, information about the resource's current condition, and discussions about the main stressors and ecological dynamics relevant to the resource. Following the sections focused on the individual benefit areas, Section 11 summarizes the data gaps, or information needed to determine methods for enhancing Utah Lake for all the benefit areas.

At this time, the Review of Existing Information task is focused on those benefit areas identified in S.B. 270 directly related to Utah Lake's ecosystem and recreational usage (benefits areas [a] through [g] and [i]; benefit area [h] was not examined). No additional benefits have been identified by FFSL for inclusion in the ULS (benefit area [j]).

2. Methodology

The Review of Existing Information task comprised a literature review and stakeholder engagement process. No field surveys were conducted as part of this Review of Existing Information task, and no new models were developed. A key focus of the literature review was to build upon previous reviews conducted for Utah Lake, including the following:

- *Utah Lake Management Plan* (ULMP; ULA 2024)
- *Utah Lake Water Quality Study* (ULWQS; DEQ forthcoming-b)
- Utah Lake Comprehensive Management Plan (FFSL forthcoming)
- Timpanogos Special Service District Utah Lake Solutions research (TSSD 2025, forthcoming)
- Invasive species removal and native vegetation restoration (Hambrecht, pers. comm. 2025; Kettenring, pers. comm. 2025)

2.1 Literature Review

With the S.B. 270 language as a guide, the consultant team reviewed relevant research, studies, plans, data, and other information developed for Utah Lake and its resources. The literature review also consisted of identifying, compiling, reviewing, inventorying, and synthesizing pertinent information in reports, white papers, peer-reviewed journal articles, book chapters, technical memorandums, and other media. Key findings relevant to each benefit area of S.B. 270 were distilled to identify missing information, or data gaps, that need to be resolved to achieve the objectives defined for Utah Lake in S.B. 270. Key aspects of the literature review methodology include the following:

- **Building on previous work:** The Review of Existing Information task incorporated findings from earlier studies, including the ULMP (ULA 2024), ULWQS (DEQ forthcoming-b), and other relevant reports. The objective of the literature review was to supplement existing literature review work—not duplicate it.
- **S.B. 270 objectives:** The review focused on addressing specific benefit areas outlined in S.B. 270 to confirm alignment with legislative goals.
- **Diverse information sources:** A wide range of materials, including peer-reviewed articles, technical reports, white papers, and other relevant documents, were reviewed as part of this task.
- **Structured analysis:** The literature review explored several key topics:
 - Historical context
 - Current lake conditions
 - Stressors and environmental changes
 - Cause-effect relationships in the ecosystem
 - Ecological dynamics
 - Data and knowledge gaps
 - Past enhancement efforts and their outcomes
- **Collaborative approach:** The consultant team worked closely with the Planning Team and external subject matter experts throughout the review.

After conducting the preliminary Review of Existing Information task, the consultant team facilitated technical workshops with the Planning Team to discuss the data sources that were reviewed, key literature that might be missing, and key findings thus far. For example, on February 25, 2025, Dr. Bajer of Carp Solutions and member of the consultant team facilitated a technical workshop with personnel from Reclamation, the June Sucker Recover Implementation Program, Utah State University (USU), DWR, and

FFSL to confirm the literature review reflected the current state of the science as understood by resource managers and researchers. Similar technical workshops were held to discuss avian biology, water quality, and vegetation management.

2.2 Initial Stakeholder Engagement

Utah Lake's issues and challenges are complex and interdependent; in some cases, the issues lack an agreed-upon common information base. Consequently, benefits associated with Utah Lake cannot be enhanced by one party working alone; implementing solutions at Utah Lake will require commitment from multiple parties working together over time. With this consideration, the consultant team conducted initial stakeholder engagement to explore the potential for collaborative solutions and better understand the history and context of the various interests surrounding Utah Lake as follows:

- Refine the focus of the literature review
- Foster understanding and dialogue among stakeholder groups
- Identify areas of mutual interest and potential conflicts of interest at Utah Lake
- Understand the spectrum of perspectives and concerns about Utah Lake and enhancing Utah Lake
- Provide an opportunity for voices to be heard
- Help surface creative and innovative solutions for enhancing Utah Lake
- Build relationships and trust to prepare for additional dialogue related to future implementation
- Discover local resources, expertise, and initiatives that can contribute to the ULS and identify potential partnerships for implementation of enhancement strategies

Initial stakeholder engagement was conducted in parallel to the literature review and consisted of in-depth interviews with a diverse range of Utah Lake partners and stakeholders, including all members from the Planning Team and Steering Committee, as well as individuals from academic institutions, water management entities, local governments, and nongovernmental organizations. The diverse range of stakeholders that were engaged reflects the complex system of interests surrounding Utah Lake. Following are organizations that were interviewed as part of initial stakeholder outreach:

▪ Utah Division of Water Rights (DWRi)	▪ DOR
▪ Public Lands Policy Coordinating Office (PLPCO)	▪ Utah Geological Survey (UGS)
▪ DWR	▪ ULWUA
▪ DWQ	▪ Jordan Valley Water Conservation District
▪ Utah State Parks	▪ Lakeshore municipalities:
▪ ULA	- American Fork
▪ CUWCD	- Genola
▪ Utah Division of Water Resources (DWRe)	- Lehi
▪ Tracy Aviary	- Lindon
▪ Utah State Extension	- Orem
▪ Utah County Community Development	- Pleasant Grove
▪ FFSL	- Saratoga Springs
▪ USU	- Springville
▪ Utah Valley University, Herbert Institute	- Spanish Fork
▪ URMCC	- Vineyard
▪ Sageland Collaborative	
▪ National Audubon Society's Saline Lakes Program	▪ Mountainland Association of Governments

Table 2-1 summarizes (in alphabetical order) the most common themes that emerged from the stakeholder engagement. Not all themes emerged in each engagement activity, and findings are not ranked; rather, Table 2-1 summarizes discussion topics and feedback that recurred with greater frequency.

Table 2-1. Summary of Most Common Themes during Initial Stakeholder Engagement

Theme	Discussion
Agency partnership and confusion	Utah Lake management involves numerous agencies and multiple jurisdictions. Stakeholders are confused about who oversees what and how the ULA interacts with the other agencies and municipalities.
Carp	Carp have an outsized detrimental effect on Utah Lake, and other enhancement efforts for Utah Lake may be futile if carp are not addressed. However, carp removal will be difficult and costly.
Cost, affordability, and funding	A critical success factor for the ULS will be whether organizational and technical capabilities to complete it will match the funding available to support its completion. The ULS needs to address costs and funding sources, not just identify strategies or opportunities.
Implementation	Because of cost and feasibility, coordination and a phased approach are needed for implementation. Implementing enhancements may be challenging and take a long time to take effect, so expectations should be set accordingly.
Legislature	Stakeholders recommended that FFSL be clear and concise when presenting ULS findings with legislators during the November interim session. FFSL's presentation to the legislature should communicate findings, a plan, associated costs, and a performance timeline. Stakeholders also want to learn whether the ULS could ultimately bring more legislative appropriation funding.
Local governments	With some exceptions, local governments are coordinating planning efforts in and around Utah Lake through the ULA. However, municipalities are preparing master plans and general plans in isolation, and not all municipalities have the same resources to dedicate to Utah Lake shoreline stewardship and recreation access enhancements.
Public messaging and education	Stakeholders agreed that the public is experiencing "plan fatigue" around Utah Lake and may be cynical about progress. As a result, uniform, consistent messaging around Utah Lake's current condition and the future condition that the ULS aims to achieve will be important.
Recreation	Diversity of recreational opportunities and access points helps people interact with and gain positive impressions of Utah Lake. "Enhancing" Utah Lake for many people means improving recreational opportunities and experiences at Utah Lake.
Stakeholder outreach	Stakeholders support initial stakeholder engagement and stressed importance of involving all key stakeholders in Utah Lake in the ULS in some way.
ULS scope	ULS's geographic extent and jurisdictional scope have caused confusion, especially regarding certain S.B. 270 benefit areas, such as water conservation, land use, and water quality. Stakeholders viewed these benefit areas as having watershed-scale geographic extents and largely outside of FFSL's management authority over sovereign lands.
Utah Lake operations	Most stakeholders are uncertain about how Utah Lake is managed, how water rights influence management, and the lake's current and historical purposes as a storage reservoir.
Water levels	Water-level fluctuations make enhancing Utah Lake's littoral zone and implementing other types of projects near the water extremely difficult.

Additional information about the initial stakeholder engagement findings, including a list of additional individuals to interview, can be found in the *Initial Stakeholder Engagement Report* (Jacobs 2025), which was circulated to the Planning Team, Steering Committee, and FFSL in April 2025. Stakeholder engagement will continue throughout the course of the ULS.

3. Conserving Water Resources in and Around Utah Lake

Key findings

- Utah Lake has operated as a storage reservoir since the mid-1800s, with a complex system of water rights established over time.
- The lake's maximum elevation was initially set at 4,516 feet above sea level (based on Salt Lake City datum) in 1885. However, because of flooding in the 1980s, the maximum elevation was revised to 4,489 feet above sea level (compromise elevation), with a storage capacity of about 870,000 acre-feet at this level.
- Over the past 30 years, the lake's elevation has fluctuated by an average of 3.3 feet annually, with a maximum difference of about 6 feet recorded in 2023.
- Providing strategies to support watershed management decisions, surface or groundwater inflow management decisions, water conservation or supply management decisions, or reservoir storage operations is not within the Utah Division of Forestry, Fire, and State Lands' jurisdictional authority; these responsibilities belong to other local, state, and federal government entities.
- As part of the Utah Lake Study, the Utah Division of Forestry, Fire, and State Lands "shall respect the need to preserve water rights and interests related to water collection, storage, or delivery and projects for water collection, storage, or delivery associated with Utah Lake" (Senate Bill 270 lines 60 through 63).
- The lake has several operational challenges, including high evaporation rates, degraded water quality, and a nonnatural hydrograph because of upstream flow controls and reservoir operations.

Information needs

- Development of seasonal lake level predictions, which could significantly improve resource managers' capabilities in overseeing the lake's diverse assets and enable more effective management of recreational access points, native plant restoration initiatives, fishery and upland habitat improvement projects, and more
 - Improved coordination between water managers and natural (and recreational) resource managers
-

Conservation of water resources in and around Utah Lake is of great importance and interest to the state of Utah. Although conservation of water resources is relevant to FFSL's management of the sovereign lands of Utah Lake, at the state level, this activity is largely tasked to the DWRe. DWRe is the water resources authority for the state and implements several programs to fulfill its mission, including municipal and industrial water use data reporting, funding assistance, the State Water Plan, and water conservation planning. Utah's water providers and suppliers with more than 500 connections are required to submit water conservation plans to DWRe every 5 years to comply with the Water Conservation Act (*Utah Administrative Code* Title 73, Chapter 10). Water conservation plans encompass current and future strategies aimed at preserving water resources and detail methods for both water providers and end users to conserve water, reduce per-person usage, and ensure long-term water availability while meeting regional conservation targets. DWRe evaluates these plans and offers support to help systems enhance their water efficiency. Notably, systems failing to submit an updated water conservation plan every 5 years are deemed noncompliant and lose eligibility for state financial assistance, including loans and funding opportunities.

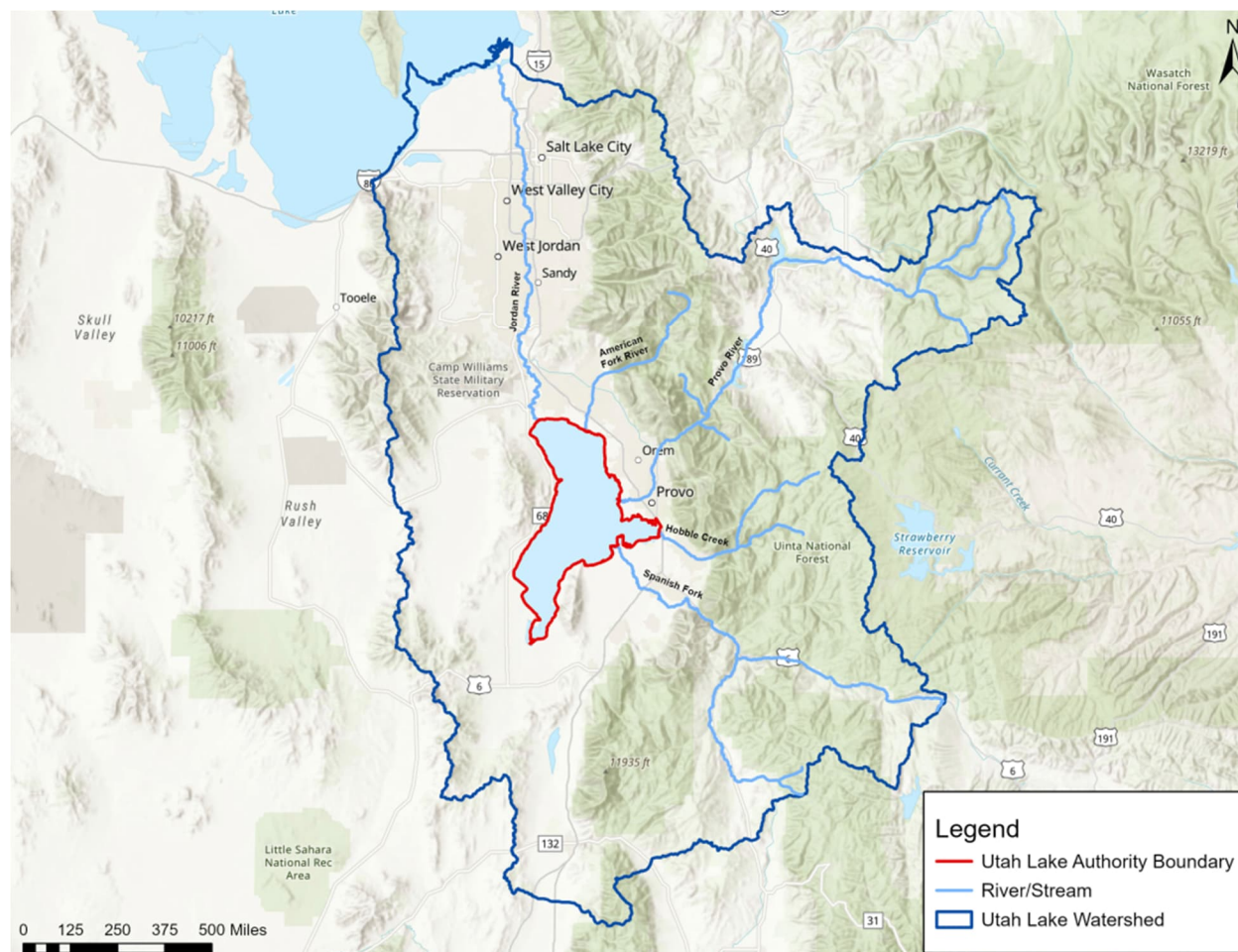
3.1 Description of Water Resource Conditions

FFSL recognizes that resource challenges occur at multiple scales and outside the boundaries of the bed of Utah Lake; however, FFSL's land management jurisdiction is limited to those resources below the lake boundary line as established by court settlements. For this reason, the description of the watershed hydrology is intentionally brief to streamline the Review of Existing Information task relevant to the lake itself. This section describes general, high-level water resource conditions at Utah Lake and describes monitoring and gauging infrastructure, reservoir management operations, evaporation losses, and fluctuating lake levels.

Utah Lake drains a 3,000-square-mile watershed, with the major tributaries being the Provo River, Spanish Fork River, Hobble Creek, and American Fork River. The major inflows to Utah Lake (Provo River and Spanish Fork River) originate in the Wasatch Mountains and feed Utah Lake through melting snowpack. The Utah Lake Basin includes two upstream reservoirs to Utah Lake, Deer Creek Reservoir and Jordanelle Reservoir, and receives water imports from the Weber and Colorado River basins. Utah Lake outflows to the Jordan River, which flows north through Salt Lake City before entering Great Salt Lake. Currant Creek is

an additional tributary from the south, and Mona Reservoir operation controls flows to Utah Lake. Figure 3-1 shows the Utah Lake watershed.

Figure 3-1. Utah Lake Watershed



Source: ULA 2024.

Utah Lake is shallow (9-foot average depth). The lake has a large surface area to volume ratio and loses approximately half of its annual inflow to evaporation (ULA 2016). Utah's desert climate and Utah Lake's large surface area and shallow depth all contribute to this high evaporation volume, which becomes a major challenge in maintaining Utah Lake levels, especially as demands in the basin continue to increase.

Historical surveys of the Great Salt Lake Basin indicate the locations of natural land cover and future sites for European settlements in the watershed, water sources to the lake, and types of bed material in Utah Lake, including locations of emergent macrophyte cover in Goshen and Provo bays (Figure 3-2; Stansbury et al. 1852).

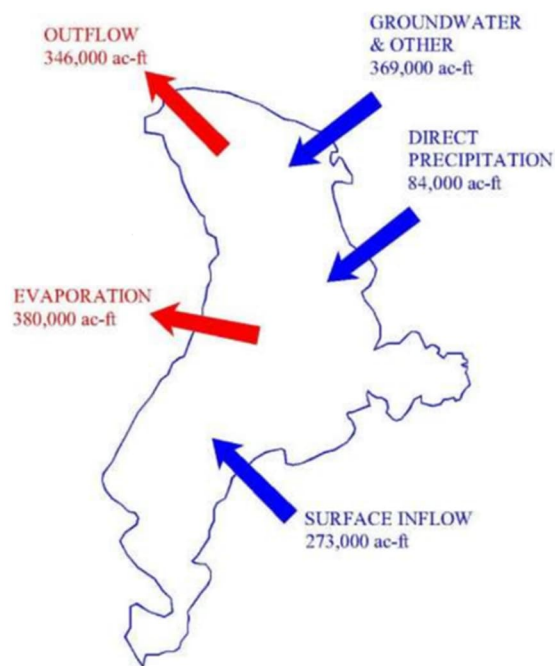
Inflows to Utah Lake are groundwater (which is the primary source of drinking water in northern Utah County), direct precipitation, and surface inflows. Water leaves Utah Lake through the reservoir outlet and evaporation (Figure 3-3). The Provo and Spanish Fork rivers make up approximately 70 percent of the inflow to Utah Lake. In addition to natural flow, these rivers receive water imports from other river basins. Water is imported to the Provo River from the Weber River Basin through the Weber-Provo Diversion Canal and the Ontario Tunnel and from the Uinta Basin through the Duchesne Tunnel. Uinta Basin water is also imported to the Spanish Fork River via Strawberry Reservoir through the Strawberry and Syar tunnels.

Figure 3-2. Original Survey of the 1852 Utah Lake Basin



Source: Stansbury et al. 1852.

Figure 3-3. Utah Lake Inflows and Outflows

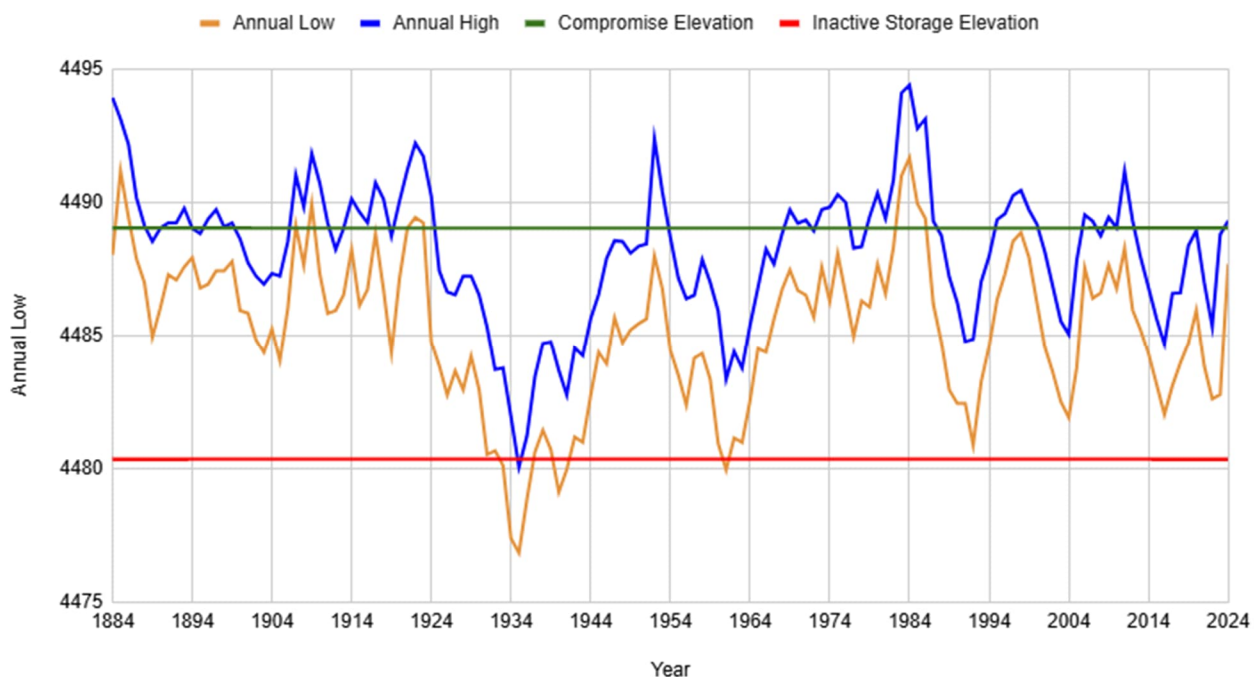


Source: Central Utah Water 2023.

ac-ft = acre-feet

The water surface elevation (feet above sea level) in Utah Lake fluctuates seasonally, annually, and over several years (Figure 3-4). Multiyear droughts impact water levels in Utah Lake significantly; however, upstream water use, changes in the lake outlet, the use of the lake as a storage reservoir, and evaporation also impact lake levels.

Figure 3-4. Utah Lake Historical Water Levels



Source: ULA n.d.f.

3.2 Water Rights and Reservoir Management

Utah Lake was historically a natural lake, but it has been managed as a storage reservoir since the 1870s. Constructed in 1872, a Jordan River dam was strategically positioned west of the Point of the Mountain. This engineering project aimed to transform Utah Lake into a vital storage reservoir for the region. The dam's primary function was to facilitate water diversion into an extensive canal network, providing crucial irrigation to agricultural lands throughout the Salt Lake Valley.

Disputes between the lakeside property owners and the Salt Lake County entities seeking to use the lake for water storage led to a contractual agreement regarding Utah Lake's use as a water storage facility. The resulting 1885 Compromise Agreement established a maximum lake elevation (the compromise elevation) to mitigate flooding concerns and establish guidelines for releases of water from the lake into the Jordan River.

In 1901, Utah Lake stakeholders met to consider plans for mitigating future water supply shortages. They planned several measures to enhance water management capabilities and expand available water resources in the region. The proposed plan included the following (Meade 1903):

- Installation of a pumping facility at Utah Lake's outlet to enable water extraction beyond the current gravitational drainage capabilities
- Acquisition or condemnation of lands adjacent to Utah Lake, allowing for increased water levels above the existing compromise level without incurring liability for damages
- Procurement of water from the Strawberry River, with the intention of channeling this water into Utah Valley via the Spanish Fork River and existing canals

Transbasin water imports to the Utah Lake Basin began in 1913, with additional projects being completed since that time, including in 1930, 1947, 1954, and 1996.

Heavy precipitation in the 1980s led to flooding and litigation. The litigation was settled through the 1985 Utah Lake Compromise Decree. The decree established a lower compromise elevation on Utah Lake; it also called for the construction of the Utah Lake outlet gates with detailed operational guidelines for flood control purposes that protect properties in both Utah and Salt Lake Counties.

In 1989, the state engineer approved applications for the exchange of higher-quality Provo River water by the Salt Lake County Water Conservancy District, now known as the Jordan Valley Water Conservancy District, for lower-quality Utah Lake water. This exchange is an example of numerous other exchanges and change applications that provide high-quality drinking water in both Utah and Salt Lake counties, which depend on an exchange of stored Utah Lake water. Growth within the Utah Lake Basin, exchanges, imports, and water rights adjudication drove the drafting of the 1992 *Interim Water Distribution Plan for the Utah Lake Drainage* (DWRi 1992), which implemented water distribution and operational guidelines for Utah Lake that still stand today.

Over the past 150 years, the operational practices governing Utah Lake have undergone significant refinement. A complex interplay of factors has driven this evolution, including lake elevation, river flow constraints, population growth in the surrounding areas, administration of water rights and appropriation of water resources, transbasin water diversions, and water exchange agreements (Hooton 1989).

3.2.1 Entities That Work Together to Manage the Water Levels of Utah Lake

The complex management of Utah Lake requires the efforts of multiple entities, all with a vested interest in lake operations. The ULWUA owns and operates the pump station and control gates at the outlet of Utah Lake. The nine members of ULWUA include water districts (water providers), an industrial water user,

and irrigation and canal companies that rely on the storage of water in Utah Lake. The following entities hold significant water rights with storage in Utah Lake:

- Utah and Salt Lake Canal Company
- Jordan Valley Water Conservancy District
- South Jordan Canal Company
- East Jordan Irrigation Company
- North Jordan Irrigation Company
- Salt Lake City Corporation
- CUWCD
- Kennecott Utah Copper Corporation
- Utah Lake Distributing Company
- Draper Irrigation Company
- Sandy Canal Company successors in interest
- Welby Jacob Water Users Company

The state engineer has appointed a water commissioner over Utah Lake to regulate the distribution of water under the direction of the state engineer (*Utah Administrative Code* 73-5-1). The ULA supports initiatives to enhance recreation around Utah Lake while supporting ecological health (ULA n.d.). The FFSL manages the lakebed. Each of these entities must work in tandem to support the management of Utah Lake.

3.2.2 Defining Documents

The following key documents define the management of Utah Lake as a storage reservoir:

- [1901 Morse Decree](#)
- [1909 Booth Decree](#)
- [1985 Utah Lake Compromise Decree](#)
- [1992 Interim Water Distribution Plan for the Utah Lake Drainage](#) (DWRi 1992)
- [1993 Amendments to Interim Water Distribution Plan](#) (DWRi 1993)

3.2.3 Administration of Water Rights in Utah: Rules and Regulations

Utah is a “first in time, first in right” state, meaning water rights are governed by the doctrine of prior appropriation and are satisfied in order of priority date. Priority date refers to the date the application for appropriation was filed with the state engineer. For dates before 1903, when the application process was adopted, priority date refers to the date water was put to beneficial use (DWRi 2010). Utah Lake has both primary storage water rights and secondary storage water rights. The primary water rights were recognized in 1901; therefore, they must be satisfied before any secondary water rights may call for water. A water right is considered satisfied if the appropriator receives all the water they are entitled to under the water right or if they choose not to divert their full water right (DWRi 2010). If a water right cannot be satisfied, a proportional share of the available water supply is given to water rights holders of the same priority date (*Utah Administrative Code* Title 73). The 1992 Distribution Plan (DWRi 1992) tabulated the annual beneficial uses of the storage rights in Utah Lake (as they stood at that time) that may be withdrawn or administered from the primary and secondary storage water available in Utah Lake.

Storage of water in Utah Lake is relied on not only to satisfy downstream water rights but also to assist with upstream storage in Deer Creek and Jordanelle reservoirs. The 1992 Distribution Plan also defined the relationship between these upstream storage water rights and storage rights in Utah Lake so that all of the reservoirs within the Utah Lake drainage basin (including Utah Lake itself) could be regulated in accordance with their respective priority dates. This coordinated reservoir management maximizes the beneficial use of water in the Utah Lake drainage and still protects prior rights. However, it also means that

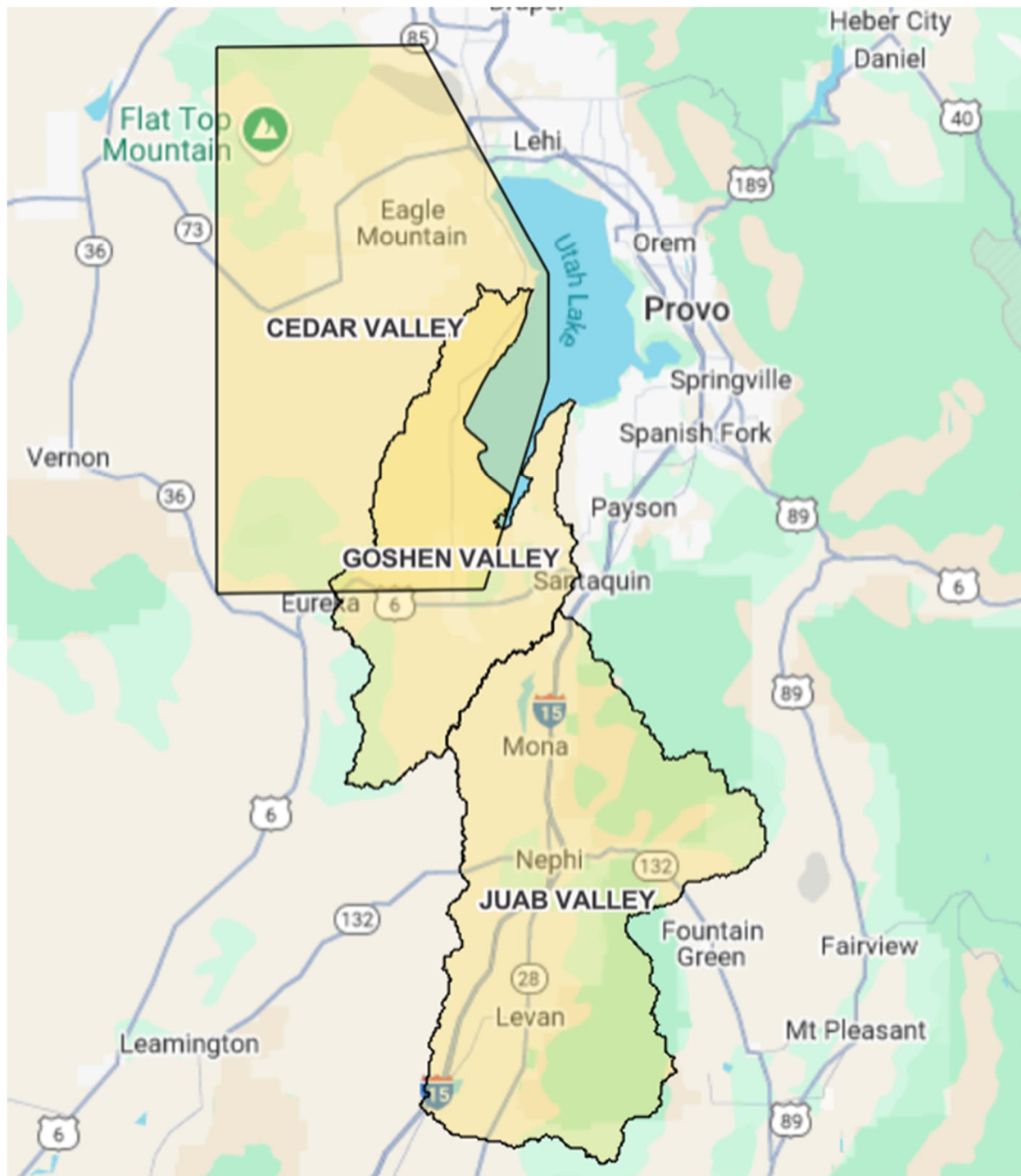
the water level in Utah Lake may be higher or lower than it otherwise might be in the absence of coordinated storage.

3.3 Monitoring

Surface inflows account for approximately 61 percent of the total inflows to Utah Lake (Psomas and SWCA 2007). Fuhrman et al. (1981) identified 51 inflow sources to Utah Lake, although only 6 of these inflows are currently continuously gauged by the U.S. Geological Survey (USGS), 4 of which are in upstream locations in the watershed (the Provo River and Hobble Creek gauge stations represent tributary flows reaching the lake). Groundwater is another major inflow source for Utah Lake. Groundwater inflows are mainly concentrated in a north-south band along the eastern portion of Utah Lake, as shown by the study extents on Figure 3-5. No UGS groundwater monitoring sites exist within the Cedar Valley or Goshen Valley groundwater areas on the west side of Utah Lake (UGS n.d.).

The Great Salt Lake Basin Integrated Plan (GSLBIP) gap analysis identified the need for additional water-level and stream-flow gauges in the Great Salt Lake Basin (DWRe 2023). USU completed a comprehensive inventory and analysis of existing diversion and stream measurement infrastructure and a preliminary investigation of measurement infrastructure gaps around Great Salt Lake in July 2024 (Lukens et al. 2024) for DWRI; these efforts identified numerous measurement infrastructure and data gaps for Utah Lake, including tributaries upstream of the lake and within the Jordan River downstream of the lake. Additionally, stakeholders suggested the need for numerous new or updated diversion measurement infrastructure upstream of Utah Lake. Through funding via House Bill (H.B.) 429 and Reclamation's basin study program (Reclamation 2022) set aside for the GSLBIP, additional gauging may be added in the Utah Lake Basin.

Figure 3-5. Utah Groundwater Study Extents in the Utah Lake Basin



Source: Jordan and Sabbah 2012.

4. Improving Clarity and Quality of the Water in Utah Lake

Key findings

- The Utah Lake Water Quality Study (ULWQS) is working to identify water quality targets for nutrients necessary to meet Utah Lake's designated beneficial uses and develop a water quality improvement strategy.
- Paleolimnological (paleo) indicators and historical accounts indicate that Utah Lake was historically a clear-water, low-nutrient system with primary production dominated by macrophytes.
- In response to human disturbances since the turn of the 20th century, Utah Lake has shifted to a phytoplankton-dominated, high-nutrient system. These disturbances include the introduction of invasive species, including carp; wastewater and other point and nonpoint pollutant loading; and land use change in the watershed.
- Today, the lake has low water clarity, which is attributed to sediment resuspension and phytoplankton growth. Sediment resuspension makes up most turbidity and is driven mainly by wind and wave action. Phytoplankton growth is driven by excess nutrient loading, which is exacerbated by sediment nutrient recycling.
- Empirical analysis of monitoring data and small-scale experiments in Utah Lake, as well as literature evidence from other lakes, indicate that nutrient reductions are needed to reduce algal growth in Utah Lake, but lag time associated with nutrient recovery is possible because of the time it will take for the sediments to reach a new equilibrium. However, in addition to nutrient reductions, rehabilitation of the ecosystem structure (for example, restoration of benthic macrophytes and stabilization of benthic sediments) has been shown to be very important to improving water quality in other lakes.
- To restore a clear-water state of a macrophyte-dominated system, several aspects of Utah Lake will need to be managed, including but not limited to nutrient loading, sediment resuspension, carp removal, and macrophyte recovery.
- Multiple forms of nutrient management are available, including external loading reductions, chemical treatments, dredging, and top-down food web management. External loading reduction is likely to be the most successful management activity long term in Utah Lake, and the ULWQS is planning for the implementation of external nutrient load reductions.

Information needs

- Information associated with completion of the ULWQS: (1) finalization of the ULWQS numeric nutrient targets for protection of beneficial uses and (2) completion of the ULWQS nutrient management plan, which will include point-source reductions and nonpoint-source best management practices
 - Identification of nutrient ranges characteristic of oligo-mesotrophic lakes that would support transition to a clear-water, stable state to achieve the objectives of this ULS
 - Improved understanding of sediment nutrient cycling and its potential impact on lake recovery time
 - Strategies that can reduce sediment resuspension and transport
 - Environmental requirements of submerged aquatic vegetation for restoration (native plant restoration toolbox)
 - Information about how benthic macrophytes can be restored with stressors such as common carp and variable water levels
 - Positive feedback and unintentional consequences of reduced phytoplankton growth, increased water clarity, and subsequent macrophyte recovery
-

4.1 Historical Context

Information retained in the sediment record has provided evidence of historical conditions in Utah Lake. Diatom remains are often used to infer environmental conditions from sediment cores because they are preserved in the paleo record and the requirements of various diatom taxa are well known. Before European settlement, diatom communities in Utah Lake were characterized by benthic and epiphytic species, as well as pollution-sensitive taxa. Sediment cores from Goshen Bay and Bird Island analyzed by Brahney et al. (2024) show diatom taxa below 30 centimeters (cm) or 40 cm represented by benthic species more sensitive to pollution, including epiphytes. Consistent with distinct periods of human settlement and disturbance in Utah Lake's watershed, phase shifts were observed across sediment cores for several paleo indicators. For diatoms, at 30 cm, corresponding to the late 1800s and the arrival of European settlers, the taxonomic representation of species shifts toward a more pollution-tolerant benthic species. Then at 10 to 12 cm, corresponding to 1960 to 1975, more pollution-tolerant species begin to appear, and planktonic species significantly increase compared to benthic species. The early parts of the cores are considered more pollution-sensitive species, followed by an increase in more pollution-tolerant species toward the surface of the cores, as indicated by the Biological Condition Gradient (Davies and Jackson 2006). Cores collected in different areas of the lake for different studies show similar shifts from a benthic-dominated, pollution-sensitive diatom community to a planktonic-dominated, pollution-tolerant

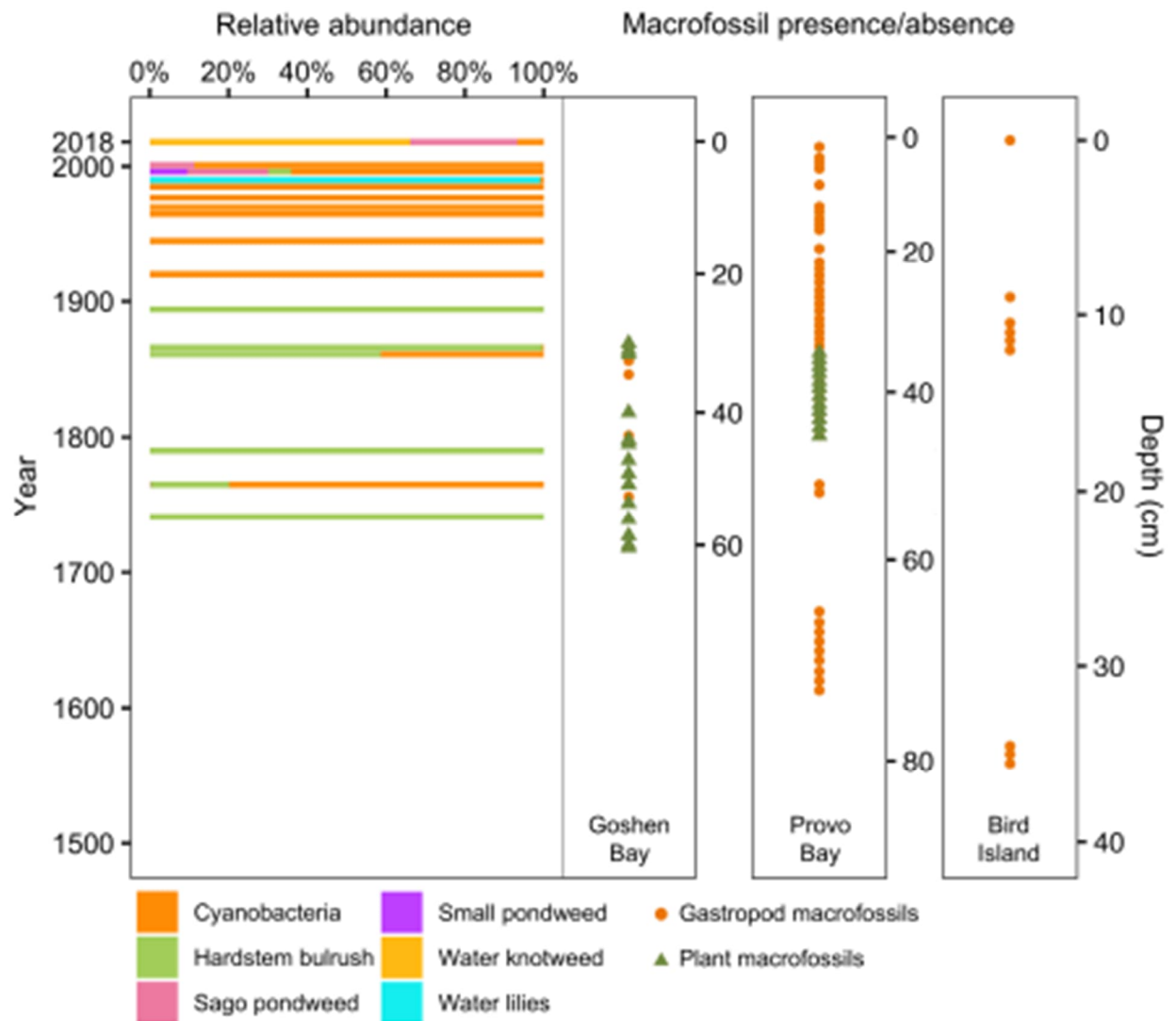
community, which has been attributed to increased turbidity because of carp and eutrophication (Bolland 1974; Javakul et al. 1983).

Analysis of sediment deoxyribonucleic acid (sedDNA) and physical remains in sediment cores revealed a distinct shift from a high prevalence of submerged and emergent macrophytes and gastropods in the 1800s to nearly no evidence of macrophyte presence in the 1900s, associated with agricultural and urban expansion in the watershed and carp introduction to the lake (Figure 4-1; King et al. 2024).

Today, three macrophyte species dominate the native assemblage in Utah Lake, although usually in low densities (Miller and Provenza 2007):

- *Stuckenia pectinata* B. (formerly known as *Potamogeton pectinatus* L.)
- *Typha latifolia* L.
- *Scirpus validus* L.

Figure 4-1. Relative Abundance of Aquatic Plants and Cyanobacteria Sequences Detected with sedDNA in Goshen Bay Core and Plant Macrofossils and Gastropod Fossils Found throughout Goshen Bay, Provo Bay, and Bird Island Cores

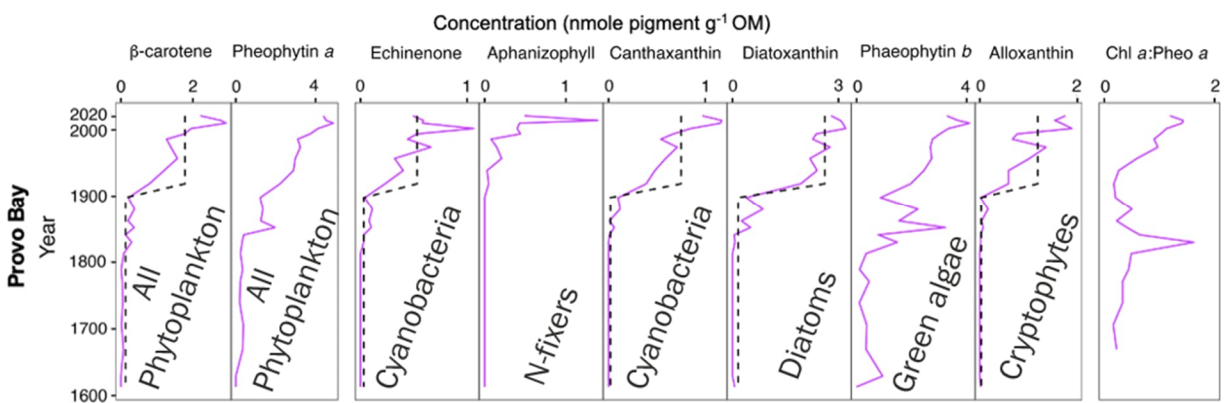


Source: King et al. 2024.

cm = centimeter(s)

Paleo analysis in sediment cores has also supported the evidence for an increase in overall phytoplankton and cyanobacteria prevalence over time. Similarly to diatom paleo indicators, photosynthetic pigments have also shown distinct phase shifts, changing from predominantly benthic algae to more suspended phytoplankton observed in the late 1800s and mid-1900s, with 4- to 58-fold increases in phytoplankton pigment concentrations observed following the first phase transition (Figure 4-2; King et al. 2024). Following the first phase transition, sedDNA markers for cyanobacteria increased, with the greatest prevalence during the latter half of the 1900s (Figure 4-2; King et al. 2024). Concentrations of photosynthetic pigments in almost all instances have increased in Utah Lake sediments since 1900. The pigment associated with nitrogen-fixing cyanobacteria (aphanizophyll) was not observed until about 1967 (Figure 4-2).

Figure 4-2. Concentrations of Photosynthetic Pigments and Degradation Ratio (Chlorophyll *a*: Pheophytin *a*) in Utah Lake Sediment Core from Provo Bay



Source: Modified from King et al. 2024.

Note: Pigment markers for several phytoplankton taxa of interest are noted. Dashed lines indicate significant, abrupt changes as detected by STARS.

g = gram

nmol g⁻¹ OM = nanomole(s) per gram of organic matter

Chl *a* = chlorophyll *a*

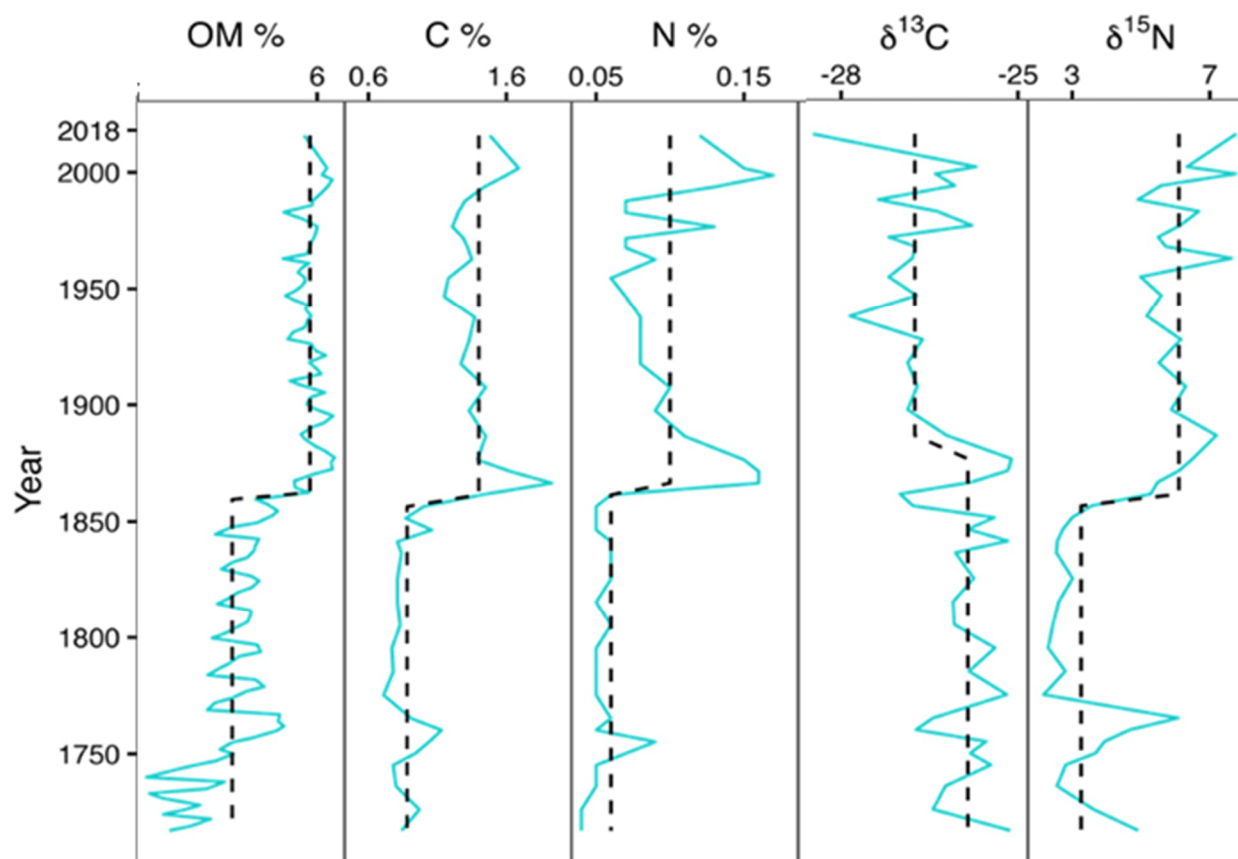
Pheo *a* = pheophytin *a*

Additional paleo indicators for various environmental conditions have been observed via elemental concentrations and isotope signatures in the sediment record of Utah Lake. These observations from pre-European settlement to present day include the following:

- **Decrease in carbon to nitrogen ratios and decrease in $\delta^{13}\text{C}$ (an isotope signature that is the measure of the ratio of the two stable isotopes of carbon ^{13}C : ^{12}C in parts per thousand):** Indicative of a decrease in macrophyte remains in organic matter (Figure 4-3; Williams et al. 2023; Brahney et al. 2024; King et al. 2024).
- **Increase in sediment organic matter:** Indicative of an increase in primary production and delivery of decaying organic matter to the sediments (Figure 4-3; Williams et al. 2023; Brahney et al. 2024).
- **Increase in $\delta^{15}\text{N}$ (measure of the ratio of the two stable isotopes of nitrogen ^{15}N : ^{14}N):** Indicative of increased wastewater influence (Figure 4-3; Williams et al. 2023; Brahney et al. 2024).
- **Increases in sediment nitrogen and phosphorus:** Indicative of nutrient enrichment, particularly in Provo and Goshen Bays. Main basin phosphorus concentrations have increased more modestly, although significant increases in the calcite (CaCO_3)-bound fraction are observed throughout the lake (Figure 4-3; Williams et al. 2023; Brahney et al. 2024).

- **Shifts in metal concentrations and ratios:** Increases in the iron to manganese ratio indicate a shift to more oxic conditions in the sediments, potentially through carp bioturbation (Brahney et al. 2024). Increases in lead and other heavy metals over time are associated with the introduction of leaded gasoline and manufacturing plants (for example, Ironton plant, Geneva Steel) in the watershed (Williams et al. 2023).

Figure 4-3. Sediment Core Profiles of Organic Matter, Carbon, and Nitrogen Content and Stable Isotope Values in the Northern Main Basin of Utah Lake



Source: Modified from Brahney et al. 2024.

Note: Dashed lines indicate significant, abrupt changes detected by STARS.

4.2 Current Conditions

Utah classifies waters based on their beneficial uses and develops water quality standards to protect those uses. Utah Lake is currently protected for the following designated beneficial uses (DWQ 2019):

- **Class 2A:** Protected for frequent primary contact recreation with a high likelihood of water ingestion or a high degree of bodily contact with the water
- **Class 3B:** Protected for warm-water species of game fish and other warm-water aquatic life, including the necessary aquatic organisms in their food chain
- **Class 3D:** Protected for waterfowl, shorebirds, and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain
- **Class 4:** Protected for agricultural uses, including crop irrigation and stock watering

The *ULWQS Numeric Nutrient Criteria Implementation Framework* details the connections between designated uses and specific management endpoints, providing a direct link from designated use support to water quality and clarity indicators (ULWQS Steering Committee and DEQ 2022).

Utah Lake has experienced extensive algal blooms, typically during late summer and fall, which degrade recreational uses and increase the potential for cyanobacteria toxin production (ULA n.d.c). As a result, in the 2016 Integrated Report, DWQ identified Utah Lake as nonsupporting for recreational use because of high levels of blue-green algae (cyanobacteria), cyanotoxins, and chlorophyll *a* (Chl *a*; DWQ 2016; Tetra Tech 2024). In the last 5 years, the State of Utah has issued several HAB advisories per year for Utah Lake, ranging from warning levels with a recommendation to avoid primary contact recreation to danger levels that trigger a waterbody closure (DWQ 2023).

Tetra Tech (2024), in collaboration with DEQ and ULWQS Science Panel, summarized nutrient and Chl *a* concentrations in Utah Lake in what are the most up-to-date lake-wide summaries available. Utah Lake is generally considered eutrophic, with median total phosphorus (TP) and total nitrogen (TN) concentrations exceeding 0.08 and 0.7 milligram per liter (mg/L), respectively (Table 4-1). The lake supports a robust growing-season phytoplankton assemblage, with a median Chl *a* concentration greater than 20 micrograms per liter (µg/L) (often exceeding 40 to 60 µg/L; Table 4-1). Although these reflect lake-wide conditions, the DWQ maintains two distinct assessment units for CWA regulatory purposes: (1) the main basin Utah Lake and (2) Provo Bay. Some analyses of water quality constituents and hydrologic properties identify the southernmost portion of the lake, Goshen Bay, as a third distinct area of Utah Lake, but this identification is not part of DWQ regulations and is used inconsistently across studies (for example, King et al. 2023; Tetra Tech 2024).

Table 4-1. Utah Lake-Wide Eutrophication-Related Water Quality Conditions during Growing Season (April through September), 2013 through 2022

Constituent	Region	25th Percentile	Median	Mean	75th Percentile
Chl <i>a</i> (µg/L)	Main Basin	5.8	17.4	39.3	46.4
	Provo Bay	41.6	82.3	117.1	165
	Goshen Bay	11.3	20.3	36.0	46.2
Secchi depth (feet) ^[a]	Main Basin	0.20	0.25	0.26	0.30
	Provo Bay	0.15	0.20	0.21	0.25
	Goshen Bay	0.15	0.20	0.21	0.25
TN (mg/L)	Main Basin	0.58	0.70	0.76	0.84
	Provo Bay	0.71	0.98	1.39	1.52
	Goshen Bay	0.60	0.77	0.89	0.89
TP (mg/L)	Main Basin	0.051	0.073	0.105	0.120
	Provo Bay	0.310	0.503	0.615	0.666
	Goshen Bay	0.053	0.094	0.222	0.208

Source: Water Quality Portal n.d.

^[a] Secchi depth is a measure of water clarity, indicated as the depth at which a white and black disk lowered into the water can no longer be seen.

Utah Lake has received widespread public attention for its prevalence of HABs and associated recreational health advisories (Table 4-2; DWQ 2024). A research study by Tate (2019) used remote sensing data to reconstruct the frequency and spatial distribution of HABs in Utah Lake over 34 years, beginning in 1984. This analysis revealed that Provo Bay and sections of the eastern shoreline have had detectable algal blooms in 30 of the 34 years analyzed. Algal concentrations were also shown to be positively correlated to water temperature and negatively correlated to lake water levels, demonstrating some predictive ability of

physical controls on algal growth (Tetra Tech 2021). Tate (2019), using a satellite-based method, noted hotspots of phytoplankton biomass in Provo Bay, in Goshen Bay, and along the eastern side of the main basin. However, they found no overall increasing or decreasing trend of mean algal concentrations lake-wide since the 1980s.

Table 4-2. Number of Harmful Algal Bloom Advisories Reported Each Year in Various Locations around Utah Lake

Year	Number of Warning Advisories	Weeks Spent in Warning Advisories	Number of Danger Advisories	Weeks Spent in Danger Advisories
2016	6	11	2	8
2017	6	18	0	0
2018	7	20	3	14
2019	7	19	1	3
2020	3	15	3	10
2021	4	20	1	4
2022	7	21	0	0
2023	5	22	0	0
2024	6	22	0	0

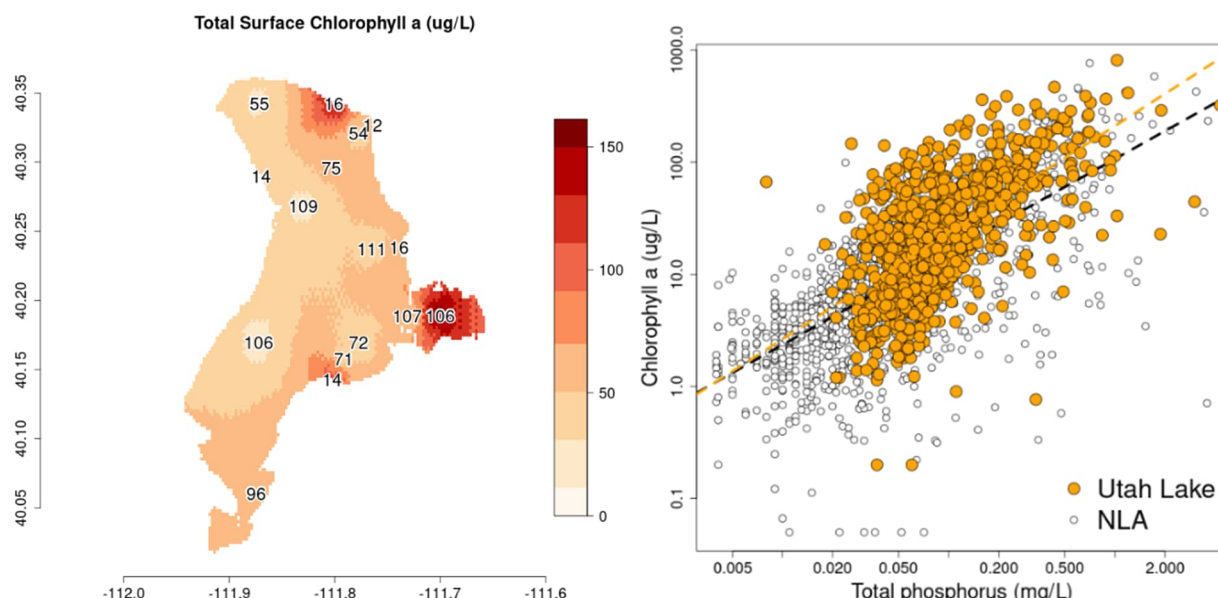
Source: DWQ 2024.

Notes:

A warning advisory is prompted by cyanobacteria cell counts exceeding 100,000 cells per milliliter and/or microcystin concentrations exceeding 8 µg/L; a danger advisory is prompted by microcystin concentrations exceeding 2,000 µg/L and would involve lake closure. The criteria that trigger an advisory have been modified over time, so the conditions for each advisory included in the table are not necessarily consistent.

Counts of advisories and length of time are based on combined evaluation of lake-wide and location-specific advisories (for example, beaches and marinas).

Of the factors that lead to algal blooms, external nutrient inputs are often considered one of the most controllable factors and receive attention from resource managers and researchers. Tetra Tech (2021) analyzed data provided by DWQ as part of the ULWQS Analysis Plan and found a strong relationship between surface water TP and Chl *a* concentration and a weaker, but still significant, relationship between TN and Chl *a*. Data from the Utah Lake Data Explorer (DWQ n.d.) show the relationship between TP and Chl *a* in Utah Lake and a series of lakes sampled nationwide as part of EPA's National Lakes Assessment (Figure 4-4; EPA 2024). Like lakes nationwide, Utah Lake displays a positive relationship between Chl *a* and TP (the same dataset is not currently available for nitrogen through the Utah Lake Data Explorer).

Figure 4-4. Interpolated Chlorophyll *a* Concentration in Surface Water in Utah Lake

Source: *Utah Lake Data Explorer (DWQ n.d.)* samples from 2000 through 2022 (June through September), accessed January 28, 2025.

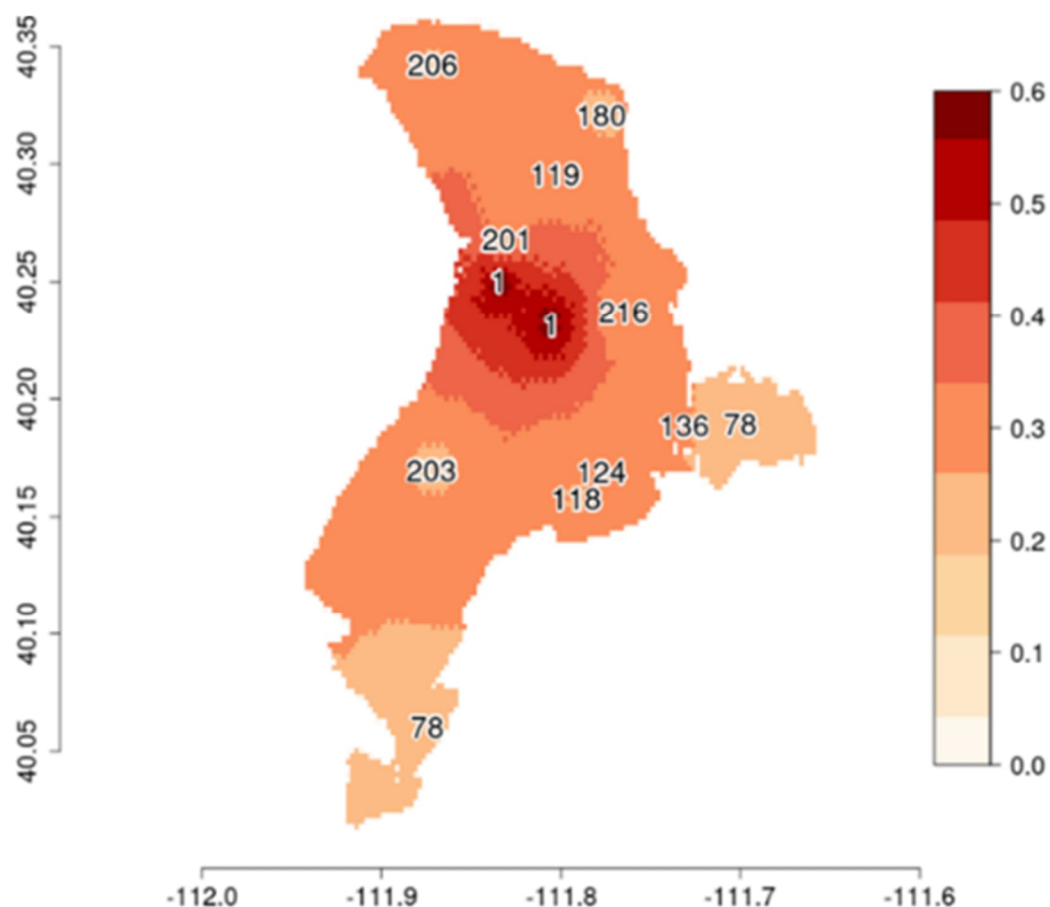
Note: Darker colors indicate greater concentrations, and numbers represent sample counts from that area of Utah Lake (left). Paired samples in Utah Lake are compared to the population of lakes in the EPA National Lakes Assessment (EPA 2024) dataset (right).

4.2.1 Water Clarity

In addition to phytoplankton growth, Utah Lake also has low water clarity as measured by Secchi depth (Table 4-1; Figure 4-5; King et al. 2023), attributed to its large surface area, shallow depth, and susceptibility to sediment resuspension from wind-driven events, which is exacerbated by a lake-wide lack of macrophytes. As described in Section 4.1, historical reports and paleo records suggest that Utah Lake was historically a clear-water system that supported a robust submerged macrophyte community. Paleo studies have attributed the current turbid conditions in Utah Lake to a shift toward a phytoplankton-dominated state, external nutrient loading, and the introduction of common carp (*Cyprinus carpio*) (Brotherson 1981; Miller and Crowl 2006; Brahney et al. 2024).

Reduced water clarity in Utah Lake is attributed to phytoplankton growth and wind-driven sediment resuspension; this can also result in nutrient release, which can have impacts on biological processes (Peng et al. 2019). Turbidity is positively related to Chl *a* in the main basin, showing the impact phytoplankton blooms have on water clarity (Figure 4-6). However, King et al. (2023) found a weak link between turbidity and Chl *a* in wind-sheltered shallow bays. Thus, reductions in both phytoplankton and sediment resuspension are likely needed to improve water clarity to a degree that supports a robust submerged macrophyte community. Tetra Tech (2021) estimated that phytoplankton are responsible for about 25 percent of total turbidity in Utah Lake, with Provo Bay acting as a notable exception with more algal-driven turbidity. Turbidity in Utah Lake increases when wind speeds are high enough to generate wave shear of sufficient strength to entrain sediments into the water column (Figure 4-6; Tetra Tech 2021). Levels of sediment resuspension are lower in Provo Bay than in the main basin, likely due to wind sheltering, and levels of primary production are higher as well. King et al. (2023) conducted benthic primary production modeling to demonstrate that improvements in water clarity to Secchi depths of 1 meter and Chl *a* concentrations of 20 $\mu\text{g/L}$ could support submerged macrophyte growth in the lake's main basin, and even more modest improvements in clarity could support macrophyte growth in Provo Bay.

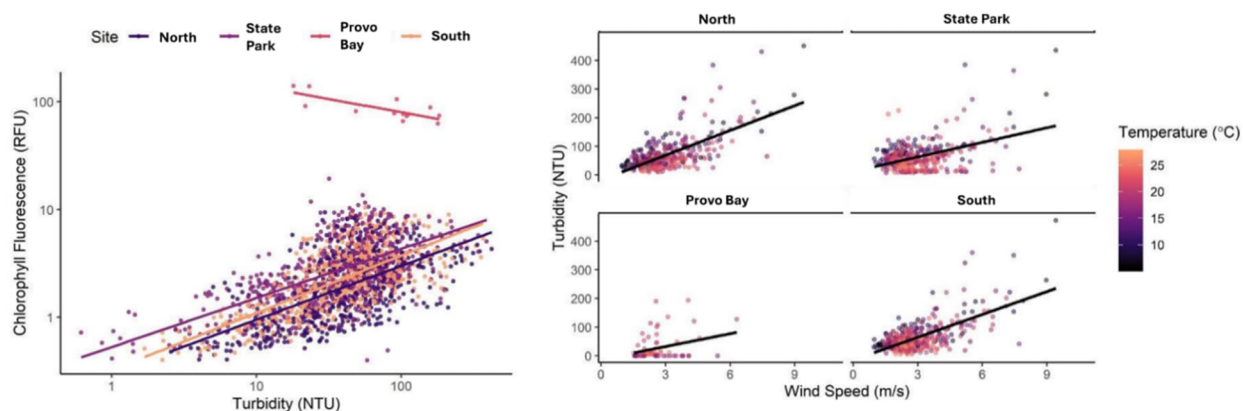
Figure 4-5. Interpolated Secchi Depths Data (meters) in Utah Lake, June through September



Source: DWQ n.d. samples from 2000 through 2022 (June through September), accessed January 29, 2025.

Note: Darker colors indicate higher water clarity, and numbers represent sample counts from that area of Utah Lake. Caution should be taken when interpreting the two 0.6-meter Secchi readings, as those are each from a single sampling event.

Figure 4-6. Correlation of Turbidity and Chlorophyll Fluorescence and Correlation of Turbidity and Wind Speed at Buoy Sites



Source: Tetra Tech 2021.

°C = degree(s) Celsius

m/s = meter(s) per second

NTU = nephelometric turbidity unit(s)

RFU = relative fluorescence unit(s)

4.2.2 Sediments and Water Clarity

The sediments in Utah Lake are dominated by CaCO_3 . During the warmer growing season, biologic activity in the lake combined with the naturally high alkalinity increases the pH of the lake water, which increases the formation of CaCO_3 precipitates. The high concentration of CaCO_3 in Utah Lake influences the adsorption and dissolution of sediment-bound phosphorus in and out of lakebed sediments (Psomas and SWCA 2007). Like many large, shallow lakes, Utah Lake is more susceptible to sediment and nutrient resuspension from wind action, carp activity, recreational boating, and other activities, exacerbated by the lack of aquatic macrophytes (Miller and Crowl 2006; Richards and Miller 2019).

Many concerns surrounding Utah lake sediments revolve around their role in nutrient dynamics, water clarity, and possible macrophyte restoration as a stabilization technique. A study by LeMonte et al. (2024), commissioned by the ULWQS Science Panel, found that most of the phosphorus in Utah Lake-bed sediments are stable and bound with CaCO_3 minerals (63 percent) and that sediments are a net sink for phosphorus entering Utah Lake. The study also found sediment porewater (the water between sediment particles) had 10 to 100 times more phosphorus than surface water, with the greatest concentrations in Goshen and Provo bays.

Because of the reservoir operation, Utah Lake also experiences great variations in lake levels, paired with wide and shallow littoral depths; large areas of Utah Lake's littoral sediments are exposed to periodic wet and dry cycles. In extreme low water years, such as 2016, many shallow bays of the lake sediments can become exposed and dry for many months (Richards and Miller 2019). Periodic drying and wetting cycles can mobilize phosphorus from the sediments to the water column, as observed in Utah Lake (Rivers et al. 2022) and elsewhere (Baldwin and Mitchell 2000; Scholz et al. 2002). This suggests lake level fluctuations play some role in the transport of nutrients from sediments to the water column of Utah Lake.

4.2.3 Watershed Loading

Utah Lake receives external nutrient inputs from a variety of sources within the watershed:

- A TMDL report estimated external TP loading as 170 metric tons per year (Psomas and SWCA 2007).
- A report from Merritt and Miller (2016) estimated TP loading as 247 metric tons per year.
- A mass balance study conducted as part of the ULWQS estimated TP loading as 183 metric tons per year (Tetra Tech 2022).

Since the mass balance study (Tetra Tech 2022), efforts have been made to update the mass balance estimates, including revising the estimates of atmospheric nutrient deposition and refining hydrologic flow paths to quantify nonpoint loading estimates, which brought the total estimated TP loading to the lake to 196 metric tons per year. Current estimates of TN loading (through 2020) are 1,611 metric tons per year (Tetra Tech 2022), compared to previous estimates of 1,946 metric tons per year (Merritt and Miller 2016). A potential area for enhanced research could be updating the lake mass balance to include the most up-to-date monitoring data, particularly given the in-progress enhancements to publicly owned treatment works (POTW) treatment technologies that have occurred in the intervening years. In-progress watershed modeling as part of the ULWQS will produce an updated mass balance to include refinements in temporal loading patterns and improved understanding of stormwater and nonpoint sources.

4.2.4 Nutrients and Spatial Patterns

Across Utah Lake, data can vary between sampling stations, but typically many eutrophication-related sampling parameters are elevated in Provo Bay (Tetra Tech 2021). A spatial analysis of continuous metered data in four locations across Utah Lake showed Provo Bay experienced greater pH swings, reduced pH values, greater Chl *a* concentrations, and frequent dissolved oxygen (DO) minima below the

The figure consists of two maps of Lake Michigan, each showing the spatial distribution of a different nutrient. The left map displays Total Surface Nitrogen (mg/L) with a color scale from 0.0 to 1.4. The right map displays Total Surface Phosphate-phosphorus (mg/L) with a color scale from 0.0 to 0.6. Both maps include latitude and longitude coordinates and numerical data points overlaid on the lake's surface.

Total Surface Nitrogen (mg/L)

Latitude: 40.05, 40.10, 40.15, 40.20, 40.25, 40.30, 40.35

Longitude: -112.0, -111.9, -111.8, -111.7, -111.6

Color scale: 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4

Map data points (approximate values): 26, 9, 7, 26, 7, 24, 26, 26, 8, 26, 24, 24, 7, 24, 24, 26, 24.

Total Surface Phosphate-phosphorus (mg/L)

Latitude: 40.05, 40.10, 40.15, 40.20, 40.25, 40.30, 40.35

Longitude: -112.0, -111.9, -111.8, -111.7, -111.6

Color scale: 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6

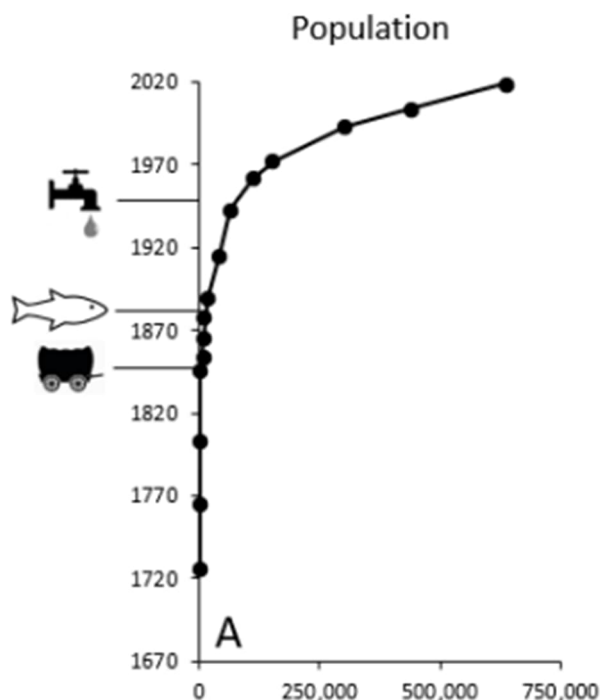
Map data points (approximate values): 57, 9, 7, 24, 55, 55, 54, 8, 24, 24, 7, 42, 48, 41.

Note: Darker colors indicate high concentrations; numbers represent sample counts from that area of Utah Lake.

As detailed in Section 4.1, major phase shifts have occurred in Utah Lake as a result of European settlement and carp introduction around the turn of the 20th century. Since that time, the human population in the area has increased substantially (Figure 4-8). Utah Lake is within Utah County, the second most populous county in Utah, with the cities of Provo, Orem, and other surrounding communities accounting for 21 percent of the state's residents (as of 2024; Harris 2025). Utah County's population is one of the fastest growing in the United States (U.S. Census Bureau 2022), and continued growth is expected, increasing the strain on already limited water resources in the area.

Today, seven major sources discharge wastewater to Utah Lake, including Orem, Payson, Provo, Salem, Spanish Fork, Springville, and Timpanogos POTWs. Several studies have attempted to calculate nutrient loading to Utah Lake from wastewater inputs. Studies from TMDL analysis, technical reports, ULWQS Science Panel, and DWQ staff indicate that 60 to 79 percent of the external phosphorus load and 33 to 55 percent of the external nitrogen load are from wastewater inputs (Psomas and SWCA 2007; Merritt and Miller 2016; Brett, pers. comm. 2019; Tetra Tech 2022). In 2015, DWQ adopted technology-based phosphorus effluent limits of 1.0 mg/L (*Utah Administrative Code* R317-1-3.3), specifying that new effluent limits will be effective as of January 1, 2020, although variances received by facilities have extended the implementation date to 2025 and full compliance to 2026.

Figure 4-8. Population Growth in Utah Lake Watershed with Timing of European Settlement (wagon icon), Carp Introduction (fish icon), and Wastewater Treatment (faucet icon)



Source: Brahney et al. 2024.

Utah Lake experiences large lake level fluctuations because of interannual hydrologic variability and active management of lake storage to maintain water availability for watershed and downstream use (Figure 3-4). Both within and among different years, the variability in lake level represents an additional stressor on water quality and clarity in Utah Lake, with impacts on nutrient cycling (Rivers et al. 2022), HABs (Tate 2019; Tetra Tech 2021), carp and native fish recruitment (Landom et al. 2022), migratory bird habitat, and submerged macrophyte recovery (Landom et al. 2022). The interactions between all of these stressors (chemical, biological, and physical) are complex and not yet well understood.

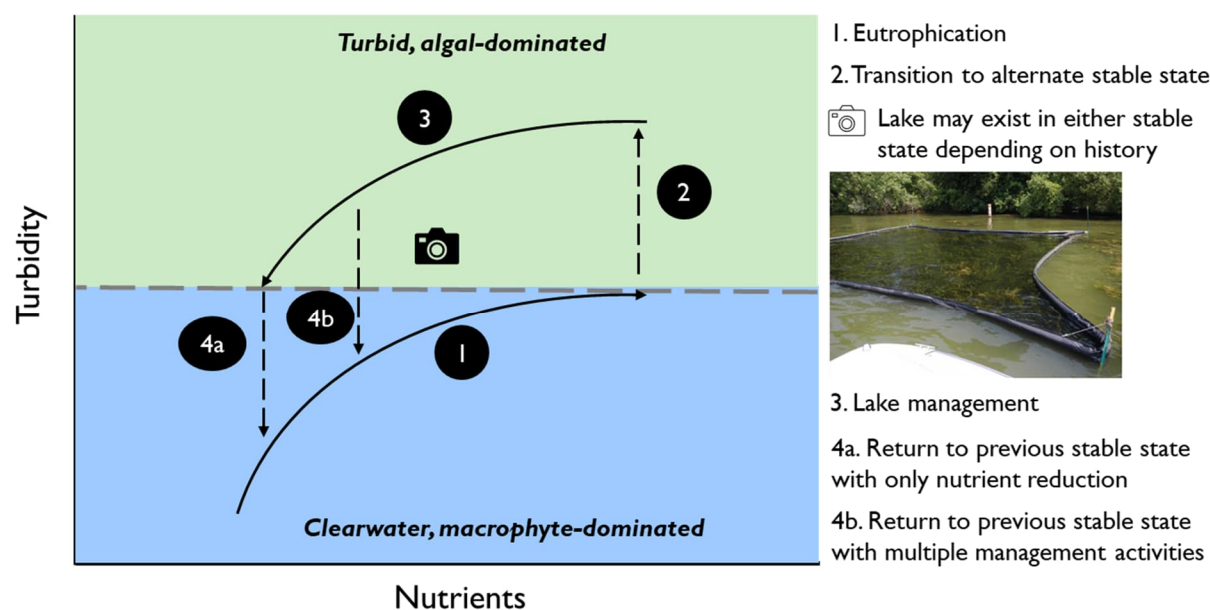
4.4 Ecological Dynamics

The historical and current water quality conditions of Utah Lake fit well within the ecological theory of alternative stable states for shallow lake ecosystems. This theory states that shallow lakes generally fall within two ecological states, a macrophyte-dominated, clear-water state or an algal-dominated, turbid state. Greater nutrient concentrations generally result in greater algal production and reduced water clarity. Both the clear-water, macrophyte-dominated state and the turbid, algal-dominated state may exist at moderate nutrient concentrations (Scheffer et al. 1993). However, the environmental change needed to shift a waterbody from one state to another is greater than the environmental conditions needed to sustain that state (Carpenter et al. 1999). In Utah Lake, the absence of macrophytes (and other taxa, such as mussels) that stabilize sediments leads to high turbidity, which prevents sufficient light from penetrating the lake to reestablish macrophytes. Up to the mid-19th century, submersed meadows of macrophytes stabilized sediments, allowing clear water, which sustained macrophyte growth. The introduction of carp (which are a major cause of the disappearance of benthic vegetation) and excessive nutrient loading (that favored epiphytic and planktonic algae) helped shift the lake to its current state.

The alternative stable states phenomenon has been theorized, modeled, and observed in other shallow lakes and is recognized as a current issue in Utah Lake restoration (Scheffer et al. 1993; Carpenter and Brock 2006; Scheffer et al. 2015; Miller and Richards 2020; Figure 4-9). Further, maintaining a

macrophyte-dense phase in large, shallow lakes has been argued to be more difficult because of wind, waves, and sediment resuspension (van Geest et al. 2003; Janssen et al. 2014). Regime shift studies in lake ecosystems also suggest that elevated levels of ecosystem variability may occur for years to a decade before actual regime shift (Carpenter and Brock 2006). Thus, tracking and emphasizing incremental progress along the management pathway to recovery may be helpful, as a whole-ecosystem regime shift may take time to realize. However, Utah Lake restoration activities should not be avoided for this reason. Instead, alternative stable states suggest that careful attention should be applied to addressing the site-specific setting, managing and monitoring multiple aspects of the system toward multiple restoration goals, applying appropriate nutrient targets, considering watershed-wide and in-lake restoration solutions, and setting realistic expectations and timelines for recovery, which could take years to decades.

Figure 4-9. Conceptual Diagram of Resistance in Alternative Stable States Theory during Recovery of Shallow Lakes



Source: Revised from Scheffer et al. 1993).

Note: This figure shows that the nutrient and turbidity reductions needed to return to a macrophyte-rich stable state may be greater than the maximum nutrient turbidity concentrations that could sustain it.

4.5 Recent Research

Several small-scale sediment core experiments have been conducted to determine the interactions between sediments and water column nutrients in Utah Lake. Goel et al. (2020) investigated the transfer of water column phosphorus into and out of lakebed sediments to determine whether phosphorus release from the sediments to the water column is occurring at ambient and experimental nutrient concentrations. They found that, with the diluted and ambient surface water phosphorus concentrations, phosphorus generally stayed similar or increased in surface water, presumably from mobilization from sediments. When surface water phosphorus concentrations were increased (with an artificial spike), phosphorus from the water column was lost into the sediments, demonstrating strong capacity for Utah Lake sediments to trap and retain phosphorus.

LeMonte et al. (2024) found that sediments in Utah Lake have a greater phosphorus-retention capacity than they currently hold and that sediments should be a net sink of phosphorus based on the phosphorus concentrations in incoming loads. However, concentrations of soluble-reactive phosphorus in the water column are typically quite low because of phytoplankton uptake, so sediments are often in equilibrium

with the water column, or they sometimes release soluble reactive phosphorus. To further complicate sediment-surface water interactions, Rivers et al. (2022) found that drying and rewetting Utah Lake-bed sediments led to an increased release of phosphorus and nitrogen using sediment cores in a laboratory setting. Rivers et al. (2022) also pulsed the water column with orthophosphate for a 7-day incubation period, and sediment from all four locations within the lake retained phosphorus, up to 65 percent of the total amendment.

The three studies investigating nutrient dynamics in sediments in Utah Lake (Goel et al. 2020; LeMonte et al. 2024; Rivers et al. 2022) demonstrate the ability of the lake's CaCO_3 -rich sediments to adsorb and bind phosphorus from the water column. Under current loadings, these sediments may be at an equilibrium with surface water concentrations, as suggested by LeMonte et al. (2024). Accordingly, if in-lake concentrations were to increase, then some additional phosphorus would be adsorbed into the sediments. If significant nutrient load reductions were to occur in Utah Lake, then the concurrent change in water column concentration would likely be offset by some mobilization of sediment-bound phosphorus into the water column. This would delay the improvements in water column phosphorus concentrations. Utah Lake has characteristics that could alternatively result in shorter or longer lag times between external nutrient reductions and improvement in in-lake water quality; refer to Section 11.2 for more details.

Although nutrient interactions vertically between sediments and the water column have received much attention in Utah Lake, so have surface water spatial patterns. Lawson et al. (2025) completed a bioassay study that collected Utah Lake ambient surface water in three locations (two open-water locations and one in Provo Bay) and amended it with dissolved nitrogen and/or phosphorus in a standard control, nitrogen, phosphorus, and nitrogen plus phosphorus bioassay experimental design. Nutrient colimitation (dissolved inorganic nitrogen and soluble reactive phosphorus) was observed in summer and late summer, except in Provo Bay, which was nitrogen limited in summer. No limitation (that is, adding more nitrogen and phosphorus did not stimulate algal growth) was rarely observed, but when it was found, it occurred in spring and early summer. The bioassay study also focused on cyanobacteria-specific nutrient limitation and found no limitation from nutrients was most common, except for summer, when all three sites were limited by nitrogen or phosphorus (Lawson et al. 2025). These results suggest nutrient limitation in Utah Lake and nitrogen, phosphorus, and colimitation (nitrogen plus phosphorus limitation) are consistent with the literature on nutrient limitation of freshwater systems (Elser et al. 2007; Andersen et al. 2019).

The concepts of nutrient limitation and dual nutrient management have important caveats in Utah Lake. Nitrogen fixation in aquatic systems confounds the simple view of nitrogen limitation for nitrogen-fixing cyanobacteria. Prominent bloom genera in Utah Lake are *Dolichospermum* (formerly known as *Anabaena*) and *Aphanizomenon*, and both are known to be nitrogen-fixing organisms (additionally, *Aphanocapsa* and *Synechocystis* have been observed). Not all bloom-forming cyanobacteria, however, fix nitrogen. *Microcystis* and *Planktothrix* are bloom-forming HABs found in Utah Lake that cannot fix nitrogen. Even when nitrogen fixation by cyanobacteria is high, the total available nitrogen in waterbodies may still limit algal growth if external loads are reduced (Andersen et al. 2019). Thus, the findings of various types of nutrient limitation across time and space in Utah Lake is consistent with ecological theory (Lawson et al. 2025). Although light is not a nutrient, light penetration into the water column may impose a limit on the energy available to photosynthetic organisms, which further complicates nutrient limitation paradigms in Utah Lake.

In the past several years, limnocorral mesocosms have been installed in Utah Lake to evaluate several potential management activities. Limnocorrals are a step forward to replicating real-world scenarios because they are larger than laboratory experiments, eliminate some of the container effects from laboratory settings, and more closely mimic real-world conditions. Although having fewer controls can be a disadvantage in detecting effects from experimental manipulations, limnocorrals do more closely match what occurs in natural systems. Richards et al. (2023) completed a study using limnocorrals to test multiple treatments, including adult carp and juvenile carp. Across all limnocorrals over five sampling

events, greater taxa richness, evenness, and diversity for phytoplankton assemblages and greater richness and diversity for macroinvertebrate assemblages within the limnocorrals were observed. The study found no consistent treatment effect of limnocorrals on zooplankton richness, evenness, or diversity. Although effects were observed within the limnocorrals for the previously mentioned metrics, no statistics were provided in the study to quantify the certainty of the difference.

Richards et al. (2025) also state that the effects seen in this study (within limnocorrals versus outside controls) were due to reducing wave action; this is a likely mechanism for the effect of limnocorrals and is supported by the reduced total suspended solids measured within the limnocorrals, but no measurements were reported to confirm or quantify the reduction in wave-induced turbulence. Additionally, Richards et al. (2024) reports that “chronic disrepair of mesocosms allowing relatively rapid flushing” confounds interpretation of the results. However, limnocorrals continue to be a strong experimental design for testing the impacts of future restoration strategies in Utah Lake.

To date, these management actions aimed at improving water quality have been conducted only on relatively small scales within Utah Lake. Activities are currently underway to explore whole-lake water quality management, including the development of numeric nutrient targets as part of the ULWQS, led by the DEQ; the ULMP (ULA 2024); and other efforts led by the ULA. Additional analyses and modeling will be conducted as part of this ULS to evaluate potential management pathways to improve water quality and clarity in Utah Lake, with considerations for effectiveness, feasibility, and recovery timelines.

5. Removing Invasive Plant and Animal Species from Utah Lake

S.B. 270 includes removing invasive plant and animal species from Utah Lake as one of the specific benefit areas for enhancement. This project focuses on *Phragmites australis* and common carp as the most important invasive plant and animal species for removal.

5.1 Common Carp

Key findings

- Common carp make up 70 to 90 percent of fish biomass in Utah Lake, as suggested by net surveys conducted during the last 2 decades.
- Carp biomass in the lake appears to range between 400 and 600 kilograms per hectare (kg/ha), as estimated by the carp population model (Walsworth et al. 2024), and exceeds the ecologically acceptable threshold of 100 kg/ha by four to six times; the 100 kg/ha threshold was identified in other North American lakes but might also apply to Utah Lake. This abundance appears to be sufficiently high to be a major driver of the lake's water quality degradation.
- Mechanical carp removal was tested from 2009 to 2023 using seine nets. Removal rates were relatively modest at 35 to 47 kg/ha per year (less than 10 percent of estimated starting biomass). Nevertheless, model-predicted carp biomass declined from 550 kg/ha in 2009 to 200 kg/ha in 2019 as a result of systematic removal; carp population then rebounded, however, to 400 kg/ha by 2023 as a result of increased young carp production and reduced removal rates.
- Production of young carp (recruitment) increases during high water years and following adult carp removal. Overall recruitment rates observed to date appear to be lower than in other systems, potentially because of the high abundance of small predatory fish in Utah Lake.
- The current carp population model (Walsworth et al. 2023a) predicts that the carp population is dominated by young individuals (ages 0 to 4), whereas empirical data suggest individuals age 5 and older dominate the population; this discrepancy suggests key data gaps in field data or model parameter estimates. Methods previously used to estimate carp age may have underestimated the age of individual fish.
- Using methods currently available, carp management would need to occur annually to continuously suppress the population.
- Carp management efforts employed to date have been relatively constrained in scope and methodology in relation to the size and scale of the lake. Integrated pest management strategies that employ multiple tools that target specific weaknesses in carp life history should be considered for Utah Lake (for example, telemetry-guided seines to target winter carp aggregations; automated box nets to target bait-induced summer aggregations; and native fish biocontrol of carp eggs, larvae, and fry). Management tools that can effectively target all carp year classes in different types of habitats would likely accelerate carp management.

Information needs

- Additional data, particularly on the abundance of juvenile carp, carp age, and carp mortality, to solidify model parameters and address the apparent discrepancy between observed data and model predictions and a robust carp population model for guiding management efforts
 - The carp density threshold in Utah Lake wherein the impacts to ecosystem are minimized
 - Updated and improved population age estimates to improve population modeling
 - Identification of the main driver for the discrepancy between the observed carp population age structure (primarily older carp) and the one predicted by model (primarily young carp)
 - Determination of whether carp form seasonal aggregations, including winter aggregations in the lake and spring spawning runs into tributaries or wetland areas
-

5.1.1 Historical Context

Before 1882, trout and suckers dominated the Utah Lake fish community (Tanner 1936). In 1882, 200 common carp were delivered to Utah from the national fish hatchery in Washington, DC, as part of a federal initiative to introduce carp to waterbodies across the country (Popov 1949; Heckmann et al. 1981). Twenty of these individuals were delivered to Utah County and introduced into ponds near the Jordan River. The population rapidly expanded until carp were abundant in Utah Lake and lower inlet streams (McDonald 1884). In total, between 1886 and 1903, when the federal program to introduce carp across the country was operating, tens of thousands of carp were delivered to Utah. Countless transplantations also were occurring among bodies of water within the state (Popov 1949; Heckmann et al. 1981).

Utah Lake underwent a phase shift associated with the common carp introductions in the late 1800s and increased nutrient loading following the expansion of agriculture and development in Utah Valley (King 2019). Historical records suggest Utah Lake was once much clearer and heavily vegetated with emergent, floating, and submergent macrophytes (Janetski 1990; King 2019). Managers initiated a carp mechanical

removal effort in 2009 as an ecosystem restoration tool to benefit recovery efforts for the endangered June sucker. Successful reduction in carp biomass is expected to improve habitat conditions, shift the zooplankton community toward a prominence of large-bodied taxa, drive an increase in benthic macroinvertebrate biomass and an increase in sport fish biomass, and likewise alter the structure of the aquatic food web in Utah Lake (Landom et al. 2014). However, as Utah Lake is located within a highly urbanized mountain valley bottom, the ecosystem experiences multiple anthropogenic disturbances that could drive ecosystem changes independent of potential carp removal effects (Psomas and SWCA 2007; King 2019).

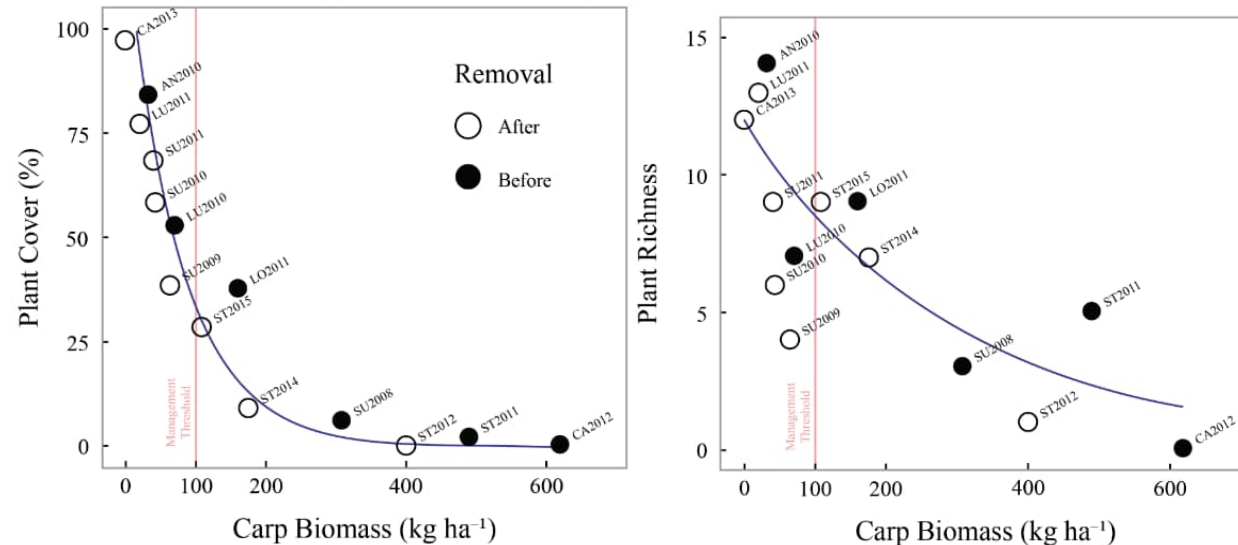
5.1.2 Current Conditions

This section discusses the current conditions of biomass and abundance, carp population age structure, and recruitment in Utah Lake.

5.1.2.1 Biomass and Abundance

Quantifying carp biomass is often important for guiding management efforts (Vilizzi et al. 2015; Bajer et al. 2016). Whole-lake experiments in the Midwest show that carp are generally not damaging to lake ecosystems if their biomass remains less than 100 kg/ha but are typically damaging to ecosystems once their biomass exceeds 200 kg/ha (Figure 5-1; Bajer et al. 2009; Vilizzi et al. 2015; Bajer et al. 2016). For that reason, lake managers have used a carp biomass of 100 kg/ha as a management threshold (Bajer 2017).

Figure 5-1. Relationship Between Carp Biomass and Macrophyte Cover and Richness in Midwestern Lakes



Source: Bajer et al. 2016.

Note: Study includes 14 lakes.

In lakes heavily infested with common carp, the carp biomass typically ranges between 300 kg/ha and 700 kg/ha (Bajer et al. 2009; Vilizzi et al. 2015; Bajer et al. 2016; Weber et al. 2016; Hirt 2024) and in exceptionally productive shallow lakes or aquaculture systems may exceed 1,000 kg/ha (Weber et al. 2016). Thus, a 75- to 80-percent reduction in carp biomass is often recommended to minimize impacts on lakes. In Utah Lake, the goal was set at 75-percent reduction in biomass (Walsworth et al. 2024) based on related research and the lack of an accurate population estimate (Mills, pers. comm. 2025). Initial biomass estimation methods ranged from mark-recapture and extrapolation from seine hauls to the

development of a model. Quantifying the actual population biomass is important because 75-percent biomass reduction may not be sufficient in systems where starting biomass exceeds 400 kg/ha.

Carp biomass estimates in the early 2000s proved to be largely unsuccessful, although a 2006 estimate for the lake was 7.5 million carp age 2 and older, with a biomass of 452 to 648 kg/ha, which is more than four times greater than the ecological management threshold of 100 kg/ha identified in Midwestern lakes (Valdez et al. 2006). The most systematic assessments of common carp biomass and abundance in Utah Lake have been conducted from 2012 to 2023, paralleling the commercial carp removal effort that started in 2009 (Landom et al. 2014; Landom et al. 2023; Walsworth and Landom 2021; Walsworth et al. 2023a; Walsworth et al. 2023b; Walsworth, Fadlovich, and Landom 2023; Walsworth et al. 2024). The overall carp biomass and abundance (all age and size classes included) in Utah Lake have not been determined empirically but instead were predicted by a statistical model that was built using field data.

The field data included the following:

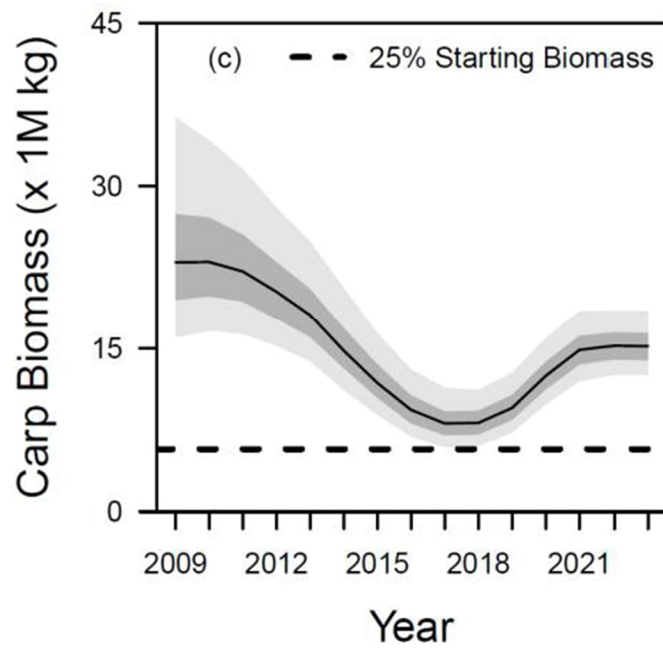
- Biomass removed per haul with commercial seines
- Abundance and size structure of carp captured during standardized seining surveys
- Empirically derived length-weight relationships and age-length relationships
- Estimates of density at age derived from the standardized survey size-structure data and age-length relationships
- Carp natural mortality rates estimated from generic relationships between fish weight at age using Lorenzen (1996) or the fish database FishLife (Thorson 2023) as priors

Using these inputs, the model was then used to estimate the overall abundance and biomass of carp in the lake, including the age and size classes of carp that were not captured by the commercial fishing nets but predicted to exist in the lake (small carp). This was largely done by reasoning that large numbers of older carp captured in commercial nets must have been associated with even greater numbers of young carp in the lake in previous years (for example, 7-year-old carp present in the lake in the current year must be the survivors of a 6-year-old cohort from last year, all the way down to age 0). These back calculations were made using the model for each age class of carp and each year (Walsworth et al. 2024).

The model predicted that at the beginning of the commercial harvest period (2009), common carp biomass in Utah Lake was approximately 22 million kilograms (kg) (Figure 5-2). This was equivalent to 566 kg/ha, approximately five times more than the management threshold of 100 kg/ha (Walsworth et al. 2024). A biomass estimate of this magnitude is in line with carp biomass observed in other lakes with abundant carp populations (Bajer et al. 2009; Vilizzi et al. 2015; Bajer et al. 2016). The model results also predicted that by 2018, carp biomass declined to about 7 million kg, or approximately 200 kg/ha, potentially in response to commercial removal. However, this decline also coincided with relatively low water years from 2014 to 2017, when the production of young carp in the lake was relatively low (Landom et al. 2023; Walsworth et al. 2024). The model predicted that carp biomass then increased to about 15 million kg by 2021 to 2023, reaching approximately 400 kg/ha, or approximately four times more than the ecological threshold of 100 kg/ha shown in other systems (Walsworth et al. 2024).

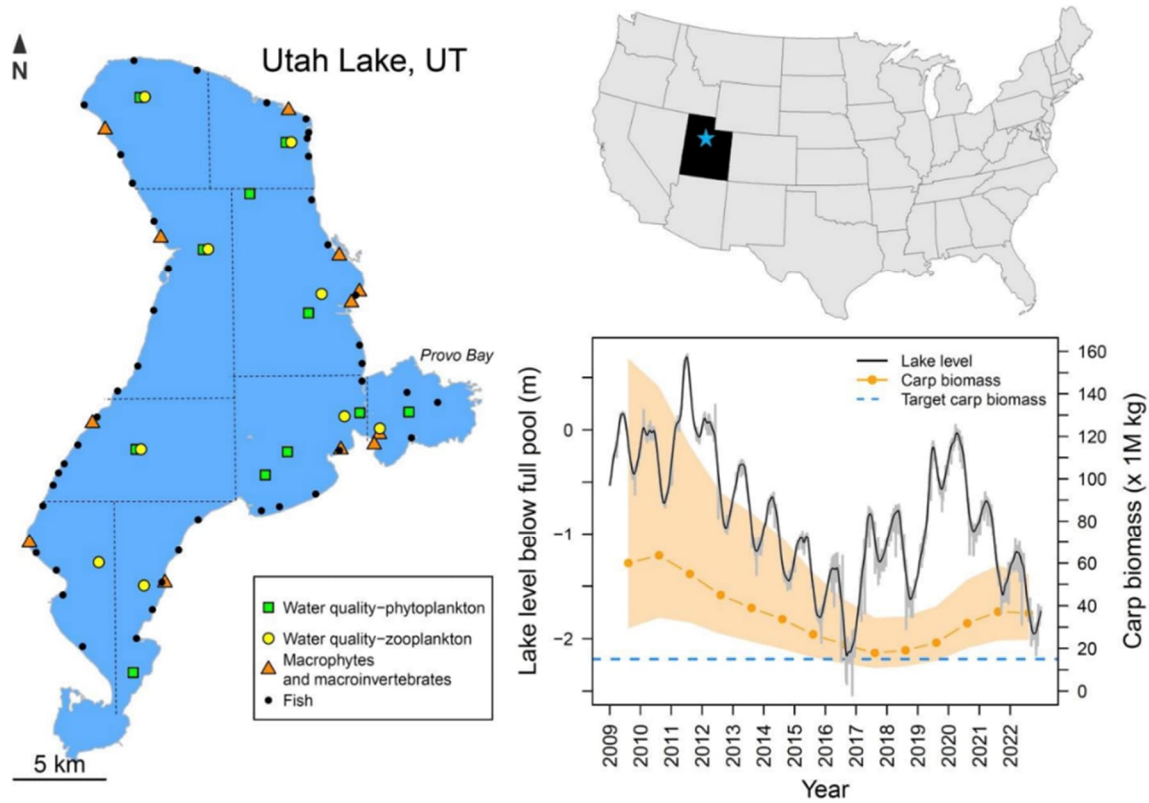
Earlier iterations of the model (Figure 5-3) predicted much greater carp biomass levels for the same time (2009 to 2023), approximately four times more than those calculated by the 2024 version of the model. Therefore, the statistical model is sensitive to field data inputs, and some of its parameters remain volatile. However, although the model is a useful tool in management, it has many limitations and may not provide accurate results.

Figure 5-2. Model-Predicted Carp Biomass in Utah Lake



Source: Walsworth et al. 2024.
M = million

Figure 5-3. Carp Biomass Predicted by Statistical Model

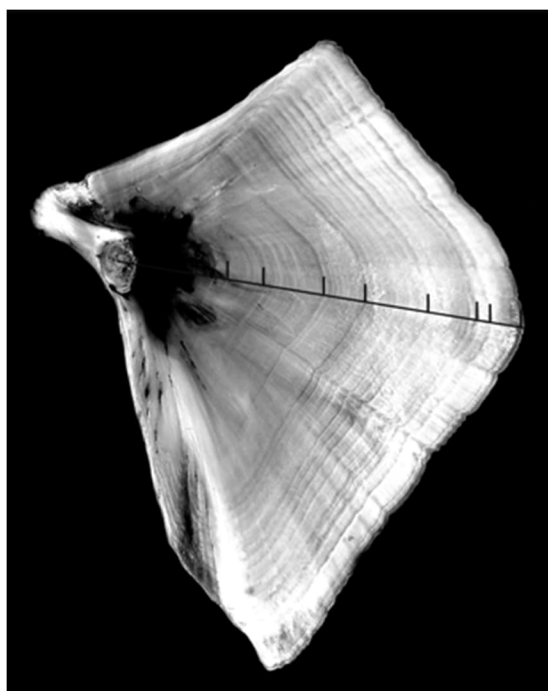


Source: Landom et al. 2023.
km = kilometer(s)
m = meter(s)

5.1.2.2 Age Structure of Carp Population in Utah Lake

Accurately aging common carp in Utah Lake is a key component of the management process and one of the most important components of the population model, as age determination affects the estimates of growth, mortality, and, most importantly, production of young (that is, recruitment). Valdez (2005) aged 111 carp collected in 2004 using operculi (Figure 5-4). The actual carp ages were not reported, but a relationship between operculi radii and carp length and age were developed. These relationships are prone to errors, as multiple age classes may have similar lengths and whether aging was verified by independent readers is not clear. Valdez et al. (2006) concluded that the carp were likely underaged, especially those age 6 and older. Recent aging of carp otoliths from Utah Lake suggests that previous aging using the opercula radii may have in fact underestimated the age of the population and that aging via otoliths may be more accurate.

Figure 5-4. Aging Carp Using Opercular Bones



Source: Valdez 2005.

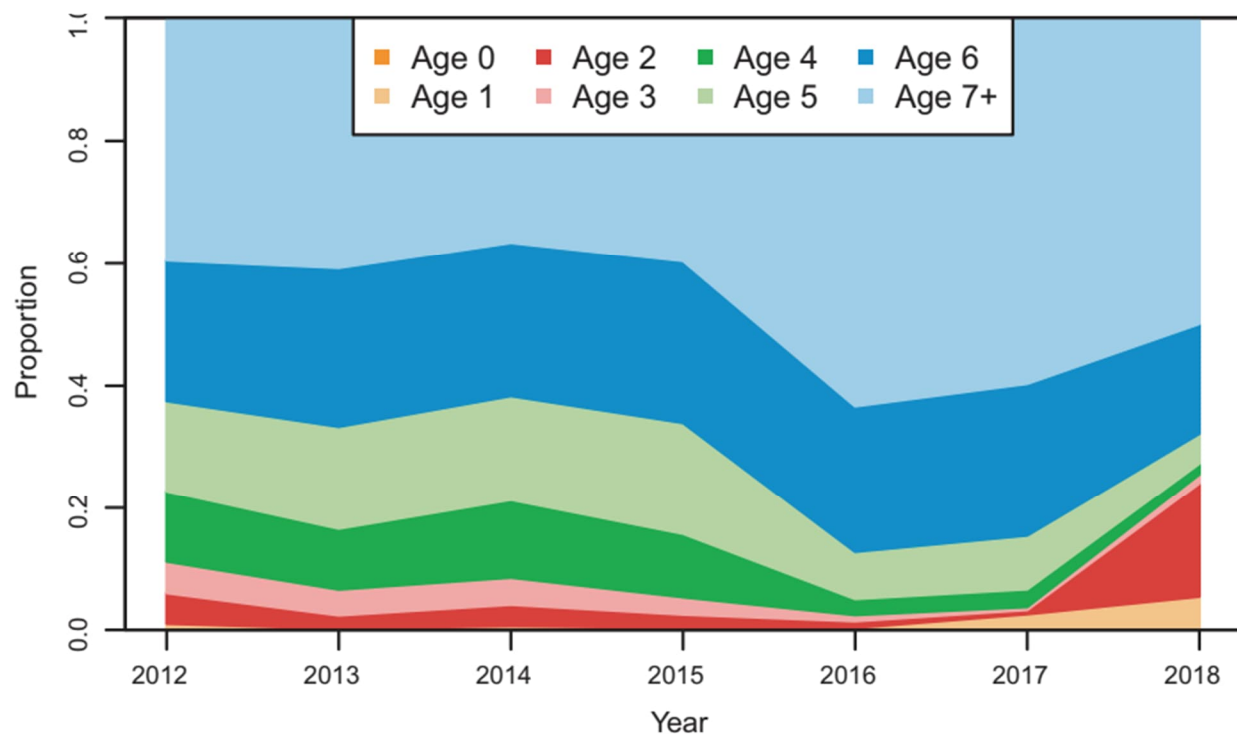
Note: Black marks indicate annual growth checks.

Valdez et al. (2006) reported that age groups 0 and 1 were not represented in the seine catches, relatively small numbers of age 2 fish were caught, no age 3 fish were present, and relatively small numbers of age 4 and age 5 fish were present. Presumably, the catch was dominated by carp age 6 and older. Valdez (2005) hypothesized that “these young fish were present in small numbers in shoreline spawning areas or entirely absent either because: (1) the smaller fish do not participate in spawning and were in open water or other parts of the lake, (2) our examination of opercles erroneously included false checks as annular rings, or (3) recruitment failures in these year classes resulted in small numbers.” Failure of four consecutive cohorts seems unlikely, so explanations 1 or 2 seem most plausible. However, carp recruitment failure for multiple years has been widely reported from other systems (Bajer, Parker, Cross, Venturelli, and Sorensen 2015); thus, repeated recruitment failure should not be automatically rejected as implausible.

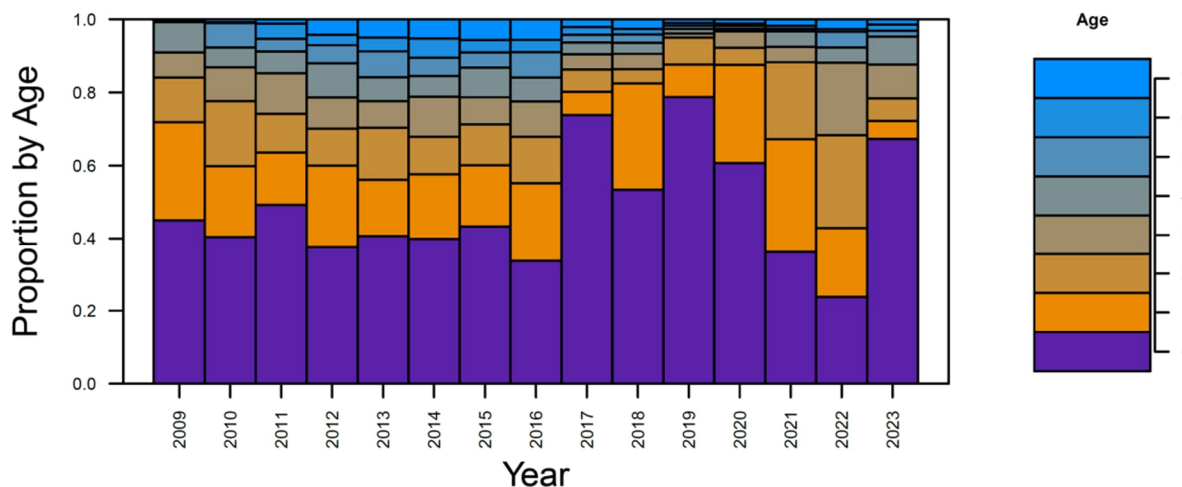
A more expansive effort to age the carp population in Utah Lake was conducted between 2016 and 2022, when 467 carp were collected from the standardized seine nets and aged using dorsal spines. This analysis

showed that carp captured in commercial seine nets were dominated by carp age 4 to age 7 and older (Figure 5-5). These empirically observed ages of carp captured in the standardized commercial seines were substantially different from those predicted to exist in Utah Lake by the statistical model. The model predicted that each year, the carp population in the lake was dominated by 0-, 1-, and 2-year-old individuals (Figure 5-6). Notably, the mesh size used in the standardized commercial seines (3-inch stretch) should be capable of capturing all carp age 2 and older, and even some age 1 carp (Walsworth et al. 2023a). This discrepancy between the observed and model-predicted age carp population led to the hypothesis that younger age classes occupy different habitats than older carp. However, alternative explanations are possible, including the under-aging of carp using dorsal spines. Recent analysis of otoliths from 10 Utah Lake carp provided by USU showed that 3 of those individuals were 22 years old, while the oldest carp previously reported from Utah Lake using dorsal spines was 19 (Walsworth, pers. comm. 2025). Further, one of those 22-year-old carp was previously aged as 9 years old using the dorsal spine. Although this analysis is preliminary, it does suggest that using otoliths may be needed to obtain a representative age structure of the carp population in Utah Lake. The discrepancy between the observed and model-predicted age structure is a major data gap that needs to be addressed.

Figure 5-5. Empirically Observed Common Carp Age Structure Captured in Commercial Seine Nets



Source: Walsworth et al. 2020.

Figure 5-6. Model-Predicted Age Structure of Common Carp Population in Utah Lake

Source: Walsworth et al. 2024.

The oldest carp aged in Utah Lake was 19 years old (Walsworth, pers. comm. 2025). Overall, carp in Utah Lake appear to be relatively young and short lived in contrast to populations in Midwestern lakes, where carp routinely survive into their 30s and 50s, at least in lakes without significant disturbance events, such as disease outbreaks or low oxygen concentrations in winter or summer (Dauphinais et al. 2018).

The carp in Utah Lake were aged using dorsal fin spines. In general, dorsal spines have been shown to be adequate for aging common carp (Yates et al. 2016; Vilizzi 2018; Weber and Brown 2011). However, Vilizzi (2018) recommended that otoliths be used for carp populations when feasible, possibly because Brown et al. (2004) verified annuli formation in common carp otoliths using tetracycline, which has not been done for fin rays. Phelps et al. (2007) showed that pectoral fin rays consistently underestimated the age of carp older than 13 (although their sample size was small). The same phenomenon of underestimating the actual fish ages using dorsal spines instead of otoliths has been reported for walleye (Koenigs et al. 2015), channel catfish (Hull et al. 2006), and smallmouth and largemouth bass (Blackwell et al. 2019). In carp, walleye, channel catfish, and bass, the pattern was the same. Spine aging was accurate for younger fish but resulted in underestimated ages for older fish, often by several years. The authors hypothesized that this was caused by the annual growth checks being more crowded and less visible near the age of the spines, potentially because of abrasion. The population age structure of a representative sample of carp in Utah Lake is an important data gap that needs to be addressed using otoliths (*asterisci*) and dorsal spines to verify the parameter estimates of the carp population model, which is the keystone of current and future carp management strategy.

5.1.2.3 Recruitment

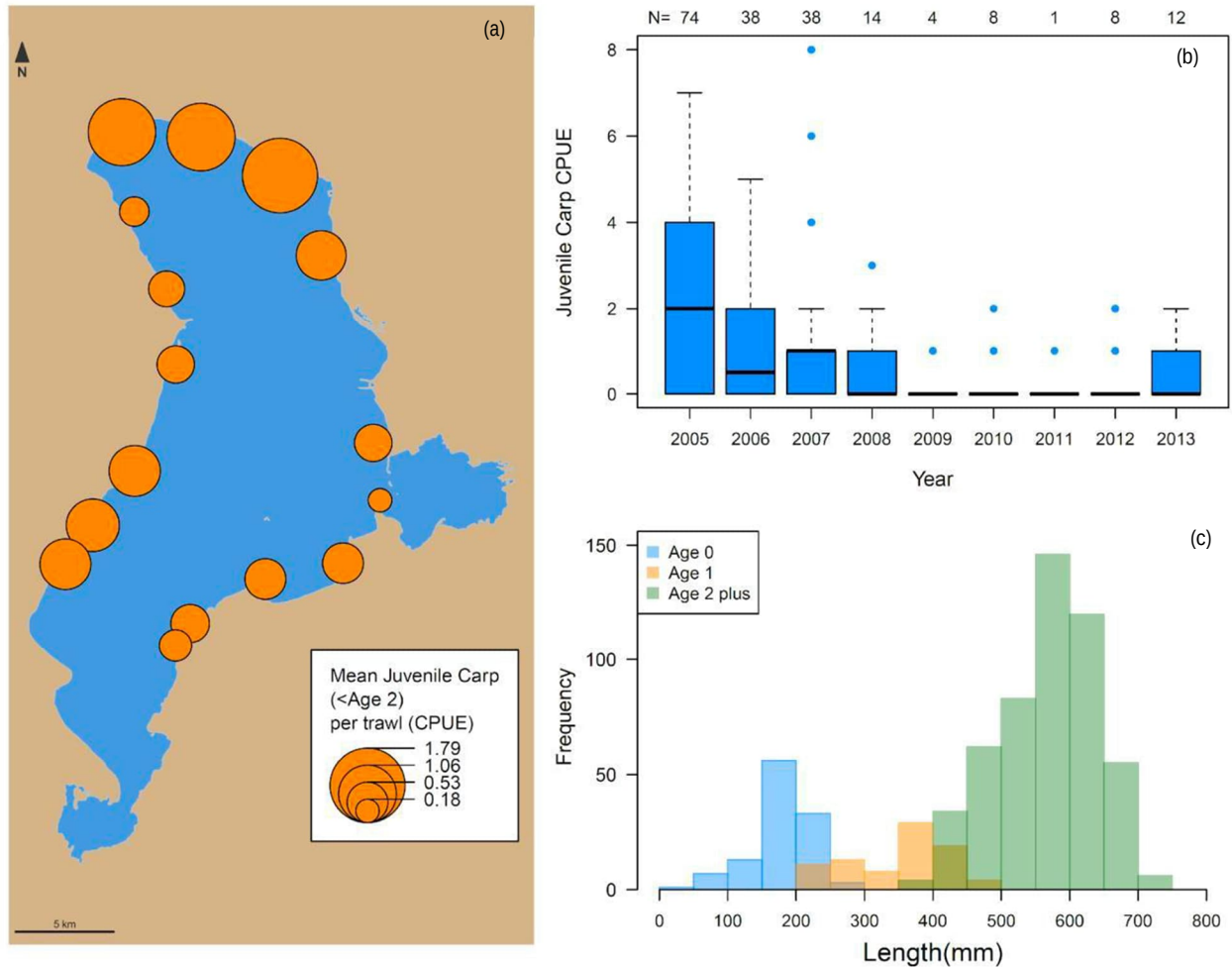
Recruitment refers to production of yearlings (age 0) carp in the population. In general, carp recruitment has been shown to be controlled primarily by adult carp abundance, micropredator abundance, ecosystem productivity, and ecological instability events, such as spring floods or winter and summer fish kills from hypoxia (Brown and Walker 2004; Phelps et al. 2008; Bajer and Sorensen 2010; Colvin et al. 2012; Weber and Brown 2013; Bajer, Parker, Cross, Venturelli, and Sorensen 2015; Bajer, Cross, Lechelt, Chizinski, Weber, and Sorensen 2015; Weber et al. 2016; Weber et al. 2017; Poole and Bajer 2019). Typically, the greatest rate of recruitment occurs at moderate to low density of adults, presumably because of competition for resources and disease and parasite transfer from adults to juveniles (Brown and Walker 2004; Colvin et al. 2012; Bajer, Parker, Cross, Venturelli, and Sorensen 2015; Weber et al. 2016). This compensatory response often complicates carp management through removal because removal of adults

may be followed by high survival of juveniles. However, high densities of micropredators such as bluegill, which feed on carp eggs and larvae, can cause total collapse of carp recruitment, regardless of adult density, and high recruitment spikes are often not seen in lakes with abundant bluegill populations, even as adults are removed (Bajer and Sorensen 2010; Bajer et al. 2012; Bajer, Cross, Lechelt, Chizinski, Weber, and Sorensen 2015; Poole and Bajer 2019). Recruitment also appears to increase in more turbid and productive waters for unknown reasons, possibly because of greater food abundance for larval carp and shelter from visual predators (Bajer, Cross, Lechelt, Chizinski, Weber, and Sorensen 2015). Seasonal instability events such as spring floods or winter hypoxia usually increase carp recruitment, most likely by creating new highly productive and sheltered habitat with few predators (Brown et al. 2005; Bajer and Sorensen 2010).

Bivens et al. (2021) reviewed processes that might regulate carp recruitment in Utah Lake. The authors concluded that although no direct studies of age 0 carp survival have occurred in Utah Lake, integrated age-structured population models indicate that age 0 carp survival is positively related to lake surface elevation, likely because of increased availability of more optimal spawning habitat and refugia from predators (Walsworth et al. 2020). During low water years, when inundated shoreline macrophyte habitats are diminished or completely absent, predation mortality of juvenile carp may be elevated compared to high water years. Although bluegill are common, direct evidence of bluegill predation on carp eggs and larvae within Utah Lake could not be found. However, in 2007, seven bluegill diets collected during May, typically a peak spawning month for carp in Utah Lake, contained fish eggs (Landom, pers. comm. 2025). Egg and larval predation by small predators, including bluegill, could be a source of high mortality for young carp life stages in Utah Lake. Juvenile carp have been observed in the diet of many fish predators in Utah Lake, including black crappie, black bullhead, channel catfish, white bass, walleye, northern pike, and yellow perch (Bivens et al. 2021). Formal studies to assess the role of local predators on carp recruitment in Utah Lake have not been conducted.

Age 0 carp in Utah Lake range in length between 50 and 240 millimeters (mm) in Utah Lake; this wide range is most likely attributable to a protracted spawning season (April to August; Bivens et al. 2021). Carp of this size have been found in Utah Lake with some regularity. For example, Landom et al. (2006) reported high catches of age 0 carp in trap nets in Provo Bay in 2003 and 2004. Age 0 carp have been captured annually (although in varying abundance) in small-mesh trawl surveys conducted by DWR from 2005 to 2013 (Figures 5-7 and 5-8; Watson et al. 2013; Fonken 2018; Walsworth, Fadlovich, and Landom 2023). Age 0 carp have also been captured in commercial seines but, again, in lower numbers than expected (Walsworth et al. 2024). Therefore, empirical data suggest that detectable levels of carp recruitment occur during most years and that predation alone does not control carp recruitment enough to suppress the Utah Lake population without mechanical removal efforts. However, predation may still have an important effect on carp recruitment and explain why the carp population model for Utah Lake predicts relatively low rates of carp recruitment. Recruitment rates of approximately 30 yearlings per typical 3-kg adult were reported under a best-case scenario of high water levels and moderately low biomass of adult carp (Bajer, Parker, Cross, Venturelli, and Sorensen 2015), whereas recruitment in predator-free lakes was shown to exceed 100 yearlings per individual adult carp (Bajer, Parker, Cross, Venturelli, and Sorensen 2015). Poole and Bajer (2019) documented even greater recruitment rates (800 recruits per adult carp) in controlled pond experiments. Thus, although predation is not able to totally control carp recruitment in Utah Lake, predation may hinder recruitment significantly, allowing for more sustainable management using physical removal.

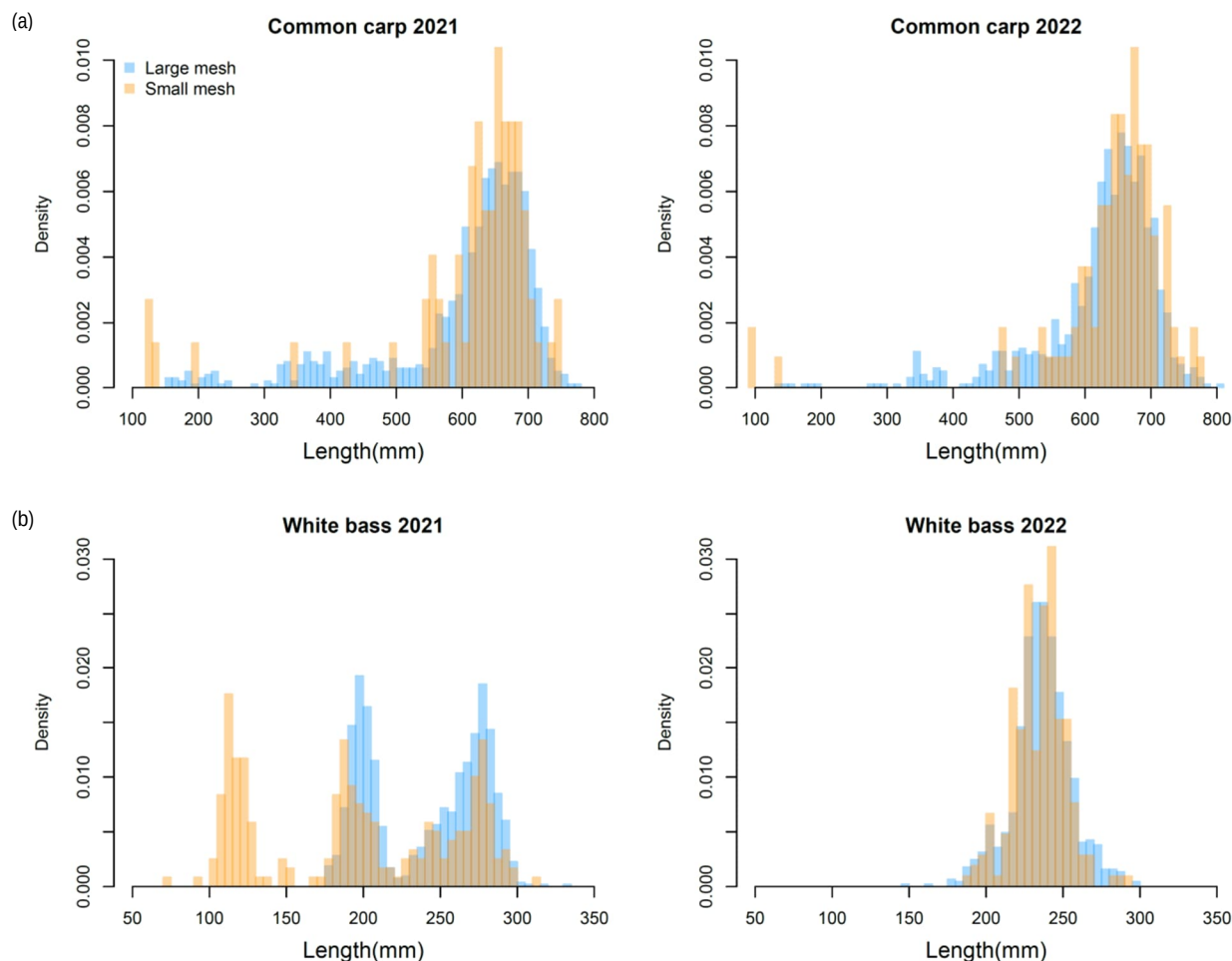
Figure 5-7. Spatial Distribution of Juvenile Carp Catch per Unit Effort Captured in Utah Lake Using Historical DWR Small-Mesh Trawl Data (a); Boxplot Comparing Historical Trawl Juvenile Carp Catch per Unit Effort Across Years (b); and Length-Frequency Comparison of Juvenile (age 0 and age 1) and Adult (age 2 plus) Carp (c)



Source: Walsworth, Fadlovich, and Landom 2023.

CPUE =catch per unit effort

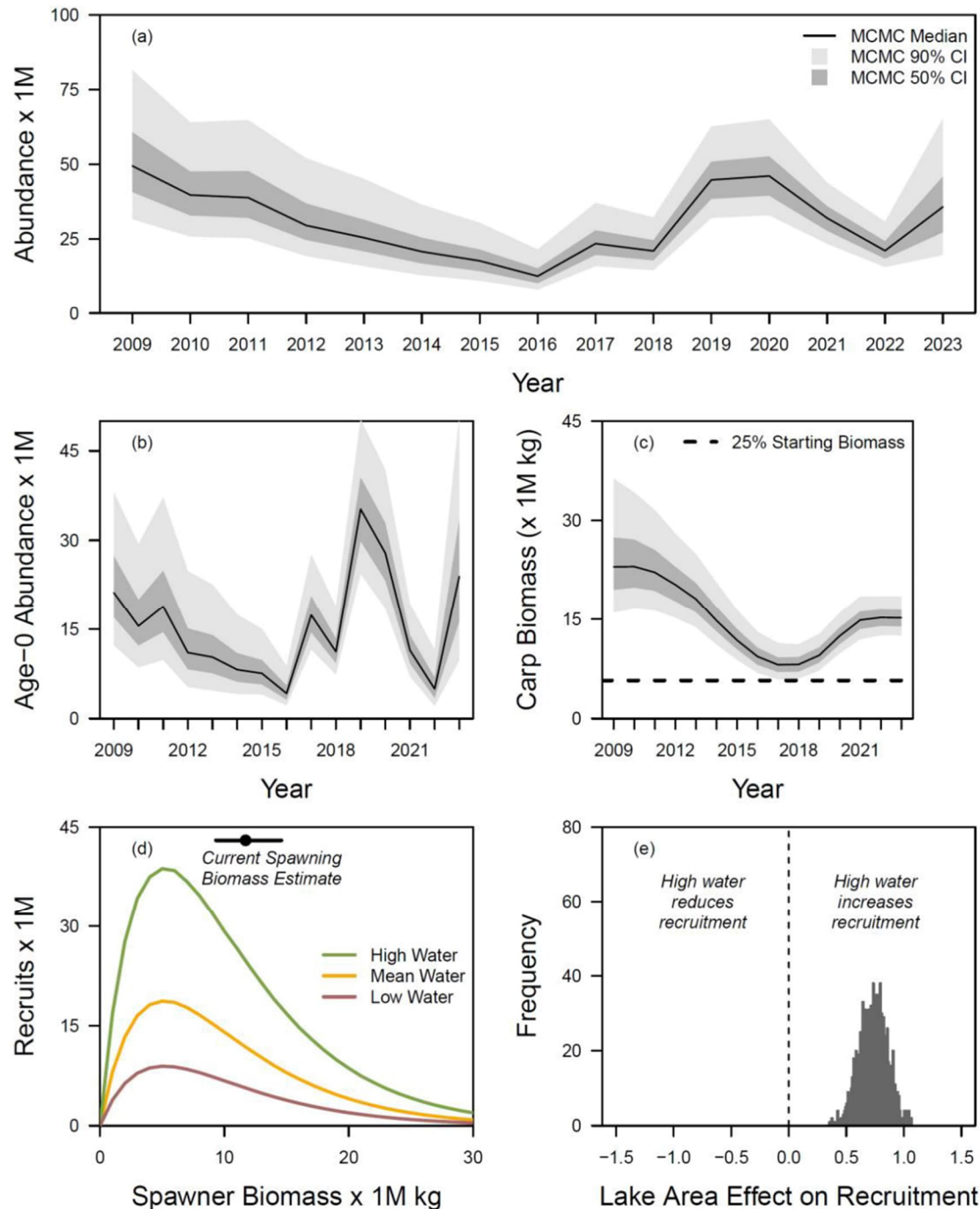
Figure 5-8. Length-Frequency Histograms of Common Carp (a) and White Bass (b) Captured in Large- (1.5-inch) versus Small-Mesh (0.75-inch) Commercial Seine Gear in Utah Lake, August 2021 and August 2022



Source: Walsworth, Fadlovich, and Landom 2023.

The statistical model developed for the carp population in Utah Lake predicts that carp recruitment increases during wet years (Figure 5-9; Walsworth et al. 2024). This increase is presumably a result of increased areas of shoreline habitats where the early life stages can find shelter and abundant food resources, but this hypothesis has not been tested. Studies specifically examining the habitat preferences of juvenile carp in Utah Lake have not yet been conducted (Bivens et al. 2021). However, existing data are available for exploring potential habitat associations. The DWR has completed small-bodied fish sampling to target juvenile June sucker and small-bodied prey fish. Small-mesh beach seines were hauled near shore within inundated macrophyte habitats, and small-mesh juvenile trap nets were set at the inundated macrophyte boundary to target young June sucker (Fonken 2018). Further analyses of these data may provide information regarding habitat preferences of juvenile carp.

Figure 5-9. Estimated Total Abundance (a), Age 0 Abundance (b), Total Biomass of Common Carp in Utah Lake by Year (c), Estimated Spawning Biomass Recruitment Relationship for Carp in Utah Lake under Different Hydrologic Conditions (d), and Posterior Distribution of Effect of Utah Lake Area on Recruitment (e)



Source: Walsworth et al. 2024.

Note: Light (dark) grey polygons on (a), (b), and (c) indicate the 90-percent (50-percent) credible interval, and solid black lines indicate median value of the posterior distribution. The blue line in (c) represents the probability of having achieved the carp biomass target within each year. On (d), years with higher lake levels (green) are predicted to have greater recruitment at a given spawning biomass than years with average (yellow) or low (purple) water levels. The black point and line on (d) indicate the median and 95-percent CI of 2022 carp spawning biomass.

MCMC = Markov chain Monte Carlo simulation

CI = confidence interval

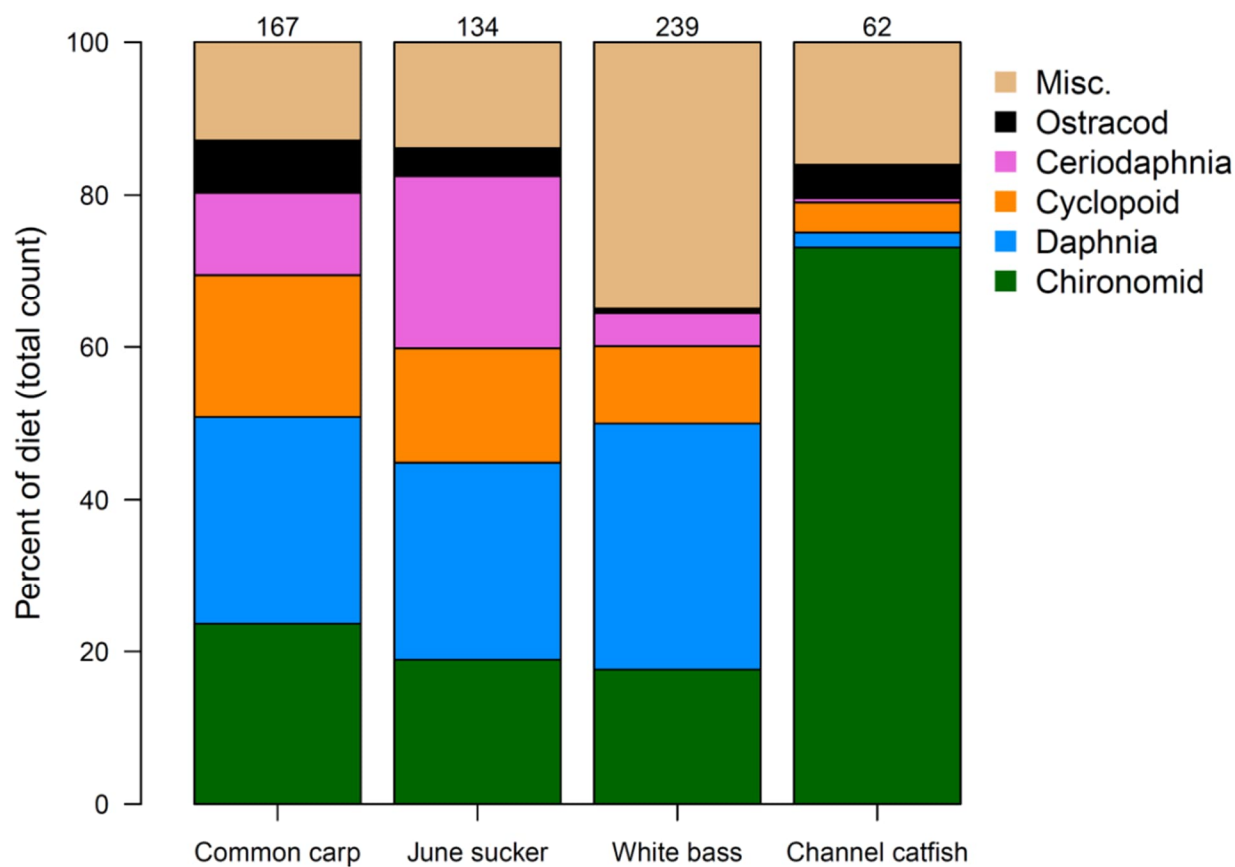
5.1.3 Ecological Dynamics

This section discusses the effects of carp on ecosystems, the life history and management efficiency of carp, and global perspectives on successful management of common carp populations.

5.1.3.1 Effects of Carp on Ecosystems

The common carp is often referred to as an ecological engineer because of its ability to fundamentally change habitat conditions and ecological processes (Matsuzaki et al. 2009). Because of its habit of rooting in the bottom of a waterbody while looking for food, carp are especially well known for uprooting macrophytes, increasing water turbidity, and increasing nutrient concentrations in the water because of sediment disturbance and excretion. Carp can cause total collapse of aquatic macrophytes, which then results in sharp declines in waterfowl and vegetation-associated macroinvertebrates. Less well known but also documented are the predatory effects of carp on tadpoles and amphibians (Kloskowski 2011). Carp eggs can contain significant amounts of polychlorinated biphenyls (PCBs) in contaminated systems, and because native fish consume carp eggs and larvae, carp can function as a direct contaminant vector. The effects can be significant because carp are both numerous and fecund (ovaries comprise up to 30 percent of female carp body weight), and they spawn annually. The effects of carp on native fish (or sympatric nonnative fish) are less known but likely significant because of, for example, competition for common food resources. Landom et al. (2023) showed that carp diet in Utah Lake was similar to that of June sucker, white bass, and channel catfish (Figure 5-10).

Figure 5-10. Diets of Common Carp, June Sucker, White Bass, and Channel Catfish in Utah Lake



Source: Landom et al. 2023.

Note: Numbers above columns represent sample sizes.

5.1.3.2 Life History and Management Efficiency

Carp life history and how it might be exploited to affect management is an important component of ecological dynamics in Utah Lake. Carp life history in Utah Lake is not well documented, and perhaps the most critical data gap centers around the effects of native predators on carp eggs, larvae, and fry. Special emphasis needs to be placed on the micro- and mesopredators (rather than the large predators) because they are most abundant and adapted to control carp's earliest life stages. For example, simple experiments with carp eggs attached to artificial spawning substrate (carp eggs are naturally adverse to structure) revealed that nearly 100 percent of carp eggs suffer mortality in bluegill-dominated systems in Minnesota (Bajer et al. 2012; Silbernagel and Sorensen 2013). Diet analyses conducted within carp spawning habitats revealed large numbers of carp eggs in the stomachs of bluegills (Bajer et al. 2012). Similar experiments could be conducted in various habitats in Utah Lake to better understand which predators may be important in controlling carp recruitment.

Carp are believed to have evolved in the Ponto-Caspian region, where adults inhabit complex systems of large rivers and brackish seas and show strong tendencies to migrate into tributaries and floodplains to spawn in inundated habitats during spring floods. In some cases, most of the recruitment originates from external sources, such as outlying marshes or upstream habitats. If Utah Lake tributaries show different isotopic signatures from the lake itself, otolith microchemistry could be used to determine whether external habitats are important recruitment hot spots. Carp's tendency to migrate into major tributaries of Utah Lake, such as the Provo River, have been documented. Telemetry surveys conducted by Landon et al. (2006) showed that carp did not employ extensive spawning migrations into Provo River; however, carp have been stranded in pools of the Provo River during low flow conditions (Mills, pers. comm. 2025).

5.1.3.3 Global Perspective on Successful Management of Common Carp Populations

Several examples of successful management of carp populations have been implemented in the United States and elsewhere. Additional examples of successful management include the use of toxins, which have been applied to eradicate carp populations in shallow Midwestern lakes (Schrage and Downing 2004) but are unrealistic for Utah Lake because of its size and scale and the presence of an Endangered Species Act-listed endemic fish species (June sucker). Several populations around the world have been controlled using IPM principles (Bajer 2017; Sorensen and Bajer 2021). For example, in several chains of lakes in Minnesota, Lake Wingra in Wisconsin, Lake Allegan in Michigan, and lakes Sorrell and Crescent in Tasmania, adult carp removal combined with suppression of juvenile carp production resulted in long-lasting and sustainable population suppression, or extirpation in the case of lakes Sorrell and Crescent (Sorensen and Bajer 2021; Yick et al. 2021).

IPM relies on identifying multiple weaknesses in a pest's life history and developing specific tools and technologies to target it. Following are identified weaknesses in carp's life history:

- Forming large aggregations during cold months in late fall and winter (Johnsen and Hasler 1977; Penne and Pierce 2008; Bajer et al. 2011)
- Having social feeding behaviors and unique diet, which allow for training carp to form large feeding aggregations in summers (Sorensen and Bajer 2021; Hundt et al. 2022)
- Homing to spawning grounds, which results in large spawning runs that can be blocked and removed (Bajer et al. 2010; Chizinski et al. 2016; Dauphinais et al. 2018, Bajer et al. 2022)
- Inability of carp early life stages to survive or develop in environments with many small predatory fish (for example, bluegills) that forage on carp eggs and larvae (Bajer and Sorensen 2010; Bajer et al. 2012; Silbernagel and Sorensen 2013; Poole and Bajer 2019)

Lechelt and Bajer (2016a) also hypothesized that carp larvae may be poor competitors for food in environments with high densities of other fish larvae. The successful IPM efforts for common carp included various combinations of the following:

- Telemetry-guided commercial seining to remove winter aggregations of adults (Bajer et al. 2011)
- Automated baited box nets to remove summer aggregations of juveniles and adults (Hundt et al. 2022; Hirt 2024)
- Seasonal barriers and autonomous aggregation systems to remove adults during spawning runs into tributary streams (Bajer et al. 2024)
- Native fish to suppress production of juvenile carp (Bajer, Cross, Lechelt, Chizinski, Weber, and Sorensen 2015)

All the systems where these IPM efforts were successful, however, were much smaller than Utah Lake (less than 5,300 hectares [ha], with most less than 500 ha); nevertheless, these efforts may offer a useful conceptual framework.

Research across various biomes also shows two distinct types of carp ecosystems and populations: (1) source-sink, where adult carp are unlikely to reproduce in the main lake (for example, because of high native fish predation) and need to migrate to outlying shallow marshes to successfully reproduce, and (2) source-in-lake, where adult carp can find adequate conditions for reproduction in the lake they inhabit (Lechelt and Bajer 2016b). Successful management to date has been conducted primarily in source-sink ecosystems (Sorensen and Bajer 2020). For source-in-lake populations, much more aggressive management schemes are needed because as the adults are being removed, production of young increases. Available data suggest that Utah Lake is within the source-in-lake category because juvenile carp are commonly found in the lake (Bivens et al. 2021; Walsworth et al. 2020; Walsworth and Landom 2021; Walsworth et al. 2023a; Walsworth et al. 2023b; Walsworth, Fadlovich, and Landom 2023; Walsworth et al. 2024). However, native fish may still have a significant role in curbing carp recruitment in Utah Lake because estimated recruitment rates (production of juveniles) in Utah Lake are much less than (one third of) those documented in predator-free lakes in the Midwest (Bajer, Parker, Cross, Venturelli, and Sorensen 2015; Wallace and Walsworth 2024).

5.1.4 Key Questions to Support Carp Control in Utah Lake

This section considers questions regarding support of carp control in Utah Lake.

5.1.4.1 Do Carp Exhibit Winter Aggregations in Utah Lake?

Common carp are known for forming large aggregations during winter months when water temperatures are less than 10°C (Johnsen and Hasler 1977; Penne and Pierce 2008; Bajer et al. 2011). These aggregations can be located using telemetry and targeted with nets to support large-scale carp removal (Bajer et al. 2011). Landom et al. (2006) conducted an acoustic carp telemetry study in Utah Lake from 2003 to 2004. The study results suggest that carp move extensively throughout the lake in the summer. However, two areas were considered congregation points throughout the seasonal surveys: (1) the northeast stratum, where 23 of the 24 tagged carp were detected during the late summer, and (2) the eastern shoreline, where nearly all carp detections occurred in winter. There is also evidence that commercial fisherman were able to target some of these aggregations during periods with solid ice cover (Walsworth, pers. comm. 2025). Whether cap aggregate in Utah Lake during winter is an important data gap to address by conducting a larger-scale telemetry study wherein hydrophones are maintained throughout the lake year-round.

5.1.4.2 Can Carp Be Trained to Form Summer Feeding Aggregations?

Common carp exhibit social feeding behaviors and can be trained to aggregate using food, or bait (Zion et al. 2007; Bajer et al. 2010; Hundt et al. 2022). These behaviors can be exploited to remove large numbers of carp using automated pop-up nets (box nets). For example, use of such nets resulted in reducing carp biomass from 450 kg/ha to 90 kg/ha in a 1,600-acre reservoir in Michigan (Hirt 2021). These net systems can be automated and remotely controlled using cloud-based computing, thus reducing labor costs. The bait (cracked corn) attracts carp primarily, which reduces bycatch and accelerates catch processing. The potential for carp to form large feeding aggregations in Utah Lake is relatively unknown. A pilot study conducted in 2024 using six relatively small-baited nets (30 by 60 feet) captured 20,000 kg of carp in 41 net pulls, with a bycatch of 7 percent. The largest catch per net exceeded 2,000 kg. These catches would likely be improved by increasing the net size (Hirt 2021). The baited traps may offer an important removal tool because they can be set in a variety of habitats, including inundated littoral areas, and can be used effectively during high water years. They should also target all size classes of carp.

5.1.5 History of Carp Management Efforts to Date in Utah Lake

Relatively large-scale carp removal in Utah Lake started in 2009 and continued through 2023 (Walsworth et al. 2024). This effort employed a 184-meter long, 3-meter deep seine net (1.5-inch square mesh) that was operated by a seining crew of 7 to 12 people with 2 boats (Figures 5-11 and 5-12). Between 150 and 350 seine hauls were conducted each year from 2010 through 2022, but less than 100 were conducted in 2023 (Figure 5-12). Annually, approximately 1,200 to 2,000 tons (1.4 to 2.8 million kg) of carp were removed from 2010 through 2018 (Figure 5-12). Removal rates then declined to about 500 tons in 2019 and to less than 200 tons in 2020 through 2023 (Figure 5-12). When calculated per surface area, commercial removal accounted for approximately 30 to 36 kg/ha per year from 2009 through 2018 and subsequently declined to less than 11 kg/ha. This is relatively low compared to the estimated biomass of carp in the lake of approximately 500 kg/ha in 2009 (Walsworth et al. 2024). In other systems with intensive carp removal, harvest rates of 200 kg/ha to 400 kg/ha per year have been reported (Weber et al. 2016; Hirt 2021).

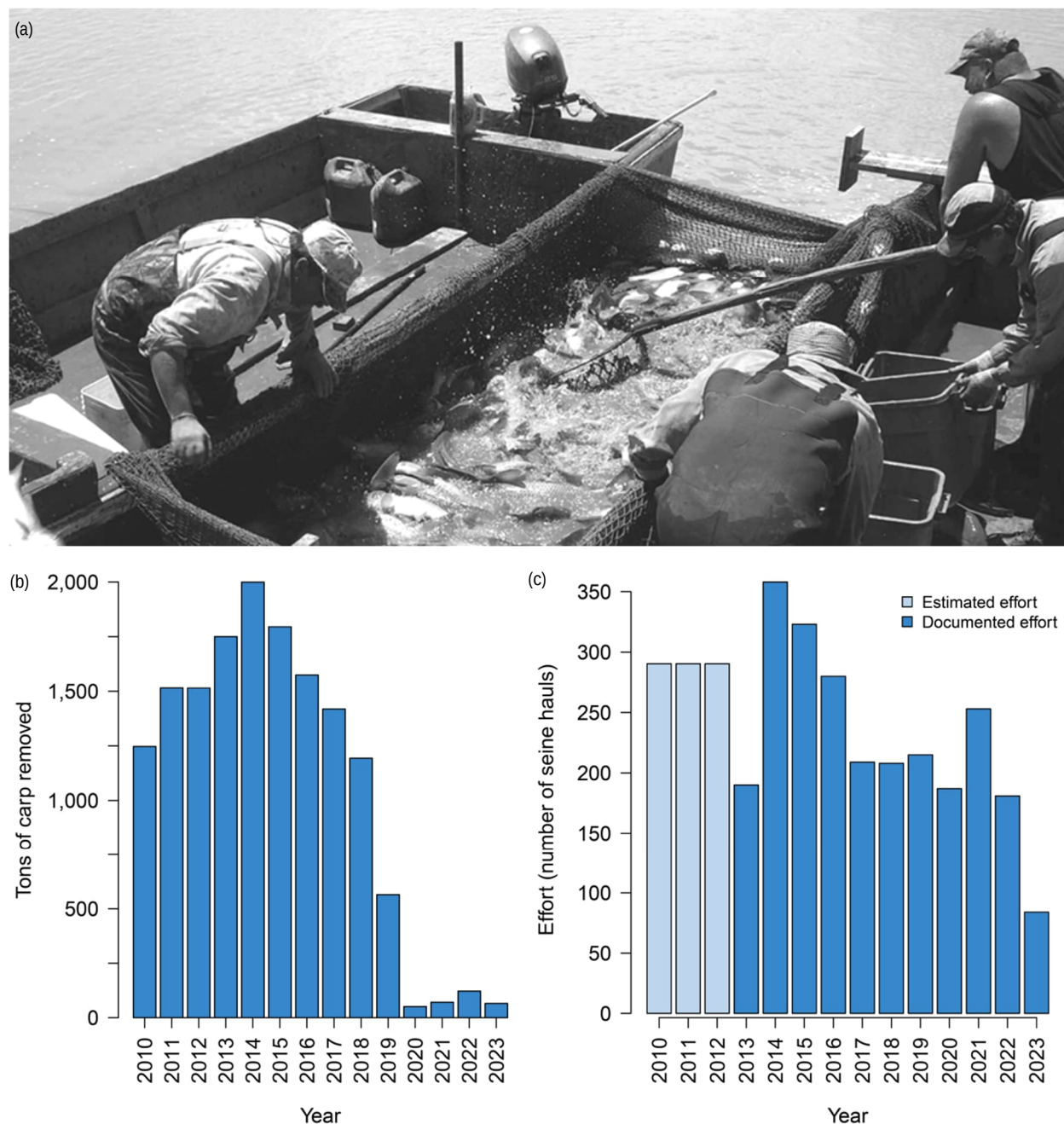
The statistical carp population model developed for Utah Lake (its latest 2024 iteration; Walsworth et al. 2024) estimated that at the beginning of the commercial harvest period in 2009, common carp biomass in Utah Lake was approximately 22 million kg (Figure 5-9 [b]), or approximately 560 kg/ha (Walsworth et al. 2024). The model also predicted that by 2017, carp biomass declined to about 7 million kg, or approximately 200 kg/ha, nearly reaching the desired 75-percent decline in carp population (Walsworth et al. 2024). The estimated decline in carp population was attributed primarily to mechanical carp removal (Walsworth et al. 2024). However, the observed harvest rates of 30 to 36 kg/ha were probably too low to fully account for this decline. This decline also coincided with relatively low water years from 2014 to 2017, when the production of young carp in the lake was relatively low (Landom et al. 2023; Walsworth et al. 2024). Monitoring during this period while the carp population was significantly reduced indicated that the condition of other fish in the lake improved, in addition to water clarity (Mills, pers. comm. 2025). The model estimated that carp biomass then increased to about 15 million kg by 2021 to 2023, reaching approximately 400 kg/ha, because of reduced catches and increased recruitment following the high water years of 2019 and 2020.

Figure 5-11. Seine Net Being Towed by Two Boats in Utah Lake



Source: Valdez 2005.

Figure 5-12. Fish Removal from Seine Net Suspended Between Two Boats (a),^[a] Tons of Common Carp Removed in Commercial Seines per Year (b),^[b] and Number of Seine Hauls Conducted per Year (c)^{[b][c]}



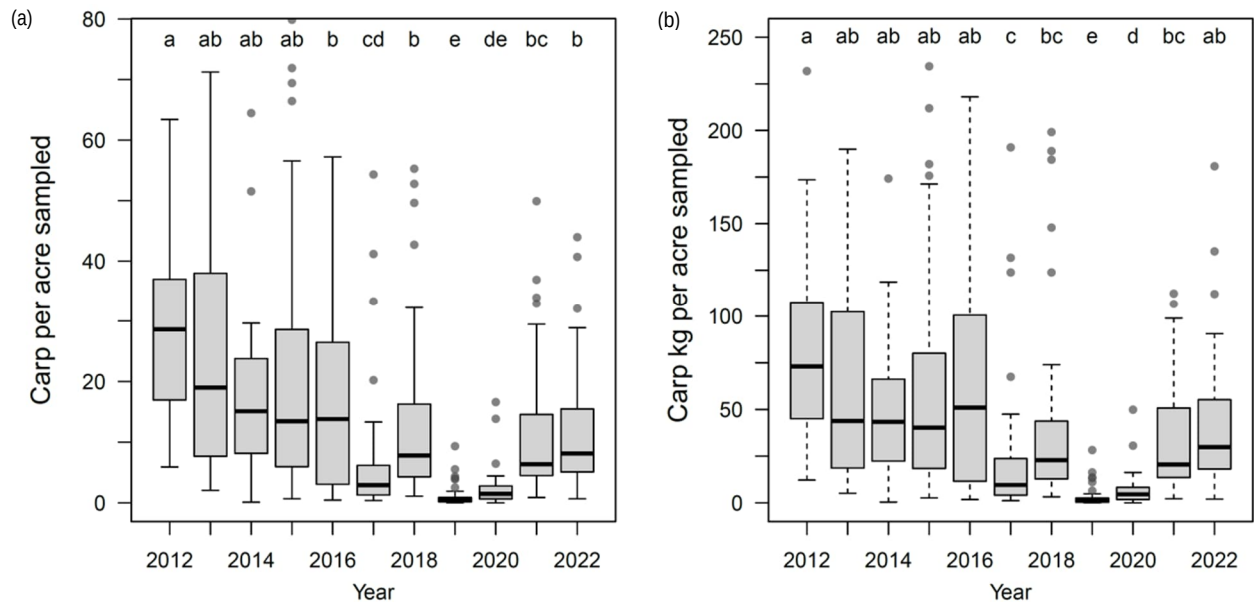
^[a] Source: Valdez 2005.

^[b] Source: Walsworth et al. 2024.

^[c] Number of seine hauls from 2010 through 2012 were approximated.

The model-estimated decline in carp population was reflected in reduced carp catches in the standardized seine nets in 2019 and 2020 (Figure 5-13). It is unclear, however, if this was attributable to fewer carp being present in the lake or structural changes in the fishing crew that occurred at that time. Also, the high lake water levels that occurred in 2019 and 2020 made seining efforts less effective because carp likely utilized the inundated shoreline areas with, for example, submersed shrubs, which cannot be effectively targeted with seine nets.

Figure 5-13. Abundance (a) and Biomass (b) of Carp Captured in Standardized Seine Nets in Utah Lake



Source: Walsworth et al. 2024.

The main conclusions from the mechanical removal during 2009 to 2023 were as follows (Walsworth et al. 2024):

- Model simulations suggested that the commercial gear used from 2009 to 2023 alone is unlikely to effectively maintain low carp abundance without more than an order of magnitude increase in fishing effort because of gear selectivity (not targeting small carp effectively enough) and compensatory recruitment effects (increased recruitment in response to adult carp removal).
- Larger and older individuals are effectively targeted by removal gears, particularly when lake levels are lower. However, smaller carp, including multiple mature age classes, are not effectively targeted by removal gears and present a source of future spawning biomass to support population growth.

5.2 *Phragmites australis* and Invasive Plants

Key findings

- *Phragmites australis* subspecies *australis* (common reed) became established at Utah Lake in or around the 1980s and has since expanded and colonized over 75 miles of the lake's shorelines, eliminating or significantly reducing ecosystem function and societal benefits. A subspecies of *Phragmites australis* (subspecies *americanus*) is native to Utah Lake, but in this report *Phragmites* refers to the subspecies *australis*. Impacts of *Phragmites* around Utah Lake include the following:
 - Reduced plant diversity
 - Reduced quantity and quality of bird, fish, and wildlife habitat
 - Increased evapotranspiration
 - Increased fire danger
 - Reduced recreational access
- FFSL and other regional partners have been actively managing large-scale *Phragmites* infestations at Utah Lake since 2014, when a major collaborative effort to mitigate invasive vegetation along the lake's shores began. Methodology for controlling and removing *Phragmites* has been refined over the years, and *Phragmites* cover on the lake has been reduced by approximately 70 percent (FFSL 2022). The goal is to maintain *Phragmites* cover at less than 20 percent across treated areas (Duncan 2023); this involves regular monitoring and adaptive management, expanding treatment to adjacent upstream locations, and smaller-scale control methods (spot spraying and boat and boom application) to confirm the effectiveness of control measures.
- Ongoing collaboration with local communities, stakeholders, and volunteers is needed to support control efforts and promote awareness about the importance of managing invasive species (Farmonaut 2025).
- Despite removal efforts, *Phragmites* remains relatively common around the lake and continues to impact its ecosystem and recreation.
- Native plant revegetation needs to be prioritized and expanded in conjunction with *Phragmites* treatments to restore vegetative communities and prevent reinvasion of invasives plants.

Information needs

- Long-term monitoring and control of *Phragmites* to maintain and extend management success at the lake and comprehensive mapping of *Phragmites* communities adjacent to the lake and within its watershed, which will be critical to planning and controlling *Phragmites* in the long term, in part to identify seed sources
 - Fine-tune and scale-up of methods and infrastructure for native revegetation on the lake scale (refer to Section 6) and support for native plant revegetation, which is critical to long-term stabilization and protection for invasive species invasion or re-establishment
-

The nonnative common reed was introduced to North America from Eurasia in the late 1700s to early 1800s. It is an aggressive, tall, dense wetland grass that crowds out native vegetation. *Phragmites australis* subspecies *australis* (referred to simply as *Phragmites* in this report) is adapted to wetland areas and thrives in lakeshore environments where soils are moist or covered with shallow water for at least part of the year.

Once established, *Phragmites* roots can reach depths of 10 feet and access groundwater even if the surface has dried. It is a robust species and can spread by seeds or by rhizomes and stolons. Once established, it creates dense stands with as many as 60 stems per square foot and can grow to a height of 15 feet. *Phragmites* rhizomes and stolons can spread 15 to 20 feet per year, and the shoots can grow 1.5 inches per day (Rupp et al. 2014). *Phragmites* is ranked as a Class 3, Containment, species on Utah State's Noxious Weeds list. Growth and spread of *Phragmites* to new locals is through seeds and rhizomes, seeds dispersed by wind and water, and lateral growth of rhizomes or root fragments. Individual plants produce hundreds to thousands of seeds per year, and although seed viability and interannual fecundity appear to be highly variable, sufficient seed is dispersed to overcome these limitations (Swearingen and Saltonstall 2010).

FFSL and other regional partners have been actively managing large-scale *Phragmites* infestations at Utah Lake since 2014. The current statistics on *Phragmites* treatment at Utah Lake include the following:

- **Historical coverage:** In 2012, an estimated 10,000 to 11,000 acres of *Phragmites* covered the Utah Lake shoreline (Duncan 2023).
- **Total area treated:** As of 2024, 11,829 acres of *Phragmites*-infested shoreline have been treated by FFSL and partners (FFSL n.d.).

- **Reduction in *Phragmites* cover:** As of 2022, *Phragmites* cover at Utah Lake has been reduced by 74 percent as a result of these treatments (FFSL n.d.).

Phragmites control methods are considered well documented by practitioners and have resulted in good initial effect at Utah Lake. Continued management and monitoring to control *Phragmites* at Utah Lake are expected to continue for the next decade.

In addition to Utah Lake shorelines, *Phragmites* also infests smaller wetlands and moist, disturbed areas, including urban areas surrounding Utah Lake. Drainage ponds, borrow pits, riparian corridors, and irrigation ditches are all susceptible to invasion. *Phragmites* has colonized vast acreages around Utah Lake and is situated to reinvade controlled areas through seed dispersal from upstream and adjacent locations.

The spread and management of *Phragmites* (and other invasive species) around Utah Lake is a research and management priority. Other nonnative invasive species that are found around Utah Lake and are designated as noxious weeds by either the State of Utah or Utah County include tamarisk (*Tamarix*), perennial pepperweed (*Lepidium latifolium*), Canada thistle (*Cirsium arvense*), and purple loosestrife (*Lythrum salicaria*). Russian olive (*Elaeagnus angustifolia*) is also a nonnative species but has not been designated as a noxious weed. Utah County has an ongoing noxious weed control program and targets both *Phragmites* and tamarisk (ULA 2008).

5.2.1 Historical Context

Aquatic and wetland plant communities on the shoreline of Utah Lake have been greatly disturbed and disrupted by human intervention. Before the disturbance and degradation, Utah Lake vegetation was a complex aquatic habitat mosaic (Coombs 1970). Utah Lake was historically a clear-water system that supported a robust submerged macrophyte community. Initial comments on the vegetation surrounding Utah Lake were recorded as early the 1700s and noted bogs, reeds, and abundant marsh grasses; infrequent patches of wild sage; and swamps filled with *Lemna* and chum (Wakefield 1933). More detailed descriptions of the historical Utah Lake vegetation communities are provided in Section 6.

Since European settlement, many nonnative plant species have been introduced into the Utah Lake environment. These species have had detrimental effects on less-competitive native wetland and aquatic plant communities, especially under altered or disturbed ecological conditions (for example, agriculture, grazing, water-level fluctuation, and nutrient inputs). *Phragmites* was first established at Utah Lake in the 1980s, and by 2012, FFSL estimates that Utah Lake wetlands had approximately 10,000 acres of *Phragmites* (FFSL 2022).

5.2.2 Current Conditions

Since 2014, a major collaborative effort to mitigate invasive vegetation along the shores of Utah Lake has been underway. Collaboration between FFSL, Utah County, the ULA, the Utah Department of Agriculture, and the WRI has enabled significant progress with *Phragmites* control. These partnerships have been crucial for reducing *Phragmites* cover and support the re-establishment of native plant species throughout the Utah Lake shoreline.

Phragmites cover on Utah Lake has been reduced by approximately 70 percent. The WRI developed an overview with mapped locations of completed, current, and proposed invasive plant control (and native plant restoration) projects in Utah, including those along the shoreline of Utah Lake. FFSL has created a story map that shows Utah Lake *Phragmites* treatment areas and acres of *Phragmites* reduction from 2011 to 2020 (FFSL 2022). Additionally, the UGS and other organizations have been working to modernize wetland mapping across Utah with updates to the National Wetland Inventory. These updates to wetland mapping are through photographic interpretation and supporting fieldwork that have resulted

in extensive wetland mapping data throughout the state, including Utah Lake (UGS 2025). Otherwise, no comprehensive map of current Utah Lake vegetation communities has been noted in the literature.

5.2.3 Methods for *Phragmites* Control

Phragmites control methods used at Utah Lake are well documented and widely used to control and reduce *Phragmites*. The methods to control *Phragmites* include integrated treatments of herbicide, mowing or trampling, prescribed fire, grazing, water control, and revegetation for an initial control cycle of 3 years (Rohal et al. 2017). As of 2023, over 10,000 acres of *Phragmites* at Utah Lake have been treated, resulting in over 70-percent reduction in *Phragmites* cover (FFSL 2024).

Research on management of *Phragmites* has indicated that control methods must be tailored to the location and size of the infestation. An integrated approach uses herbicide spraying, mowing, grazing, burning, water management, and revegetation, with the choice of methods dependent on the size and location of the infestation. Appropriate timing of treatments is crucial. FFSL and its partners implement an integrated management approach to control *Phragmites* at Utah Lake, which is detailed in Rohal et al. (2017). Some additional notes on *Phragmites* treatment follow:

- **Monitoring and revegetation:** Three years of continuous management has demonstrated approximately 95-percent elimination of *Phragmites*. Revegetation, spot treatment, and constant monitoring for *Phragmites* re-establishment and regrowth are required after 3 years of maintenance (Rohal et al. 2017). Planting native species to limit reintroduction of *Phragmites* into treated areas is recommended following 3 years of integrated *Phragmites* control.
- **Effects of drought:** *Phragmites* treatment is most effective on healthy plants. Drought-stressed *Phragmites* should not be sprayed. Drought-stressed plants poorly absorb herbicide and have limited herbicide translocation to underground biomass. Herbicide application is not conducted in dry areas, as it is not effective.
- **Prevention and early detection:** The most effective strategy for *Phragmites* control is to prevent the spread of *Phragmites*. Regularly inspect undeveloped lands for *Phragmites* establishment and promptly address any infestations before they spread.
- **Smaller-scale herbicide control methods:** Because of the reduced coverage of *Phragmites* from coordinated large-scale control efforts around Utah Lake, management focus has moved to include smaller-scale control methods, including spot spraying and using a boat and boom setup to treat previously unreachable patches of *Phragmites* offshore. The smaller-scale control requires more labor and is logistically more challenging to implement.
- **Seed viability and seed bank:** Buried *Phragmites* seeds may be a source of propagules for re-establishment after eradication efforts. Generally, *Phragmites* seeds can remain viable in the seed bank for several (3 to 5) years, but their germination success is influenced by inundation, land cover, and seed predation, among other factors (Baldwin et al. 2010).
- **Seed source:** *Phragmites* has colonized in many creeks and waterways that flow into Utah Lake. These areas of adjacent invasive populations act as a continual seed source for *Phragmites* re-establishment in Utah Lake. Many current practitioners and Utah Lake researchers have noted that identifying, quantifying, mapping, and controlling upstream and adjacent *Phragmites* populations is critical to supporting a *Phragmites*-resistant native plant community adjacent to Utah Lake.
- ***Phragmites* control in areas adjacent to Utah Lake:** In addition to Utah Lake, *Phragmites* is also found in smaller wetland areas at the urban-rural interface. Controlling small, urban populations is also important to reducing the spread of this weed in general and to minimizing reintroduction at Utah Lake. Removing *Phragmites* from adjacent urban landscapes and waterways will reduce the potential for infestation of additional land through dispersal of seeds, rhizomes, or stolons. Small infestations of

Phragmites in urban landscapes can be effectively controlled by cutting the plants in mid-summer and then spot treating with herbicide in late summer to early fall.

- **Biological control:** No biological control methods are authorized in the United States for suppressing *Phragmites*. In 2019, Canada began biological control of *Phragmites* using two host-specific stem-boring moths, *Archanara neurica* (Hübner) and *Lenisa geminipuncta* (Haworth). Results from 3 years of monitoring were favorable (McTavish et al. 2024), with feeding damage at 92 percent, which persisted into years 2 and 3 after release.
- **Natural recruitment of species in *Phragmites*-treated areas:** The Utah Lake *Phragmites* Project has reported achieving its target (2022) of reducing average *Phragmites* cover to less than 20 percent on treated sites. Natural recruitment of native and nonnative species was identified as an increase from 7- to 83-percent average cover in post-treatment areas (no information was provided on short- or long-term survival of naturally recruited species). The following species were observed (Duncan 2023):
 - Native species:
 - Fringed willowherb (*Epilobium ciliatum*)
 - Hardstem bulrush (*Schoenoplectus acutus*)
 - Alkali bulrush (*Bolboschoenus maritimus*)
 - Western goldentop (*Euthamia occidentalis*)
 - Fremont cottonwood (*Populus fremontii*)
 - Introduced species:
 - Cattail species (*Typha*)
 - Sweetclover (*Melilotus officinalis*)
 - Prickly lettuce (*Lactuca serriola*)
 - Creeping meadow foxtail (*Alopecurus arundinaceus*)
 - Oakleaf goosefoot (*Chenopodium glaucum*)
 - Annual rabbitsfoot grass (*Polypogon monspeliensis*)
 - Burning bush (*Bassia scoparia*)

5.2.4 Stressors, Perturbances, and Changes

Utah Lake's variable water levels increase *Phragmites* management (and native plant re-establishment) complexity, affect site access and spot spraying, and cause drought stress. These complexities make control and planning more difficult.

5.2.5 Ecological Dynamics

The ecological dynamics of *Phragmites* is well documented in the literature, as are its effect on Utah Lake ecosystems, which includes degradation of ecosystem function, habitat reduction, and degradation of social benefits. Since its arrival at Utah Lake in the 1980s, *Phragmites* has expanded and colonized over 75 miles of Utah Lake shorelines, eliminating or significantly reducing ecosystem function and societal benefits. *Phragmites* stands reduce plant diversity and reduce habitat function and area for birds, fish, and wildlife, effecting and reducing Utah Lake water levels, increasing fire danger, and reducing recreational access. FFSL and other regional partners are actively managing large-scale *Phragmites* infestations at Utah Lake since 2014. As of 2022, there has been a 74-percent reduction in *Phragmites* cover at Utah Lake as a result of these treatments (FFSL 2022).

Phragmites control methods are considered to be well established and effective (Valdez, pers. comm. 2025; Hambrecht, pers. comm. 2025) and have resulted in good initial effect at Utah Lake (Rohal et al. 2017). Continued *Phragmites* management, monitoring of new and treated areas, and native revegetation of Utah Lake shoreline are expected to continue for the next decade and beyond.

6. Restoring and Improving Littoral Zone and Other Plant Communities in and around Utah Lake

Key findings

- Restoring native vegetation communities in and around Utah Lake is a cornerstone for returning the lake to a functioning ecosystem. Lakeshore vegetation supports many valuable aspects of lake ecosystems, including foraging areas for birds, rearing grounds for fish, nutrient cycling, carbon storage, and aesthetic and recreation aspects. Yet, the native vegetation of Utah Lake has been lost or heavily impacted by humans and land management objectives.
- During the past 100 years, Utah Lake native emergent or lakeshore communities have been largely lost and replaced by invasive monocultures of *Phragmites*, and submerged aquatic vegetation (SAV) has been reduced or eliminated by fluctuating water levels and bioturbation. Restoring native plant communities can improve ecosystem function and diversity and provide a positive feedback loop for numerous ecosystem elements, including wildlife habitat and water quality conditions.
- Re-establishing native plant communities in Utah Lake could provide opportunities to improve and support related ecosystem functions, including the following:
 - Wildlife habitat (that is, shorebird nesting and general habitat)
 - Native fish conservation (including Bonneville cutthroat trout and June sucker, which use native vegetation as nursery habitat)
 - Water quality (that is, sediment stabilization and transferring primary production from the water column to the benthos, nutrient reduction in the water column, suspended sediment reduction, and harmful algal bloom reduction)
 - Littoral zone restoration (that is, sediment stabilization, reduced shear stress from wind and wave action and water circulation, and turbidity reduction)

Information needs

- Prioritized species for restoration in different landscape positions and hydrologic conditions that will help guide adaptive management of succession of different species over time, given the constraints of fluctuating water levels
 - Mapping of areas with high potential for native plant community restoration, including the following:
 - Methods to support establishing emergent communities from water-level dynamics that create extreme drought and flood conditions
 - Water quality targets (clarity) and corresponding optimal water depths to support SAV community establishment
 - Methods to support and protect SAV establishment from carp disturbance, wave action, and sheer stress
 - Establishment and expansion of large-scale native emergent and SAV plant nurseries to grow and support large-scale restoration activities
-

The vegetative communities of Utah Lake have been severely degraded over time. In addition to other vegetative communities, the lake littoral zone is of particular importance due to its role in influencing the trophic state of the lake and affecting water quality. The following sections provide significant information related to the vegetative communities of the lake.

6.1 Historical Context

Historical reports and paleo records suggest that Utah Lake was historically a clear-water system that supported a robust submerged macrophyte community. Initial comments on the vegetation surrounding Utah Lake were recorded as early 1776 and noted bogs, communities containing reeds and abundant marsh grasses, infrequent patches of wild sage, and swamps filled with *Lemna* and chum (Wakefield 1933; Brotherson 1981). Utah Lake surface water-level fluctuations were historically naturally controlled by spring melt surface water inputs from the American Fork River, Provo River, Hobbie Creek, and Spanish Fork creeks, as well as water surface reductions from evaporation, outflows through the Jordan River, and limited agricultural uses.

Early accounts describe Utah Lake littoral vegetation as dense and reedy, “low, reedy banks for 0.25 mile up with some willows, then some small box elder ... near where the large [Cottonwood] trees terminate” (Coombs 1970). Other reports noted that Goshen Bay was so filled with bulrush that it was impossible for a boat to cross its waters. Upland slopes contained sagebrush and greasewood but few trees. On the west side of the lake, sandy beaches could be found south of the head of the Jordan River, and the lake was rimmed by a few reeds and many bulrush, some of which grew into the lake. Such abundant vegetation and plant life would have maintained water clarity, protected fish from birds, provided shade, and cooled the water around the shoreline (Carter 2005).

As described in Section 4.1, paleo studies have attributed a shift in Utah Lake from a macrophyte-dominated clear-water state to the current turbid, phytoplankton-dominated state presumably associated with external nutrient loading and the introduction of common carp (Brotherson 1981; Miller and Crowl 2006; King et al. 2024). Section 4 provides more information on Utah Lake conditions.

6.2 Current Conditions at Utah Lake

This section describes the current conditions at Utah Lake and the status of native revegetation efforts.

6.2.1 Overview of Current Condition of Utah Lake Emergent and Submerged Aquatic Vegetation Communities.

Utah Lake has roughly 75 miles of shoreline, which could be used for recreation and the development of functional wetland habitats. Wetland characteristics for Utah Lake include riverine, riparian, scrub-shrub, emergent, and deepwater habitats. Freshwater emergent wetlands total approximately 8,411 acres, freshwater forested and shrub wetlands total 572 acres, and riverine wetlands total 46 acres (USFWS n.d.).

6.2.1.1 Plant Communities

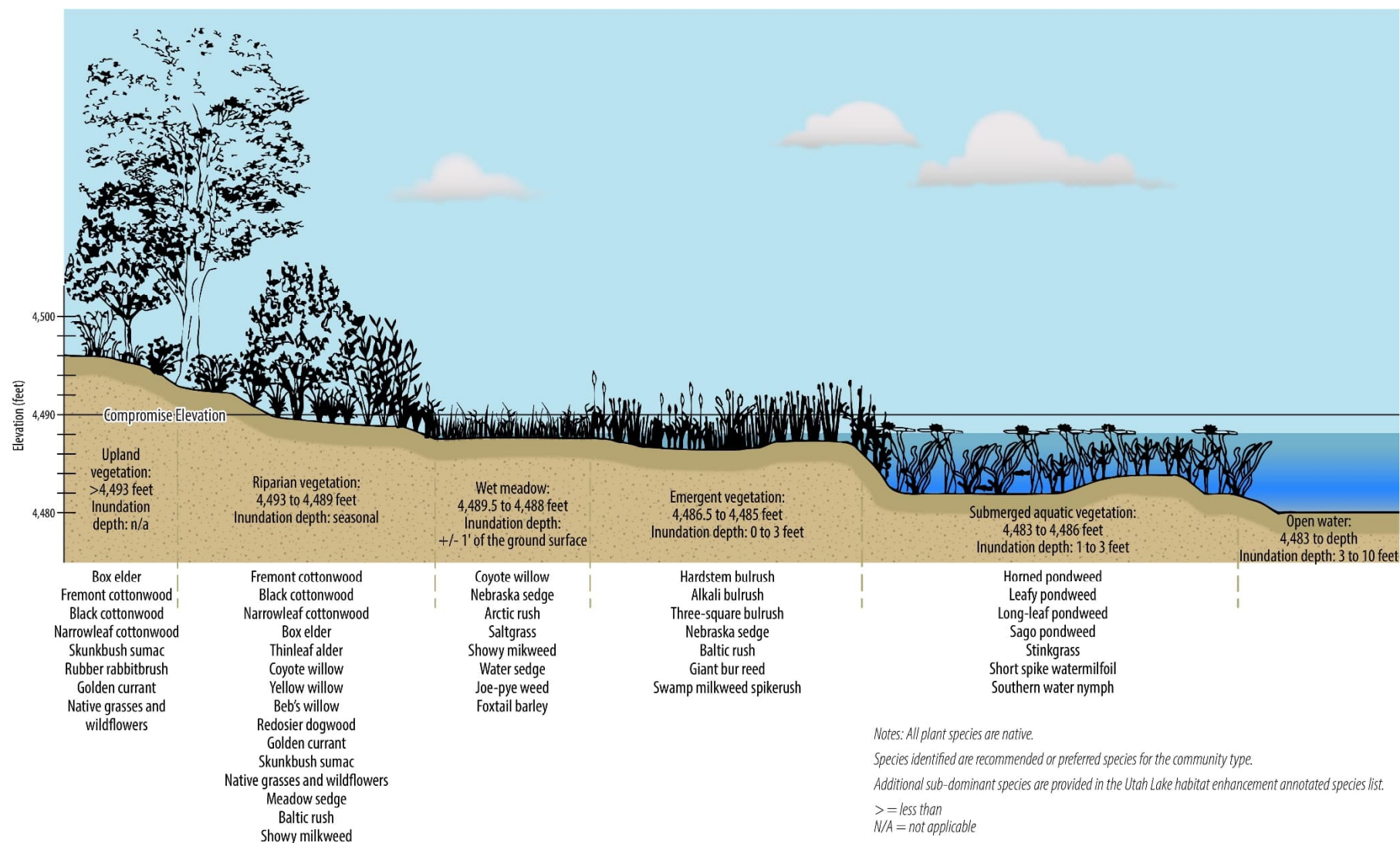
Utah Lake's aquatic and wetland plant communities have been greatly disturbed and disrupted by human intervention and widespread establishment of invasive *Phragmites* and invasive carp, as noted by Coombs (1970), but were originally zonal and interconnected, which created complex aquatic habitat mosaics. Two vegetation assemblages are common at Utah Lake: (1) fringe, or littoral, wetlands located along the water's edge, and (2) deepwater aquatic vegetation in water 3 to 6 feet deep (depending on lake conditions). Fringe wetlands may consist of multiple communities but predominantly comprise bulrush-cattail marsh community. Figure 6-1 shows a typical cross-section of Utah Lake native vegetation communities. Additional details on Utah Lake vegetation communities are provided by Brotherson (1981), who describes seven major aquatic and semiaquatic communities surrounding Utah Lake, which can form a band of vegetation along the lake shore varying in width from 20 meters on the western shore to 400 meters on the eastern shore. A total of 483 plant species were identified, 150 were deemed significant, and 13 were prevalent. Prevalent or most common Utah Lake species included the following:

- Salt grass (*Distichlis spicata*)
- Chairmaker's bulrush (*Scirpus americanus*)
- Common spike rush (*Eleocharis palustris*)
- Baltic rush (*Juncus balticus*)
- Nebraska sedge (*Carex nebraskensis*)
- Tamarisk (*Tamarix ramosissima*)
- Hardstem bulrush (*Scirpus acutus*)
- Foxtail barley (*Hordeum jubatum*)
- Cattail (*Typha latifolia*)
- Duckweed (*Lemna minor*)
- Alkali sacaton (*Sporobolus airoides*)
- Rocky Mountain glasswort (*Salicornia rubra*)
- Common ragweed (*Ambrosia artemisiifolia*)

Major vegetation communities found and described at Utah Lake include the following (Brotherson 1981):

- **Pondweed.** Pondweed (*Potamogeton latifolia*) communities are continuously inundated by water and monospecific types that occupy the lake's open water areas. Stand dimensions in the lake range from about 8 to 400 square feet (the largest being about 40 feet long by 12 feet wide). Stands occur in water as deep as 8 feet (Brotherson 1981). The communities consist of rooted, submersed aquatic plant species in the deeper waters of Utah Lake at depths between 3 and 5 feet. The communities can be distributed along the outward edges of fringe wetlands and can continue into open waters. This community type once covered vast areas of Utah Lake (BIO-WEST 2019).
- **Bulrush-cattail marshes.** These communities tolerate continuous inundation, with water depth not exceeding 2 feet, and saturation is often at ground level. Organic material accumulates in soil profile.

Figure 6-1. Typical Cross-Section of Utah Lake Native Vegetation Communities



Source: BIO-WEST 2019.

- **Spikerush-bulrush meadows.** These communities are generally situated in areas inundated in early seasons but dry by September. Soil type varies but generally consists of peaty sandy loams (Coombs 1970). The soil's organic matter content is high, and in places the communities occur on peat beds 30 inches deep. The two most important species are *Eleocharis macrostachya* and *Carex nebrascensis*. The communities are restricted to the lake's eastern side, extending from near White Lake in Goshen Bay to Jordan River, and they are best developed in Provo Bay and Benjamin Slough.
- **Grassrush-sedge meadows.** These communities inhabit the largest area of any semiaquatic herbaceous community around Utah Lake and are situated geographically much like the spikerush-bulrush meadows but tend to differ in at least the following ways: (1) although seasonally saturated, excess water has generally drained away by late spring, (2) soils generally are less peaty, and (3) soils are often slightly to moderately saline. Sedges (*Scirpus americanus*, *Eleocharis macrostachya*, and *Carex nebrascensis*) tend to be dominant in those areas of seasonal inundation, and grasses (*Distichlis stricta*, *Hordeum jubatum*, and *Sporoholus aeroides*) tend to dominate the higher, dryer areas.
- **Lowland woody communities.** These communities are broadly scattered type occupying several distinct sites around the lake and found most often in seasonally submerged sites, often near flowing streams. Soils are predominantly mineral (sandy to sandy clay loams) with varying degrees of incorporated organic matter. These communities have one of the lowest diversity indices and two layers: (1) the tree-shrub overstory and (2) a grass-annual or aquatic herb understory. *Tamarix ramosissima* and *Elaeagnis angustifolia*, two of the most important species listed, are exotic invaders.

Currently, the native vegetation communities at Utah Lake are greatly disturbed, fragmented, absent, or scarcely documented. Landom et al. (2023) identified the following species from Utah Lake vegetation monitoring (Table 6-1). These species represent emergent and SAV community types.

Table 6-1. Summary of Taxa Observed during Utah Lake Line-Intercept Macrophyte Transect Sampling

Common Name	Latin Name	Classification	Nativity
Alkali bulrush	<i>Bolboschoenus maritimus</i>	Emergent	Native
Cattail	<i>Typha latifolia</i>	Emergent	Native
Coontail	<i>Ceratophyllum demersum</i>	Submerged	Native
Cottonwood	<i>Populus fremontii</i>	Emergent-terrestrial	Native
Curly dock	<i>Rumex crispus</i>	Emergent-terrestrial	Invasive
Dead emergent	Various species	Emergent-dead	Various species
Duckweed	<i>Lemna minor</i>	Free-floating	Native
Filamentous algae	Various species	Free-floating	Various species
Hardstem bulrush	<i>Scirpus acutus</i>	Emergent	Native
Mosquito fern	<i>Azolla microphylla</i>	Free-floating	Native
Common reed	<i>Phragmites australis</i>	Emergent	Invasive
Sago pondweed	<i>Stuckenia pectinata</i>	Free-floating	Native
Sago pondweed	<i>Stuckenia pectinata</i>	Submerged	Native
Tamarisk	<i>Tamarix ramosissima</i>	Emergent-terrestrial	Invasive
Water plantain	<i>Alisma</i> spp.	Emergent	Native
Willow	<i>Salix</i> spp.	Emergent-terrestrial	Native
Yellowcress	<i>Rorippa sphaerocarpa</i>	Emergent-terrestrial	Native

Source: Landom et al. 2023.

Two nonnative plant species, *Phragmites* and salt cedar (or tamarisk), have significant establishments on Utah Lake shorelines. *Phragmites*, a nonnative invasive species, currently dominates some shoreline and seasonally submerged parts of the lake, replacing native species (primarily bulrush and cattail). Over 10,000 acres of *Phragmites* have been treated at Utah Lake and its tributaries (FFSL 2024). This introduced species is aggressively replacing native species and, in many areas, has created a monoculture. The spread and management of *Phragmites* (and other invasive species) around the lake is a research and management priority (Section 5.2).

The presence of SAV macrophytes substantially contributes to the structure and function of shallow lake ecosystems. Macrophytes stabilize lake sediments, limiting resuspension of sediments and associated nutrients by wave action. Also, they provide refuge for zooplankton, macroinvertebrates, and small fish against predation from larger fish and birds. As a result, vegetated shallow lake ecosystems tend to have low turbidity and a much richer biotic community than shallow lakes with little to no aquatic vegetation (Scheffer 1998). In Utah Lake, combined anthropogenic impacts, including nutrient loading, water-level fluctuations, spread of the invasive *Phragmites*, and common carp establishment, have significantly reduced the richness and density of macrophytes (Miller and Crowl 2006; King 2019). Consequently, Utah Lake has experienced increased water turbidity and decreased abundance and diversity of aquatic macrophytes (Janetski 1990; Landom et al. 2023).

6.2.1.2 Resource Preservation Areas

Eight resource preservation areas around Utah Lake are managed as habitat for wildlife and for restoration, conservation, and preservation. The properties identified are described as follows:

- **McLachlan Property:** This property on the north shore of Utah Lake is designated for the purpose of creating a wildlife preserve.
- **Powell Slough:** This federally owned property is a highly valued wetland system that is designated to be managed for wildlife purposes, specifically the June sucker.
- **Taylor Property:** This property was identified to preserve, enhance, and restore its wetlands and relatively significant natural features and values. Specific objectives include conserving important habitat for wildlife, protecting rare or unique native plants, and conserving wetland communities and the wildlife inhabiting these wetlands.
- **Despain Property/PRDRP:** This land was identified so that it will be retained forever in its natural, scenic, agricultural, and/or open space condition and to prevent any use of the property that will impair or interfere with the conservation values of the property. The majority of the Despain property was developed into the PRDRP, which is a large restoration area that restores a braided channel delta area connecting the Provo River to Utah Lake. The PRDRP was created and managed by the URMCC but will be transferred to DWR for future management.
- **Provo City Wetland Mitigation Site:** The Utah Lake Provo City Wetland Mitigation site is part of the larger ULWP. This site is a network of wetland and upland habitats near the southern end of Utah Lake. Mitigation goals include conserving plant resources; conserving upland and aquatic wildlife, including migratory birds; and providing public access for compatible wildlife-dependent recreation.
- **Hobble Creek Restoration Project:** The JSRIP purchased property along lower Hobble Creek and has completed a project to restore a naturally functioning wetland and delta where Hobble Creek enters Utah Lake to provide an additional spawning habitat for June sucker. This site also includes an area upstream of Interstate 15 that was restored to provide spawning habitat for June sucker.
- **Benjamin Slough Unit of the Utah Lake Wetlands Preserve:** As this refuge was created, wildlife refuge management requirements were established that are now guiding DWR's management of the preserve.

- **Goshen Bay Unit of the Utah Lake Wetlands Preserve:** This preserve will be established to include much of the area along and upland from Goshen Bay. The two units of the preserve will be managed by DWR and combined to provide thousands of acres of protected wetland areas.
- **Southern Shoreline of Provo Bay:** The Central Utah Project Completion Act (CUPCA) restricts federal permits for development along the southern shoreline of Provo Bay, extending 2,000 feet out into the Bay from the ordinary high water mark beginning at the mouth of the Spanish Fork River and extending eastward to the intersection of the ordinary high water mark with the Provo City limit. Exceptions are recreational development consistent with wildlife habitat values.

6.2.2 Current Status of Native Revegetation Efforts at Utah Lake

Restoring native plant communities in dynamic lakeshore environments can be difficult due to the dynamic nature of the lakeshore transitional zones (Vanderbosch and Galatowitsch 2010). Significant research interest has been focused on the restoration of native plant communities at Utah Lake in recent years. The research, spearheaded by wetland restoration experts, has focused on several critical areas (such as species selection, planting techniques, planting and seeding density, and large-scale seed and plant sources, monitoring, and adaptive management) to test restoration concepts and support greater restoration success.

Studies to date have mostly focused on small-scale experiments at Utah Lake to evaluate potential pathways toward successful native plant community restoration. However, more large-scale native plant restoration projects based on restoration best practices are needed to make significant improvements to the composition and ecological character of Utah Lake. Braun et al. (2024) identifies best practices for lakeshore revegetation in the arid west, providing a stepwise approach to successful revegetation that includes the following:

- Site characterization
- Planning and collaboration
- Mapping and prioritizing restoration sites
- Invasive species management
- Active revegetation (species selection, plant propagule type, planting density, planting techniques)
- Monitoring
- Community involvement
- Adaptive management

6.2.2.1 Active Revegetation

Active revegetation is essential to managing and competing against *Phragmites* reinvasion and restoring native biodiversity. This involves assessing species selection and planting native species that are well adapted to the local conditions. Analysis and review of appropriate planting techniques and plant material, such as dispersing seeds, planting individual plugs, and installing sod mats, have been employed to reintroduce native vegetation. Some of the critical considerations involved in revegetation efforts are described in this section.

Species Selection

Shoreline environments can be hydrologically stressful for plants (Vanderbosch and Galatowitsch 2010). Plants experience drought and flooding at unpredictable times, potentially exceeding physiological tolerances (Allen and Klimas 1986). A wider range of potential native species recommended to withstand variable and harsh conditions for shoreline restoration is provided by Braun et al. (2024), who identified selected native species appropriate for Utah Lake and its region. These species recommendations are

grouped into restoration ecological zones (upland, meadow, and emergent) to improve planting results based on hydrology.

Some of the most important native plants in these regional wetlands are perennial bulrushes, including alkali bulrush (*Bolboschoenus maritimus*), hardstem bulrush (*Schoenoplectus acutus*), three-square bulrush (*Schoenoplectus americanus*), and saltgrass (*Distichlis spicata*). These species often occur in large, monotypic stands; provide important nesting and resting habitat for a variety of bird species; and serve as a food source for many birds (Oring et al. 2013; Downard et al. 2017; Kettenring and Martin 2018). Salt grass is also noted as a significant species for restoration at Utah Lake. Saltgrass seeds are relatively easy to germinate (compared with the bulrushes), and they confer additional habitat benefits to a wider array of bird species. These bulrush and saltgrass are primary choices for restoration seed mixes because of their ability to establish quickly, compete with invasive species, tolerate hydrologic extremes, and support local wildlife. An extensive list of suitable species recommended for arid west and lakeshore revegetation are provided in Braun et al. (2024) and Table 6-2.

Plant Materials (Seed, Plug, Bareroot, Mat, and Canes and Poles)

Numerous types of plant materials—seeds, plugs, poles and cuttings, rhizomes, and mats—can be introduced into a restoration site, with each having distinct costs, benefits, and success potentials. Braun et al. (2024) provides information on the benefits and limitations of plant materials. All plant materials have ecological limitations and will not survive if they are not installed at correct hydrologic conditions. All plant materials are susceptible to adverse environmental conditions, including the flooding, drought, herbivory or predation, scour, and wave action, all of which are present at Utah Lake. The pros and cons of the various types of plant materials for use in revegetation are as follows:

- Seeds are low cost but may have greater than 90 percent mortality.
- Plugs generally have greater survival rates than seeds, but they are more expensive and, like all plant material, are vulnerable to mortality if the planting location is too dry or too inundated or the soil conditions are too saline.
- Bareroot have high survival rates relative to seeds and plugs. Mortality can be high if hydrology is incorrect.
- Vegetated mats are expensive and time intensive but have best establishment success. Mats are a good option for high-energy environments or steep slopes.
- Canes and poles require special handling and storage.

Seeding Density

Recommended planting and seeding densities for wetland restoration at Utah Lake can vary based on the specific goals and conditions of the site. Research generally points to short-term benefit to survival and establishment of greater seeding densities than typical restoration recommendations. In one grassland study, researchers found that a 100 percent increase in current restoration seeding rates (currently 400 to 600 pure live seed per square meter [PLS/m²]) and a 300-percent increase in seed mix diversity (currently 3 to 10 species) may result in better restoration outcomes. A separate study indicated that greater sowing densities (1,500 to 6,000 PLS/m²) increased native plant density in upland systems in the first year, but plant density fell the following year as a result of density-dependent mortality (as described in Braun et al. [2024]). Feldman (2024) examined the effect of seeding density on impending re-establishment of *Phragmites* in an experimental framework; they found that increased native seed density both increased native cover and decreased *Phragmites* cover. Seeding and planting densities are highly site dependent (for example, the extent of flood or drought events causing mortality) and require fine tuning for plant community recovery at a particular site (Braun et al. 2024).

Table 6-2. Recommended Plant Species for Revegetating Lakeshores in Great Basin Region

Latin Name	Common Name	Family	Type of Plant Community ^[a] and Lifeform ^[b]	Wetland Indicator Status ^[c]	Sun/Shade Tolerance ^[d]	Adaptations and Notable Features ^[e]
<i>Allenrolfea occidentalis</i>	Iodine bush	Chenopodiaceae	Playa; shrub	FACW	 	Thrives in saturated saline wetlands; drought tolerant and great for soil stabilization (roots can spread up to 10 meters)
<i>Asclepias incarnata</i>	Swamp milkweed	Asteraceae	Emergent; forb	OBL	 	Can tolerate a pH up to 8.0; deer resistant
<i>Asclepias speciosa</i>	Showy milkweed	Asteraceae	Upland; forb	FAC		Drought tolerant; extensive root system and minimal nutrient requirements make it good for stabilization and restoration
<i>Bidens cernua</i>	Nodding beggartick, bur marigold	Asteraceae	Meadow; forb	OBL		Tolerates seasonal flooding for short durations; can be weedy (fast growth rate)
<i>Bolboschoenus maritimus</i>	Alkali bulrush	Cyperaceae	Emergent; sedge	OBL		Can handle a pH up to 9.0; can survive flooding up to 1 meter deep; fire resistant
<i>Carex nebrascensis</i>	Nebraska sedge	Cyperaceae	Emergent; sedge	OBL		Dense root mass makes species resistant to soil compaction and erosion; great for soil stabilization
<i>Carex praegracilis</i>	Clustered field or meadow sedge	Cyperaceae	Meadow; sedge	FACW	 	Tolerant of alkaline soils; can thrive in wet to seasonally dry meadows
<i>Cleome serrulata</i>	Rocky Mountain bee plant	Cleomaceae	Upland; forb	FACU	 	Pink flowers attract bees; seeds are important food for doves and other small birds; drought and salinity tolerant; annual; reseeds easily
<i>Distichlis spicata</i>	Saltgrass	Poaceae	Meadow; grass	FAC		Useful for revegetating unusually saline, interior areas; extensive, creeping rhizomes enable species to colonize an area quickly; adapts to drier soils, including silts, clays, and even sands
<i>Eleocharis palustris</i>	Common spikerush	Cyperaceae	Meadow; sedge	OBL		Can grow in water up to 1 meter deep; rhizomatous plant that will eventually fill in large areas
<i>Epilobium ciliatum</i>	Fringed willowherb	Onagraceae	Emergent; forb	FACW	 	Rapid grower; completes life cycle from seed to seed in as little as 9 to 10 weeks
<i>Euthamia occidentalis</i>	Western goldentop	Asteraceae	Emergent; forb	FACW		Stout and branching perennial species ideal for stream side plantings and bank stabilization
<i>Eutrochium maculatum</i>	Joe-pye weed	Asteraceae	Meadow; forb	OBL	 	Root system is fibrous and rhizomatous; forms small clonal colonies; resistant to damage by deer

Review of Existing Information Report

Latin Name	Common Name	Family	Type of Plant Community ^[a] and Lifeform ^[b]	Wetland Indicator Status ^[c]	Sun/Shade Tolerance ^[d]	Adaptations and Notable Features ^[e]
<i>Grindelia squarrosa</i>	Curlycup gumweed	Asteraceae	Upland; forb	FACU		Able to survive and grow under adverse conditions; seedlings are easily transplanted to field and grow rapidly; drought resistant because of its deep roots and resinous secretions; facultative selenium absorber
<i>Helenium autumnale</i>	Common sneezeweed	Asteraceae	Meadow; forb	FACW	 	Easy to grow in most sunny sites; thrives in wet or evenly moist soil but will tolerate a bit of drought after establishment; pest resistant and unpalatable to deer and other herbivores
<i>Helianthus annuus</i>	Common sunflower	Asteraceae	Upland; forb	FACU		Spreads rapidly by seed, especially in disturbed sites; shown to have an allelopathic effect on other plants
<i>Helianthus nuttallii</i>	Nuttall's sunflower	Asteraceae	Meadow; forb	FACW		Can grow up to 4 meters tall; great host for up to 27 different butterflies and moths; prefers loamy or clay soils
<i>Juncus arcticus</i>	Arctic, mountain, or Baltic rush	Juncaceae	Adow; forb	FAC		One of the most widespread plant species worldwide; thick rhizomes help bind wetland soils; tolerates saline soils; fixes nitrogen in soil
<i>Populus fremontii</i>	Fremont's cottonwood	Salicaceae	Meadow; tree	FAC	 	Good for bank and sediment stabilization, water quality improvement, groundwater recharge, flood abatement, and fish and wildlife habitat
<i>Puccinellia nuttalliana</i>	Nuttall's alkaligrass	Poaceae	Emergent/meadow grass	FACW		Tolerates saturated to shallowly flooded saline wetlands
<i>Rumex maritimus</i>	Golden dock	Polygonaceae	Emergent; forb	FACW		Seeds germinate easily in moist conditions; tolerates saline soils and waterlogged conditions
<i>Sagittaria latifolia</i>	Broadleaf arrowhead	Alismataceae	Emergent; forb	OBL	 	Underground tubers are preferred by at least 15 species of ducks and by snapping turtles
<i>Salsicornia rubra</i>	Pickleweed	Chenopodiaceae	Playa; forb	OBL		Similarly performing species: <i>S. utahensis</i> ; capable of growing in saline or highly alkaline wetlands
<i>Salix exigua</i>	Coyote willow	Salicaceae	Emergent/meadow; tree	FACW	 	Excellent for stream stabilization because the plant suckers profusely
<i>Schoenoplectus acutus</i>	Hardstem bulrush	Cyperaceae	Emergent; sedge	OBL		Dense root mass; excellent choice for soil stabilization; aboveground biomass provides protection from erosive wave action and stream currents

Review of Existing Information Report

Latin Name	Common Name	Family	Type of Plant Community ^[a] and Lifeform ^[b]	Wetland Indicator Status ^[c]	Sun/Shade Tolerance ^[d]	Adaptations and Notable Features ^[e]
<i>Schoenoplectus americanus</i>	Olney's three-square bulrush	Cyperaceae	Emergent; sedge	OBL		Can live in brackish (somewhat salty) waters; great source of food and nesting habitat for waterfowl and small mammals
<i>Senecio hydrophifus</i>	Water ragwort	Asteraceae	Meadow; forb	OBL		Can grow in standing water, including alkaline and saline water
<i>Sparganium ewycarpum</i>	Broadfruit bur-reed	Sparganioaeae	Emergent; forb	OBL		Can form dense stands under the right conditions; buried rhizomes help plants survive periods of drought, fire, or ice scour; seeds are an important food source for waterfowl
<i>Symphyotrichum ciliatum</i>	Rayless aster	Asteraceae	Meadow; forb	FACW		Thrives in moist, brackish soils and areas with fluctuating water levels, as well as winter-salted roadways
<i>Triglochin maritima</i>	Seaside arrowgrass	Juncaginaceae	Meadow; forb	OBL		Can thrive in saturated, saline wetlands
<i>Verbena hastata</i>	Swamp verbena	Verbenaceae	Meadow; forb	FACW	  	Plants tolerate moderate salt levels, loamy or wet mucky soils, and temporary standing water; bitter foliage makes plant fairly herbivore resistant

Source: Braun et al. 2024.

^[a] Groups of plants that commonly occur together in similar environments based on factors like climate, soil type, and topography.

^[b] Plants are classified based on their overall structure, growth habit, and strategies for survival and reproduction.

^[c] Likelihood of a species being found in wetland or upland habitats:

FAC = facultative wetland species (equally likely to occur in wetlands and uplands)

FACW = facultative wetland species (usually occurs in wetlands)

OBL = obligate wetland species (almost always occurs in wetlands)

FACU = facultative upland species (usually occur in uplands)

^[d] Plant's ability to grow in different light conditions (references for sun/shade tolerances are same as those in the Adaptations column):



= full sun (species that thrive in high light)



= half-shaded sun (species that are adapted to shade)



= shaded sun

^[e] Important species characteristics to consider with specific site stressors.

Kettenring and Martin (2018) used standard restoration seeding densities for their study, but future work needs to quantitatively determine what native seed density is required for rapid native plant community establishment to best outcompete any reinvading *Phragmites*. Initial research indicates that *Phragmites* stem densities tend to be relatively high overall and not impacted by increasing stem density of any native species.

Planting Density, and Other Materials

General plant density guidelines for containerized plant material include the following (Sound Native Plants 2025):

- **Forbs and grasses:** Planting densities typically average 2 feet on center. This allows for adequate space for growth, while providing coverage to outcompete invasive species (Braegger 2022).
- **Shrubs:** For larger shrubs, densities are often around 6 feet on center. This spacing helps prevent overcrowding and allows each plant to establish properly.
- **Trees:** If trees are included in the restoration plan, they are usually planted at densities of 12 to 15 feet on center, depending on the species and desired canopy cover.
- **Aquatic plants:** Submerged and emergent aquatic plants are often planted at greater densities, such as 1 to 2 plants per square foot, for rapid establishment and coverage.

These densities are designed to balance plant competition, growth, and the overall health of the restored wetland ecosystem. Planting densities are highly site dependent and will require site-specific adjustments.

Timing

Vanderbosch and Galatowitsch (2010) found that that installation timing of plant material is critical for emergent vegetation success in lakeshore environments. Survival of bulrush planted later in the growing season was poor, regardless of the plant material used, and should be avoided. The optimal planting season of early to mid-summer transplants from pots are more likely to outperform mats, despite lower pre-planting biomass. Water depth is only important immediately after planting; after this time, water depth's influence on successful establishment diminishes.

Cluster Planting

Clustering plant material may increase success as a result of biologic and management advantages. Clustered planting may increase beneficial soil conditions and withstand erosional forces (Braun et al. 2024). Management of installed plant communities may be advantageous because clustered areas may be less labor intensive to maintain, monitor, and manage. Further study pertaining to cluster plantings, as compared to uniform plant spacing, at Utah Lake should be conducted.

Seed Dormancy

To promote rapid seed germination and establishment in variable lakeshore conditions, three methods have been used to break dormancy based on the species profile preference: (1) cold stratification, (2) 24-hour bleach treatment, and (3) no treatment. Treatment for 30 days under moist, cold conditions (4°C) is recommended for salt grass, hardstem bulrush, and three-square bulrush seeds (Marty and Kettenring 2017). Alkali bulrush requires a 24-hour bleach treatment to break dormancy by weakening the seed coat; this is the most effective technique developed for this species (Kettenring and Martin 2018; Marty and Kettenring 2017). Baltic rush seeds are not pretreated because this species has no seed dormancy based on the published literature (reviewed in Baskin and Baskin [2014]) and preliminary germination trials.

Water-Level Timing

Seed application or other plant material installation timing should consider the anticipated and existing water levels to fine-tune planting or seeding activity when conditions are most favorable. In general, seeding should occur when flood waters are receding, and plant material should be installed when substrates are wet, but not during flood, high precipitation or high melt-off events.

Planting Protection from Fish and Wave Action and Scour

Carp foraging activity (Knopik and Newman 2018) and wave action can affect plant establishment, stability, and distribution in shallow lakes (Schutten et al. 2004). Two studies investigating wave action on macrophyte establishment found that large wave forces can significantly inhibit the establishment of submerged macrophytes. These studies concluded that reducing these forces can help with the establishment and growth of macrophytes in shallow lakes (Schutten et al. 2004; van Zuidam and Peeters 2015). The literature supports restoring SAV communities following carp removal; protections from these disturbances (sheer stress and carp) may improve SAV establishment in areas prone to disturbance.

6.2.2.2 Monitoring and Adaptation

Continuous monitoring of the revegetation sites is crucial to site adaptation and revegetation progress and success. Restoration researchers have emphasized the importance of adaptive management, where strategies are adjusted based on ongoing observations and results. This approach helps address unforeseen challenges and improves the overall success of restoration projects (Endter-Wada et al. 2020). Replanting restoration sites annually to increase plant establishment, density, and/or diversity is recommended from years 1 through 5 following the initial planting event.

6.2.2.3 Community Involvement

Engaging the local community through planting events and educational programs may be very beneficial to restoration efforts. Doing so supports labor required for planting and also fosters a sense of stewardship and long-term commitment to the health of Utah Lake (Strayer and Findlay 2010). Recent research findings underscore the importance of a multifaceted approach to native plant restoration, combining scientific techniques with community involvement and adaptive management to achieve long-term ecological success at Utah Lake.

6.2.2.4 Submerged Aquatic Vegetation Current Revegetation Conditions

SAV community decline in Utah Lake has two overarching causes: (1) eutrophication and (2) the impacts of nonnative invasive species, primarily carp. It is well-supported in the literature that nutrient enrichment leads to increased algal production, which, along with increased sediment loads and direct disturbance from carp activities, results in shading and eventual loss of macrophytes (Hofstra et al. 2024). Several papers, some recent, on large and small lakes have explored and discussed revegetation of SAV macrophyte communities (Scheffer et al. 2001; Meijer et al. 1999; Hofstra et al. 2024; Knopik and Newman 2018). Like revegetation of emergent communities on lakeshores, revegetation of SAV communities requires multiple restoration actions to reverse the negative feedback loop that degrades lake conditions.

Degraded shallow lakes are permanently turbid, and macrophytes no longer grow. Without macrophytes, wave action resuspends lake-bed sediments. Poor water quality, caused by excessive algae and suspended sediments, the browsing impacts of fish and waterfowl, and the loss of seed bank or propagules, pose significant barriers to revegetation goals that will be further exacerbated by the warmer temperatures and more extreme weather events expected with climate change (Hofstra et al. 2024). Authors recognize a need for fish removal, water clarity improvements, nutrient reduction, and macrophyte re-establishment

to reduce the likelihood of a relapse to poor lake conditions (Hilt et al. 2006; Gulati et al. 2008; Meijer et al. 1994; Bakker et al. 2013; Hofstra et al. 2024; Matsuzaki et al. 2009; Bajer et al. 2016). A combination of experimental and field studies, determining optimal environmental ranges of different macrophyte species, methods to culture en masse, and techniques to promote sufficient water clarity and sediment density to sustain SAV, are needed. Once minimum vegetation cover thresholds are exceeded, sustainable restoration to a macrophyte-dominated, clear-water state should eventuate.

The known or quantifiable factors that influence SAV restoration actions are as follows:

- Water clarity
- Water quality (nitrogen and phosphorus content, suspended sediment, and propensity for algal blooms, which influence light penetration)
- Substrate suitability (such as, density and cohesion)
- Physical characteristics (such as, size, shape, fetch, and bathymetry, as it relates to light climate and available habitat)
- Macrophyte records and existing seedbank quality (diversity, abundance, and viability)
- Availability of plant propagules

These known factors are critical to determining the optimal area of habitat for SAV and whether prior lake restoration actions have been sufficient to create suitable light conditions for macrophytes to recolonize (Bakker et al. 2013; Hofstra et al. 2024).

Extensive efforts have been made in the past to improve the ecological quality of lakes, mainly by reducing external nutrient loading and removing benthivorous and planktivorous fish to stimulate development of submerged vegetation (Meijer et al. 1999; Jeppesen et al. 2005; Søndergaard et al. 2007). In many cases, these restoration efforts did not lead to long-term vegetated lakes (Hilt et al. 2006; Søndergaard et al. 2007; Gulati et al. 2008) due to long-term limiting factors, including: wave action, unsuitable substrates, nutrient loading, algal blooms, water clarity, and browsing impacts of fish, warm weather, or climate change. Van Zuidam and Peeters (2015) notes that wave-induced turbulence at the benthic layer can limit the establishment of submerged macrophytes in large, shallow lakes. Measures aimed at reducing wave forces at the lake bottom by sheltering potential habitat with permanent or temporary structures or barriers can promote submerged vegetation (Gulati et al. 2008). In certain cases, temporary reduction of the wave forces at the bottom may be sufficient to create a window of opportunity for vegetation to establish. This reduction in wave stress could also be achieved by temporarily changing the water level. Lowering the water level has been suggested as a method for temporarily increasing light availability (Coops and Hosper 2002), but in large lakes this might also be useful for temporarily reducing wave stress.

Knopik and Newman (2018) studied macrophyte revegetation following carp removal and control. The study indicated that light availability (water clarity) was the most important factor determining SAV transplanting success. Transplanting whole, submersed, aquatic macrophytes can help to restore the littoral community in degraded systems, but ecological stressors, such as common carp, should first be addressed. Poor mid-summer water clarity will limit the depth and distribution of successful transplants and taxa that survive. Taxa with large perennial structures are more likely to establish and persist (Knopik and Newman 2018).

6.3 Key Stressors, Perturbances, and Changes

Among the most cited factors inhibiting the recovery of native vegetation at Utah Lake are nonnative invasive species, primarily *Phragmites* and carp; water-level fluctuations; and water clarity. Descriptions of these follow:

▪ **Invasive species:**

- *Phragmites australis*: This invasive reed has aggressively spread along Utah Lake's shores, displacing native vegetation and degrading habitat quality (WRI n.d.). Its dense growth reduces wetland function relative to species richness, diversity, general wildlife habitat, avian habitat, and, to a lesser degree, fish life-cycle support. *Phragmites* is a strong competitor for lakeshore habitats and outcompetes many native emergent species, unless managed for long-term control.
- *Invasive carp*: Utah Lake underwent a phase shift associated with common carp introduction in the late 1800s and increased nutrient loading following the expansion of agriculture and development in Utah Valley (King 2019; Landom and Walsworth 2021). Historical records suggest Utah Lake was once much clearer and more heavily vegetated with emergent, floating, and submergent macrophytes (Janetski 1990; King et al. 2024).

Invasive fish species, such as common carp, disturb sediment, decrease water clarity, and uproot plants, removing SAV communities and further hindering the establishment of native vegetation (May 2023). These invasive fish also compete with native fish for habitat and resources. Landom et al. (2023) found an increase in nearshore macrophyte species richness, beginning in 2016, which coincides with a substantial reduction in carp biomass. Landom et al. (2023) found that the presence of submerged macrophytes is significantly correlated with reduced carp population biomass at the sample site scale. However, both macrophyte species diversity and the densities of submerged macrophytes have decreased since 2017 as carp biomass has recovered. At the lake scale, lake level is the primary driver of macrophyte habitat establishment.

Landom (2024) monitored changes in vegetation composition and density in response to the carp removal program. Successful reduction in carp biomass is expected to improve habitat conditions, shift the zooplankton community toward a prominence of large-bodied taxa, drive an increase in benthic macroinvertebrate biomass and sport fish biomass, and likewise alter the structure of the aquatic food web in Utah Lake (Landom et al. 2014). However, as Utah Lake is within a highly urbanized mountain valley bottom, the ecosystem experiences multiple anthropogenic disturbances that could drive ecosystem changes independent of potential carp removal effects (Psomas and SWCA 2007; King et al. 2024).

Quantifying carp biomass is critically important for management efforts because the effects of carp on ecosystems are biomass dependent (Vilizzi et al. 2015; Bajer et al. 2016). Whole-lake manipulations in the Midwest have shown that carp are generally not damaging to lake ecosystems if their biomass remains less than 100 kg/ha, but they are damaging to ecosystems once their biomass exceeds 200 kg/ha (Bajer et al. 2009; Vilizzi et al. 2015; Bajer et al. 2016). Often, lake managers use a carp biomass of 100 kg/ha as a management threshold (Bajer et al. 2016).

▪ **Water-level fluctuations:**

- Variability in lake levels affects native vegetation restoration and vegetation coverage. Elevated water levels can decrease submerged vegetation, while increasing emergent vegetation (May 2023). These fluctuations make it challenging to establish stable plant communities. Landom et al. (2023) and May (2023) note that lake level fluctuations play a key role in regulating vegetation community establishment or presence. May (2023) finds that lake level fluctuations significantly affect both submerged (negative relationship) and emergent (positive relationship) vegetation coverage.

▪ **Water clarity:**

- Water clarity is important in SAV revegetation because these submerged and floating plant communities require light penetration to survive and reproduce. Poor light penetration from low

water clarity has a negative effect on SAV. Water clarity in Utah Lake is reduced from organic and inorganic suspended particles.

- Excess nutrients from agricultural runoff and urban development contribute to eutrophication, promoting algal blooms that can outcompete native plants and reduce water quality.
- In addition to reduced clarity due to phytoplankton growth, Utah Lake has nonalgal turbidity that also contributes to low water clarity (King et al. 2023), attributed to its large surface area, shallow depth, and susceptibility to sediment resuspension from wind-driven events, which is exacerbated by a lake-wide lack of macrophytes. As described in Section 1.1, water-level fluctuation and wind and wave events have been suggested to limit submerged vegetation persistence, particularly in eastern areas of Utah Lake that endure a disproportionate number of high wind and wave events compared to the western areas of the lake (Miller and Crowl 2006).
- Carp have been implicated in uprooting SAV, removing the sediment-binding root system, which increases suspended sediments and reduces the buffering effect of SAV communities to wind and wave action (further increasing suspending sediments).

These studies and efforts highlight the complex interplay of factors affecting native revegetation at Utah Lake and underscore the need for coordinated management strategies to overcome these obstacles.

6.4 Ecological Dynamics

The shoreline emergent plant community of Utah Lake is affected by *Phragmites*, which outcompetes and displaces native plants, and the wide range of hydrologic conditions associated with water-level management. Emergent communities are primarily degraded or excluded by *Phragmites* establishment and spread resulting from historical land management activities and regional disturbances. The methods for managing and controlling the invasive species are well documented but take considerable effort and time to be successful (Valdez, pers. comm. 2025; Hambrecht, pers. comm. 2025). Fluctuating water levels in Utah Lake create conditions that are generally limiting (for example, too dry or too inundated) to support reliable establishment of native emergent plant communities (Kettenring, pers. comm. 2025).

Shallow lakes can exist in a clear-water state, with abundant submerged macrophytes, or a turbid state, with high concentrations of phytoplankton and suspended sediment particles in the absence of macrophytes. The pristine state of most shallow lakes is typically marked by a clear-water phase, where light is not limiting to its rich and diverse SAV community. Excessive nutrient loading has changed this situation in many cases. Remarkably, water clarity often seems to be hardly affected by increased nutrient concentration until a critical threshold is passed, at which the lake shifts abruptly from clear-water to a turbid state. With this increase in turbidity and associated light limitation, submerged aquatic plants largely disappear. The loss of floral and faunal diversity and high biomass of planktonic algae, including HAB, make this state undesired (Hofstra et al. 2024; Gulati 2008; Hilt et al. 2006; Bakker et al. 2013).

Experimental work suggests that well-established SAV communities increase water clarity, thereby enhancing their own growing conditions. Submerged macrophytes prevent sediment resuspension, take up nutrients from the water, and provide a refuge for zooplankton against predation by planktivorous fish. Filtering activities by zooplankton reduce algal biomass, further promoting and sustaining a clear water state. The reduction of phytoplankton biomass and turbidity by vegetation thus involves a suite of direct and indirect mechanisms, including reduction of nutrients in the water column; protection of phytoplankton grazers, such as *Daphnia* against fish predation; and anchoring and stabilization of the sediment layer, which reduces sediment resuspension (Hilt et al. 2006; Knopik and Newman 2018; Hofstra et al. 2024, and others).

Fish are central to maintaining the turbid state (van Donk and Gulati 1995) because they control zooplankton in the absence of plants. Planktivorous fish are visual feeders, preferring relatively large-

bodied zooplankton such as *Daphnia*, reducing its abundance. Fish can also resuspend sediments in their search for benthic food, adding to turbidity in the water column. Bioturbation activities by carp further exacerbate the problem. Whole-lake experiments show that a temporary strong reduction of fish biomass can bring such lakes back into a permanent clear state if the nutrient level is not too high (Scheffer et al. 2001). Several case studies have been completed on biomanipulation in shallow lakes; two of these are as follows:

- **The Netherlands:** An evaluation of 18 shallow lakes in the Netherlands showed that biomanipulation, involving drastic reduction of fish stock, led to significant improvements in water clarity and submerged macrophyte growth. In most cases, a reduction of more than 75 percent of the fish stock was necessary to achieve clear water (Meijer et al. 1999).
- **Lake Væng, Denmark:** Over a 30-year period, Lake Væng underwent two biomanipulations, involving the removal of roach and bream. Both interventions successfully shifted the lake from a turbid, phytoplankton-dominated state to a clear, macrophyte-dominated state. The improvements included reduced Chl *a* levels and increased coverage of submerged macrophytes (Søndergaard et al. 2017).

Drawbacks and negative effects of biomanipulation can include the following:

- **Short-term instability:** Initially, reducing fish stock can lead to short-term instability in the ecosystem. This might include temporary increases in algal blooms or changes in water quality before the ecosystem stabilizes.
- **Unintended consequences:** Biomanipulation can have unintended consequences, such as the proliferation of other unwanted species or changes in the food web dynamics that were not anticipated.
- **Mixed long-term results:** The long-term effectiveness of biomanipulation can be mixed. Some studies have shown that the benefits may diminish over time, and the lake may revert to its turbid state if not managed continuously.
- **Impact on biodiversity:** Reducing fish populations can impact biodiversity, particularly if the reduction is not carefully managed. This can affect not only the fish species, but also other aquatic organisms that depend on them.

Utah Lake's fish populations include several introduced planktivorous and benthivorous species that affect the lake's ecosystem by influencing water quality and the overall health of the aquatic environment. Some of these species include (Pond Informer 2022):

- **Planktivorous fish:**
 - White bass (*Morone chrysops*): This species is known for feeding on zooplankton and small fish.
 - Bluegill (*Lepomis macrochirus*): Bluegills primarily consume zooplankton, insects, and small invertebrates.
- **Benthivorous fish:**
 - Common carp: Carp are notorious for disturbing sediments while feeding on benthic organisms, which can increase water turbidity.
 - Channel catfish (*Ictalurus punctatus*): These fish feed on a variety of benthic invertebrates and detritus.

Knopik and Newman (2018) investigated restoration of submersed macrophytes in Lake Susan (88 acres, Minnesota), where carp biomass was reduced by winter seining from 307 kg/ha to 41 kg/ha (Sorensen and Bajer 2020). After carp removal, the lake experienced a spring clear-water phase for the first time in 37 years (Jacobs unpublished data). Following restoration of spring clear-water conditions, restoration of submersed macrophytes was investigated. The study transplanted and monitored local, native submersed macrophytes and observed that macrophyte recovery was slow and far from complete. Light was found to

be a critically limiting factor, with no plants surviving below 1.4 meters depth. Although the spring clear-water phase was restored, high algal turbidity commenced in early July and persisted throughout the summer, limiting light penetration and, in turn, recolonization by submersed vegetation. Restoring and maintaining native vegetation along Utah Lake's shores is critical for several reasons, including:

- **Ecological resilience:** Native plant communities are better adapted to local conditions and more resilient to environmental stressors, supporting long-term ecosystem health.
- **Wildlife habitat:** Re-establishing native vegetation enhances habitat quality for numerous species, including migratory birds and other wildlife dependent on riparian and wetland areas.
- **Water quality improvement:** Healthy wetlands filter pollutants and reduce nutrient runoff, improving water quality in Utah Lake.
- **Preventing reinvasion:** A robust native plant community is essential to outcompete invasive species and prevent *Phragmites* from reclaiming the shoreline.
- **Community and recreational benefits:** Enhancing the ecological health of the lake also supports recreational opportunities, agriculture, and the aesthetic value of the area, benefiting both residents and visitors.

7. Restoring and Conserving Native Fish and Other Aquatic Species in Utah Lake

Key findings

- Utah Lake native fish species and other native aquatic organisms (for example, mollusks and amphibians) have drastically declined due to habitat loss, water diversion, pollution, and invasive species introduction.
- Nonnative fish, especially common carp, northern pike, and piscivorous species like white bass and channel catfish, continue to heavily impact native species through competition, predation, and habitat degradation.
- Conservation efforts, including stocking programs, habitat restoration, and management programs like the June Sucker Recovery Implementation Plan, have increased June sucker populations from hundreds to approximately 14,000 individuals.
- Despite population increases, low juvenile June sucker recruitment is a critical bottleneck, primarily because of predation by nonnative piscivores and a lack of quality rearing habitat. Systemic improvements to spawning and rearing habitats, water quality, and lake stabilization will be critical for supporting native species recovery. The bottleneck in June sucker recovery is the successful recruitment of juveniles following spawning in the Provo River.
- Native unionid mussels, historically vital for water filtration and sediment stabilization, are extirpated from Utah Lake, replaced by invasive *Corbicula*, which may offer ecosystem benefits initially but present major threats to the ecosystem.
- Restoration and monitoring efforts and, specifically, additional tributary restoration projects (for example, American Fork River, Currant Creek, and Spanish Fork River) must be prioritized for long-term species recovery.

Information needs

- Detailed knowledge of June sucker recruitment (*Where are juvenile June suckers ending up?*)
 - Improved knowledge of June sucker spawning and recruitment limitations to inform adaptive management of Provo River Delta Restoration Project and other areas to increase recruitment
 - Improved knowledge of diets of various fish species in the lake to inform fisheries management to improve carp and June sucker management
-

7.1 Historical Context

Before Anglo settlement of Utah Valley in the 1850s, Utah Lake's fish community was composed of the following 13 native species:

- June sucker (*Chasmistes liorus*)
- Utah sucker (*Catostomus ardens*)
- Utah Lake sculpin (*Cottus echinatus*)
- Bonneville cutthroat trout (*Oncorhynchus clarkii utah*)
- Least chub (*Lotichthys phlegethontis*)
- Bonneville redbelly shiner (*Richardsonius balteatus hydrophlox*)
- Mottled sculpin (*Cottus bairdii*)
- Leatherside chub (*Lepidomeda copei*)
- Utah chub (*Gila atraria*)
- Speckled dace (*Rhinichthys osculus*)
- Longnose dace (*Rhinichthys cataractae*)
- Mountain whitefish (*Prosopium williamsoni*)
- Mountain sucker (*Catostomus platyrhynchus*)

The diverse aquatic community included myriad species of invertebrates, such as the western pearlshell (*Margaritifera falcata*) and the floater mussel (*Anodonta* sp.), in addition to amphibians, such as the Columbia spotted frog (*Rana luteiventris*). Utah Lake population of *Anodonta* sp. was likely the largest population in Utah (DNR 2011).

Following the Anglo settlement of Utah Valley, water diversion for agriculture, runoff pollution, overfishing, and the subsequent introduction of exotic fish species drastically decreased, and even exterminated, native aquatic species (Heckmann et al. 1981). Perhaps the most consequential effect of water diversion from Utah Lake and its tributaries was when lake levels dropped 12 feet in the 1930s, causing local extirpations of most native fish species, mollusks, and plants, and the extinction of the Utah

sculpin (Abbott et al. 2021). Furthermore, regional food security issues and overfishing of Utah Lake resulted in the introduction of nonnative sport fish species, which began in 1872 and continued into the 20th century. Over 20 nonnative fish species have been introduced to Utah Lake and, of these, at least 15 species have become established (Andersen et al. 2007; Abbott et al. 2021). Among the most successful and threatening to native fish species are the following:

- Common carp (*Cyprinus carpio*)
- White bass (*Morone chrysops*)
- Channel catfish (*Ictalurus punctatus*)
- Black bullhead (*Ameiurus melas*)
- Black crappie (*Pomoxis nigromaculatus*)
- Bluegill (*Lepomis macrochirus*)
- Channel catfish (*Ictalurus punctatus*)
- Walleye (*Sander vitreus*)
- Green sunfish (*Lepomis cyanellus*)
- Yellow perch (*Perca flavescens*)
- Most recently, northern pike (*Esox lucius*)

By 1977, most of the fish in Utah Lake were exotic fish species (Hovingh 2004).

7.2 Current Conditions

Today, of the 14 native fish species once common in Utah Lake, the only persisting native fish species are the June sucker and the Utah sucker (SWCA 2002, as referenced in Strohm et al. 2017; Buelow 2006; ULA 2023). Mollusk surveys in Utah Lake have found thousands of *Anodonta* sp. shells; however, *Anodonta* is thought to have been extirpated from the lake since the 1930s (Mock et al. 2004). Currently, no native mussels are present in Utah Lake (Richards 2017). A population of Columbia spotted frog was recently discovered in the Powell Slough area of the Utah Lake shoreline (Lawrence, pers. comm. 2025).

Because of the intense restoration focus the June sucker has received since its federal listing in 1986 (51 *Federal Register* 10851), the June sucker population has significantly rebounded from the 1987 estimates of a few hundred individuals remaining (Abbott et al. 2021) to the preliminary estimates of around 30,000 to 50,000 individuals (Landom and Conner 2020). This population rebound resulted in a federal reclassification of the June sucker from endangered to threatened (86 *Federal Register* 192). Recovery of the June sucker population in Utah Lake is a direct result of the establishment of the JSRIP in 1999; hatchery supplementation of the June sucker; collective focus on habitat restoration, especially spawning and rearing habitat restoration in tributaries; and nonnative fish species control, especially common carp removal efforts (Abbott et al. 2021; ULA 2023). A significant component of the recovery are instream flows provided by the JSRIP for June sucker spawning in Hobble Creek and the Provo River to ensure that spawning adults have sufficient flows for spawning (Mills, pers. comm. 2025). Since JSRIP's inception, carp removal efforts have resulted in a large reduction in Utah Lake (Abbott et al. 2021), but June sucker recruitment remains low. Additionally, carp abundance has been increasing in recent years. Research indicates that one of the main drivers in June sucker decline is the lack of recruitment (Modde and Muirhead 1994). In response, the PRDRP, the Hobble Creek Restoration Project, and the East Hobble Creek Restoration Project have been implemented, targeting the restoration of June sucker spawning and rearing habitats, stream stabilization, and water-flow stabilization to facilitate spawning habitat recovery (BIO-WEST 2019, 2002). These long-term restoration projects are ongoing.

The Bonneville cutthroat trout, specifically mentioned as a recovery goal in S.B. 270, has been extirpated from Utah Lake since 1936 (Randant and Sakaguchi 1981; SWCA 2002, as referenced in Strohm et al. 2017). Utah Lake is generally too warm and turbid to support Bonneville cutthroat trout (Budy et al. 2012). As of 1977, spawning habitat destruction in the Provo River eliminated spawning migrations, and only fragmented populations of hybridized Bonneville cutthroat trout remain in Utah Lake's surrounding

tributaries (Heckmann et al. 1981). The current range of Bonneville cutthroat trout remains fragmented and largely restricted to high elevation tributaries because of competition, habitat loss, disease, and overharvesting (Kershner 1995; Fausch 2008; Budy et al. 2012). A 1985 survey of Utah cutthroat trout populations resulted in the collection of only 26 cutthroat specimens from Utah Lake tributaries: 5 specimens from the northern fork of the American Fork River and 21 specimens from the Left Fork of Hobbie Creek (Martin et al. 1985). This study also highlights the challenges of genetically distinguishing, much less managing, cutthroat trout subspecies because of hybridization with other trout species.

The western pearlshell (*Margaritifera falcata*) and floater mussels (*Anodonta californiensis*), two native mussel species historically present in Utah Lake, have state status classifications of “critically imperiled” and “imperiled,” respectively (DNR 2011). These imperiled statuses are largely because of anthropogenic effects, including habitat loss and/or degradation, water withdrawal, water pollution, and loss of appropriate host fish species for larval floaters (DNR 2011). Until recently, the Jordan River watershed, which includes Utah Lake, had an extensive and diverse assemblage of freshwater mollusk species (Richards 2017). Much is unknown about these populations. Although more intensive mussel surveys are needed to document local population numbers, surveys conducted in 2015 and 2016 only identified *Anodonta* spp. Shells, no live individuals, in Mill Pond near Utah Lake (Richards 2017).

The Columbia spotted frog is a highly aquatic, lentic-breeding amphibian classified as rare in Utah because of its restricted geographic range (DWR 2021). Isolated populations of Columbia spotted frog exist in the West Desert and along the Wasatch Front; however, habitat degradation and loss have led to declines of many of the populations. A population of Columbia spotted frog was recently discovered in the Powell Slough area of the Utah Lake shoreline. Government agencies are working cooperatively to better define the size of this population and search for other areas around the lake where the species might still occur or can be introduced. Columbia spotted frog depend on shallow, open water areas with a permanent water source; the species is known to burrow in the mud and become inactive in the winter months.

7.3 Stressors, Perturbances, and Changes

Among the most cited factors inhibiting the recovery of native aquatic species are droughts, water-flow alterations, nonnative species pressures, and habitat loss and alteration (Billman 2008). The combined effect of these stressors and perturbances has negatively impacted native aquatic life of Utah Lake. As interest in enhancing Utah Lake has grown, further development of conservation and management strategies to respond to these stressors and perturbances is needed to facilitate positive ecological enhancements.

Water-flow alterations from downstream water demands and upstream water storage and droughts at Utah Lake and its tributaries result in large water elevation changes that threaten the persistence of native aquatic species (Andersen et al. 2007). Native aquatic vegetation that affects sediment stabilization and nutrient cycling and provides protection for juvenile June sucker fish (Billman 2008; May 2023) is directly impacted by lake level fluctuations. In a 2023 study, native vegetation restoration efforts demonstrated increased vegetation spatial coverage at localized sites around Utah Lake, but water-level fluctuations were found to be a primary impediment to the large-scale success of these efforts (May 2023). In this study, SAV decreased in richness and emergent vegetation increased during elevated lake level events (May 2023). When macrophyte communities are depleted in a system like Utah Lake, with high winds and wave action, sediment and benthic nutrient resuspension increases, thus increasing turbidity and decreasing water quality (Hilt et al. 2018). The resulting inadequate light levels can inhibit macrophyte recovery and greatly impact rearing habitat and predator refugia for juvenile fish. Both native and nonnative juvenile fish rely on stable aquatic vegetation for predator refugia (Billman 2008). Therefore, the implications of these relationships indicate that water-level stabilization, reduced nutrient loading (Hilt et al. 2018), and nonnative fish control are crucial and connected components of native fish species recovery.

The introduction and establishment of 15 nonnative fish species has directly impacted native aquatic species, mostly through competition and predation. For most nonnative fish species in Utah Lake, introduction followed the decline of native species from overfishing, most notably Bonneville cutthroat trout and native suckers. Out of the 15 nonnative fish species that have established in Utah Lake, removal efforts have heavily targeted common carp because of their rapid reproduction and growth, resource competition, and destructive feeding behaviors (that is, bioturbation). A female carp can reach sexual maturity by age 2, live for up to 30 years, and produce up to 3,000,000 eggs each spawning season (Richards and Miller 2022). During their lifespans, common carps directly and indirectly dismantle macrophyte communities through consumption and mechanical damage (Miller and Crowl 2006). Because of carp removal efforts over the years, data on June sucker recovery have been collected during times of reduced carp biomass. The resulting analyses indicate that significant improvements occur in the body conditions of June suckers when carp biomass is reduced, likely because of the availability of resources (ULA 2023; Kindschi et al. 2008).

More recently, with the introduction of piscivorous northern pike in Utah Lake, the preservation and expansion of predator refugia is more important than ever for June sucker conservation and restoration. In recent research presented from USU, the relative risk of vulnerability by Utah Lake's piscivorous fish was modeled for June suckers across a variety of sizes (Garner et al. 2025). Despite the inclusion of other prey fish species from predator diet data in the model analysis because of limited June sucker abundance, this modeling highlights the predation pressures exerted by mesopredators. White bass, black bullhead, and channel catfish species notably posed the greatest predation risks to June sucker juveniles in this model (Garner et al. 2025). Although this adjustment weakens the specificity of the implications for juvenile June suckers, the findings emphasize the potential negative pressures that nonnative piscivorous species might exert on juvenile June sucker recruits. Furthermore, these findings highlight primary data gaps in the understanding of juvenile June sucker predation in Utah Lake. The number of adult pike collected from Utah Lake each year has rapidly increased and, although monitoring efforts have focused on telemetry initiatives and removal strategies, more intense population control plans are needed to mitigate the risk pike pose to June suckers and managed sportfish species (ULA 2023). DWR is conducting ongoing stomach content examinations on northern pike from the Provo River delta and Hobble Creek to assess their diets. Brown trout and white bass may also exert predation pressure on juvenile suckers, and dietary analysis is also under consideration for these species. Preliminary analyses show much of their diets consist of small fish (ULFMAC forthcoming). Further in-depth assessments are needed to determine the impact these piscivorous fish species have on juvenile June suckers that use these tributaries for shelter and growth before reaching the open waters of Utah Lake.

Habitat loss and alteration impacting native aquatic species in Utah Lake are, in part, influenced by water-flow alterations and lake level changes, land development, and nonnative species pressures. Efforts to stabilize spawning and rearing habitats, as well as water flows, in the Provo River delta and Hobble Creek have great potential to aid June sucker recovery. However, because these projects have only recently been completed, it is too early to meaningfully assess June sucker recovery from the data. As these projects, in part, aim to enhance native vegetation for improved June sucker rearing habitat, the efficacy of various vegetation structures should be considered. The recent changes to these important tributaries could provide critical insight for this project to build on.

With lake level changes being a factor inhibiting the establishment of native aquatic vegetation in Utah Lake (May 2023), close monitoring should be conducted to identify trends of lake hydrography from year to year, as well as trends within the year. Lake level changes, which are large-scale ecological stressors, are demanding challenges that may only increase in intensity as weather patterns are altered because of climate change. Because Utah Lake is a managed water reservoir, water needs and usages will play a large role in the feasibility of solving this issue, especially during drought and intense rainfall events. Although warming climate shifts can provide benefits through richer fish abundances, the adverse effects might outweigh any potential benefits, especially for threatened species, such as the June sucker. Extended

summer periods can adversely affect species spawning periods and create perilous temperature conditions for juvenile fish (Woolway et al. 2017).

7.4 Ecological Dynamics

The increasing population of June suckers in Utah Lake is a promising outcome of various conservation and management initiatives. However, key ecological dynamics must be further studied to achieve systemic enhancements. Beyond restoring June suckers, this section highlights critical ecologic dynamic considerations for other native aquatic species, such as native unionid mussels and the Columbia spotted frog. Important ecological dynamics for the restoration of Bonneville cutthroat trout are discussed in Section 11.

The persistent lack of new June sucker recruits points to low juvenile survivorship. Nonnative predation and competition remain significant threats, jeopardizing both past and ongoing enhancement efforts. These pressures are widely recognized as primary contributors to the low recruitment rates observed annually. Ongoing management projects in Utah Lake aim to address these issues by enhancing June sucker spawning habitats in historically used tributaries. Essential actions include stabilizing tributary flow rates, stabilizing lake levels, restoring streams and channels, and creating predator refugia and nursery habitats. For example, average annual lake levels in Utah Lake have dropped 1.5 feet based on hydrography data from 2003 to 2019 compared to data from 1994 to 1999 (BIO-WEST 2019). Furthermore, the large hydrograph swings within a given year challenge the establishment of native submergent and emergent macrophyte communities (May 2023), which are essential predator refugia for juvenile fish. Such predator refugia are critical for increasing juvenile June sucker survivorship given the prevalence of nonnative piscivorous fish in Utah Lake. Young June suckers, particularly age 0 recruits, heavily rely on the shadows and structure provided by SAV for refuge. As they grow, shoaling becomes a vital survival strategy (Billman 2008). Without adequate macrophyte coverage, especially in spawning habitats, many juveniles are likely consumed before reaching maturity. Until juvenile fish species outgrow their vulnerability to predation (that is, grow larger than the mouths of gape-limited predatorial fish), macrophyte coverage for predator refugia remains critical.

Freshwater mussels are among the most imperiled organisms worldwide (Goldsmith et al. 2021). Considering their unique role in Utah Lake's ecosystem, they cannot be overlooked when formulating management and enhancement plans. Re-establishment of mollusk populations could help to stabilize the benthic sediments of the lake and improve water clarity via water filtration. However, given the poor state of mussels in Utah Lake coupled with the lake's complex sedimentation and water quality issues, restoring native mussels is not likely feasible in the near term. Careful consideration is needed to address the roles of both native and invasive mollusks in Utah Lake's system.

The poor water quality of Utah Lake, specifically its high turbidity and suspended solids, has hindered the re-establishment and propagation of native mussels (in addition to the loss of native fish hosts for mussel glochidia) (Hovingh 2004). Before European settlement of the area, native filter feeders were likely able to improve the water clarity of Utah Lake (Abbott et al. 2021). Native mussels, including *Anodonta* sp. and western pearlshell (*Margaritifera falcata*), both belonging to the Unionidae family (hereafter unionids), are particularly sensitive to high concentrations of suspended solids, which disrupt reproduction and life cycles (Gascho Landis et al. 2013). In highly turbid environments, like Utah Lake, total suspended solids significantly reduce the clearance rates of filter feeders, impeding nutrient uptake and fertilization processes (Gascho Landis et al. 2013). Unionid mussels provide critical ecological benefits to Utah Lake, including water quality enhancement, sediment stabilization, nutrient cycling, and food web contributions (Vaughn et al. 2008). Unionids can filter up to 8 gallons of water in 4 hours, significantly improving water quality (Richards 2017). By removing suspended solids, they allow greater sunlight penetration, which enhances photosynthetic production on the bottom. Further sediment stabilizing benefits provided by filter feeders are the production of pseudo-feces. Pseudo-feces are mucosal membrane "sacs" containing

filtered sediment waste secretions that sink to the lakebed and accumulate. This in turn consolidates fine sediment and creates a layer more resistant to wind-driven resuspension. Considering these combined benefits of filter feeders, especially of the tremendous population size historically seen in Utah Lake, it is plausible that a population decline has cascading effects on ecosystem structure and function (Heath et al. 2014, as referenced in Goldsmith et al. 2021).

Recent monitoring efforts have documented populations of *Corbicula* in several areas in Utah Lake (Rotter, pers. comm. 2025), although these populations are currently likely limited by the lake's high suspended sediment load. Although an increase in *Corbicula* (concurrent with reductions in suspended sediment loads and improvements in water quality) has the potential to benefit Utah Lake with water filtration and sediment stabilization, *Corbicula* is an invasive species and poses multiple threats to the Utah Lake ecosystem such as outcompeting native unionids. Close monitoring of *Corbicula* populations will be needed as the water quality conditions improve. Additionally, monitoring for invasive species like quagga and zebra mussels must continue in perpetuity to prevent their introduction to Utah Lake.

Native aquatic vegetation serves as preferred habitat for young northern pike (BIO-WEST 2020). Enhancing aquatic vegetation may inadvertently promote northern pike proliferation, increasing predation pressure on June suckers. The continuation of close monitoring of northern pike populations and implementation of a rigorous removal program in Utah Lake with biologically meaningful targets may help mitigate this undesirable outcome further.

8. Increasing Suitability of Utah Lake and Its Surrounding Area for Shorebirds, Waterfowl, and Other Avian Biology

Key findings

- Utah Lake historically supported a rich and diverse bird community, but recent declines in diversity and abundance are evident.
- Fluctuating water levels, invasive species, pollution, and the effects climate change have fragmented and degraded habitat.
- Monitoring and scientific information of bird populations and habitat use in the lake is limited.
- A multifaceted approach, including increasing monitoring efforts, addressing stressors, improving habitat suitability, and incorporating monitoring and research, is needed to support and restore bird populations at the lake.
- More natural patterns in lake water levels, restoration of native vegetation, and improvements in water quality will benefit shorebirds, waterfowl, and other avian species at the lake.

Information needs

- Expanded monitoring to understand avian use of Utah Lake, including habitat use patterns, nesting sites, foraging areas, migratory stopovers, and food web dynamics (*What do different birds eat in Utah Lake? How are changes in fish and invertebrate populations affecting birds?*)
-

8.1 Historical Context

Historically, Utah Lake provided vital habitat for a diverse array of shorebirds, waterfowl, and other avian species. The lake's extensive wetlands provided abundant resources and nesting sites, supporting large populations of avian species. Pritchett et al. (1981) documents a diverse range of bird species that relied on the lake's wetlands and surrounding habitats for breeding, feeding, and migration. This included numerous species of waterfowl, shorebirds, and other birds that thrived in the region's rich and varied habitats. Goodwin (1904) provides an early account of pelicans nesting at Utah Lake, highlighting the importance of the lake as a breeding ground for these large waterbirds. Over time, however, human activities, such as agriculture, urban development, over-hunting, and water diversion have significantly altered the landscape (Pritchett et al. 1981), leading to habitat degradation and loss (Abbott et al. 2021; Abbott et al. 2022). These changes have resulted in the fragmentation and reduction of suitable habitats for many bird species, possibly contributing to population declines. However, although it is likely true that Utah Lake once supported a larger diversity and number of birds, no historical or background data are available to help understand how those populations or the species representation have changed at Utah Lake and its wetlands over time. This information can be inferred only from the limited literature available.

Egg collectors provide another source of information about what birds nested at Utah Lake. Many of their collections from the 1800s and early 1900s are now in museums. The John Hutchings Museum (Lehi, Utah) houses a collection of nests and eggs taken from Utah Lake in the early 1900s. Unfortunately, this collection is not available electronically and cannot be found in museum databases, such as Arctos or VertNet, or in an electronic spreadsheet. However, about 370 nest cards can be viewed at the museum, and the data could be entered into a spreadsheet. Each card contains detailed information, including the species, nest location, number of eggs, and collection date.

Although this information would undoubtedly be valuable for the ULS, accessing and recording it would take significant time and effort. Digitizing these records could greatly enhance their accessibility and utility for this ULS and for other researchers. The possibility of a collaborative project with the museum to digitize this collection, which could benefit both the museum and the broader scientific community, might be worth discussing, as little historical data are available to help understand population declines.

8.2 Current Conditions

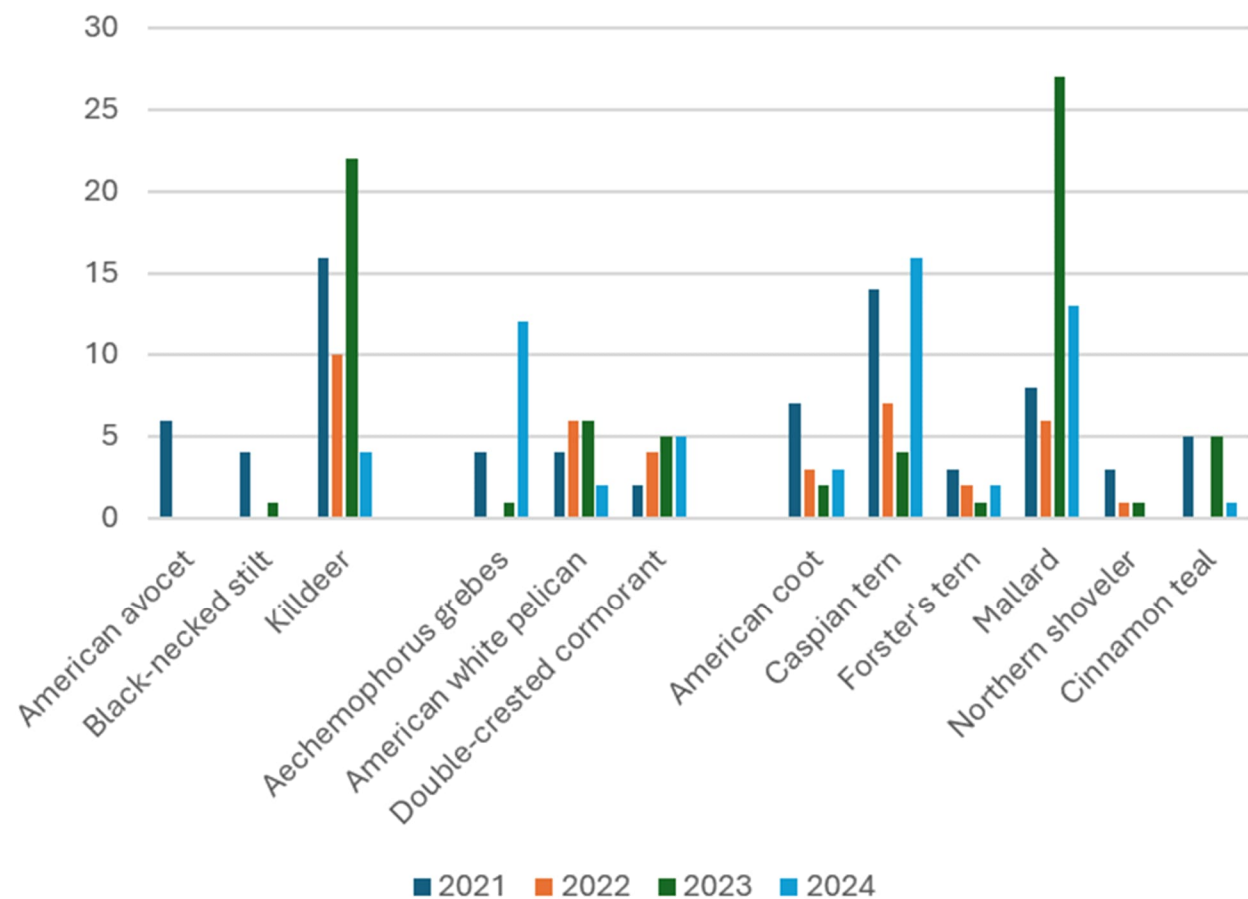
Although no formal habitat assessment has been conducted as part of the Intermountain West Shorebird Survey, raw count data from Utah Lake collected during the Fall Migration 2024 effort (Clark, Gardner,

Malmquist, and Neill 2024; Clark, Hamel, Malmquist, and Neill 2024) may warrant future analysis to evaluate potential changes in avian use patterns. Previous studies (for example, Abbott et al. 2021; Abbott et al. 2022) have noted broader regional habitat pressures that could be relevant to Utah Lake. The remaining wetlands are often subject to fluctuating water levels, invasive plant species, and pollution. These conditions have likely reduced the availability of suitable nesting and foraging areas for shorebirds and waterfowl, leading to possible declines in their populations. These conditions may have reduced the availability of suitable nesting and foraging areas for shorebirds and waterfowl, leading to declines in their populations.

Preliminary raw count data from Utah Lake collected during the Fall Migration 2024 Intermountain West Shorebird Survey (Clark, Gardner, Malmquist, and Neill 2024; Clark, Hamel, Malmquist, and Neill 2024) have not yet been analyzed. Therefore, no conclusions can be drawn at this time regarding changes in shorebird diversity or abundance. However, ongoing concerns about habitat loss, water quality, and invasive species in the region may warrant future investigation.

Although the recent Intermountain West Shorebird Surveys (Clark, Gardner, Malmquist, and Neill 2024; Clark, Hamel, Malmquist, and Neill 2024) provide valuable information about birds using Utah Lake, the methodology, which involved one date in August for autumn bird use and one date in April for spring bird use, was not designed to provide a comprehensive view of bird populations at Utah Lake. This approach offers only a snapshot and does not fully capture fall migrants or nesting birds. Autumn counts likely include a mix of migrating birds and young of the year from Utah Lake and nearby nesting areas, whereas spring counts may occur before many breeding birds arrive. Some species continue to use the lake as a stopover during migration, but overall shorebird numbers and variety may have decreased compared to historical records (for example, Pritchett et al. 1981; Clark, Gardner, Malmquist, and Neill 2024). The comparison of recent observations to historical data suggests declines; but, the lack of detailed historical data makes it difficult to quantify these declines precisely. Pritchett et al. (1981) documented a rich and diverse bird community at Utah Lake, providing a baseline for understanding the historical avian population. However, the recent studies by Clark, Gardner, Malmquist, and Neill (2024) and Clark, Hamel, Malmquist, and Neill (2024) indicate a decline in both diversity and abundance, highlighting ongoing ecological challenges. Although these recent observations are concerning, the studies by Clark et al. rely on contemporary surveys and observations, which, although indicative of negative trends, underscore the need for more comprehensive, long-term data to make statistically significant comparisons. Establishing a robust, lake-wide monitoring program would be essential to bridge this data gap and provide a clearer picture of how bird populations have changed over time.

Similarly, there are limitations to Tracy Aviary's Breeding Season Survey Protocol, which primarily focuses on songbirds. The data on 12 common shorebird and waterbird species, although informative, may not accurately represent the broader waterbird populations at Utah Lake, especially given its coverage of only a small section of the north shore. Additionally, the 3 years of data collected are insufficient for robust statistical analysis to infer population declines. Despite these constraints, this limited dataset is one of the few available sources of information on avian populations at Utah Lake. It underscores the need for a more comprehensive, lake-wide monitoring program that can provide a more accurate and statistically significant understanding of bird population trends over time. Preliminary data from the Tracy Aviary nesting bird surveys on the north shore at Utah Lake from 2021 to 2024 (Trumbo, pers. comm. 2025) reveal several trends among some common waterbird species. Some species, such as American avocet and black-necked stilt, show a sharp decline to zero after the first year. Killdeer experienced an increase in 2023 but dropped again in 2024. *Aechmophorus* grebes (western and Clark's grebes) also had a notable increase in 2024. American white pelicans and double-crested cormorants maintained relatively stable numbers with minor fluctuations. American coots and Forster's terns had a general decline over the years. Caspian terns had an increase in 2024, whereas mallards had a peak in 2023 before a decline in 2024. Northern shovelers declined to zero by 2024, and cinnamon teal had fluctuations without a clear trend (Figure 8-1).

Figure 8-1. Number of Birds Observed during Breeding Season (April through July) Surveys

Source: Trumbo, pers. comm. 2025; Tracy Aviary.

During the 2021 to 2024 period, Utah Lake experienced consistently low water levels, as illustrated on Figure 3-4. These low levels, coupled with fluctuations in water levels, have had a profound effect on the lake's ecosystem. The lake also faces frequent algal blooms, elevated Chl *a* concentrations, and excessive phytoplankton growth, all contributing to its poor water quality (Section 4.2). These environmental challenges likely influenced the nesting bird survey results conducted by the Tracy Aviary, because fluctuating water levels and degraded water quality can affect bird habitats and food availability. Understanding these conditions is important for interpreting the survey results.

The changes in bird populations based on the results of these preliminary surveys at Utah Lake's north shore can possibly be explained, in part, by considering the different bird guilds and their habitat preferences. Bird guilds, such as piscivores (fish eaters), omnivores, insectivores, and herbivores, interact with their environment in distinct ways, influenced by factors like water level, water clarity (turbidity), prey abundance, and vegetation.

Piscivores, including species like double-crested cormorant and *Aechmophorus* grebes, are adept at diving to catch their fish prey, whereas American white pelicans typically hunt on the water's surface. Other piscivores include Caspian and Forster's terns, which are aerial predators diving on fish from the air. All these birds rely heavily on the availability of fish, making them particularly sensitive to changes in their aquatic environment. Fluctuations in water levels can affect fish populations and their accessibility, thereby influencing the food sources for these piscivores. Additionally, high turbidity in the water can reduce the hunting efficiency of these birds, as murky conditions make it more challenging to spot and

capture prey. In contrast, clear-water conditions can greatly enhance their foraging success, allowing them to see and catch fish more easily. Therefore, maintaining a stable and clear aquatic environment is crucial for these piscivorous bird species.

Omnivores, such as the American coot, American avocet, northern shoveler, and cinnamon teal, have a diverse diet that includes plants, insects, and small aquatic animals. This varied diet allows them to adapt more readily to changes in food availability than more specialized feeders. Their ability to consume a wide range of food sources provides them with a significant advantage in fluctuating environments. However, despite their adaptability, changes in vegetation from fluctuating water levels can still affect their nesting and foraging habitats. These changes can alter the availability of both plant and animal food sources, potentially leading to challenges in finding adequate nutrition. Additionally, alterations in vegetation can affect the structure and safety of their nesting sites, further influencing their reproductive success and overall population stability. Therefore, although omnivores are generally more resilient to environmental changes, they are not entirely immune to the effects of habitat alterations.

Insectivores, such as the black-necked stilt and killdeer, rely heavily on insects and other invertebrates for their diets. The availability of these food sources is closely tied to water levels and vegetation structure, which are crucial for providing suitable foraging grounds. Wetlands with diverse and abundant vegetation tend to support larger insect populations, thereby benefiting insectivores by offering a rich and reliable food supply. Although high turbidity in the water might not directly affect insectivores, it can influence the overall health of the wetland ecosystem. Murky water conditions can affect the growth and diversity of aquatic plants, which, in turn, can reduce the habitat quality for insects. Consequently, this can lead to a decrease in insect availability, indirectly affecting the foraging success of insectivores. Therefore, maintaining clear water and diverse vegetation in wetlands is essential for supporting healthy insect populations and, by extension, the insectivores that depend on them.

Herbivores, such as the mallard, primarily feed on aquatic plants, making them greatly dependent on the availability and health of these plants. Changes in water levels can impact their food supply by either exposing or submerging vegetation. When water levels drop, plants that were previously submerged may become accessible, providing an abundant food source. Conversely, rising water levels can submerge these plants, making them inaccessible to herbivores like the mallard. Clear-water conditions are important for promoting healthy plant growth, as they allow sunlight to penetrate the water and facilitate photosynthesis by aquatic vegetation. However, high turbidity can hinder photosynthesis by blocking sunlight, thereby reducing plant availability. Turbid water conditions can result from various factors, such as sediment runoff, algal blooms, or pollution, all of which can negatively affect the aquatic ecosystem. Consequently, maintaining clear water and stable water levels is vital to a consistent and healthy food supply for herbivorous birds like the mallard.

Overall, the interplay between water levels, water clarity, and vegetation structure influences the habitat quality and food availability for different bird guilds. Understanding these dynamics may help explain the observed population changes and highlight the importance of maintaining balanced and healthy wetland ecosystems for supporting diverse bird communities.

Given the significant degradation of Utah Lake (Abbott et al. 2021; Abbott et al. 2022), the number of individuals and species has likely been adversely affected. Environmental stressors, including pollution, habitat loss, and water quality issues, have degraded the ecosystem. Despite the presence of several water-associated species in recent eBird checklist surveys (eBird 2025), the overall health and diversity of bird populations at Utah Lake have likely declined. Species, such as killdeer, Canada goose, and snowy egret, may still be nesting, but their numbers and the variety of other species have probably decreased compared to historical data (Pritchett et al. 1981). However, many species are likely present, but in reduced numbers; these include double-crested cormorants, American white pelicans; Clark's, eared, and pied-billed grebes; various waterfowl species; black-necked stilts; American avocets; and Forster's terns.

8.3 Stressors, Perturbances, and Changes

Historically, Utah Lake supported a rich and diverse bird community (Pritchett et al. 1981). While recent raw count data from the Intermountain West Shorebird Survey (Clark, Gardner, Malmquist, and Neill 2024; Clark, Hamel, Malmquist, and Neill 2024) include observations from Utah Lake, these data have not yet been analyzed to assess trends in diversity or abundance. Nonetheless, regional concerns, such as habitat degradation, water quality issues, and invasive species, may be influencing avian communities and warrant further investigation. Several stressors possibly affect the avian habitat at Utah Lake, including water management practices that do not align with the ecological needs of bird species, the spread of invasive species such as *Phragmites*, and pollution from agricultural runoff and urban sources. Climate change also poses a long-term threat by altering precipitation patterns and water availability.

The introduction of common carp has had a dramatic effect on waterbird populations in various regions, including Utah Lake. Maceda-Veiga et al. (2017) found that carp invasions in shallow Mediterranean lakes led to the destruction of macrophyte beds and significant changes in waterbird communities. Carp presence reduced the numbers and species richness of diving ducks while increasing the abundance of piscivores, such as herons. This pattern is likely to be similar at Utah Lake, where carp disturb sediment and uproot aquatic plants, increasing water turbidity and degrading water quality, which negatively affects the availability of prey and suitable nesting sites for waterbirds (Vilizzi et al. 2015). The increase in piscivorous birds, including cormorants, grebes, and pelicans, could be due to the increased carp prey base or other indirect effects of carp, which may have caused increased predation on other native fish species. These findings underscore the need for effective carp management to support the conservation of waterbirds at Utah Lake.

Mitchell (1977) studied the breeding biology of the double-crested cormorant on Utah Lake and noted that habitat alterations, such as diking, could severely affect cormorant populations by eliminating existing or potential nesting areas. These effects, along with the carp perturbations identified by Maceda-Veiga et al. (2017) and Vilizzi et al. (2015) discussed previously, and possibly other indirect effects of carp, may lead to increased competition among species because of the increased carp prey base. This highlights the importance of considering the specific habitat requirements of different bird species when planning restoration efforts.

Additionally, the presence of invasive species, such as *Phragmites*, further complicates habitat restoration. *Phragmites* outcompete native vegetation, reducing habitat diversity and availability for nesting and foraging (Robichaud and Rooney 2017; Dinehart et al. 2023). Due to their horizontal, as opposed to vertical, leaf orientation, monotypic stands of *Phragmites* have less light availability under the canopy than stands of cattails (*Typha* spp.). This reduced light availability influences the recruitment and growth of *Phragmites* individuals within the stands but also impedes the establishment of other plant species (Hirtreiter and Potts 2012; Kotowski and van Diggelen 2004). High-density stands of *Phragmites* also result in increased aboveground biomass and high litter accumulation, which cause smoothed microtopography, raised soil, and reduced standing water levels, thereby decreasing the extent of open water, which is essential for waterbirds and shorebirds (Robichaud and Rooney 2017). The combined effects of invasive species, pollution, and habitat alteration create challenging conditions for avifauna, potentially leading to decreased reproductive success and population declines.

In 2009, the total PCBs in 25 fish (rainbow and brown trout) collected from the Provo River upstream of Utah Lake had a geometric mean concentration of 212 µg/kg (parts per billion [ppb]), with a range from 95 ppb to 465 ppb. This concentration exceeds thresholds identified as causing adverse effects on fish (Berninger and Tillitt 2019), with the lowest observed, adverse effect residue concentration for PCBs in fish set at 100 µg/kg (0.1 microgram per gram [µg/g]), affecting mortality, growth, and reproduction. The concentrations found in Utah Lake fish exceed this threshold. High summation PCB concentrations can lead to various adverse effects, including reproductive, immunological, and neurological impairments in wildlife. For the lake's ecosystem, such contamination can disrupt the food web, reduce biodiversity, and

impair the health of aquatic organisms. Whole-body residues of 0.4 µg/g fresh weight are associated with reproductive toxicity in rainbow trout, and eggs containing 0.33 µg/g fresh weight are associated with reduced hatch rates and an increase in larval deformities. Birds seem relatively resistant to PCBs, although greater dietary exposures of 5 µg/g in chickens and 10 µg/g in mourning doves resulted in reproductive impairment. Fertilized eggs of ringed turtle doves containing 16.0 µg/g summation PCBs fresh weight showed delays in growth (Eisler 1986); thus, development and residues of this magnitude should be considered as presumptive evidence of significant PCB contamination. These findings underscore the urgent need for remediation efforts to address PCB pollution and protect the ecological and human health of the Utah Lake area.

Addressing these stressors requires a multifaceted approach, including the removal or reduction of invasive species, pollution control, and habitat restoration. By restoring SAV and native plants in the littoral zone, the habitat quality for waterbirds will be enhanced, providing better foraging, nesting, and shelter opportunities. Reintroducing native fish species should help to rebalance the food web and provide a more stable and diverse ecosystem that supports the dietary needs of piscivorous birds like pelicans, cormorants, and grebes (Choi et al. 2025). Additionally, reducing invasive species, such as *Phragmites* and carp, should mitigate their negative effects on water quality and habitat structure, further benefiting waterbirds.

Overall, a more balanced and native-dominated ecosystem at Utah Lake should lead to increased biodiversity, improved water quality, and greater opportunities for both wildlife and human enjoyment. Addressing these stressors through targeted research and monitoring programs is expected to provide the insights needed to develop and implement effective enhancement strategies for avifauna at Utah Lake.

8.4 Ecological Dynamics

The ecological dynamics of Utah Lake's avian habitat are complex and influenced by both natural and anthropogenic factors. Effective habitat restoration requires an understanding of these dynamics, including the interactions between water levels, vegetation, and bird populations. The study by Galbraith et al. (2014) is highly relevant to Utah Lake, as it underscores the potential impacts of climate change on shorebird populations. Climate change can alter precipitation patterns, leading to changes in water levels and the availability of suitable habitats. For Utah Lake, this means that fluctuating water levels and altered hydrological patterns could further continue to stress shorebird populations, making it essential to incorporate climate resilience into restoration efforts.

Although such stresses can be inferred only from the historical literature, over time, the avifauna at Utah Lake has likely experienced significant changes because of various factors, such as habitat alteration, water quality changes, and human activities. In the early 1980s, the Utah Lake region supported a diverse range of bird species, with numerous species of waterfowl, shorebirds, and other birds relying on the lake's wetlands and surrounding habitats for breeding, feeding, and migration (Pritchett et al. 1981). However, urban development, agriculture, and industrial activities likely have led to the loss and degradation of wetlands and other critical habitats around Utah Lake (Abbott et al. 2021; Abbott et al. 2022), resulting in reduced populations of many bird species that depend on these habitats. Additionally, pollution and changes in water quality have affected the availability of food resources and suitable nesting sites for birds. For example, eutrophication and algal blooms reduce the abundance of aquatic invertebrates (Münze et al. 2017; Quanz et al. 2021), which are essential food sources for many bird species. The introduction of invasive plant and animal species has also altered the ecosystem dynamics of Utah Lake, affecting native bird populations by changing the structure of habitats and likely making them less suitable for native birds (Abbott et al. 2021; Abbott et al. 2022).

Despite these challenges, Utah Lake still supports a variety of bird species (; Clark, Hamel, Malmquist, and Neill 2024). Conservation efforts, such as habitat restoration and pollution control, have been

implemented to help protect and restore bird populations. Birdwatchers can still observe a range of species, including migratory waterfowl, shorebirds, and raptors. Overall, although the avifauna at Utah Lake appears to have faced significant challenges over time, ongoing conservation efforts aim to mitigate these effects and support the recovery of bird populations.

Studies like those by Schaffer-Smith et al. (2018) and Zalai et al. (2024) highlight the importance of maintaining optimal water depths and restoring native vegetation to support diverse avian communities. Water management practices significantly influence the availability of shorebird habitats, with shallow water depths being essential for these birds. Additionally, fluctuations in water levels can affect the distribution of native vegetation, which provides crucial foraging and nesting sites (Schaffer-Smith et al. 2018). Similarly, stable water levels promote diverse and robust plant communities, which are vital for providing habitat for various bird species. Zalai et al. (2024) also emphasized the importance of considering time-lag effects, where changes in water levels have delayed effects on vegetation dynamics, affecting bird habitats over extended periods. The complex interplay between water levels, native vegetation, and bird habitats underscores the need for effective water management and conservation strategies to maintain healthy bird populations.

Phragmites monoculture has a negative effect on bird habitat because of its effect on habitat heterogeneity and bird community composition. The invasion of *Phragmites* in Lake Erie coastal marshes led to the biological homogenization of wetland bird communities. The dense stands of *Phragmites* reduced habitat complexity, which is essential for supporting diverse bird species (Robichaud and Rooney 2017). This homogenization resulted in a decrease in species richness and beta diversity, as the bird community in *Phragmites*-invaded areas became a nested subset of the species present in uninvaded marshes. Similarly, the expansion of *Phragmites* in Saginaw Bay, Michigan, significantly reduced the carrying capacity and connectivity of wetland landscapes for marsh-dependent birds (Dinehart et al. 2023). The dense monoculture of *Phragmites* limited the availability of suitable nesting and foraging sites, leading to a decline in marsh bird populations. These results highlight the negative ecological dynamics associated with *Phragmites* monoculture and emphasize the need for effective management to restore native vegetation and maintain diverse bird habitats.

Wetlands provide a variety of ecosystem services, including enhanced water quality; water storage; flood attenuation; pollutants filtration; wildlife habitat; and aesthetic, commercial, recreational, and educational uses (Sutula et al. 2007; de Groot et al. 2018). As in other waterbodies, the various habitats in and around Utah Lake would be expected to provide several beneficial uses for avifauna, supporting their diverse needs throughout different life stages. Open water areas are crucial for piscivorous birds like grebes and cormorants because they offer fish populations for feeding, and safe resting and roosting sites, especially during migration periods. Wetlands with dense vegetation provide nesting sites for many waterbird species, offering protection from predators and harsh weather while also being rich in invertebrates and small aquatic organisms needed for feeding and breeding. The shallow waters of the littoral zone are foraging areas for shorebirds and dabbling ducks, with vegetation providing cover and nesting materials. Riparian zones along the lake's edge support a variety of plant species, creating diverse habitats for different bird species and serving as important stopover points for migratory birds. Mudflats, with their rich invertebrate populations, offer excellent foraging grounds for shorebirds and resting sites during low-tide periods. Marshes with emergent vegetation like cattails and reeds provide secure nesting and breeding sites for species, such as marsh wrens and bitterns, along with a food supply of insects and small aquatic animals. Overall, these diverse habitats support a wide range of bird species, contributing to biodiversity and indicating a well-functioning ecosystem. Maintaining and restoring these habitats is crucial for the continued health and diversity of bird populations in the area.

9. Maximizing, Enhancing, and Ensuring Recreational Access and Opportunities on Utah Lake

Key findings

- Detailed visitation data and recreation dynamics are currently limited, but efforts are underway to collect this information as part of the Utah Lake Recreation Access Plan (ULA forthcoming).
- Managing Utah Lake's recreational resources is complex, involving multiple stakeholders and a bottom-up approach, which allows for local expertise and community engagement, but also has coordination and consistency challenges.
- Utah Lake recreation access points are managed by multiple stakeholders using a bottom-up (as opposed to top-down) approach, meaning various stakeholders and partners work together to make improvements at each access point. This approach has both advantages (alignment with local priorities and adaptability to site-specific challenges) and disadvantages (resource disparity and inconsistent standards). Lakeshore municipalities have diverse visions for recreational improvements, generally aligning with current land use patterns.
- Key challenges include jurisdictional confusion, lack of clarity on approval processes, unequal resource distribution, and lack of dedicated funding source for recreational improvements.
- The Utah Lake Management Plan (ULMP; ULA 2024) outlines goals, objectives, and strategies that support Utah Lake Authority's (ULA's) vision of world-class recreation at Utah Lake. Since the ULMP's inception, ULA has demonstrated considerable progress, particularly in executing short-term strategies. The ULA has been diligent in adhering to the implementation schedule set forth in the ULMP, indicating a strong commitment to realizing their vision for enhanced recreation at the lake.
- Successful implementation will depend on a delicate balance between respecting local autonomy, coordinating across jurisdictions, and aligning visions into cohesive strategy for the lake's recreational future. ULA is dedicated to finding this balance by leading cooperative efforts to implement the ULMP's short-, mid-, and long-term strategies (ULA 2024).
- A central goal of enhancing the lake ecosystem is to facilitate an increase in recreation and other human uses of the lake. A stronger and healthier Utah Lake ecosystem will result in improved public perception of the lake, interest in recreation, and interest in other uses of the lake by residents and visitors. Without enhancing water clarity and quality, in addition to other aspects of the lake ecology, greatly enhancing recreation or improving the use of the lake for residents and visitors will be difficult.

Information needs

- Streamlined, clear approval processes and improved resource allocation are needed to effectively enhance recreational opportunities
 - Utah Lake economic analysis of recreational potential, which could hold significant value for understanding and quantifying benefits of enhanced opportunities for the state, visitors, and residents
 - Information needs for determining methods to enhance recreational access and opportunities at Utah Lake, which are consistent with those in the ULMP (ULA 2024)
-

9.1 Current Conditions

Utah Lake offers a diverse array of recreational opportunities, catering to various interests throughout the seasons. Water-based activities are prominent, including motorboating, sailing, kayaking, and stand-up paddleboarding. Fishing enthusiasts can enjoy shore fishing, boat fishing, and even ice fishing during winter months. The lake also supports water sports, such as water skiing, wakeboarding, and jet skiing. Beach activities like swimming and sunbathing are popular in designated areas. Nature lovers can engage in wildlife viewing, birdwatching, and photography; and hikers can explore shoreline trails. The lake area provides facilities for picnicking and camping, and hunters can participate in seasonal waterfowl hunting. Winter brings opportunities for ice skating, snowshoeing, and cross-country skiing along the shorelines. Educational activities, including nature programs and school field trips, are available. The lake hosts special events such as fishing tournaments, sailing regattas, and community festivals. Additionally, scenic driving routes around the lake offer sightseeing opportunities for visitors. This wide range of activities makes Utah Lake a versatile recreational destination throughout the year.

Recreational visits to Utah Lake are likely diminished due to degraded water quality conditions, a dominance of invasive species, and a concern for health risks due to HABs. Improved water quality conditions and a reduction in invasive species abundance would likely result in increased recreational visitation to the lake.

A central goal of enhancing the lake ecosystem is to facilitate an increase in recreation and other human uses of the lake. A stronger and healthier Utah Lake ecosystem will result in improved public perception of the lake, interest in recreation, and interest in other uses of the lake by residents and visitors. Without

enhancing water clarity and quality, in addition to other aspects of the lake ecology, greatly improving recreation or the use of the lake for residents and visitors will be difficult.

Information about the public access points and recreational opportunities at Utah Lake can be found on the ULA's website in an embedded Google Map (ULA n.d.b). Although the map currently shows 29 access points to Utah Lake, the ULA now believes there are 35 public access points (ULA forthcoming). Additional access points were discovered during development of the *Recreation Access Plan*. At each of the 29 public access points on the map, the user can click on a pin to view photographs of the site, directions to the site, and a description of the access point, including the existing amenities, popular recreation activities, and site manager contact information (Figure 9-1).

The ULA's public access map (ULA n.d.b) provides a high-level summary of existing recreation points to Utah Lake; however, data and information describing nuanced visitation dynamics at Utah Lake were not readily available at the time this report was written. The ULA is actively working on building qualitative and quantitative baseline recreation data at Utah Lake, such as the following:

- Visitation numbers at each access point on an annual basis, by season, and by user type
- Geographic distribution of visitation
- Status of existing infrastructure and facilities, and associated maintenance needs
- Stakeholder surveys and interviews on desired improvements
- Geographic information system (GIS) mapping of recreational zones and potential new access points

The ULA's efforts to establish baseline recreation data are summarized in Section 9.2.1.

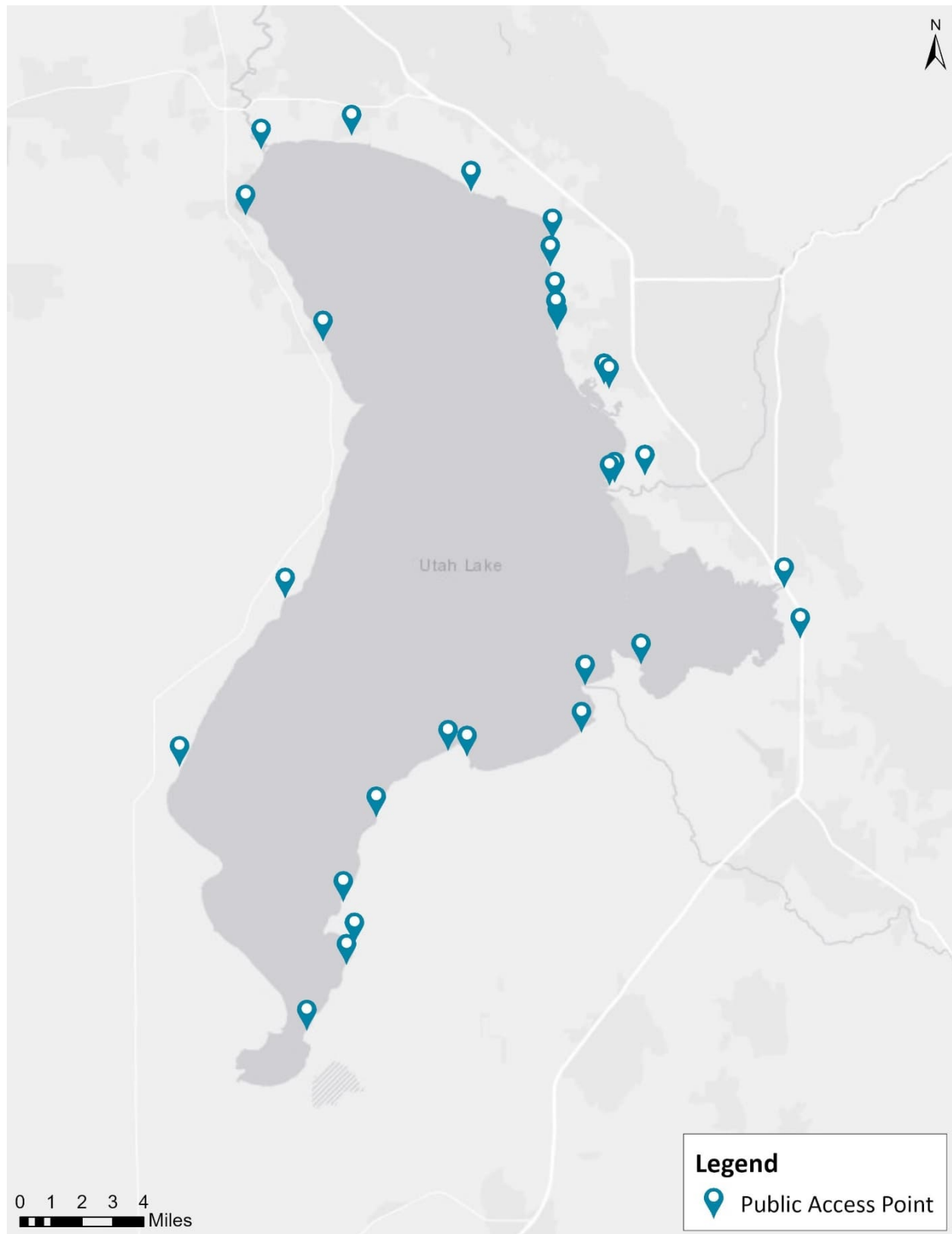
9.2 Ongoing Efforts to Enhance Recreational Opportunities

Many partners are working together to enhance recreational opportunities, including the ULA, lakeshore municipalities, and state agencies. In 2022, H.B. 232 created the ULA as an independent, nonprofit, separate body and politic, with perpetual succession. H.B. 232 has been codified as the Utah Lake Authority Act (*Utah Administrative Code* Section 11-65-1 et seq.). The ULA replaced the Utah Lake Commission, which had served in a similar role since 2007. The ULA is committed to enhancing and preserving Utah Lake as a recreational and environmental asset. In partnership and collaboration with government entities, local property owners, and community members, the ULA aims to promote the lake's natural beauty and accessibility. The ULA's mission, reflected in the ULMP (ULA 2024) focuses on making Utah Lake an enjoyable, safe, and sustainable destination for all, while protecting it for future generations.

9.2.1 Utah Lake Management Plan

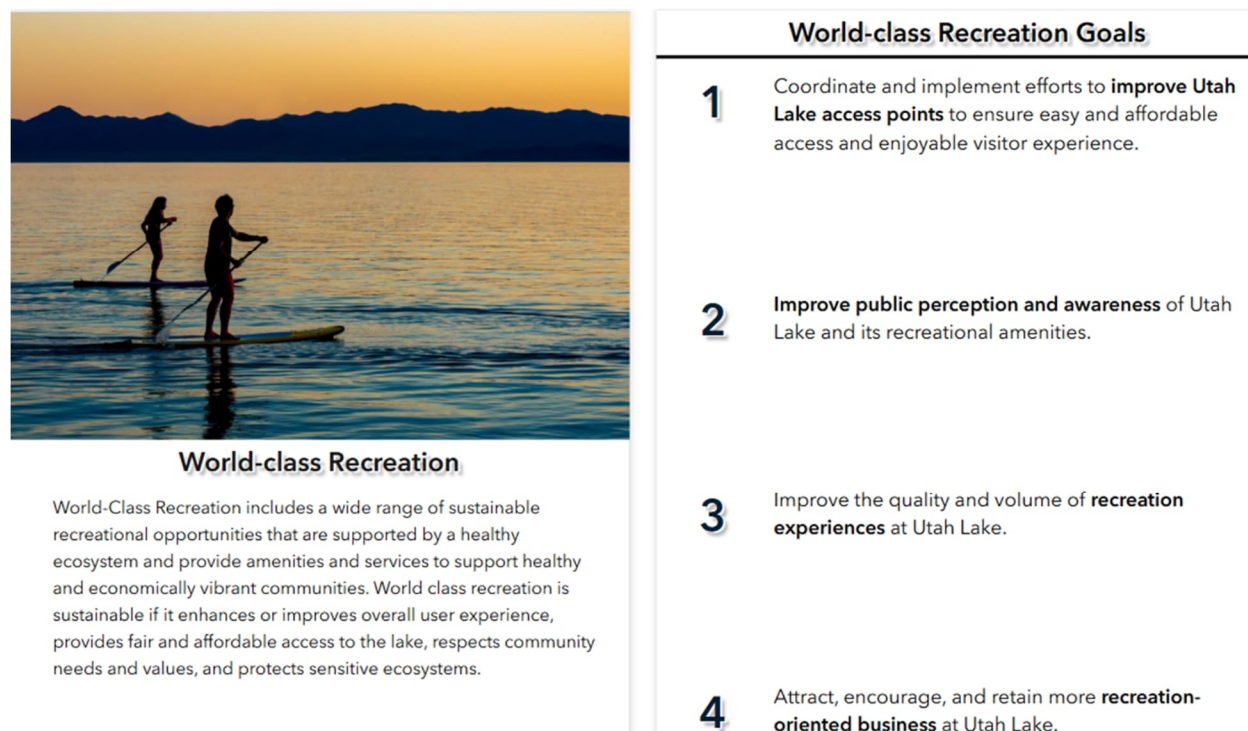
The ULMP (ULA 2024) was developed to provide a roadmap for the ULA to follow over the course of the Plan's 10-year planning horizon to enhance the ecological function of Utah Lake and the value that it provides adjacent communities, residents of the state, and visitors to the region. The ULMP (ULA 2024) outlines the ULA's mission to lead collaborative efforts in implementing projects that improve the lake's ecosystems, recreational opportunities, and surrounding communities. The plan's vision portrays Utah Lake as a national gem, focusing on three key themes: (1) thriving ecosystems, (2) world-class recreation, and (3) vibrant communities. Four broad goals are identified under the *world-class recreation* theme of the vision statement, ranging from improving existing access points to attracting and encouraging more recreation-oriented businesses at Utah Lake (Figure 9-2).

Figure 9-1. Points of Public Access to Utah Lake



Source: ULA n.d.b.

Figure 9-2. Utah Lake Authority's Goals to Support World-Class Recreational Opportunities at Utah Lake



Source: ULA n.d.e.

In the context of the ULMP, “world-class recreation” means having a wide range of sustainable recreational opportunities at Utah Lake, which are supported by a healthy ecosystem, and providing amenities and services that support healthy and economically viable communities. Table 9-1 shows the world-class recreation goals, objectives, and strategies for the full 10-year planning horizon of the ULMP. Short-term strategies for fiscal years 2024 to 2026 include developing a *Recreation Access Plan* (ULA forthcoming), conducting outreach to property owners, maintaining volunteer programs, gathering public feedback, and formalizing the ULA’s recreation access program. Over the 10-year planning horizon of the ULMP, the ULA hopes to address the information, policy, and funding gaps that were documented in the plan. In fact, since the plan’s adoption, the ULA has made progress on all short-term strategies, adhering to the implementation schedule outlined in the plan (ULA 2024).

9.2.2 Recreation Access Plan

ULA is currently developing a *Recreation Access Plan* (ULA forthcoming) to provide ULA and other stakeholders with a plan for enhancing recreation access at Utah Lake. The *Recreation Access Plan* evaluated a total of 38 access points (33 public access points, 2 public access points that are under construction, and 3 private access points) to identify existing challenges and opportunities for improvement. During development of the *Recreation Access Plan*, the ULA identified six additional public access points that had not been previously inventoried, increasing total number of public access points from 29 (Figure 9-1) to 35.

The objectives of the *Recreation Access Plan* (ULA forthcoming) are as follows:

- 1) *assess current conditions, amenities, and pain points at public access points;*
- 2) *identify recreation improvements and potential new access points;*
- 3) *provide implementation strategies including project prioritization and feasibility; and*
- 4) *develop management strategies and initiatives to expand recreational use.*

Table 9-1. Utah Lake Authority's Goals, Objectives, and Strategies to Achieve Progress Toward World-Class Recreation

Goal	Objectives	Strategies
1. Coordinate and implement efforts to improve Utah Lake access points to facilitate easy and affordable access, and enjoyable experiences.	Develop strategy to improve existing access points and increase the number of access points, taking into consideration their geographic distribution and quality.	Establish a formal ULA Recreation Program. ^[a] Develop a Recreation Access Plan for Utah Lake. ^[a] Explore opportunities to Increase Utah Lake Access Points.
	Develop a strategy to improve easy and affordable access to recreational amenities.	Collaborate with public access marinas and prioritize the improvements needed to maintain access to recreational amenities.
	Support the construction of the shoreline trail segments outlined in the Utah Lake Shoreline Trail Plan in collaboration with jurisdictional partners and private property owners.	Conduct targeted outreach to property owners adjacent to existing and proposed segments of the Utah Lake Shoreline Trail, with an aim toward maintaining positive visibility and community relations. ^[a]
		Facilitate the creation of a memorandum of understanding between ULA and jurisdictional partners to jointly fund and implement a construction and maintenance program associated with the Utah Lake Shoreline Trail Plan.
2. Improve public perception and awareness of Utah Lake and its recreational amenities.	Develop and maintain a recreation activities website (or use space on an existing website).	Develop web content that highlights recreational opportunities, access points, and events at Utah Lake.
	Understand how users perceive recreation at Utah Lake, including recreational service needs, and solicit feedback about existing and new projects.	Provide opportunities for the public to provide feedback on existing and future recreational experiences each year. ^[a]
	Understand the dynamics of visitation to Utah Lake, including the number of visitors to the lake, the timing of visitation, and the purpose of visits.	Develop a Recreation Access Plan for Utah Lake.
	Increase the number of recreators to Utah Lake.	Through the development and implementation of the Recreation Access Plan, increase exposure of Utah Lake and its recreational opportunities to a larger pool of potential recreators.
	Develop strategies to improve recreational safety at Utah Lake.	Promote and coordinate overall recreational and boater safety best practices and training courses.

Review of Existing Information Report

Goal	Objectives	Strategies
3. Improve the quality and volume of recreational experiences at Utah Lake.	Improve operations and maintenance activities at existing recreational destinations.	Identify gaps in operations and maintenance activities at existing recreation destinations over the course of a year to identify seasonal deficits.
	Identify opportunities to increase the number of facilities that provide year-round recreational opportunities at the lake, while protecting the natural characteristics of the area.	Identify various funding sources for potential future recreational facilities and amenities at Utah Lake.
		Coordinate volunteer efforts with community groups to assist with operations and maintenance of existing and future recreational facilities and amenities.^[a] Investigate use of park passes or parking permits to manage access issues, such as overcrowding and overuse of sensitive lake resources, if and when there is a problem.
4. Attract, encourage, and retain more recreation-oriented businesses at Utah Lake.	Work with partners and landowners to expand the availability of concession opportunities and streamline the permitting or contracting process for concessions to operate at public recreational destinations.	Provide up-to-date information for small businesses about the availability of concession opportunities and the types of permits required for recreational businesses on Utah Lake.
	Work with economic development partners to identify and develop business opportunities that support all types of recreational activities in and around the lake.	Develop business recruitment promotional materials.
		Connect potential new, expanding, or relocating recreation businesses with available real estate properties surrounding Utah Lake. Provide information on a public website for small businesses about funding opportunities.

Source: ULA 2024.

^[a] Short-term strategies for fiscal years 2024 to 2026

Each existing access point (public and private) was categorized by type (Table 9-2) and evaluated using a framework with three categories: (1) pain points, (2) planned improvements, and (3) strategic improvements. Recommendations for each category were given priority, such that recommendations to resolve *pain points* are the highest priority and *strategic improvements* are the lowest priority, as they may require additional planning and stakeholder engagement (ULA forthcoming).

Table 9-2. Access Points at Utah Lake Summarized by Type

Access Point Type	Description	Utah Lake Access Points
Marina	High-capacity access points that cater to a wide range of recreational activities and offer many amenities	- Utah Lake State Park - American Fork Marina - Lindon Marina - Saratoga Springs Marina - Lincoln Beach - North Saratoga Springs Marina
Community park	Access points with grassy areas, playgrounds, benches, and other park amenities	- Inlet Park - Sunset Beach - Sandy Beach - Shoreline Park
Beach	Access points with convenient water access and sandy or gravel shorelines, ideal for swimming and shoreline recreation	- Mulberry Beach - Goose Point North Access - Vineyard Beach - Vineyard Center Street - Vineyard 170 South Access
Boat launch	Access points dedicated to launching small boats, with few or no recreational facilities	- Mill Race - Swede Lane
Sportsman access	Undeveloped access points that have limited recreational facilities, ideal for hunting and fishing or launching small, hand-carried watercraft	- Powell Slough North - Powell Slough South - Lower Hobbie Creek WMA - Provo River Delta - Goose Point South Access - Big Cover Angler Access - Provo 5th West Angler Access - The Knolls - Mosida Acres - Tower View Point - Lincoln Point - LeBaron Point - Airport Dike - Battle Creek WMA
Trailhead	Access points primarily serving the Utah Shoreline Trail, offering shoreline access for trail users	Skipper Bay Trailhead

Source: ULA forthcoming.

WMA = wildlife management area

The *pain points* category includes recommendations to resolve common challenges observed at multiple access points, such as the following:

- Lack of wayfinding signage
- Prevalence of litter or insufficient number or size of trash bins
- Limited or no parking
- Overgrown vegetation
- Rough roads
- Lack of shade or shade structures

Recommendations under the *planned improvements* category include improvements that are already planned by municipalities or the ULA, as well as commonly suggested improvements from stakeholders.

Finally, recommendations under the *strategic improvements* category include new recommendations or features that add value to specific access points to make them more enjoyable. Potential new access points were evaluated based on gaps in coverage and anticipated usage at nearby access points (ULA).

9.3 Lakeshore Municipalities

Utah County officials and representatives from Genola, Lehi, Lindon, Orem, Provo, Saratoga Springs, Springville, and Vineyard were interviewed as part of the initial stakeholder engagement (Section 2.2). Interviewees were asked to describe their city's vision for maximizing, enhancing, and ensuring recreational access and opportunities on Utah Lake. In general, each municipality's vision was aligned with the current land use and development patterns of Utah Lake, where more numerous and more developed recreational opportunities exist on the north end of Utah Lake and agriculture, sportsman access, and open-space preservation are more predominant on the southern end of the lake.

During the initial stakeholder engagement interviews, each municipality was asked to describe what *enhanced recreation* means. The municipalities surrounding Utah Lake envision a diverse range of recreational improvements that collectively aim to enhance public access, connectivity, and enjoyment of Utah Lake. These visions encompass the development of comprehensive trail systems, including the completion of the Utah Lake Shoreline Trail, linking communities to the lakeshore and each other. Some cities plan to improve or construct marinas, beaches, and access points to facilitate water-based activities. There was a strong collective emphasis on creating multiuse spaces that cater to various interests, from active recreation, like fishing and beach activities, to passive enjoyment, like bird watching and wildlife observation. Several municipalities are focusing on integrating the lake into their broader urban planning to provide seamless connections between residential areas, parks, and the lakeshore. Additionally, there was a shared commitment to preserving natural areas and wetlands, while determining appropriate recreational opportunities within these sensitive ecosystems.

With some exceptions, local governments are coordinating activities in and around Utah Lake through the ULA. However, municipalities are preparing master plans and general plans in isolation, and not all municipalities have the same resources to dedicate to Utah Lake shoreline stewardship and recreation access enhancements. Although all lakeshore municipalities agreed that a diversity of recreational opportunities helps people interact with and gain positive impressions of Utah Lake, challenges about planning and project implementation were also shared.

Initial stakeholder engagement revealed some confusion about jurisdictional authority on the lake and, in some cases, landownership. Interviewees expressed a desire to maintain and improve recreational access points within their municipal boundaries; they also indicated that a streamlined process for obtaining approvals from relevant authorities to implement best management practices would be beneficial. Many interviewees were confused about roles and responsibilities on Utah Lake because of the multiple agencies and jurisdictions that manage Utah Lake or Utah Lake resources.

9.4 State, Local, and Federal Agencies

The following state, local, and federal agencies have a role in managing and enhancing recreational opportunities at Utah Lake:

- FFSL
- Utah Division of State Parks (DSP)
- DWR
- DWQ
- DOR
- PLPCO
- LHDs and DHHS
- URMCC

9.4.1 Utah Division of Forestry, Fire and State Lands

FFSL is currently updating their *Utah Lake Comprehensive Management Plan*, which, when complete, will outline strategies and decision support tools to confirm that state sovereign lands are managed under multiple-use, sustained-yield principles and the public trust doctrine (FFSL forthcoming). *Utah Administrative Code* R652-90-800, Multiple-Use Framework, states the following:

Comprehensive management plans shall consider the following multiple-use factors to achieve sovereign land management objectives:

- *The highest and best use for the sovereign land resources in the planning unit;*
- *Present and future use for the sovereign land resources in the planning unit;*
- *Suitability of the sovereign lands in the planning unit for the proposed uses;*
- *The impact of proposed use on other sovereign land resources in the planning unit;*
- *The compatibility of possible use as proposed by general public comments, application from prospective users or division analysis; and*
- *The uniqueness, special attributes and availability of resources in the planning unit.*

Utah Administrative Code R652-70-200 states that sovereign lands may be classified based on their current and planned uses and includes definitions for six potential classes. FFSL uses these classes to guide management activities and decisions for sovereign lands.

At the time this report was prepared, FFSL was soliciting input via a spatial survey regarding current and potential future proposed actions (that is, actions, activities, and projects) on, or directly adjacent to, sovereign lands of Utah Lake. In the context of the survey, proposed actions are activities that may be associated with an easement, general permit, right of entry, or other authorization to conduct the activity on sovereign lands. The results of the spatial survey will help FFSL better understand current land use patterns and future development potential around Utah Lake, which will inform FFSL's management strategies and confirm alignment with local planning efforts.

9.4.2 Utah Department of Health and Human Services and Local Health Departments

LHDs play a key role in managing public health at Utah Lake by issuing health advisories and closing waterbodies when necessary. Using thresholds established by the DHHS, LHDs assess whether HABs pose a risk to human health. DWQ supports this process through targeted monitoring and sampling of high-use or high-risk waterbodies, including those used for recreation or drinking water. DWQ analyzes and reports

sampling results and, in collaboration with DHHS, provides data-driven and technical recommendations to LHDs regarding the issuance of advisories. Utah's recreational health advisory guidance for HABs, last updated in 2023 (DWQ 2023) is based on EPA recommendations and incorporates the latest research on cyanotoxins, including microcystin, cylindrospermopsin, and anatoxin-a, as well as toxigenic cyanobacteria cell densities.

9.4.3 Utah Division of Outdoor Recreation

DOR is committed to improving outdoor experiences throughout Utah and can assist with planning and technical issues on Utah Lake. DOR oversees the state's Off-highway Vehicle Program in addition to the Boating Program. DOR offers a range of grant programs designed to support various entities in developing, restoring, and maintaining outdoor recreation infrastructure and programs. These grants provide essential funding for diverse projects, from trail construction and public space renovation to educational outdoor programs for young people. In addition to providing grants to local communities, DOR seeks to provide statewide recreation data in the Recreation Asset Database (Smith 2024). At Utah Lake, DOR acts as a support organization for local communities and can offer grants for specific projects. DOR staff were interviewed as part of initial stakeholder engagement (Section 2.2).

9.4.4 Utah Division of State Parks

DSP manages Utah Lake State Park, which is one of Utah Lake's marinas that offers a variety of amenities, such as boat ramps, fishing docks, restrooms, picnic areas, playgrounds, campgrounds, and parking.

9.4.5 Utah Division of Water Quality

DWQ, operating under the DEQ, plays a critical role in implementing the federal CWA within the state. Through delegated authority from EPA, DWQ is responsible for developing and enforcing water quality standards that apply to surface waters in Utah. A key component of DWQ's CWA implementation is the administration of the UPDES, which mirrors the federal NPDES. This program regulates point-source discharges from facilities such as wastewater treatment plants and industrial operations.

DWQ also fulfills CWA requirements by conducting statewide water quality monitoring and preparing integrated reports under Sections 305(b) and 303(d), which assess the condition of Utah's waters and identify impaired waterbodies. For waters that do not meet designated standards, DWQ develops TMDLs to guide restoration efforts. In addition, DWQ facilitates public involvement in water quality rulemaking and planning processes, maintaining transparency and stakeholder engagement. These responsibilities are especially relevant to Utah Lake, where DWQ applies its regulatory and scientific expertise to address nutrient pollution, HABs, and other water quality challenges in alignment with the goals of the CWA.

9.4.6 Utah Division of Wildlife Resources

DWR plays a significant role in managing public access at Utah Lake through its oversight of WMAs. These areas, which include several access points around the lake, are managed to conserve critical wildlife habitats, support recreational opportunities such as hunting and fishing, and mitigate wildlife-related impacts on surrounding lands. Access to WMAs is regulated, with some requiring a valid Utah hunting, fishing, or combination license, particularly in high-population counties like Utah County. The DWR maintains infrastructure, enforces seasonal closures, and implements habitat restoration projects to ensure these areas remain safe and ecologically sound for public use. As such, WMAs should be clearly identified and included in any comprehensive inventory of lake access points to reflect their dual role in conservation and recreation. Clarifying what constitutes an official access point—whether for recreation, education, or wildlife management—is essential for coordinated planning and public communication.

9.4.7 Utah Public Lands Policy Coordinating Office

PLPCO was interviewed as part of initial stakeholder engagement (Section 2.2) and reported that currently, PLPCO has no initiatives at Utah Lake.

9.4.8 Utah Reclamation Mitigation and Conservation Commission

URMCC, in conjunction with DWR, manages federally acquired lands within the ULWP, which spans approximately 21,750 acres across Goshen Bay and Benjamin Slough. These areas were established to mitigate environmental impacts from the Central Utah Project and are managed under a comprehensive plan that includes public access for compatible recreational activities such as birdwatching, hunting, and nature study. Despite their significance, many of these access points are not currently reflected in broader inventories of lake access, highlighting the need for clearer definitions and inclusion of WMAs and preserve sites in access planning and reporting.

9.5 Recreation Access Management Framework

Utah Lake recreation access points are managed from the bottom up (as opposed to top down), meaning various stakeholders and partners work together to make improvements at each access point. The stakeholders working together at each site varies depending on landownership, municipal or county zoning, site accessibility, and site-specific challenges. The ULA's goal is to bring all potential stakeholders together and work in a cooperative capacity to facilitate enhancements at Utah Lake.

A bottom-up approach to managing Utah Lake recreation access points, as described, offers several benefits, including tailoring improvements to each specific location with support from the communities they serve. This collaborative, bottom-up approach aligns well with the ULA's statewide public purpose which is to "work in concert with applicable federal, state, and local government entities, property owners, owners of water rights, private parties, and stakeholders to encourage, facilitate, and implement the management of Utah Lake" (*Utah Administrative Code* Section 11-65-1 et seq.). Although a bottom-up approach to managing Utah Lake recreation access points has many advantages, it also presents several potential disadvantages (Table 9-3).

9.6 Enhancing Public Safety

As recreational access points around Utah Lake are improved, a critical opportunity emerges to enhance public safety and emergency response capabilities in parallel. Coordinated planning among managing partners—including law enforcement, emergency services, and local agencies—is essential to integrating safety infrastructure and protocols into access point upgrades. Coordinated planning includes considerations such as signage, emergency access routes, communication systems, and water safety equipment. The ULA plays a central role in public education and outreach related to lake safety. Following are current initiatives led by the ULA:

- The Life Jacket Loaner Program
- Dissemination of water safety guidelines through social media and blogs
- Seasonal messaging on winter and ice safety
- Updates on HAB advisories
- Dissemination of information on *Phragmites* management

These efforts collectively contribute to a safer and more informed public, supporting responsible recreation and emergency preparedness across the lake.

Table 9-3. Advantages and Disadvantages of the Current Bottom-Up Approach to Managing and Enhancing Recreation Access and Opportunities at Utah Lake

Advantages	Disadvantages
▪ Local expertise: Leverages the in-depth knowledge of local stakeholders who are most familiar with site-specific site conditions and challenges. Allows improvements to be tailored to unique needs of each access point. ▪ Increased stakeholder buy-in: Fosters a sense of ownership and responsibility among local partners and community members. Enhances the likelihood of long-term support and maintenance of improvements. ▪ Diverse resource pooling: Allows for combination of various resources, skills, and expertise from different stakeholders. Potentially leads to more cost-effective and innovative solutions. ▪ Adaptability to site-specific challenges: Enables flexible responses to the unique characteristics of each access point, considering factors like landownership, zoning, and accessibility. Facilitates customized solutions that may not be apparent in a one-size-fits-all approach. ▪ Enhanced community engagement: Encourages active participation from local communities in the decision-making process. Builds stronger relationships between the ULA and various stakeholders. ▪ Improved problem-solving: Allows for a more comprehensive understanding of issues from multiple perspectives. Facilitates creative problem-solving by incorporating diverse viewpoints. ▪ Alignment with local priorities: Aligns improvements with needs and preferences of communities directly affected. Helps balance recreational development with other local concerns and priorities. ▪ Efficient resource allocation: Enables more targeted and efficient use of resources by focusing on the most pressing needs identified by local stakeholders. ▪ Increased transparency: Promotes open communication and transparency in the decision-making process. Builds trust between governing bodies and local communities. ▪ Long-term sustainability: Encourages ongoing involvement and commitment from stakeholders, potentially leading to more sustainable management practices.	▪ Coordination challenges: Managing diverse stakeholders with varying interests can be complex and time consuming. Achieving consensus among multiple parties may slow the decision-making processes. ▪ Inconsistent standards: Different access points may develop inconsistent quality standards or management practices. Lack of uniformity could lead to confusion for visitors moving between different areas of the lake. ▪ Resource disparities: Some access points may benefit from more resources or influential stakeholders, leading to uneven development around the lake. Areas with less engaged or resourced stakeholders might lag behind in improvements. ▪ Potential for localized focus: Stakeholders might prioritize local interests over broader, long-term vision for Utah Lake as a whole. Losing sight of larger ecosystem management goals in favor of site-specific improvements is a risk. ▪ Complexity in policy implementation: Implementing consistent policies or regulations across all access points could be challenging because of the varied management approaches. Enforcing lake-wide standards may become difficult with diverse management structures. ▪ Possible conflicts of interest: Local stakeholders might push for improvements that benefit specific groups rather than wider public interest. ▪ Fragmented planning: Lack of centralized planning might lead to duplicated efforts or missed opportunities for synergies between different access points. Implementing large-scale, lake-wide projects that require coordinated action across multiple sites will be difficult. ▪ Variable expertise: Stakeholder groups may not have equal expertise in lake management or recreational development. The quality of planning and execution may be inconsistent across different access points. ▪ Funding challenges: Securing and distributing funding equitably across various projects and stakeholder groups may be complex. ▪ Accountability issues: With multiple stakeholders involved, the party ultimately responsible for maintenance or addressing issues at specific sites may be unclear. Blame shifting may occur when problems arise.

9.7 Recreation Enhancement in Context of Other Ecological Factors

A central objective in S.B. 270 is to support increased recreational and other human uses of Utah Lake. A healthier ecosystem—marked by improved water clarity, quality, and overall ecological balance—serves as the foundation for safe and enjoyable activities such as swimming, boating, fishing, and wildlife viewing. These improvements are essential for shifting public perception of the lake from degraded to desirable, fostering greater community engagement and interest among both residents and visitors. Without addressing key ecological challenges, particularly water quality, efforts to expand recreation and other uses will be limited and potentially unsupportable. Therefore, ecological enhancement is not only an environmental priority but also a strategic investment in the lake's social and economic value.

10. Accommodating Current Land Uses and Improving Utah Lake for Public Benefit

Key findings

- A 2-mile buffer around the Utah Lake boundary reveals a complex mosaic of land ownership. This includes state sovereign lands (within the lake boundary), state trust lands, wildlife/waterfowl management areas, Utah Department of Transportation lands, federal lands (managed by the U.S. Bureau of Land Management, U.S. Bureau of Reclamation, and the U.S. Forest Service), and private lands. Some municipal boundaries extend into sovereign lands.
- Zoning data collected from Utah County and individual municipalities show distinct patterns—the northern half of Utah Lake is zoned for higher-density urban development, and the southern half is primarily zoned for agricultural or mixed residential-agricultural use.
- Land cover data from the National Land Cover Database (USGS 2024a) closely mirror zoning patterns. The northern region of the lake is characterized by developed land, and the southern region remains largely open space and agricultural land.
- The mosaic of land ownership and zoning around a shared resource like Utah Lake presents several challenges, including coordination complexity, environmental impact management, and resource allocation.
- Hydrologically connected wetlands surrounding Utah Lake play a critical role in maintaining the lake's ecological health by improving water quality, stabilizing shorelines, mitigating floods, supporting biodiversity, and sustaining groundwater levels. Agricultural lands near Utah Lake can, under certain conditions, function as hydrologically connected wetlands, contributing to the lake's ecological health.

Information needs

- Senate Bill 270 includes provisions aimed at improving the use of Utah Lake for residents and visitors (element [h]) and substantially accommodating existing uses on land in or around the lake (element [i]). However, the specific enhancements intended under these provisions remain unclear, particularly in relation to the Utah Division of Forestry, Fire and State Lands' management authority over the sovereign lands underlying Utah Lake.
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To provide a foundation for future planning and decision-making, this analysis focuses on documenting the current conditions surrounding land use, zoning, ownership, and patterns of growth and development within a 2-mile buffer of Utah Lake. The geographic extent of this analysis was limited to an arbitrary buffer distance of 2 miles around the negotiated settlement boundary of Utah Lake (FFSL 2023). A 2-mile buffer was chosen based on best professional judgement to examine land use patterns immediately adjacent to the lake or immediately upland of the lake, as activities in this area are more likely to have a potential impact on the lake and the various benefit areas identified in S.B. 270.

10.1 Land Ownership, Zoning, and Land Cover

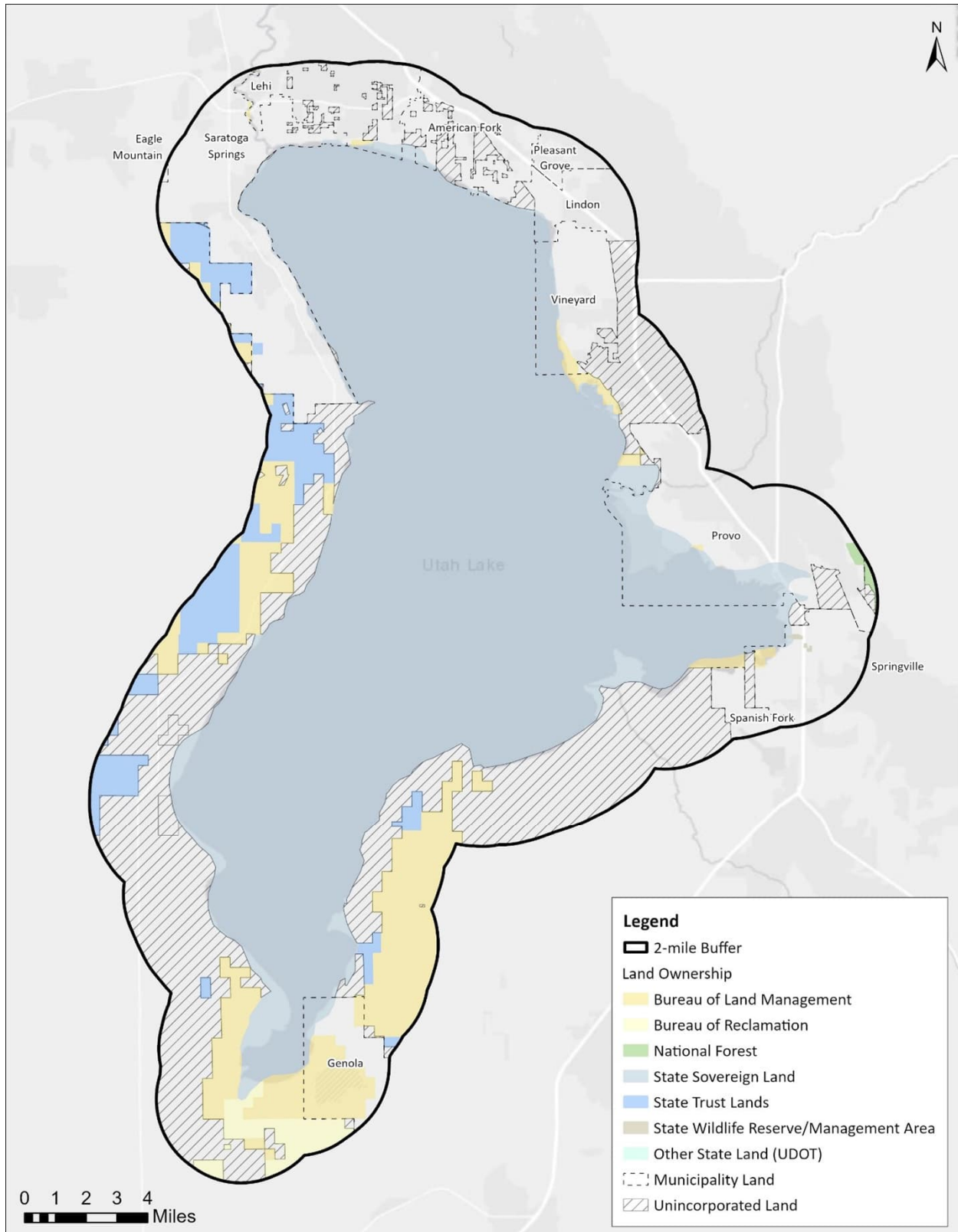
Within the 2-mile buffer around the Utah Lake boundary line, landownership is mix of state lands (state sovereign land, state trust land, state WMAs, and Utah Department of Transportation land), federal land (Reclamation, U.S. Bureau of Land Management [BLM], and U.S. Forest Service), and private land (Figure 10-1). Some municipal boundaries extend into sovereign lands below the Utah Lake boundary line. Federal landownership around Utah Lake is mostly related to the CUPCA, which set terms and conditions for completing the Central Utah Project, which diverts, stores, and delivers large quantities of water to meet the needs of central Utah's citizens.

The URMCC in partnership with the CUWCD, CUPCA Office of the U.S. Department of the Interior, and JSRIP are implementing the PRDRP. URMCC is an executive branch of the federal government that was authorized under CUPCA. Reclamation owns land on the southern end of Utah Lake, and BLM owns land directly adjacent to sovereign lands around Utah Lake.

Zoning data were first acquired from Utah County through the county's ArcGIS Hub (Utah County 2025). When possible, publicly available GIS data were retrieved from a lakeshore municipality's government website to supplement the generic Utah County zoning data with site-specific detail. The following cities had publicly available zoning data:

- Provo (Provo City 2014)
- Vineyard (Vineyard City 2023)
- Spanish Fork (Spanish Fork City n.d.)

Figure 10-1. Land Ownership around Utah Lake



For most lakeshore municipalities, zoning data were not publicly available but were available upon request by contacting the cities:

- **Genola:** portable document format (PDF) map of zoning data, with areas immediately adjacent to Utah Lake zoned for agricultural activities (Brown, pers. comm. 2025)
- **Lehi:** Shapefile of Lehi zoning (DeWitt, pers. comm. 2025)
- **Springville:** shapefile of Springville zoning (Krivova, pers. comm. 2025)
- **Saratoga Springs:** shapefile of Saratoga Springs zoning (LeFors, pers. comm. 2025)
- **Orem:** (awaiting response)
- **American Fork:** (awaiting response)
- **Lindon:** (not requested)
- **Pleasant Grove:** (not requested)

Figure 10-2 shows the current zoning around Utah Lake with a 2-mile buffer of the Utah Lake boundary line (FFSL 2023). Mixed use areas in the map (light green) indicate Utah County data, because supplemental municipal zoning data were not available or had not been received at the time this report was written. Acquisition of zoning data around Utah Lake is an ongoing activity that will continue during development of the draft ULS report. Higher-density urban development occurs on the northern side of Utah Lake, whereas the southern half of Utah Lake is predominantly zoned for agricultural activities or a mix of residential and agriculture activities (Figure 10-2).

Land cover data within the 2-mile buffer around Utah Lake boundary lines (FFSL 2023) were examined using the National Land Cover Database (USGS 2024a). The land cover (Figure 10-3) mirrors zoning around Utah Lake. The northern half of Utah Lake is currently used for higher-density development, whereas the southern half of Utah Lake has more open space and agricultural areas.

10.2 Existing Land Uses Supporting Utah Lake's Ecosystem and Public Use

The land areas immediately adjacent to lakes is extremely important and can have an outsized effect on the water quality of the lake. While extensive development and urbanization has occurred, remaining wetland and agricultural land areas may provide important ecological services to Utah Lake.

10.2.1 Wetlands

Many surrounding lands around Utah Lake serve as hydrologically connected wetlands to Utah Lake; these hydrologically connected wetlands are essential to the ecological integrity and functionality of the Utah Lake systems. These wetlands enhance water quality by acting as natural filtration systems, capturing sediments and retaining excess nutrients and pollutants from the surrounding watershed before they enter the lake; this process helps mitigate issues such as HABs and oxygen depletion, which can adversely affect aquatic ecosystems and recreational water use. In some cases, constructed wetlands, also known as natural treatment systems, have proven to be effective complements to conventional wastewater treatment methods.

Figure 10-2. Zoning around Utah Lake

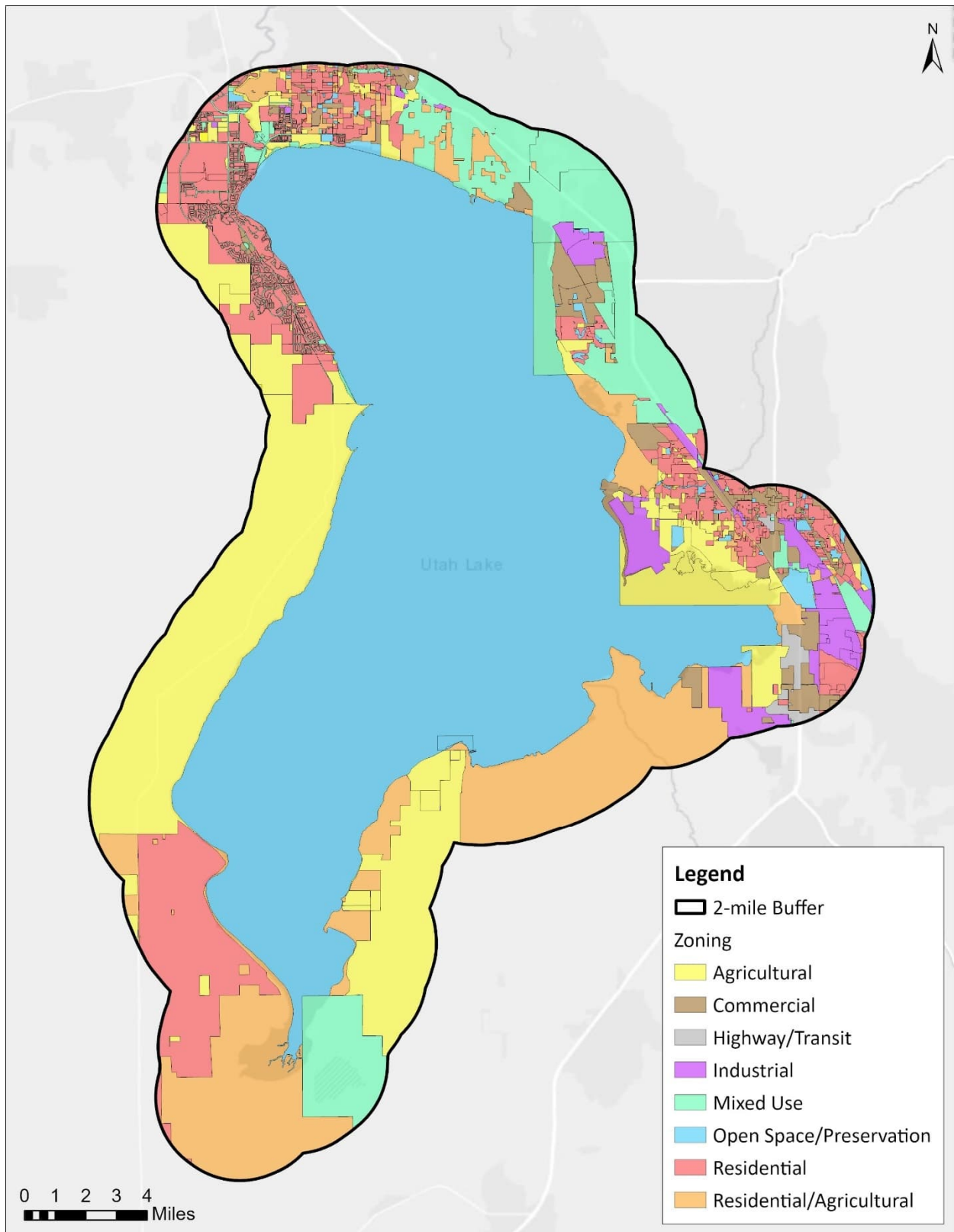
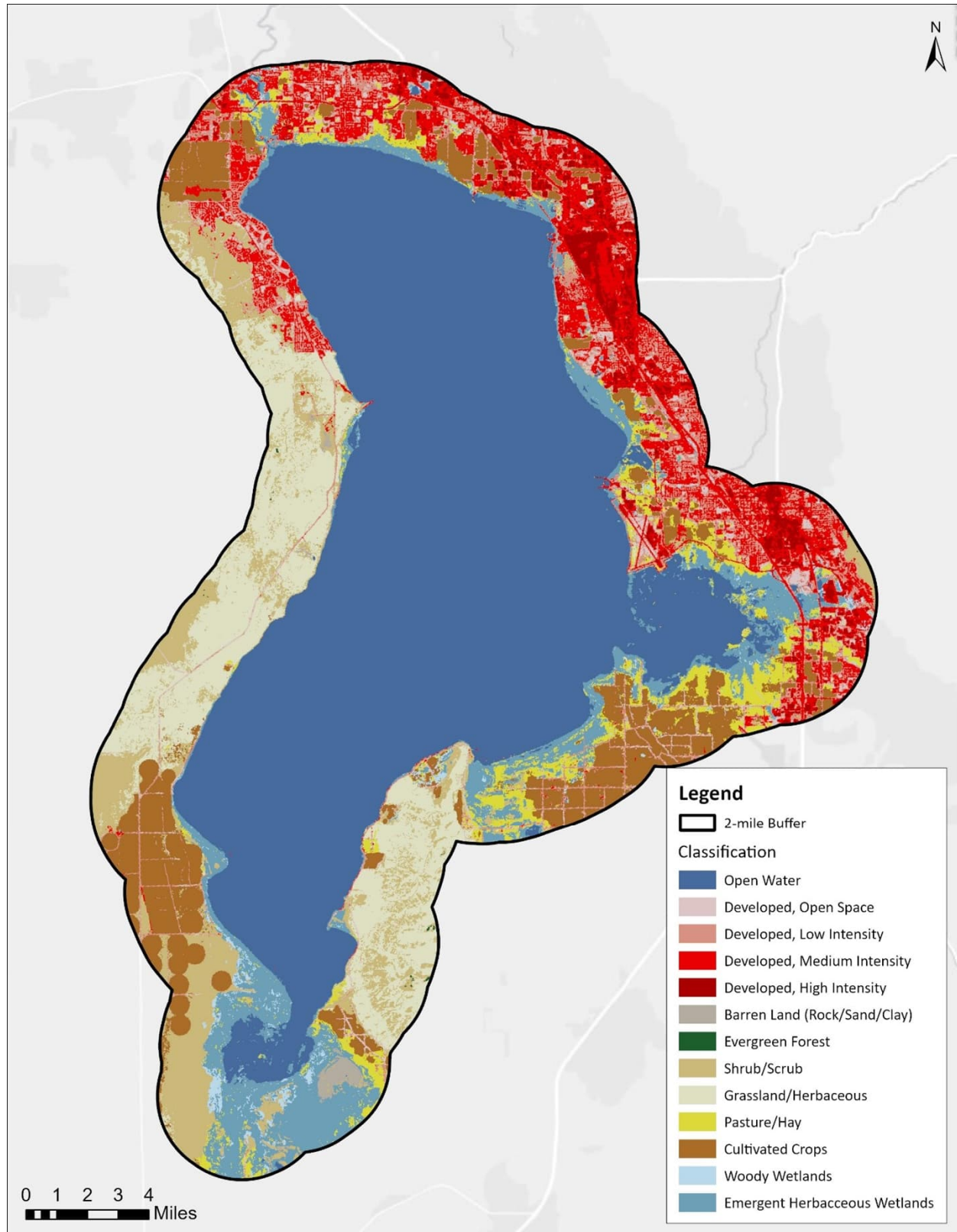


Figure 10-3. Land Cover around Utah Lake



Additionally, wetlands contribute to shoreline stabilization and erosion control; the dense root systems of wetland vegetation absorb wave energy and anchor soil, reducing erosion along lake margins and riverbanks. They also provide critical flood protection by absorbing and gradually releasing excess water from precipitation, snowmelt, and flood events, thereby reducing downstream flood risks. Ecologically, wetlands offer vital habitat for a diverse range of species, including migratory birds, threatened and endangered wildlife, and fish that depend on these areas for spawning and nursery grounds. Further, wetlands support groundwater recharge and help maintain stream and lake levels during dry periods by facilitating the slow infiltration of water into aquifers. Collectively, these functions underscore the importance of hydrologically connected wetlands in sustaining the health, resilience, and biodiversity of Utah Lake and the surrounding watersheds.

The ULWP exemplifies the ecological and hydrological importance of these connected wetland systems. The ULWP, located southwest of Provo in Utah County, encompasses a network of wetland and upland habitats near the southern end of Utah Lake. It was established under the 1992 CUPCA to mitigate past and anticipated environmental impacts from the Central Utah Project. CUPCA authorized the URMCC in collaboration with DWR and USFWS to acquire private lands and water rights from willing sellers within the preserve boundary.

Land acquisition began in 1996, followed by interim management agreements with DWR for federally owned parcels. The ULWP spans approximately 21,750 acres across two primary units—Goshen Bay and Benjamin Slough. Of this, 15,782 acres are actively managed by the following project partners:

- URMCC (7,200 acres)
- BLM (4,150 acres)
- State of Utah (4,500 acres, primarily open water administered by FFSL)
- Utah County (19 acres)

In compliance with CUPCA and the National Environmental Policy Act, the URMCC and U.S. Department of the Interior, acting as joint lead agencies, prepared an environmental assessment to evaluate the transfer of federally acquired ULWP lands to the State of Utah and develop a comprehensive management plan. CUPCA requires that the State of Utah enter into an agreement under which DWR will manage the preserve in accordance with the National Wildlife Refuge System Administration Act of 1966. The resulting 15-year management plan outlines goals and strategies for habitat conservation, vegetation management, restoration, and wildlife-dependent recreation while confirming compliance with state regulations. Following public review and interagency coordination, the environmental assessment concluded that the proposed actions would not significantly affect the natural or human environment. A Finding of No Significant Impact was issued in July 2022 (CUPCA and URMCC 2022).

10.2.2 Agriculture

Agricultural lands near Utah Lake can, under certain conditions, function as hydrologically connected wetlands, contributing to the lake's ecological health. Many irrigated agricultural areas in Utah are in valley bottoms near surface water sources, where seasonal flooding, high water tables, and irrigation practices can create wetland-like conditions. These lands can act as buffers, filtering sediments and nutrients before they reach the lake, thereby supporting water quality and aquatic habitat. Although not all agricultural lands meet the criteria for wetlands, those with appropriate hydrology, soils, and vegetation, or those managed to support these features, can perform similar ecological functions and contribute positively to the Utah Lake watershed (Mushet and Effland 2020).

11. Discussion

An immense amount of information is available on Utah Lake. Its location proximal to the main population center of Utah and its importance as an ecosystem, water storage reservoir, and recreational resource have made it the subject of an overwhelming amount of research and management efforts. This section discusses the various benefit areas to be enhanced and some of the potential options that exist and might be explored in research and management efforts moving forward.

11.1 Conservation of Water Resources

S.B. 270 tasks the FFSL with conducting a comprehensive study to identify strategies for conserving water resources and improving conditions in and around Utah Lake, among other benefit areas outlined in the legislation. In fulfilling this directive, FFSL is also required to respect and preserve existing water rights and interests related to water collection, storage, and delivery. Importantly, all activities undertaken as part of the study must be consistent with FFSL's statutory authority over sovereign lands.

FFSL does not hold jurisdictional or operational authority over several key aspects of water resource management. These include watershed planning, regulation of surface and groundwater inflows, water supply and conservation planning, and reservoir operations, specifically the management of Utah Lake water levels. These responsibilities fall under the purview of other state agencies with the appropriate regulatory mandates.

This division of responsibilities presents a complex challenge. FFSL must evaluate and support opportunities for water resource enhancement while remaining within its legal boundaries and avoiding encroaching on the responsibilities of other agencies. Successfully navigating this challenge will require close coordination with relevant stakeholders and a clearly defined role for FFSL in contributing to water conservation through land management, habitat restoration, and stewardship of sovereign lands. FFSL's limited jurisdiction over water resources requires coordination and consultation with its sister agencies and the stakeholder community.

As part of this Review of Existing Information for the ULS, fluctuations in water levels, particularly the magnitude and rate of change, as well as the duration of dry and inundated periods along the shoreline, have been identified as significant ecological stressors. These fluctuations impact the restoration and functionality of the littoral zone, which is critical to the lake's ecological health. However, as previously noted, FFSL does not have the authority to directly manage lake levels or mitigate this stressor.

In addition to lake level variability, disrupted tributary flows and channel alterations have further stressed the Utah Lake system. Diversions, channelization, and dredging have reduced the functionality of tributaries, with some no longer reaching the lake in most years. These changes have also degraded hydrologically connected wetlands, which play a vital role in maintaining the ecological integrity of the lake. Hydrologically connected wetlands serve as natural filtration systems, capturing sediments and retaining excess nutrients and pollutants from the surrounding watershed before they enter the lake. Their restoration and protection are essential to improving water quality and supporting biodiversity within the Utah Lake ecosystem. The loss of these wetlands has contributed to reduced native species abundance, increased invasive vegetation, and reduced water quality.

To mitigate the effects of water-level fluctuations and support lake enhancement efforts, Utah Lake may benefit from formal programs that restore tributary flows and stream environments in a manner consistent with the hydrologic needs of connected wetlands (for example, the PRDRP) and continued investigation of new means or methods of addressing conditions below the shoreline to support ecological and water quality goals.

Though developing such programs would be beneficial, it would present challenges for the broader water scarcity concerns across northern Utah and the state as a whole, including the fact that Utah Lake is also a link in the chain that connects Great Salt Lake with upstream waterways and bodies of water and is used to help deliver water to Great Salt Lake. Any such initiative must be pursued in coordination with partner agencies that hold the relevant jurisdiction and expertise.

Utah Lake enhancement requires a holistic, multiagency approach grounded in a shared vision. Despite limitations in jurisdiction, FFSL continues to play a critical role in supporting water resource outcomes through its stewardship of sovereign lands, habitat restoration efforts, and ecological enhancement initiatives. Its leadership in these areas will be essential to advancing the goals of the ULS in a collaborative and legally responsible manner. Despite limitations in jurisdiction, FFSL has and continues to play a critical role in supporting water resource outcomes through land stewardship, habitat restoration, and ecological enhancement.

11.2 Water Quality and Clarity

To date, only relatively small-scale experiments have been conducted to evaluate the potential pathways of enhancing water quality and clarity in Utah Lake. This section outlines the microcosm and mesocosm experiments that have been conducted to date, draws insights from whole-ecosystem management efforts in other shallow lakes, and details the management and regulatory pathways possible in Utah Lake. To date, these management actions directed toward water quality have been conducted only on relatively small scales within Utah Lake. Activities are currently underway to explore whole-lake water quality management, including the development of nutrient targets as part of the ULWQS led by DEQ, the ULMP (ULA 2024), and other efforts led by the ULA. Additional analyses and modeling will be conducted as part of this ULS to evaluate potential management pathways to improve water quality and clarity in Utah Lake, with considerations for effectiveness, feasibility, and recovery timelines.

11.2.1 Similar Lake Restoration Efforts

The lag between reduction in external loads and the observation of lower water column concentration can vary considerably. Utah Lake has mixed recovery characteristics that could promote both a shorter recovery timespan (that is, rapid flushing times, sediment binding dominated by CaCO_3 rather than redox-sensitive iron and manganese compounds, and chemistry favoring high rates of phosphorus retention) and a longer recovery timespan (that is, long history of nutrient loading, active sediment interaction with the water column) (Søndergaard et al. 2017; Jeppesen et al. 2005). Phosphorus reduction lags and timelines have been modeled in other systems (for example, USGS 2018 and Robertson and Diebel 2020), and a literature review indicated that common times for recovery are 10 to 15 years (Jeppesen et al. 2005). A Utah Lake-specific mechanistic model and mass balance model, which are in development by the ULWQS Science Panel, would be required to determine Utah Lake-specific levels of nutrient reduction required and timelines for recovery.

In the meantime, insights can be gained from other lakes with ongoing restoration efforts to remediate eutrophication to infer possible future scenarios for Utah Lake. For example, Lake Winnebago is a large (532 square kilometer), shallow (4.5-meter mean depth and 6.4-meter maximum depth), eutrophic lake in east-central Wisconsin with many similar characteristics to Utah Lake. Lake Winnebago is subject to a TMDL by the Wisconsin Department of Natural Resources because it exceeds the TP water quality standard, with a mean mid-lake TP concentration of greater than 0.1 mg/L and TN of greater than 1.1 mg/L (USGS 2018). Modeling efforts have evaluated the potential recovery times for Lake Winnebago to reach its TP water quality criterion given the sediment internal loading that occurs (Jensen et al. 2006); near-term improvements were noted when external loading was reduced by 75 percent or more, with more than 100 years needed to fully meet the water quality standard. However, notably, other factors,

including alkalinity, sediment nutrient, organic content, and redox conditions, are key drivers of sediment nutrient loading and may differ between Lake Winnebago and Utah Lake, despite morphological similarities. Thus, comparing other systems can be useful to inform modeling but should be interpreted with caution with regard to the factors that make systems different or comparable. Further comparisons to large-scale datasets (for example, National Lakes Assessment [EPA 2024]) and literature meta-analysis may help to contextualize Utah Lake's setting within the range of conditions and management activities across lake systems.

11.2.2 Dredging

Dredging nutrient-rich sediments has been offered as a solution to speed up nutrient-related recovery in many eutrophic systems. The regulatory, financial, and logistical issues of mechanical removal, waste disposal, and concerns over nontargeted effects need to be addressed for any such project to be successful. Dredging nutrient-rich sediments has been shown as a possible solution in some aquatic systems, albeit usually much smaller areas than Utah Lake. In general, dredging experiments result in short-term improvements in water clarity and quality before returning to their original conditions. This phenomenon has been observed in several studies where dredging was conducted but external nutrient loading was not reduced, and all benefits were short lived (Søndergaard et al. 2007; Riza et al. 2023; Lui et al. 2016). If the rate of phosphorus mechanically removed is not equal to or greater than the amount entering the system from external sources, then the system will eventually return to its nutrient-laden condition.

Finally, even if dredging were a useful nutrient management tool, it would not be practical in all of Utah Lake because of scale, cost, and legal issues. Conceptual costs can be understood by assuming that 10 to 25 percent of the lake area would have the top 3 feet of sediments removed by a hydraulic dredge and trucked out of the watershed. If U.S. Army Corps of Engineers (2019) contracted dredging costs are escalated at 6-percent per year to 2025, the spoils management site is conservatively estimated to be 10 miles from Utah Lake, and a 50-percent contingency is assumed; dredging costs would range between \$2.3 billion and \$5.7 billion. This conceptual cost estimate may be underestimated given the absence of infrastructure near Utah Lake to support a large-scale dredging project.

11.2.3 Chemical Treatments

Chemical treatments for eutrophication have been a common remediation method in lakes since the 1970s. The main product used is aluminum sulfate (alum), which is directly added to surface water and removes phosphorus through binding and eventual precipitation into the sediment. When successful, the alum floc reduces the exchange of phosphorus from sediments to the water column, reducing internal loading. Without control of watershed phosphorus loading, alum treatments need to be reapplied approximately every 10 years to maintain effectiveness (Welch and Cooke 1999; Brattebo et al. 2017). However, alum treatments have been used for much smaller systems than Utah Lake, and it is unknown whether treatments are feasible at this scale or whether the solution is cost prohibitive. Using a rough estimate calculation on minimum alum applications costs (\$1,000 per acre in the approximately 96,000-acre Utah Lake), the minimum treatment cost is greater than \$100 million but, in practice, likely would cost much more. Other chemical treatments, such as copper sulfate, can be applied directly to surface waters as an algaecide to directly control HAB growth. While copper sulfate directly reduces algal growth with few direct risks to nontarget species, it is a short-term solution to algal growth that can cause post-treatment algal rebounds and low dissolved oxygen, pose a toxicity risk to fish and invertebrates, and is most appropriate for smaller ponds (Willis and Bishop 2016; Anantapantula et al. 2025). Some work has been done treating isolated bays with alum in larger lake systems, which may be possible for areas such as Provo Bay or isolated marinas (Tetra Tech 2010; Barr 2007). Much like sediment dredging, water quality benefits for any chemical treatment are likely to be short lived without first reducing external nutrient

loading and may pose environmental risks with frequent or long-term applications. Additionally, state agencies have various rules regarding alum use, concentrations, and potential NPDES permitting requirements that need to be investigated before planning and modeling the effectiveness of any chemical treatments.

Additionally, alum treatments likely will be ineffective if the carp population is high. An alum application to Lake Susan in Chanhassen, Minnesota, appeared to be successful in spring but failed by mid-summer of the same year (Jacobs unpublished data). At the time, the carp population was thought to be small, but 10 years later, the population was determined to be 90 percent of the fish biomass (Sorensen and Bajer 2020). Huser et al. (2022) asserted that bioturbation from carp foraging behavior, which entails rooting in sediments, likely negates the efficacy of alum application for phosphorus management by burying settled alum sludge. An alum application in Grand Lake St. Mary's provided no to very short-lived benefits to water quality (McCarthy 2023). The lake is well known for its large carp population of 281 kg/ha to 560 kg/ha (KCI Associates 2021) and even has an annual Grand Lake Carp Derby with prizes (St. Mary's Rotary Club 2022). Although the effects of carp on alum application success have yet to be studied in detail, the evidence that large carp populations would destroy an alum application is compelling. Table 11-1 summarizes the management pathways for potential water quality and clarity enhancements in Utah Lake.

Table 11-1. Management Pathways for Potential Water Quality and Clarity Enhancements in Utah Lake

Management Activity	Benefits	Drawbacks	Pathway
Watershed nutrient management	▪ Straightforward, well-supported management path with great degree of certainty	▪ Uncertain recovery timeline ▪ Potential diminishing returns at high levels of wastewater load reductions	▪ Regulatory pathway through CWA policy (that is, nutrient targets, TMDL, and permitting)
Carp reduction	▪ Well-documented method to reduce bioturbation and associated nutrient and sediment mobilization	▪ Need for regular maintenance ▪ Low likelihood of substantial water quality improvement with this activity alone	▪ Long-term "learn by doing" management plan that will evolve ▪ Possible implementation through invasive species TMDL or Use Attainability Analysis process
Dredging	▪ Possibly effective in smaller bays and marinas	▪ Temporary management lever ▪ High cost	▪ Federal and state permits ▪ Required scientific justification in Utah Lake
Chemical controls (alum and algaecide)	▪ Algaecide may be effective in smaller bays and marinas	▪ Temporary management lever ▪ High cost ▪ Algaecide at a large scale may not be technically or ecologically viable ▪ Alum efficacy at scale is unknown in Utah Lake	▪ Required scientific justification for large-scale application in Utah Lake ▪ Required state permits

11.3 Invasive Fish (Carp)

Since their introduction, common carp have become the most abundant aquatic organism in Utah Lake and in the process have played a large role in fundamentally altering the ecosystem. As documented in aquatic ecosystems throughout the world, carp cause bioturbation of benthic sediments, resulting in the degradation of water quality and representing one of the major challenges to enhancing water clarity and

quality in Utah Lake. As described in this document, carp have played a significant role in devastating populations of benthic vegetation in Utah Lake, resulting in unstable benthic sediments that are easily mobilized during wind events. Carp also have played a significant role in reducing populations of June sucker and degrading benthic invertebrate communities via bioturbation. While the ecological impacts of common carp are well documented throughout the world, so is carp's resilience and the magnitude of the challenge that carp removal represents. Carp removal efforts on Utah Lake have been ongoing for many years, and past efforts and research could be built on to improve management and removal efforts into the future.

Carp management efforts employed to date have been relatively constrained in scope and methodology in relation to the size and scale of Utah Lake. IPM strategies that employ multiple tools to target specific weaknesses in carp life history should be considered for Utah Lake, such as the following, among others:

- Telemetry-guided seines to target winter carp aggregations
- Automated box nets to target bait-induced summer aggregation
- Native fish biocontrol of carp eggs, larvae, and fry

Management tools that are able to effectively target all mature year classes of carp in different types of habitats would likely accelerate carp management. Additional data, particularly on the abundance of juvenile carp, carp age, and carp mortality, are needed to solidify model parameters and address the apparent discrepancy between observed data and model predictions. A robust carp population model is key for guiding management efforts.

This section describes alternative management strategies for carp, including YY male release and gene-drive technologies, poison bait, and viral biocontrol. A variety of potential genetic control strategies are being considered for invasive fish (brief review in Bajer et al. 2019). In species with XY chromosome sex determination systems, such as common carp or brook trout, YY "supermales" or YY phenotypic females generated by hormone treatments only have YY or XY male offspring (Bongers et al. 1999). Such supermales are generally socially accepted as a control method because they are not really "genetically modified;" rather, their chromosomal makeup is determined via hormonal manipulations and selective breeding.

Stocking YY supermales in large numbers may eventually shift wild populations to male only, leading to population collapse. The benefit of this technique is that the YY supermales may be relatively easy to produce and stock, but this strategy has low potency. YY supermales will produce male-only offspring when breeding with wild XX females, but their offspring will produce "normal" XY males and XX females. Once enough XY males exist in the environment, the strategy breaks down. Therefore, such sex ratio biasing approaches are predicted to work best for relatively short-lived species with few offspring, such as the brook trout. In fact, successful application of this technique for brook trout control in mountain streams has already been demonstrated.

For species such as the common carp, which can live for over 50 years and are extremely fecund (up to 3 million eggs per female), YY supermales face odds against their success. Walsworth et al. (2024) simulated the potential effectiveness of YY male release in Utah Lake. The model predicted that stocking rates of 25 million to 100 million YY carp into Utah Lake annually for 15 years would be needed to reduce carp biomass by about 50 percent in 40 years. On its own, YY male strategy does not appear to be effective in Utah Lake. However, Wallace (2025) demonstrated how mechanical removal and Trojan Y chromosome stocking could be an effective strategy for carp control in Utah Lake. Gene-drive technologies might be significantly more effective, as in this strategy, all offspring (and their offspring) inherit the deleterious genetic construct. For example, genetic engineering can be applied to control hormone levels that determine sex in fish. The "daughterless carp" strategy involves blocking aromatase, an enzyme responsible for converting male-determining androgen hormones into female-determining

estrogen hormones (Thresher et al. 2014). Effectiveness of gene-drive technologies should be addressed via statistical modeling.

Because common carp can be trained to aggregate using bait, the bait-and-switch strategy has been considered for their control. In this scenario, carp would be first conditioned using nontoxic bait, which would then be replaced with similar but toxic bait for brief periods of time (Poole et al. 2018; Hundt et al. 2020). Antimycin-A, which carp do not appear to detect or avoid, has been tested as toxic carp bait and has been incorporated into food pellets (Hundt et al. 2020). Laboratory tests have suggested that the toxin may be relatively specific to carp, does not leach out of the pellets, and would break down relatively quickly in the environment (Poole et al. 2018). The lethal dose was 8 milligrams of Antimycin-A per 1 kg of carp.

Pond experiments have shown that this strategy might be relatively effective. However, one of its main downsides is potentially uneven bait consumption among carp, where some would eat more toxic bait than required to affect mortality, and others would eat not enough and later develop avoidance behaviors (Hundt et al. 2020). Nontarget effects on native organisms also need to be considered. Further, if carp can be trained to aggregate at baited sites, it might be better to remove them with automated box nets rather than poison them.

Walsworth et al. (2024) modeled the potential effect of toxic bait application in Utah Lake. The authors predicted the following:

"...if lethal dosage is only 0.5% of carp body weight, approximately 6 tons of bait must be deployed annually to achieve 50% probability of maintaining carp below the biomass target after 20 years of application. Adding mechanical removal effort on top of poison bait application reduces the amount of bait needed to achieve biomass goals. Probabilities of achieving the biomass target >90% can be achieved with either >7.5t of highly potent poison bait deployed annually or with higher amounts (>15t) of lower potency baits deployed annually alongside elevated levels of mechanical removal." Walsworth et al. (2024)

How the authors defined bait potency is not clear, however. Walsworth et al. (2024) assumed 0.5 to 1 percent of carp body weight as lethal dose of bait. However, the mass of the active ingredient (Antimycin-A) probably does not need to exceed 8 milligrams per kilogram (mg/kg) (0.0008-percent body weight) (Poole et al. 2018).

The concept of common carp biocontrol using viruses was most seriously considered in Australia following this country's success in controlling other pest species using viruses (McColl and Sunarto 2020). In this approach, Cyprinid herpesvirus 3 (CyHV-3) was considered as a potential biocontrol agent because of its specificity and low risk of affecting other species. Evidence of herpesvirus in carp in Utah Lake was discovered in the early 2000s, but further studies were never funded despite recommendations (Mills, pers. comm. 2025). This effort was (at least for now) abandoned because of social and logistic concerns. Model simulations and epidemiologic experience have suggested that after an initial drop in carp abundance, the populations would rebound after gaining resistance to the pathogen (Tolo et al. 2023). Model simulations have also suggested that an additional control strategy would be needed (perhaps a genetic method) to effectively reduce carp abundance.

Similar analyses have been conducted for carp populations in North America. Tolo et al. (2023) surveyed five Midwestern lakes with carp disease outbreak episodes and found CyHV-3 to be present in all five lakes in 10 to 50 percent of collected samples. Clearly CyHV-3 is present in the United States, but tests for its presence have not been conducted in Utah Lake. Tolo et al. (2023) also concluded that on its own, CyHV-3 is unlikely to affect long-term control of carp populations, primarily because adult carp populations will ultimately be composed of individuals that are resistant to the disease. However, the authors also

suggested that CyHV-3 may play a role in curbing carp recruitment. Juvenile carp do not inherit immunity to CyHV-3 from their parents; thus, juvenile carp would remain susceptible to CyHV-3. Outbreaks of juvenile carp mortality might be expected once they are exposed to contact with adult individuals. However, juvenile carp experience multiple survival bottlenecks in their development, and the effect of CyHV-3 would be significant only if it were one of the last such bottlenecks. Because CyHV-3 has been detected in multiple regions of the United States, it might be informative to determine if it is also present in Utah Lake.

11.4 Invasive Vegetation

Efforts to control *Phragmites* at Utah Lake have benefited from well-established regional best practices, which FFSL and its partners have been successfully applying. Since 2014, a coordinated initiative has focused on managing invasive vegetation along the lake's shoreline. Through collaboration among FFSL, Utah County, ULA, UDAF, and WRI, substantial progress has been made in curbing the spread of *Phragmites* (FFSL 2022).

Consistency in funding, alignment of goals, coordinated planning, and agency and stakeholder collaboration have been key to the program's success (approximately 80-percent reduction in coverage). The outlook for *Phragmites* control at Utah Lake is promising but will require long-term coordination and management to reduce *Phragmites* and restore native communities to Utah Lake. Challenges remain in the long term for continuing *Phragmites* control, stabilizing Utah Lake vegetation communities, and preventing recolonization of areas previously controlled. Key areas that will support long-term *Phragmites* control at Utah Lake include the following:

- **Continued integrated management:** FFSL will continue using an integrated, adaptive approach, combining herbicide application, mowing, grazing, burning, water management, and revegetation to control *Phragmites* (Duncan 2023).
- **Long-term goals:** The goal is to maintain *Phragmites* cover at less than 20 percent across treated areas (UDAF 2023). This involves regular monitoring and adaptive management, expanding treatment to adjacent upstream locations, and smaller-scale control methods (spot spraying and boat and boom application) to confirm the effectiveness of control measures.
- **Community involvement:** Ongoing collaboration with local communities, stakeholders, and volunteers is needed to support control efforts and promote awareness about the importance of managing invasive species (Farmonaut 2025).
- **Long-term scheduled treatments:** Long-term monitoring and control of *Phragmites* is required to maintain and extend management success at Utah Lake. Comprehensive mapping of *Phragmites* communities adjacent to Utah Lake and within the watershed will be critical to planning and controlling *Phragmites* in the long-term.
- **Monitoring and research:** Continuous monitoring and research will be needed to assess the effectiveness of treatments and adapt management strategies as needed. This includes tracking changes in *Phragmites* cover, density, and impact on native vegetation (UDAF 2023).
- **Revegetation of resilient native plant communities:** Supporting native plant revegetation is critical to long-term stabilization and protection for invasive species invasion or re-establishment.

FFSL's and Utah County's efforts to manage and reduce *Phragmites* at Utah Lake aim to restore and protect the natural habitat of Utah Lake, providing a healthier ecosystem for native species and improved recreational opportunities.

11.5 Littoral Zone and Native Vegetation in and Around Utah Lake

Successful and resilient revegetation of native emergent lakeshore and SAV communities is influenced by many watershed- and lake-specific stressors (for example, *Phragmites*, carp, water clarity, and fluctuating water levels). Native revegetation success must include an ecologically comprehensive and systematic approach to be successful. Efforts to enhance the lakeshore emergent habitats involve targeted revegetation and invasive species management, which are essential for maintaining the ecological health of the lake. Native plant community restoration efforts are a vital component for sustaining the biodiversity and ecological balance of Utah Lake. Several existing Utah Lake conditions must be managed in advance of or in coordination with native revegetation efforts.

Enhancing or re-establishing native plant communities at Utah Lake involves a combination of strategies to address various stressors and improve the persistence of native plant communities. Implementing more natural and less extreme water management systems to mimic natural hydrological patterns can significantly enhance vegetation establishment on lakeshore and floating or SAV. Research at Utah Lake has clearly identified that significant and extreme water surface elevations have a negative effect on native plant restoration establishment and persistence.

Restoring native vegetation and controlling invasive species, such as *Phragmites*, will create a more diverse and resilient ecosystem. Invasive *Phragmites* outcompete native vegetation, reducing habitat diversity and availability. Continuing coordinated and consistent *Phragmites* control within the Utah Lake watershed is necessary to promote sustainable and resilient native emergent communities on the lake shore. Native emergent restoration activities should only occur following a 3-year cycle of initial *Phragmites* control as *Phragmites* are likely to return if the full cycle is not implemented. Long-term maintenance of *Phragmites* control is expected to be part of a successful revegetation program.

Large carp disturb sediment and uproot aquatic plants, increasing water turbidity and degrading water quality, which negatively affects and eliminates SAV macrophyte communities. Reduction or elimination of carp populations in Utah Lake is critical in SAV restoration. Carp control in the Utah Lake watershed is necessary to promote sustainable and resilient native SAV communities and must occur before SAV restoration. The target control limits and management levels to reduce the carp population by 75-percent systemwide and/or carp biomass of 100 kg/ha (unless an alternate density is determined for Utah Lake).

Poor water quality, exacerbated by nutrient pollution, algal blooms, and suspended sediment further reduces SAV establishment in Utah Lake. Light penetration is a significant and limiting factor to SAV establishment. Sediment resuspension via wind and wave action negatively impacts the establishment and germination of SAV, limiting the restoration success. Implementing measures to reduce nutrient inputs to decrease algal growth, measures to reduce carp abundance to decrease bioturbation, and submerged wave breaks to reduce wave resuspension of sediments are some actions that could improve water clarity and support SAV community establishment. Clear-water clarity goals need to be established to determine appropriate actions that could be considered to improve water clarity and promote SAV establishment.

Revegetation success and planning is site specific. Emergent revegetation at Utah Lake should be expanded to the landscape scale. *Phragmites* control is well documented, and controlled areas tend to support better revegetation outcomes. Some initial lessons-learned from revegetation efforts are listed as follows:

- Site-specific analysis is needed to inform species selection, planting density, and plant material type. Research should emphasize the identification and testing of transitional emergent species that have a wide range of tolerances and can withstand significant water-level fluctuations to survive periods of inundation and drought. Utah Lake native emergent transition species well suited for Utah Lake emergent revegetation may include saltgrass, bulrush, and Nebraska sedge.

- Experiments at Utah Lake and supporting literature suggest that plant mixes with high species diversity and higher seeding and planting density have better outcomes in plant establishment. For example, in grassland ecosystems, researchers found that a 100-percent increase in current restoration seeding rates (10,000 PLS/m²; currently 400 to 600 PLS/m²) and a 300-percent increase in seed mix diversity (12 to 40 species; currently 3 to 10 species) may result in better restoration outcomes.
- Seeding is most successful directly adjacent to the water line.
- Because sites with protected shorelines are more likely to support native vegetation, choosing structures to disperse wave energy, and using wave-break tools can improve plant establishment. Measures implemented to protect installed vegetation from wave action using wooden fascines or other breakwater systems until the plants become established should help improve restoration outcomes. Structures to dissipate wave energy should be used until plants are well established, sometimes up to 3 or 4 years.
- In areas with wave action or sediment transport, clustering planting arrangements should be considered to protect establishing plants.
- Plant material and seeds should be anchored with biodegradable materials in areas affected by wave action and erosion (for example, burlap, coir mats, exclusion, tackifier, and sterile cover crops).
- Native species should be reseeded and replanted each year if they do not establish sufficiently to meet restoration goals. Each year, revegetation area should be monitored for survival and vigor. If plantings failed to establish, the same or new potentially more adaptable species should be replanted and reseeded. Building these restoration activities (reseeding, replanting) into the project budget and timeline is essential. Monitoring, invasive species treatment, and reseeding and replanting should continue for a minimum of 5 years.
- SAV revegetation can be conducted where carp control and water clarity targets are already or can be achieved, or possibly in protected areas that can establish protected populations that could create localized beneficial conditions (sediment stabilization, oxygenation of substrates, resistance to sheer stress, and increase water clarity) for SAV community expansion.
- The literature suggests that transplanting whole SAV plant material has a positive effect on establishment. SAV planting methods and materials should be explored and tested.

Similar to the FFSL coordinated *Phragmites* control efforts, revegetation efforts should be coordinated lake-wide, as follows:

- Native plant revegetation efforts in Utah Lake may benefit from centralized coordination to develop a cohesive and comprehensive revegetation plan and coordinate restoration priorities and actions. Revegetation activities should be a multidiscipline effort, addressing ecosystem limitations and other research and enhancement activities currently underway to improve the Utah Lake ecosystem.
- A Utah Lake Vegetation Map should be created to identify Utah Lake plant communities, with emphasis on emergent and SAV communities and existing conditions and plant associations.
- Remaining native emergent, wetland, riparian, or upland communities adjacent to Utah Lake should be identified and protected.
- Long-term planning for revegetation of the Utah Lake system should be created to identify targeted and prioritized restoration areas, milestones, and timelines for restoring Utah Lake emergent and SAV communities.
- GIS layers for soils, topography, lake surface water elevation modeling, inundation depth and duration, and the character of existing conditions could be used to create a Utah Lake revegetation database and to characterize and prioritize areas for revegetation efforts. Revegetation efforts should be mapped using GIS with standardized data collection and included in a spatial land database.

- Monitoring and maintenance activity may consider using imagery to track vegetation establishment, developing conditions, and adaptive management needs. Results from restoration monitoring and maintenance should be shared quickly and inform adaptive management of the site.
- Numerous and consistent sources of native emergent and SAV plant materials should be developed for large-scale revegetation projects at Utah Lake.

Based on the literature review of revegetation information at Utah Lake, the overall recommendations are to prioritize, coordinate, and conduct large-scale, lake-wide restoration for emergent lakeshore communities. Prioritized restoration areas should be identified based on previously treated *Phragmites* locations and should have favorable hydrologic conditions specifically in lakeshore environments based on topography and reduced variation of inundation extremes or changes in water surface elevation. Restoration activities are site specific, and the use of workhorse transitional species is critical to support establishment because of the extreme water-level fluctuations. Revegetation efforts should be maintained and reseeded or replanted for years 1 to 5, with continuous *Phragmites* control. Restoration areas should be evaluated for additional mechanical support to promote community establishment. These supports may include protections from herbivory, erosion, wave action, or drought. If possible, varied vegetation structure (shrubs and trees) should be included in locations that are hydrologically appropriate.

When establishing SAV communities, targeted water clarity goals and the reduction of carp populations must be achieved before, or in tandem with, SAV restoration enhancements. SAV communities should be prioritized in shallower areas to create positive growth conditions with greater light availability. Appropriate SAV restoration locations should be identified in part using GIS spatial analysis and inundation modeling identifying depth and duration. Priority sites would be located in more protected areas with reduced sheer stress and wave action. Installed SAV restoration communities will require maintenance and protection from wave action and herbivory or disturbance from carp. SAV revegetation should not be conducted where light availability and carp biomass targets have not been achieved or are modified locally to support SAV community establishment.

Obtaining large quantities of native emergent and SAV plant material for large-scale revegetation projects requires additional development and will be valuable for future progress in returning Utah Lake to a more natural vegetation composition.

11.6 Native Fish and Aquatic Organisms

Over the past two decades, significant conservation efforts have focused on the recovery of the endangered June sucker (*Chasmistes liorus*) and the preservation of Utah Lake as a critical ecological, historical, and recreational resource. Increased ecological understanding has highlighted key factors—urban development, climate change, and invasive species—that necessitate adaptive management of this dynamic system. As noted by May (2023), “without addressing multiple concurrent stressors, the benefits realized from restoration activities may be limited.”

Enhancing spawning and rearing habitats for juveniles remains a priority for June sucker recovery. Renewed efforts to restore spawning and rearing habitats across the Utah Lake system could be pivotal for long-term re-establishment success. However, recent research has shown that re-establishment of native aquatic vegetation may not necessarily benefit June sucker if nonnative fish species outcompete June sucker for the habitat (May 2023). A 2002 BIO-WEST feasibility report recommended targeting restoration efforts on Hobbie Creek and the American Fork River, with smaller-scale projects on streams like Currant Creek (BIO-WEST 2002). Given the dramatic changes in land use, ownership, and urbanization since 2002, an updated feasibility analysis is essential for guiding future projects.

Additional recommendations for June sucker recovery include increasing the size of hatchery-raised fish beyond the gape limit of predators like northern pike (*Esox lucius*), intensifying predator control efforts,

and conducting bioenergetics studies on piscivorous species such as black bullhead, channel catfish, walleye (*Sander vitreus*) and white bass (*Morone chrysops*). According to findings presented by Dale Fonken and Keith Lawrence at a 2021 Brigham Young University symposium, most hatchery-raised June suckers are stocked at approximately 300 mm, a size vulnerable to predation by northern pike. These predators, known for their rapid growth (exceeding 600 mm by ages 3 to 4 in Utah Lake), pose a substantial threat to hatchery-raised juvenile June suckers. Consequently, increasing stocking sizes and intensifying predator management, particularly for northern pike, are strongly recommended (Fonken and Lawrence 2021; ULA 2023). Furthermore, stocking efforts in spring, as opposed to other seasons, yields greater survival rates for hatchery-raised June suckers (Fonken et al. 2023). Addressing data gaps related to piscivorous sportfish is also crucial for future recovery efforts.

Currently, there is no clear path to restoring Bonneville cutthroat trout populations in Utah Lake. However, the establishment of more suitable conditions—such as creating a functional littoral zone with submergent and emergent native vegetation, reducing turbidity, and improving water quality—could increase the potential for their re-establishment. Given the present status of Utah Lake, the restoration and conservation of Bonneville cutthroat trout remains a premature objective. Bonneville cutthroat trout have historically played a critical role as the primary predators of June suckers before the introduction of nonnative piscivorous fish species (Kershner 1995). Enhancing fringe wetlands, submergent vegetation, and floating vegetation and controlling nonnative piscivorous fish species could mitigate predation impacts on June suckers. These improvements would provide increased spawning refugia and support a return to historical, stable population levels (Billman 2008; BIO-WEST 2019). Furthermore, effective conservation efforts should prioritize protecting critical spawning tributaries from anthropogenic impacts and sedimentation to preserve the essential habitats needed for the recovery of Bonneville cutthroat trout. However, other introduced fish species, such as rainbow and brown trout, have been shown to impact cutthroat populations, and these fish species are present in Utah Lake tributaries.

Given the complexity and intensity of the efforts required to restore and enhance the native mollusk communities of Utah Lake, these efforts would be premature and are outside the scope of this project. Like with Bonneville cutthroat trout, systemic enhancements of Utah Lake are needed before strategy implementation. The invasive *Corbicula fluminea* (*Corbicula*) has established in Utah Lake (Benson et al. 2024), where native unionid mussels are currently extirpated. In part, “to protect freshwater mussel habitats and populations from nonnative unionid mussel introductions, fish health inspectors should be particularly vigilant for the presence of glochidial cysts in fish stocks” (Mock et al. 2004). As water quality improves through ongoing management efforts, *Corbicula* is likely to outcompete native mussels and proliferate more rapidly, capitalizing on its tolerance for variable conditions and efficient reproductive strategies. Although this proliferation could be perceived as a negative outcome because of competition with potential unionid reintroduction, *Corbicula* could also provide ecosystem benefits. As efficient filter feeders, *Corbicula* can enhance water clarity, promote nutrient cycling, and stabilize sediment, potentially contributing to broader ecological improvements within Utah Lake, and these ecological services could contribute to broader restoration objectives for Utah Lake. Thus, although the risks of *Corbicula*'s expansion must be carefully managed, its role in improving certain water quality parameters may offer pragmatic benefits to the lake's restoration efforts. Stakeholders must weigh these benefits against the challenges posed by the continued dominance of this invasive species.

Invasive species and threats to the Columbia spotted frog, such as mosquitofish, should be managed. Work should be done to identify key habitat for Columbia spotted frog (ponds that do not shrink in size throughout the year and have emergent vegetation but also deep littoral zones) (Welch and MacMahon 2005) and create additional habitat to expand populations around Utah Lake.

Small-scale remedies with the potential to inform large-scale implementations are valuable for advancing ecological enhancement projects. One possible example is constructed floating wetlands (CFWs), although the details of installation in Utah Lake are unclear. Relatively recently gaining recognition as a scalable

solution to challenges such as water quality improvement, these engineered floating platforms use emergent macrophytes to enhance water quality and provide ecological benefits. Their customizable design—including variations in materials, size, macrophyte ratios, and anchoring mechanisms—makes CFWs an “inexpensive low energy eco-technology” (Pavlineri et al. 2017) and a versatile tool for multiple enhancement objectives beyond native aquatic species restoration.

In the context of Utah Lake, CFWs offer potential benefits such as nutrient cycling, expanded aquatic habitat, wave and wind action buffering, and native macrophyte community promotion. The structural complexity created by macrophyte roots hanging below the floating mats provides shelter for diverse aquatic organisms (Bi et al. 2019). Strategically placing CFWs near the deltas of June sucker spawning tributaries could support juvenile fish as they grow and establish in the lake system. CFWs also play a crucial role in nutrient cycling by reducing nitrogen and phosphorus through plant uptake and microbial activity (Bi et al. 2019; Pavlineri et al. 2017). Furthermore, the application of CFWs have shown promise for the goal of protecting the littoral zones of freshwater bodies (Pavlineri et al. 2017; Zhu et al. 2011). These processes help mitigate eutrophication, algal blooms, and wind-driven turbidity, thereby improving water quality. Despite their promise, challenges with CFWs remain, including data gaps on the nutrient uptake rates of different plants, maintenance requirements, and the seasonal robustness of individual plots, which may limit their feasibility and large-scale application (Likitswat et al. 2023).

11.7 Avifauna

Restoring shorebird, waterfowl, and piscivorous bird habitats at Utah Lake is a key ecological endeavor. Efforts to enhance these habitats involve targeted revegetation and invasive species management, which are essential for maintaining the ecological health of the lake. For instance, efforts of resource managers aim to improve habitat quality by planting native vegetation and controlling invasive species like *Phragmites*. This not only supports diverse wildlife, including migratory birds, amphibians, and fish, but also helps stabilize shorelines and improve water quality. Native plants provide essential food and nesting sites for shorebirds like American avocets and black-necked stilts, as well as waterfowl like ducks and geese. Additionally, piscivorous birds such as pelicans, cormorants, and grebes benefit from healthier fish populations supported by improved water quality and habitat conditions. Overall, these restoration efforts are vital for sustaining the biodiversity and ecological balance of Utah Lake so it can become a thriving habitat for a wide range of bird species.

Enhancing the avian habitat at Utah Lake involves a combination of strategies to address various stressors and improve habitat suitability. Implementing dynamic water management systems to mimic natural hydrological patterns can significantly enhance habitat suitability. For example, Larson et al. (2020) demonstrated that managed lakes with controlled water levels had greater waterbird abundance and species richness. This approach currently cannot be applied to Utah Lake to improve conditions for migratory shorebirds and other waterbirds, due to existing water agreements and distribution plans.

Restoring native vegetation and controlling invasive species, such as *Phragmites*, will create a more diverse and resilient ecosystem. Invasive *Phragmites* outcompete native vegetation, reducing habitat diversity and availability for nesting and foraging. Large carp disturb sediment and uproot aquatic plants, increasing water turbidity and degrading water quality, which negatively affects the availability of prey and suitable nesting sites for waterbirds (Haas et al. 2007; Kloskowski et al. 2010; Nieoczym and Kloskowski 2018). Large carp may also affect nesting behavior in some birds. Santolo (2021) observed that grebes changed their nesting habitat on a pond with large carp from their typical floating nests to ground nesting on islands, possibly to avoid nest destruction by the carp. This was also observed at a pond with large carp in Utah, where many western and Clark's grebe nests were built on rock outcrops, and an American coot nest was found destroyed, likely by carp, after egg-laying had begun.

Research and monitoring in other systems has shown that poor water quality, exacerbated by nutrient pollution and algal blooms, further diminishes habitat suitability and can lead to health issues for birds. Increased turbidity reduces the ability of birds to locate prey, affecting their foraging efficiency (Ortega et al. 2020). Additionally, toxicological stressors, such as contaminants from industrial effluents and pesticides, can harm invertebrate populations (Münze et al. 2017; Quanz et al. 2021; Enns et al. 2023) and fish (Mehdi et al. 2021), which are crucial food sources for many bird species. These combined stressors, which are also found at Utah Lake, create challenging conditions for avifauna, potentially leading to decreased reproductive success and population declines, ultimately threatening the ecological balance and biodiversity of Utah Lake.

Wang et al. (2024) investigated the temporal and spatial variations of nutrient and trace metal loading in Utah Lake and identified significant implications for waterbird habitat restoration. Elevated concentrations of trace metals and nutrients, particularly in certain hotspots, can adversely affect the health and survival of waterbirds. These variations allow for targeted remediation efforts to reduce pollutant levels in critical areas, thereby improving the overall water quality. Additionally, knowledge of the lake's mixing patterns can inform habitat management strategies to confirm that waterbird nesting and feeding areas are in regions with reduced pollutant concentrations. By addressing these specific issues, restoration efforts can create a safer and more supportive environment for waterbird populations, ultimately contributing to the success of habitat restoration at Utah Lake.

Restoring waterbird habitat at Utah Lake by creating or enhancing existing wetlands would provide additional habitat for migratory shorebirds to offset the loss of wetland habitat. Water for wetland restoration or creation could be augmented using effluent from wastewater treatment plants. The contaminants, health, and survival of migratory shorebirds in natural versus effluent-augmented wetlands would need to be assessed. Ross et al. (2023) found no significant differences in blood pollutant concentrations between birds in natural and effluent-augmented wetlands, suggesting that this approach could be viable. Monitoring and managing pollutant levels in these artificial habitats will be crucial to confirm they do not exceed safe thresholds for wildlife. Regular health assessments of the bird populations using these habitats can help identify and mitigate potential health risks, such as disease outbreaks or physiological stress. Appropriately managing the artificial habitats to support the specific needs of different bird species, including providing safe nesting and feeding areas, is essential. Implementing long-term monitoring programs to track the survival and health of bird populations in these habitats will allow for adaptive management practices to be applied as needed. By incorporating these strategies, the restoration efforts at Utah Lake can create a sustainable and supportive environment for waterbird populations.

Larson et al. (2020) demonstrated that shallow lake management, including water-level management, can significantly enhance habitat quality and attract waterbirds during fall migration. Their study found that managed lakes had lower water depths, greater water quality and clarity, more SAV, and more wild rice compared to unmanaged lakes. Waterbird abundance and species richness were positively influenced by these managed conditions, highlighting the importance of water-level management in creating favorable habitats for waterbirds. This approach can be applied to Utah Lake to improve habitat conditions for migratory shorebirds and other waterbirds.

Water-level fluctuations can significantly affect bird nesting success. Riensche et al. (2009) developed artificial nest platforms for western and Clark's grebes to address the challenges posed by fluctuating water levels. These platforms were designed to remain stable despite changes in water levels, resulting in high utilization and nest success rates. That study underscores the importance of stable water levels during the nesting season to prevent nest failures and promote successful reproduction. Implementing similar strategies at Utah Lake could help mitigate the negative effects of water-level fluctuations on bird nesting.

Hansson et al. (2010) found that waterfowl abundance and species richness were greater in shallow lakes with clear water and abundant macrophytes. The study suggests that maintaining clear-water conditions and promoting macrophyte growth can enhance habitat quality for waterfowl. This finding supports the need for water quality management and vegetation restoration at Utah Lake to improve conditions for avian species.

Holopainen et al. (2024) highlighted the effects of both bottom-up processes (for example, nutrient pollution) and top-down processes (for example, predation by nonnative species, which refers to the influence of predators on the ecosystem from the higher levels of the food web) on waterbird populations. Their study found that nutrient pollution and increased predator abundance negatively affected waterbird populations, particularly in eutrophic lakes. This underscores the importance of addressing both nutrient pollution and invasive species control (that is, carp) in the restoration efforts at Utah Lake. Invasive species control involves managing nonnative species that disrupt the ecosystem, which can include both animal species, such as carp, and plant species, such as *Phragmites*, that outcompete native vegetation. Effective control measures are needed to restore ecological balance and support the health of native wildlife populations.

Improvements and enhancements related to the removal or reduction of stressors, along with the reintroduction of native plant and animal species and habitats, can significantly improve the beneficial uses of Utah Lake for avifauna. By restoring SAV and native plants in the littoral zone, the habitat quality for waterbirds will be enhanced, providing better foraging, nesting, and shelter opportunities (Lantz et al. 2010; Miller et al. 2018; Larson et al. 2020). Reintroducing native fish species can help rebalance the food web, providing a more stable and diverse ecosystem that supports the dietary needs of piscivorous birds like pelicans, cormorants, and grebes. Additionally, reducing invasive species such as *Phragmites* and carp will mitigate their negative effects on water quality and habitat structure, further benefiting waterbirds. These ecological improvements will not only support avifauna but also enhance recreational activities for humans, such as waterfowl hunting and birdwatching, by creating a healthier and more vibrant ecosystem. Overall, a more balanced and native-dominated ecosystem at Utah Lake will lead to increased biodiversity, improved water quality, and greater opportunities for both wildlife and human enjoyment.

11.8 Recreation Conditions and Access

Utah Lake offers a diverse range of year-round recreational opportunities, including boating, fishing, swimming, wildlife viewing, hiking, camping, and winter sports. To support and enhance these activities, the ULA has identified and mapped 35 public access points, each with detailed site information available online, including amenities, recreation types, and site management contacts. To further improve access and user experience, ULA is developing a comprehensive Recreation Access Plan that assesses current conditions, identifies infrastructure improvements, and proposes new access points. This planning effort is informed by stakeholder engagement, including interviews with lakeshore municipalities, which revealed a shared vision for enhancing connectivity, creating multiuse recreational spaces, and preserving natural areas and wetlands.

Recreation access around Utah Lake is managed through a bottom-up framework, where local stakeholders collaborate to tailor improvements to site-specific needs. Although this approach fosters community engagement, it also presents challenges related to coordination and consistency. Multiple state, local, and federal agencies, including FFSL, DWR, DSP, DOR, and URMCC, play active roles in recreation management, highlighting the need for clear jurisdictional coordination. Public safety and education are also key priorities, with ULA leading initiatives such as signage improvements, emergency

planning, and outreach on water safety and HAB advisories. Ecological health, particularly water quality, is foundational to expanding recreational use and improving public perception of Utah Lake.

11.9 Supporting Current Land Uses and Improving Utah Lake for Public Benefit

Elements (h) and (i) of S.B. 270 direct FFSL to study strategies for “otherwise improving the use of Utah Lake for residents and visitors,” (element [h]) and “substantially accommodating an existing use on land in or around Utah Lake” (element [i]).

These provisions recognize the need to balance ecological restoration with human use and land-based activities. Many lands surrounding Utah Lake function as hydrologically connected wetlands, which are essential to the lake’s ecological integrity. These wetlands naturally filter sediments and nutrients, stabilize shorelines, mitigate flooding, and support biodiversity. Their health directly influences water quality and clarity, key factors in enabling safe and enjoyable recreational activities such as swimming, boating, and fishing.

Improving the lake’s usability for residents and visitors (element [h]) depends on addressing these ecological functions. Without clean water and stable shorelines, recreational access and public perception of the lake will remain limited. Thus, ecological enhancement is not only an environmental priority but also a strategic investment in the lake’s social and economic value.

Element (i) emphasizes the importance of accommodating existing land uses, which may include agriculture, recreation, conservation, and infrastructure. Agricultural lands near Utah Lake, particularly those in valley bottoms with seasonal flooding or irrigation, can mimic wetland functions. When managed appropriately, these lands can act as buffers that support water quality and aquatic habitat. Recognizing and integrating these multifunctional landscapes into lake management planning aligns with S.B. 270’s goal to enhance both ecological and human benefits.

12. Information Needs and Next Steps

In the process of reviewing existing information and discussing the potential enhancement of Utah Lake with key stakeholders, managers, and researchers, several outstanding information needs were identified. These information needs (Table 12-1) will help to inform future research and management efforts aimed at enhancing the various benefit areas specified in S.B. 270. The next phase of the ULS will focus on further exploring the information needs described in Table 12-1 and the path forward to enhance Utah Lake.

Table 12-1. Scientific, Technical, Measurement, and Other Information Needs by Benefit Area

Benefit Area	Information Need
Restoration of the littoral zone	Identification of potential treatments for stabilizing sediments beyond revegetation of the lakebed and the recolonization of the lakebed with benthic mussels or other macroinvertebrates. It remains unclear if these treatments are feasible for Utah Lake given the nature of the sediments.
	Conducting hydrodynamic modeling of Utah Lake is crucial to identify key areas where sediment resuspension and transport occur. This analysis aims to answer two primary questions: <i>which locations within the lake are most susceptible to sediment disturbance and movement?</i> and <i>what innovative technologies or treatments could effectively mitigate sediment resuspension and transport in these critical areas?</i> Potential solutions to explore include submerged wave breaks, strategic placement of underwater structures, and other engineered interventions designed to alter currents and reduce sediment mobility.
	Positive feedback and unintentional consequences of reduced phytoplankton growth, increased water clarity, and subsequent macrophyte recovery.
Water quality and clarity	Development of nutrient targets for Utah Lake to support designated beneficial uses are currently under development through the ULWQS. It remains unclear whether future numeric targets developed by ULWQS will be supportive of the restoration of submergent benthic vegetation and specifically allow for improved water clarity/increased light penetration to support SAV growth. In addition, it remains unclear to what external nutrient load (and subsequent nutrient concentrations) will be required to revert Utah Lake back to a clear-water state.
Invasive fish management (carp)	Identification of the threshold density of carp in Utah Lake at which impacts to the lake ecosystem (such as turbidity and benthic vegetation) are diminished.
	Identification of the main driver for the discrepancy between the observed carp population age structure (primarily older carp) and the structure predicted by the model (primarily young carp).
	To develop an effective carp management plan, addressing two critical questions is proposed. First, recruitment hotspots: <i>are there specific areas within the lake where carp reproduction is particularly successful? and if so, can these locations be identified?</i> Second, seasonal behavior patterns: <i>do carp exhibit seasonal aggregation behaviors in the lake?</i> This includes potential winter aggregations within the lake, and spring spawning migrations into tributary streams or adjacent wetland areas. Understanding these aspects of carp behavior and life cycle will significantly inform the management approach and help to establish more effective targeted interventions.
Invasive vegetation (<i>Phragmites</i>)	Invasive vegetation mapping in and around Utah Lake, including into watershed to identify seed sources.
	Identification of which active revegetation methods are most successful in re-establishing native plant communities following <i>Phragmites</i> treatments.
	Most efficient methods for breaking down mats of dead <i>Phragmites</i> that remain following treatments.
Native littoral zone and other vegetation	Mapping of areas with high potential for native plant community restoration.
	A native vegetation restoration toolbox will help identify a prioritized list of species for restoration in different landscape positions and hydrologic conditions to help guide adaptive management of a succession of different species over time given the constraints of fluctuating water levels.
	Knowledge of environmental tolerances and methods for controlled propagation of SAV species.
	Adaptive restoration efforts to restore SAV while controlling specific variables, such as carp exclusion.
	Greater knowledge of the existing seedbank around Utah Lake, including an inventory of species that are present.
	Improved seeding methods to improve the success of native vegetation seeding efforts.

Review of Existing Information Report

Benefit Area	Information Need
Native aquatic organisms	Detailed knowledge of June sucker recruitment and knowledge of their movement throughout the lake at different life stages (juvenile, adult).
	Improved knowledge of June sucker spawning and recruitment limitations to inform adaptive management of the PRDRP and other areas to increase recruitment.
	Improved knowledge of the diets of the various fish species (<i>who is eating what?</i>) in the lake will inform fisheries management efforts, and specifically the efforts to improve carp and June sucker populations.
	Survey information for presence of Columbia spotted frog and available habitat in and around Utah Lake.
	Feasibility analysis of the potential to restore native unionid mussels to Utah Lake.
Avifauna	Expanded bird monitoring programs are needed to understand avian use of Utah Lake, including habitat use patterns, nesting sites, foraging areas, migratory stopovers, and food web dynamics. It is also unclear how changes in fish and invertebrate populations affect bird usage of Utah Lake.
	Improved understanding of Utah Lake avian habitat needs, including water depth requirements and the effects of different stressors (such as invasive species, water quality degradation, and habitat alteration).
	Understanding of the effects of restoration efforts (such as reintroduction of native plants and animals) on improving habitat quality for birds.
	Understanding of contaminants' presence and effects on different bird species and in the lake ecosystem (benthic sediments, plants, and other organisms).
Recreation access and opportunities	An economic analysis of Utah Lake's recreational potential holds significant value for understanding and quantifying the benefits of enhanced opportunities for the state, visitors, and residents. By conducting a comprehensive economic analysis, stakeholders can make informed decisions about the future of Utah Lake so that enhancements not only improve recreational opportunities but also contribute significantly to the economic well-being of the state, visitors, and residents. An economic analysis would provide data-driven support for public and private investments in lake enhancements and demonstrate return on investment for proposed recreational improvements. In addition, an economic analysis would support grant applications and funding requests with economic impact projections. An economic analysis could examine the following: ▪ What are direct and indirect economic contributions to local and state economies from Utah Lake, as well as potential job creation and income generation from increased tourism? ▪ What is the economic value of improved water quality and ecosystem health? ▪ What are long-term economic benefits of environmental conservation efforts? ▪ How can enhanced recreation at Utah Lake benefit the broader regional economy?

13. References

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Appendix B Steering Committee and Planning Team



UTAH LAKE STUDY



Appendix B. Steering Committee and Planning Team Members

Name	Position	Affiliation
Steering Committee		
Jamie Barnes	Director	Utah Division of Forestry, Fire and State Lands
Darlene Batatian	State Geologist, Director	Utah Geological Survey
Mike Begley	Assistant Attorney General	Utah Attorney General's Office
Jason Curry	Director	Utah Division of Outdoor Recreation
Joel Ferry	Director	Utah Department of Natural Resources
Candice Hasenyager	Director	Utah Division of Water Resources
Redge Johnson	Director	Utah Public Lands Policy Coordinating Office
John Mackey	Director	Utah Division of Water Quality
Mike Mills	Director	Utah Reclamation Mitigation Conservation
Riley Peck	Director	Utah Division of Wildlife Resources
Luke Peterson	Director	Utah Lake Authority
Scott Strong	Director	Utah State Parks
Teresa Wilhelmsen	State Engineer, Director	Utah Division of Water Rights
Planning Team		
Bryce Armstrong	Associate Director	Utah County Community Development
Mark Boshell	Deputy Director	Utah Public Lands Policy Coordinating Office
Sam Braegger	Deputy Director	Utah Lake Authority
Terry Camp	Vice President	Utah Farm Bureau Federation
Joe Crawford	Watershed Programs Manager	Central Utah Water Conservancy District



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Name	Position	Affiliation
Scott Daly	Utah Lake Watershed Coordinator	Utah Division of Water Quality
Becka Downard	Wetlands Section Manager	Utah Geologic Survey
Keith Hambrecht	Restoration Program Manager	Utah Division of Forestry, Fire and State Lands
Ryan Hamilton	Utah Lake and Jordan River Regional Engineer	Utah Division of Water Rights
Chris Haramoto	Deputy Director	Utah Division of State Parks
Emily Jainarain	Geologist	Utah Geologic Survey
Carly Lansche	Trails and Planning Program Director	Utah Division of Outdoor Recreation
Keith Lawrence	Native Aquatics Project Leader	Utah Division of Wildlife Resources
Suzy Lee	Lands Program Manager – Utah Lake/Jordan River	Utah Division of Forestry, Fire and State Lands
Max Malmquist	Saline Lakes Engagement Manager	Audubon Society
Anna McEntire	Managing Director	Institute for Land, Water and Air
Richard Nielsen	Director	Utah County Public Works
Sarah Seegert	Recovery Program Director	Utah Division of Wildlife Resources
Ben Stireman	Deputy Director – Sovereign Lands	Utah Division of Forestry, Fire and State Lands
Wade Tuft	President	Utah Lake Water Users Association
Tim Walsworth	Professor	Utah State University
Joel Williams	Deputy Director	Utah Division of Water Resources



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Appendix C

Goose Point Pilot Project Exclosure Construction Conceptual Design

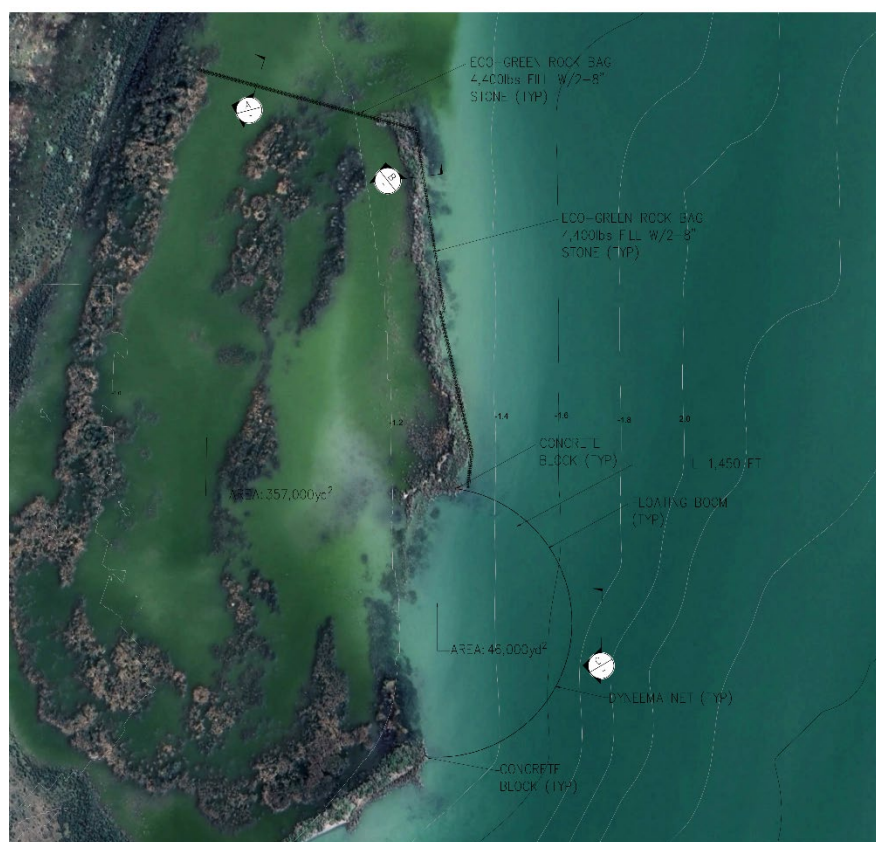
Appendix C. Goose Point Pilot Project Enclosure Construction Conceptual Designs

For the Goose Point pilot project, three designs (Options 1, 2, and 3) have been developed for constructing a robust carp-free enclosure zone at Goose Point that fosters a clearer, healthier aquatic environment for natural protection. These conceptual design options are based on preliminary site reconnaissance and hydrodynamic modeling and could be moved forward following more detailed site investigations and modeling.

C.1 Option 1

The first option (Option 1) proposes the strategic use of gravel-filled rock bags to effectively seal off Goose Point at the northern boundary, just below Pelican Point (Figure C-1). Additionally, similar rock bags may be stacked along the outer edge of a gravel bar feature that stretches in a north-south alignment. The need for these additional rock bags would depend on evaluation of the competency of the gravel bar to serve as robust barrier and potential wave heights that could be anticipated at the gravel bar. For a cost estimate, the need for these additional rock bags is assumed. At the northern boundary closure, the rock bags would be stacked in seven layers, while only three layers would be necessary on the outer side of the gravel bar to enclose an area of approximately 298,500 square meters (m^2) within Goose Bay. A natural opening just south of the gravel bar would allow water to flush into the pilot project enclosure.

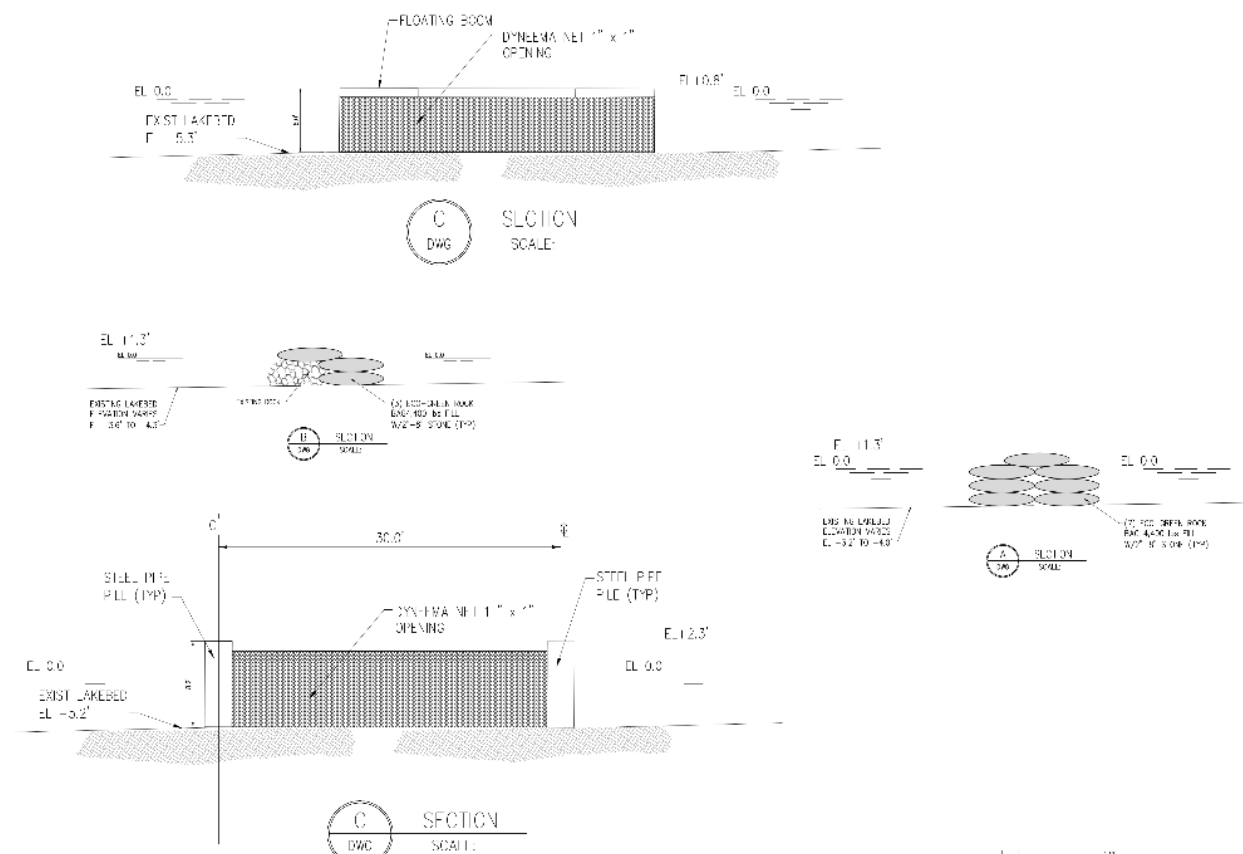
Figure C-1. Option 1 Conceptual Design



To the east of this entrance, a half-circle barrier net will be introduced, creating an additional area of 38,500 m² that will remain unaffected even during low water season (illustrated on Figure C-1). This barrier, approximately 440 meters long, would consist of a series of high-density-polyethylene floating booms connected by stainless-steel chains. High-tension netting would be attached to the bottom of the floating booms to prevent carp, algae, and floating debris from entering the enclosed area. This high-tension netting would be crafted from high-modulus polyethylene fiber (HMPE), which resists abrasion and offers superior fatigue performance compared with steel wire and also lightweight enough to float. Moreover, this fiber is highly ultraviolet-resistant and resilient against a broad range of industrial chemicals. Its smooth surface, characterized by a low coefficient of friction, minimizes damage to other system components and marine life and also significantly reduces the risk of biofouling growth. Figure C-2 depicts a cross-section of rock bags along the northern and eastern boundaries of the Goose Point enclosure including a section of floating boom system with HMPE netting.

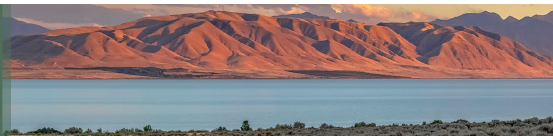
By adopting this comprehensive approach, a pilot site would be created that would serve as a model for future conservation efforts. The estimated rough cost for construction of this pilot project is \$2,150,000.

Figure C-2. Option 1 Cross-Section



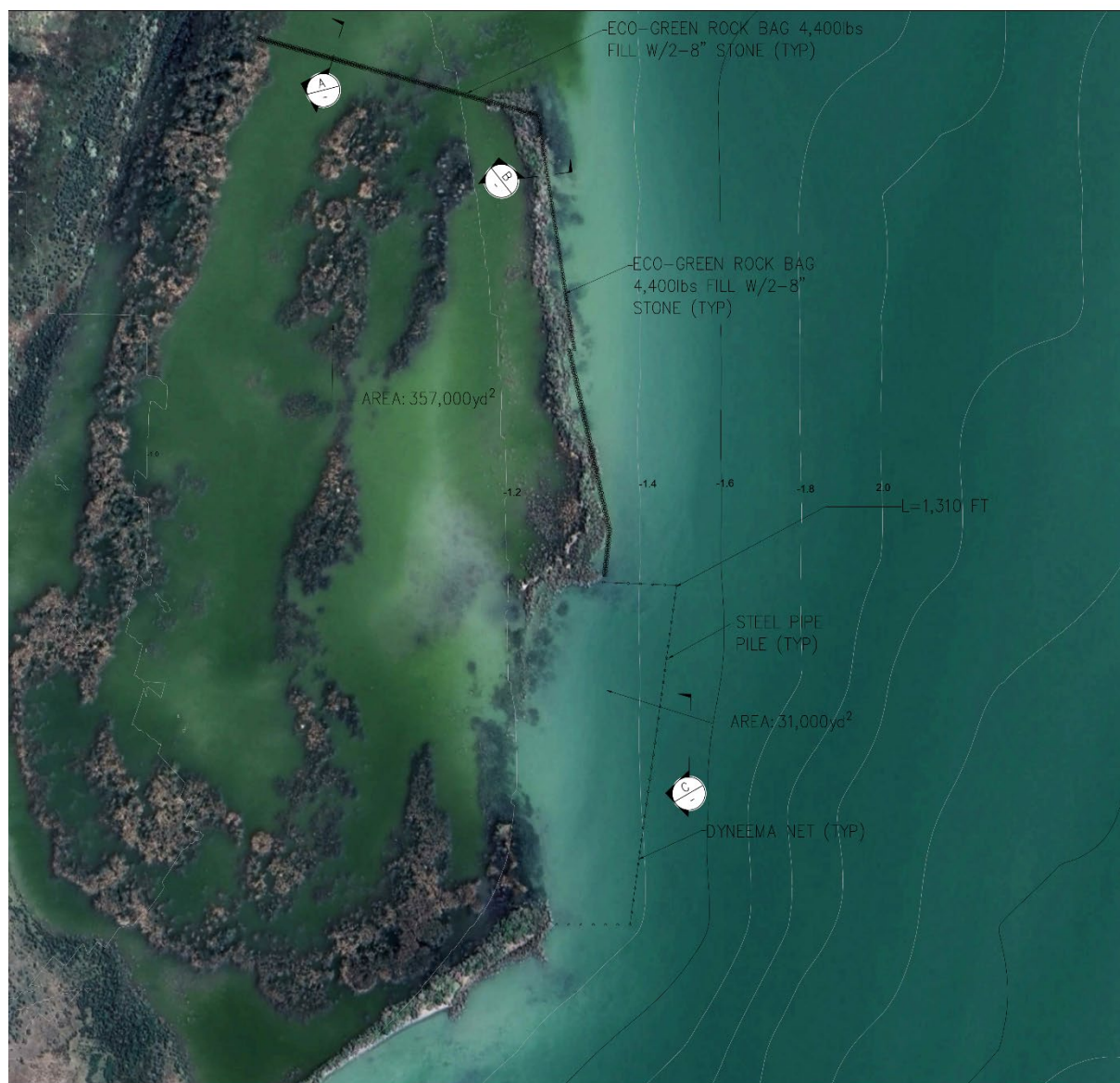
C.2 Option 2

The second option (Option 2) closely mirrors Option 1 in its concept, as it would create a large enclosure measuring approximately 298,500 m², located just south of Pelican Point



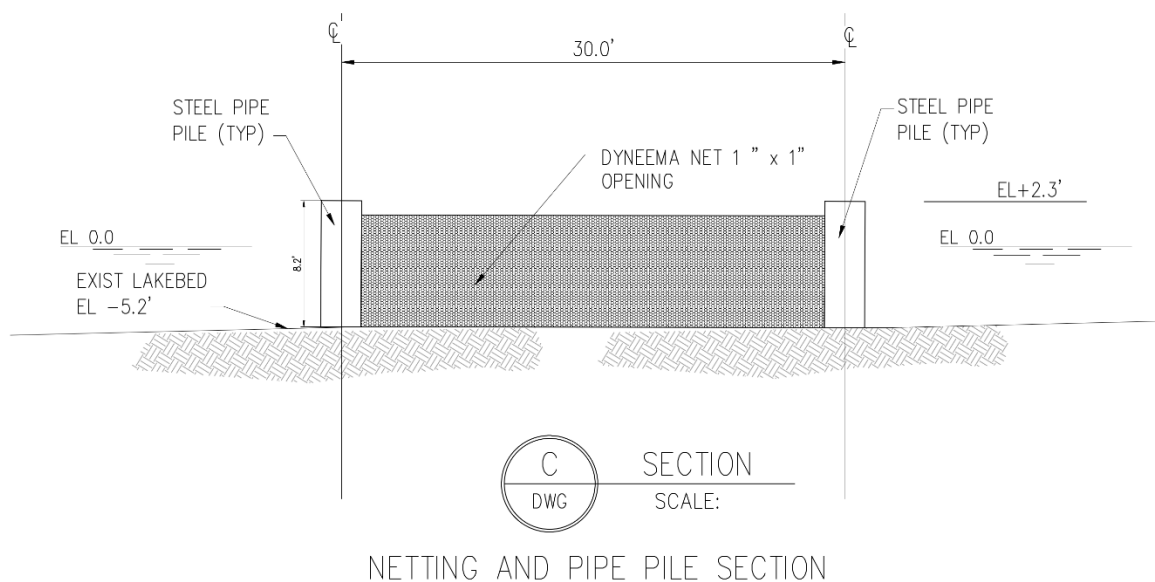
(Figure C-3). To construct the barrier, galvanized steel pipe piles would be installed along the eastern side of the enclosure; this area would have a rectangular shape, extending about 400 meters in length. To the east of the entrance, an additional 26,000 m² would remain unaffected, even during low water levels. HMPE) would be attached to the steel piles to prevent the entry of carp, algae, and floating debris into the enclosed space (illustrated on Figure C-3). A sectional view of the steel piles and HMPE fiber netting is shown on Figure C-4. The rough construction cost of this option is \$3,500,000.

Figure C-3. Option 2 Conceptual Design



Notes: H:\Halla Breakwater\Project Files\Contract\X-Ref\1500-600-A1.dwg

Figure C-4. Option 2 Cross-Section



C.3 Option 3

The third option (Option 3) is a modified version of Option 1 (Figure C-5). In this option, the rock bags along the northern boundary are replaced with a floating boom that has HMPE netting, and rock bags on the gravel bar on eastern boundary side are removed (depicted on Figure C-5). The total surface area of the enclosure remains the same as in Option 1 (298,500 m² plus the additional 38,500 m² enclosed by the half-circle barrier net). The estimated construction cost for this project is approximately \$2,250,000.

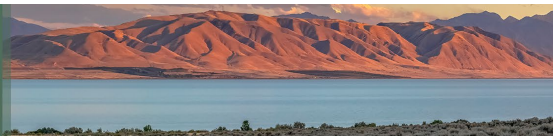
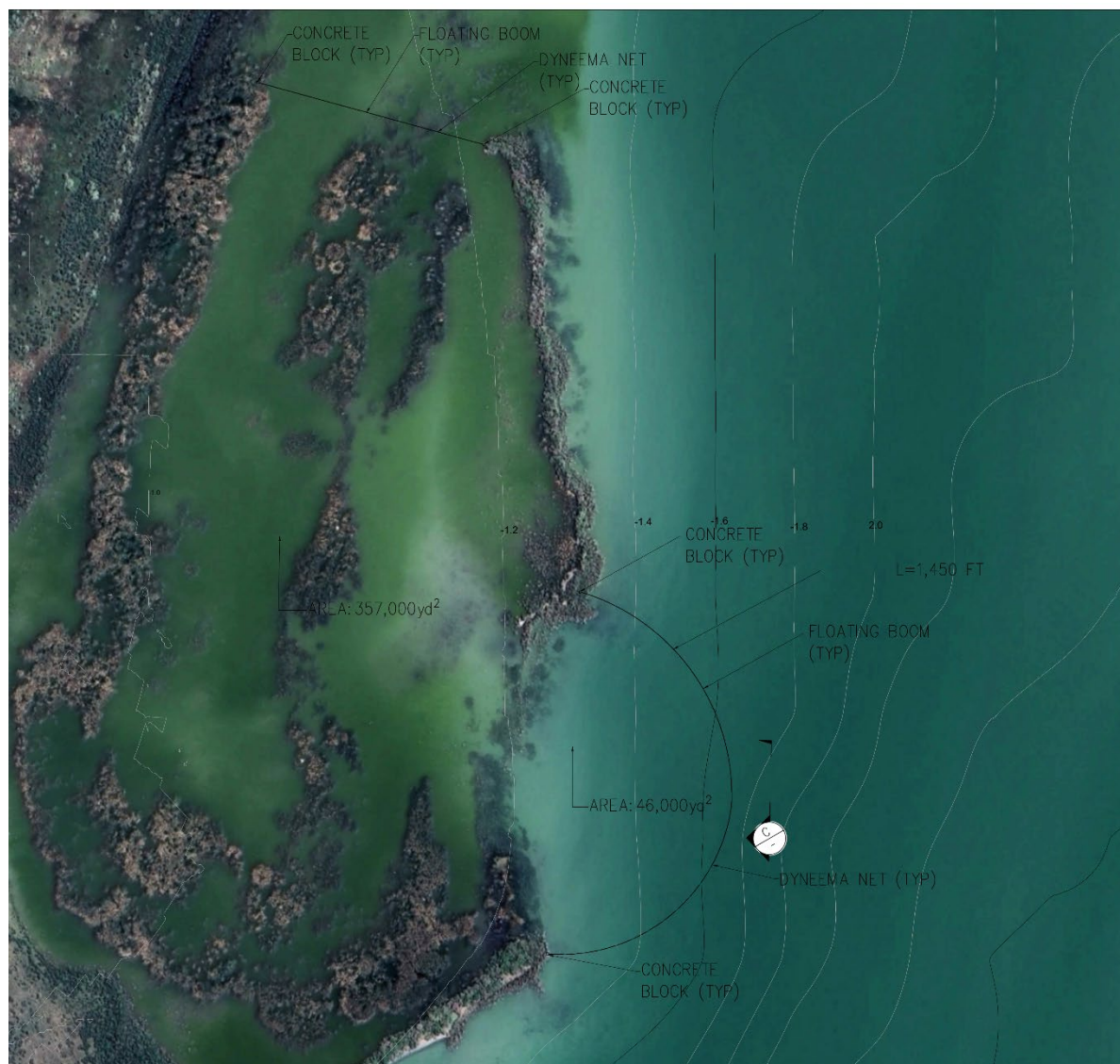


Figure C-5. Option 3 Conceptual Design



C.4 Summary

The following summarizes the three conceptual design options, and Table C-1 summarizes their advantages and disadvantages:

- **Option 1** would provide a larger enclosure surface area and be more economical to construct than Option 2. However, using rock bags to seal off the northern and eastern boundaries of the area presents a risk of remaining dry during periods of low lake levels, which could have negative ecological consequences. Rock bags also could restrict water exchange between wetlands and lake. While interpreting how wetlands reduce turbidity could be difficult, Options 1 and 2 could be blended to allow sufficient water exchange to observe wetland attenuation of turbidity, while also using lower cost construction methods for most of the barrier.

- **Option 2** would be more resilient to ice load impacts compared with Options 1 and 3 because the floating boom could experience ice build-up in front of it. However, this option could require site-specific geotechnical investigations, and its construction costs would be higher than those of the other two options.
- **Option 3** would be the second least-expensive to construct, but it would frequently face the risk of wave overtopping. Additionally, the gravel bar, aligned in a north-south direction, might not provide adequate protection against carp intrusion from the lakeside.

Table C-1. Advantages and Disadvantages of Conceptual Design Options

Option	Advantages	Disadvantages
Option 1	▪ Has lowest construction costs	▪ Has risk of forming a dry area behind barrier during low water levels in the lake, which may have ecological implications ▪ Inhibits turbid water exchange with the lake
Option 2	▪ Provides most resiliency to ice loads ▪ Allows free exchange of turbid water with lake	▪ Requires site-specific geotechnical investigation is required ▪ Has highest construction costs
Option 3	▪ Has relatively low construction cost	▪ Has potential risk of wave overtopping ▪ North-south aligned gravel bar provides inadequate protection against carp fish intrusion from the lake side

In summary, Option 1 is more appealing regarding design and construction costs compared with the other options, making it the preferred option, provided that a portion of it is replace with fencing or netting to allow enough free exchange of turbid water with the lake to evaluate turbidity reduction in wetlands. However, detailed design and construction costs must be thoroughly evaluated to move this concept forward.

To minimize the stirring of fine-grained suspended sediment in the lake's water column, particularly along the shoreline, structural mitigation alternatives should be considered. Such alternatives, including nearshore reef structures or shore-perpendicular groins, could reduce energy caused by waves and currents. To effectively recommend a structural mitigation alternative, annual fluctuations in local wave and current conditions during both low and high lake levels need to be comprehensively understood and considered; therefore, additional coupled wave and current modeling are recommended to explore these alternatives further across varying lake levels. To support this effort, an internal scope of work has been prepared to outline the necessary numerical modeling (see Appendix G of the *Draft Utah Lake Study Report*).



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Appendix D

Utah Lake Revegetation Plant List



Appendix D. Utah Lake Revegetation Plant List

Table D-1. Location Suitability Criteria for Revegetation

Category	Criteria
Hydrology	Water inundation depth
	Duration of Inundation
	Probability of Inundation
Substrate	Sediment Characterization (for example, fines, gravel, sand)
	Shear stress; relative shear stress
Light	Light availability at bottom and in the water column
Nutrients	Nutrient requirements for macrophytes
	Nutrient availability
Biological promoters	Proximity to current native vegetation areas
	Proximity to known seed bank locations
Biological stressors	Presence and absence of phragmites
	Phragmites control areas
	Presence or absence of carp (latter in carp exclosures)
	Potential for periphyton growth on macrophytes



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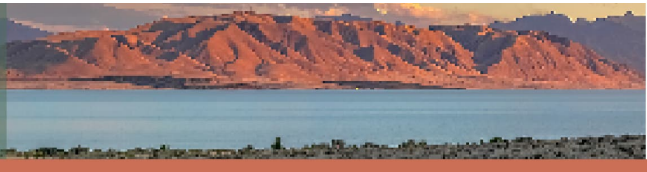
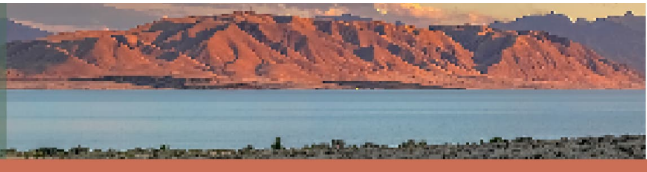


Table D-2. Submerged Aquatic Vegetation Species

Common Name	Scientific Name	Classification	Lifespan	Inundation Preference	Revegetation Establishment Notes	Light Compensation Point (μmol/m²/s)	Species Notes and Propagation
Longleaf pondweed	<i>Potamogeton nodosus</i>	Submerged and floating	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Recommended; provides complexity		Recommended; has some ability to withstanding carp.
Leafy pondweed	<i>Potamogeton foliosus</i>	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Good structure		N/A
Sago pondweed	<i>Stuckenia pectinata</i> [<i>Potamogeton pectinatus</i>]	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Similar to leafy pond; easy to establish from cuttings; very common; did well in Provo River delta; easy to propagate with cuttings; good structure and complexity; waterfowl eat all parts	44.8 ^[a] and 41 ^[b]	Recommended; easy to establish common
small pondweed	<i>Potamogeton foliosus</i>	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV			Very good growth in buckets and soil from pellets but must transplant within 3 weeks maximum
fine leaf pondweed	<i>stucknina filiformus</i>	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV			May hybridize with sago pondweed; robust but not common species.
broadleaf pondweed	<i>Stucknia striata</i> (<i>Potamogeton latifolius</i>)	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV			Uncommon
Spiral ditchgrass	<i>Ruppia cirrhosa</i>	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Experiment where the excavated channels had standing water; clumped vs unclumped; good success initially, but long term they could not find it; potentially due to higher water, it may like saline water or higher alkalinity water		Saline water; more stressed ecosystems; root spread; poor competitor in areas with established plants; similar to horned pond weed; grow in tub with soil and place clump into restoration area
Southern water nymph	<i>Najas guadalupensis</i>	Submerged	Annual	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Easy to propagate from soil in Farmington Bay; hard to propagate from plant cuttings. Sources: Farmington Bay - contains a healthy population		
Spiny water nymph	<i>Najas marina</i>	Submerged			Aquatic nonindigenous species by NOAA		Propagation notes: Push cutting into soil to root; if not bagged and refrigerated, then degrades quickly; very hardy once rooted; either cuttings or pellets needs access to soil; species would be good for further study- easy to grow. 5-gallon buckets with 3 to 4 inches soil; transport clump of veg/soil directly to restoration plot



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Common Name	Scientific Name	Classification	Lifespan	Inundation Preference	Revegetation Establishment Notes	Light Compensation Point (μmol/m²/s)	Species Notes and Propagation
Horned pondweed	<i>Zannichellia palustris</i>				Recommended. habitat: fresh to brackish, standing to slow-flowing water, sea level to moderate elevations in the mountains; flowers: June through August; origin: native; growth duration: perennial. Sources: easy to find in several wildlife management areas.		Mostly grows with roots spread; poor growth from pellet method; grows well in bucket with soils high growth; delicate species; needs care in handling.
White water-crowfoot	<i>Ranuncuus aqautilus</i>	Rooted		1 foot to 2 feet standing water maximum	white flowers		May be an annual plant; good spread but may not return next year; sprouts and spreads fast; may not persist.
Coontail	<i>Ceratophyllum demersum</i>	Submerged/ floating/ not rooted	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Not recommended; coontail: universally seems to be disliked due to its aggressive growth that can cause problems with boat motors; coontail is present at Utah Lake and Provo River Delta because it is rootless; boaters do not like it because it gets caught in motors	7.2 ^[c]	Carp and boaters do not like it
Common waterweed	<i>Eloda canadensis</i>	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Not recommended; much evidence for its invasiveness in other regions so was decided against	3.5 through 10 ^[c] and 12 ^[d]	Semi-invasive in Alaska and Canada; not recommended
Duckweed	<i>Lemna minor</i>	Free-floating	Perennial	N/A	Not recommended; blocks light penetration; not a restoration species		
Northern or shortspike watermilfoil	<i>Myriophyllum sibiricum</i>	Submerged	Perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Not recommended; <i>Myriophyllum</i> was potentially too hard to work with due to its potential to hybridize with <i>M. spicatum</i>		
Mosquito fern	<i>Azolla microphylla</i>	Free-floating	Annual or perennial	N/A	Not recommended		Not recommended
Stinkgrass/ muskgrass/ stonewart	<i>Chara sp.</i>	Submerged	Annual or perennial	Assume 1 foot to 3 feet of standing water for rooted/ SAV	Not recommended; aquatic algae-prefers still water-shallow water; not typically used for restoration and difficult to identify; not a vascular plant; may introduce nonnative species; was prevalent in PRD; after project it was eliminated due to high flow and deeper water	15.7 ^[c]	Not recommended; very competitive /outcompetes vascular species; in low flow velocity locations.

^[a] Source: Spencer, David F., and Marcel Rejmánek. 2010. "Competition between two submersed aquatic macrophytes, Potamogeton pectinatus and Potamogeton gramineus, across a light gradient." *Aquatic Botany* 92 (4):239-244. doi: 10.1016/j.aquabot.2010.01.001 .

^[b] Source: Hootsmans, M. J. M., and J. E. Vermaat. 1991. "Macrophytes, a key to understanding changes caused by eutrophication in shallow freshwater ecosystems." PhD, Agricultural and Environmental Sciences, University of Wageningen

^[c] Sand-Jensen, K., and T. V. Madsen. 1991. "Minimum Light Requirements of Submerged Freshwater Macrophytes in Laboratory Growth Experiments." *Journal of Ecology* 79 (3):749-764. doi: 10.2307/2260665

^[d] Madsen, J. D., and C. W. Boylen. 1988. The Physiological Ecology of Eurasian Watermilfoil (Myriophyllum Spicatum) and a Native Macrophyte (Potamogeton praelongus): Depth Distribution of Biomass and Photosynthesis. Troy, NY: Rensselaer Fresh Water Institute.

Sources:

BIO-WEST, Inc. 2019. *Provo River Delta Restoration Project Vegetation Management Plan*. Appendix A. Final. Prepared for Allred Restoration Inc. and Utah Reclamation Mitigation and Conservation Commission. September.

Brotherson, J.D. 1981. "Aquatic and semiaquatic vegetation of Utah Lake and its bays." *Great Basin Naturalist Memoirs*. 5(5).

Landom 2023.

μmol/m²/s = micromole(s) per square meter per second

N/A = not applicable

NOAA = National Oceanic and Atmospheric Association

PRD = Provo River Delta

SAV = submerged aquatic vegetation



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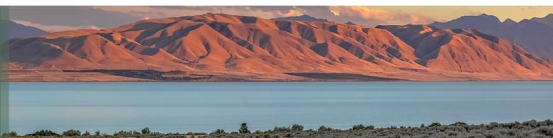


Table D-3. Suitable Riparian Species

Common Name	Scientific Name
Black cottonwood	<i>Populus trichocarpa</i>
Box elder	<i>Acer negundo</i>
Coyote willow	<i>Salix exigua</i>
Redosier dogwood	<i>Cornus sericea</i>
Golden currant	<i>Ribes aureum</i>
Skunkbrush sumac	<i>Rhus trilobata</i>
Baltic rush	<i>Juncus balticus</i>
Meadow sedge	<i>Salvia pratensis</i>



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Table D-4. Emergent Species

Common Name	Scientific Name	Arid West Facultative Rating ^[a]	Community Type	Notes
Hardstem bulrush ^[b]	<i>Schoenoplectus acutus</i>	OBL	Emergent wetland	Plant in shallow water; excellent for wildlife habitat and shoreline stabilization; dense root mat-protection from waves
Alkali bulrush ^[b]	<i>Bolboschoenus maritimus</i>	OBL	Saline wetland	Tolerates high salinity; plant in moist, alkaline soils; can survive flooding up to 1-meter deep
Broadleaf cattail	<i>Typha latifolia</i>	OBL	Emergent wetland	Plant in shallow water; spreads aggressively; monitor growth
Seaside arrowgrass	<i>Triglochin maritima</i>	OBL	Saline wetland	Plant in moist, saline soils; supports diverse wetland fauna
Water sedge	<i>Carex aquatilis</i>	OBL	Wet meadows and marshes	Plant in saturated soils; provides cover for wildlife
Spikerush ^[b]	<i>Eleocharis palustris</i>	OBL	Emergent wetland	Plant in shallow water; ideal for wetland restoration; can grow in 1-meter deep water
Swamp milkweed	<i>Asclepias incarnata</i>	OBL	Wet meadows and marshes	Plant in moist soils; attracts pollinators like monarch butterflies
Broadleaf arrowhead	<i>Sagittaria latifolia</i>	OBL	Emergent wetland	Plant in shallow water; attracts waterfowl and pollinators
Nodding beggartick	<i>Bidens cernua</i>	OBL	Wetland margins	Plant in moist soils; annual species that reseeds readily; seasonal flooding
Giant bur reed	<i>Sparganium americanus</i>	OBL	Emergent wetland	Plant in shallow water; provides habitat for aquatic species
Three-square bulrush ^[b]	<i>Schoenoplectus americanus</i>	OBL	Emergent wetland	Plant in shallow water or saturated soils; ideal for shoreline stabilization and wildlife habitat
Broadfruit bur reed	<i>Sparganium eurycarpum</i>	OBL	Emergent wetland	Plant in shallow standing water; supports aquatic insects and birds



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Common Name	Scientific Name	Arid West Facultative Rating ^[a]	Community Type	Notes
Nebraska sedge	<i>Carex nebrascensis</i>	FACW	Wet meadow, riparian	Thrives in saturated soils; excellent for filtration and erosion control
Arctic rush	<i>Juncus arcticus</i>	FACW	Wet meadow, riparian	Tolerates seasonal flooding; plant in moist soils with full sun
Water sedge	<i>Carex aquatilis</i>	OBL	Wet meadow, marsh edge	Prefers saturated soils; provides cover for wildlife and stabilizes soil
Coyote willow	<i>Salix exigua</i>	FACW	Riparian zone	Fast-growing; plant along streambanks for erosion control and habitat
Joe-pye weed	<i>Eutrochium maculatum</i>	FACW	Wet meadow	Plant in moist, sunny areas; attracts pollinators like butterflies
Water ragwort	<i>Senecio hydrophilus</i>	OBL	Wet meadow, marsh edge	Plant in saturated soils; supports pollinators and wetland diversity

^[a] Arid west wetland indicator status: FAC = facultative; OBL = obligate; FACW = facultative wetland

^[b] Preferred highly competitive species for fluctuating water levels.

Sources:

BIO-WEST, Inc. 2019. *Provo River Delta Restoration Project Vegetation Management Plan*. Appendix A. Final. Prepared for Allred Restoration Inc. and Utah Reclamation Mitigation and Conservation Commission. September.

Braun, J.V., R. Robinson, A.L. Henry, and K.M. Kettenring. 2024. *Restore the shore—A guide to lakeshore revegetation in the Great Basin*. Utah State University Wetland Ecology and Restoration Laboratory and Utah State University Extension.

Brotherson, J.D. 1981. "Aquatic and semiaquatic vegetation of Utah Lake and its bays." *Great Basin Naturalist Memoirs*. 5(5).



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Table D-5. Wet Meadow Species

Common Name	Scientific Name	Arid West Facultative Rating ^[a]	Planting Notes	Notes
Fremont cottonwood	<i>Populus fremontii</i>	FAC	Riparian zone (low elevation, moist soils)	Plant near streambanks or moist areas; requires full sun and access to groundwater
Boxelder	<i>Acer negundo</i>	FAC	Riparian zone	Tolerates wide range of soils; best planted in moist, shaded areas
Coyote willow	<i>Salix exigua</i>	FACW	Riparian and wetland margins	Plant in saturated soils; ideal for erosion control and wildlife habitat
Nebraska sedge	<i>Carex nebrascensis</i>	FACW	Emergent wetland and wet meadow	Thrives in saturated soils; plant in shallow water or wet meadows
Baltic rush	<i>Juncus balticus</i>	FACW	Wetland and riparian zones	Tolerates saline soils; plant in moist areas with full sun
Saltgrass	<i>Distichlis spicata</i>	FAC	Saline flats and wet meadows	Tolerates drought and salinity; ideal for soil stabilization
Pickleweed	<i>Salicornia rubra</i>	FACW	Saline wetland	Plant in high salinity areas; supports salt-tolerant ecosystems
Joe-pye weed	<i>Eutrochium maculatum</i>	FACW	Wet meadows and riparian zones	Plant in moist soils; supports pollinator populations
Pickleweed	<i>Salicornia rubra</i>	FACW	Saline wetland	Halophyte; plant in salty, alkaline soils; supports salt-tolerant ecosystems
Arctic rush	<i>Juncus arcticus</i>	FACW	Wet meadow and riparian zones	Tolerates seasonal flooding; plant in moist soils with full sun
Water sedge	<i>Carex aquatilis</i>	OBL	Wet meadow and marsh edge	Prefers saturated soils; provides cover for wildlife and stabilizes soil
Foxtail barley	<i>Hordeum jubatum</i>	FACW	Wet meadow	N/A
Iodine bush	<i>Allenrolfea occidentalis</i>	FACW	Playa	Saturated saline wetlands and drought tolerant good for soil stabilization



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Common Name	Scientific Name	Arid West Facultative Rating ^[a]	Planting Notes	Notes
Meadow sedge	<i>Carex praegracillis</i>	FACW	Meadow	Tolerant of alkaline soils and wet to seasonally dry meadows
Curly cup gumweed	<i>Grindelia squarrosa</i>	FACU	Upland forb	Grows under variable conditions; drought resistant
Black cottonwood	<i>Populus balsamifera</i>	FAC	Meadow	N/A
Golden dock	<i>Rumex maritimus</i>	FACW	Meadow/ emergent	Tolerates saline soils and waterlogged conditions
Joe-pye weed	<i>Eutrochium maculatum</i>	FACW	Wet meadow	Plant in moist, sunny areas; attracts pollinators like butterflies
Water ragwort	<i>Senecio hydrophilus</i>	OBL	Wet meadow, marsh edge	Plant in saturated soils; supports pollinators and wetland diversity
Showy milkweed	<i>Asclepias speciosa</i>	FAC	Upland forb	N/A

^[a] Arid west wetland indicator status: FAC = facultative; OBL = obligate; FACW = facultative wetland

N/A = not applicable

Sources:

BIO-WEST, Inc. 2019. *Provo River Delta Restoration Project Vegetation Management Plan*. Appendix A. Final. Prepared for Allred Restoration Inc. and Utah Reclamation Mitigation and Conservation Commission. September.

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UTAH LAKE STUDY



Table D-6. Most Prevalent Historic Species at Utah Lake (Ranked by Importance-Partial List)

Common Name	Latin Name	Arid West Facultative Rating ^[a]	Rating of Importance ^[b]
saltgrass	<i>Distichlis spicata</i>	FAC	3,364
Bulrush spp.	<i>Scirpus americanus</i>	OBL	2,587
spikerush	<i>Eleocharis palustris</i>	OBL	2,315
Baltic rush	<i>Juncus balticus</i>	FACW	1,832
Nebraska sedge	<i>Carex nebraskensis</i>	FACW	1,318
Hardstem bulrush	<i>Scirpus acutus</i>	OBL	1,039
Meadow foxtail	<i>Hordeusm jubatum</i>	FACW	1,033
Cattail	<i>Typha latifolia</i>	OBL	1,030

^[a] Classifications: FAC = facultative; OBL = obligate; FACW = facultative wetland

^[b] Source: Brotherson, J.D. 1981. "Aquatic and semiaquatic vegetation of Utah Lake and its bays." *Great Basin Naturalist Memoirs*. 5(5).

Appendix E

Analysis of Water Clarity and Potential Impacts on Macrophyte Restoration in Utah Lake Memorandum

To:	Jacobs Team
From:	Tetra Tech: Kateri Salk, Mike Shupryt, Kristen Parry
Date:	July 25 th , 2025
Subject:	Analysis of Water Clarity and Potential Impacts on Macrophyte Restoration in Utah Lake

The Utah Division of Forestry, Fire, and State Lands along with the Department of Water Quality are conducting a study to determine how to enhance various benefits associated with Utah Lake, including:

1. Improving the clarity and quality of the water in Utah Lake
2. Conserving water resources around Utah Lake
3. Removing invasive plant and animal species, including phragmites and carp from Utah Lake
4. Restoring and improving the littoral zone and other plant communities in and around Utah Lake

This memo addresses sunlight penetration through the water column in Utah Lake. The shallow nature and large surface area of Utah Lake results in conditions that frequently entrain sediments into the water column that inhibits light penetration. Additionally, the eutrophic conditions in Utah Lake result in frequent algal blooms that block sunlight from penetrating deeper through the water column. Highly turbid conditions mixed with high concentrations of suspended algae (i.e. algal blooms) both could inhibit the restoration of submerged aquatic vegetation by limiting sunlight and the sediment surface. The analysis described below addresses:

- Light requirements for establishment of common macrophyte species
- Rate of light extinction through the water column in Utah Lake (i.e., light attenuation coefficient)
- Spatial and temporal variation in light attenuation coefficient
- Relative contributions of algal and non-algal turbidity to reduced water clarity
- Turbidity and algal requirements for sunlight to reach different water depths in Utah Lake

1.0 SUMMARY OF MAJOR FINDINGS

- Light requirements for growth of submerged macrophytes historically observed in Utah Lake were sourced from the literature. These light requirements, specifically the minimum light requirement called the “light compensation point,” were cross-referenced to light profiles from monitoring data in Utah Lake to determine areas of suitability for macrophyte restoration.
- The light attenuation coefficient, which defines how rapidly light decreases with depth, was strongly related to suspended sediment and phytoplankton biomass in Utah Lake. Water clarity did not display strong seasonal patterns, though predictive models were aided by accounting for seasonality.
- The majority of reduced water clarity in Utah Lake is driven by sediment resuspension, as evidenced by low ratios of volatile suspended solids (i.e., phytoplankton cells) to total suspended solids in most locations. Provo Bay was notably a location with a higher relative contribution of phytoplankton cells to reduced water clarity.

Phytoplankton blooms around the entire lake were also found to be event-driven conditions of increased relative contributions of phytoplankton to reduced water clarity.

- At current water quality conditions, the light environment at the bottom of the lake was predicted to be sufficient for growth of submerged macrophytes only at shallower locations in Utah Lake. Specifically, low light-tolerant species were predicted to have sufficient light conditions at 1 m depth and shallower, with the probability of sufficient light decreasing down to approximately 1.5 m depth where the probability approached zero. Low light-sensitive species were predicted to have sufficient light conditions at 0.6 m depth and shallower, with the probability of sufficient light decreasing down to approximately 1 m depth where the probability approached zero.
- Improving water clarity in Utah Lake will require management of both sediment-driven turbidity and phytoplankton growth. Increasing light penetration deeper into the water column to support submerged macrophyte restoration is possible with even modest improvements in turbidity and chlorophyll-a levels. While sediment-driven turbidity drives most of the reduced water clarity in Utah Lake, reducing chlorophyll-a levels is also necessary to inhibit the growth of epiphytic algae on macrophytes.

2.0 LITERATURE REVIEW AND DATA PROCESSING

2.1 MACROPHYTE LIGHT COMPENSATION POINT

For submerged macrophytes, the light compensation point (i.e., the photosynthetic active radiation (PAR) level at which photosynthesis matches respiration and net growth is zero) can help predict potential limitations on colonization depth. Light compensation points for species documented in Utah Lake (*Ceratophyllum demersum*, *Chara aspera*, *Elodea canadensis*, *Potamogeton pectinatus*, *P. praelongus*; (Brotherson 1981; Miller and Crowl 2005; Landom, Dillingham, and Gaeta 2019; Brothers et al. 2021) range from 3.5-45 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Hootsmans and Vermaat 1991; Madsen and Boylen 1988; Sand-Jensen and Madsen 1991; Spencer and Rejmánek 2010); Table 1). *C. demersum*, a submerged macrophyte documented in the most recent report (Landom, Dillingham, and Gaeta 2019), had a light compensation point of 7.2 $\mu\text{mol m}^{-2} \text{s}^{-1}$, within the range of compensation points for seven species ($6.9 \pm 1.9 \mu\text{mol m}^{-2} \text{s}^{-1}$; Sand-Jensen and Madsen 1991).

To define potential light requirements for macrophyte restoration efforts in Utah Lake, we identified two PAR thresholds representing the light compensation point of 8 and 45 $\mu\text{mol m}^{-2} \text{s}^{-1}$, representing thresholds for light-tolerant and light-sensitive submerged aquatic vegetation (SAV) species, respectively.

Table 1. Comparison of light compensation points of various macrophyte species included in literature review.

Species	Observed in recent survey? (Landom and Walsworth 2024)	Light Compensation Point $\mu\text{mol m}^{-2} \text{s}^{-1}$	Citation
<i>Ceratophyllum demersum</i> Coontail	Yes	7.2	Sand-Jensen and Madsen 1991
<i>Chara vulgaris</i> * Stonewort	No	15.7	Sand-Jensen and Madsen 1991
<i>Elodea canadensis</i> American waterweed	No	3.5-10.0 ~12	Sand-Jensen and Madsen 1991 Madsen and Boylen 1988
<i>Potamogeton pectinatus</i> , or <i>Stuckenia pectinata</i> Sago pondweed	Yes	44.8 41	Spencer and Rejmanek 2010 Hootsmans and Vermaat 1991
<i>Potamogeton praelongus</i>	No	~12**	Madsen and Boylen 1988

*Potential proxy for *Chara aspera* in Utah Lake.

**Raw value was not reported in the paper; estimate was taken from a graph.

2.2 LIGHT ATTENUATION

Light attenuation is determined by measuring light intensity at various depths and calculating its rate of decrease with depth. In a freshwater lake, sunlight may penetrate only a few meters or centimeters before diminishing significantly due to suspended particles and dissolved organic matter. Utah DEQ regularly monitors photosynthetic active radiation (PAR, $\mu\text{mol m}^{-2} \text{s}^{-1}$) using light meters and recording PAR at several depths from the surface to near the bottom of the water column (i.e., profiles) in Utah Lake. PAR data for Utah Lake was downloaded from the Water Quality Portal and included PAR profiles at 16 sites and with 354 unique profiles between 2019 and 2024. Surface water quality parameters were also downloaded from the WQP, including several measures such as turbidity, total suspended solids (TSS), chlorophyll a, and water temperature. Water quality data were joined with PAR profiles collected at the same location on the same day. Typically, sites located within sheltered marinas (Figure 1) had fewer profiles and were dropped from subsequent analysis, as marinas have far different physical characteristics than other main basin and bay locations (Goshen Bay, Provo Bay). This removed five unique locations and 25 light profiles from the dataset collected within marinas. Sample sizes ranged from 18-38 PAR profiles including samples at the four buoy locations used for critical shear stress analysis (Vineyard (n = 36), State Park (n = 38), Provo Bay (n = 19), and Bird Island (n = 37)).

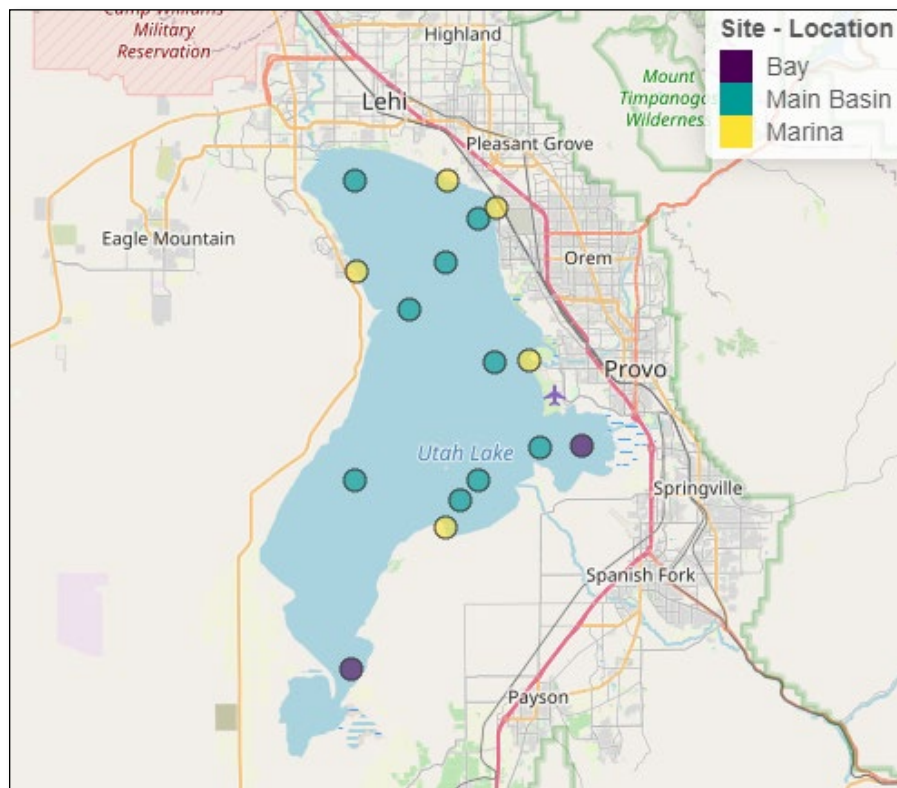


Figure 1. Locations of Utah DEQ monitoring locations for photosynthetic active radiation (PAR) profiles in Utah Lake

The light attenuation coefficient (K_d) quantifies how rapidly light intensity decreases as it penetrates deeper into the water column. For each distinct sampling event, K_d was estimated to capture the optical properties of the water at that time and location. Because light attenuation in water follows an exponential decay pattern, the relationship between light intensity and depth can be linearized by applying the natural logarithm to the PAR values. This transformation allows for a more straightforward estimation of K_d . Specifically, K_d was calculated using an exponential decay model of PAR, using the Beer-Lambert Law, which describes how light diminishes as it passes through a medium due to absorption and scattering:

$$I(z) = I_0 e^{-\alpha z}$$

where $I(z)$ is PAR at depth z , I_0 is initial PAR at the water surface, and α is the attenuation coefficient. To linearize this relationship, the natural logarithm of PAR values was taken, allowing K_d to be calculated as the absolute value of the slope of the resulting linear regression line (Figure 2). A larger K_d value indicates a faster decay of light with depth.

To explore the spatial and temporal variability in K_d , we statistically evaluated its relationship with water quality parameters and seasonal patterns using linear mixed effects models (LMMs). This approach allowed us to account for both fixed effects (e.g., chlorophyll concentration, turbidity) and random effects (e.g., site-specific variability), providing a robust framework for understanding the drivers of light attenuation across locations and times of year.

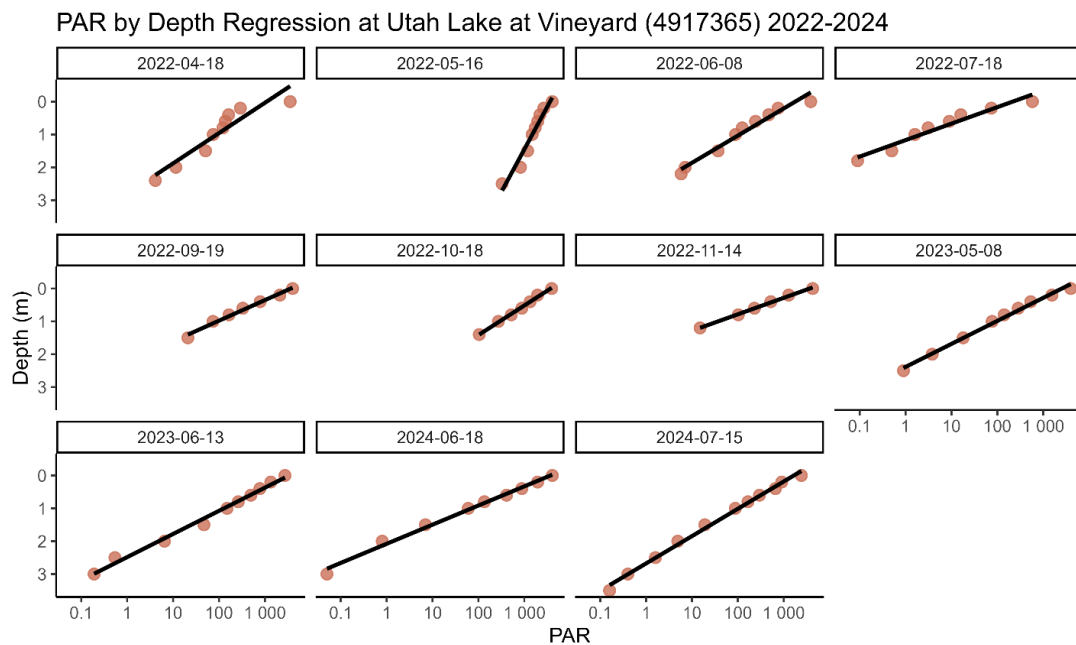


Figure 2. Photosynthetic active radiation (PAR) by water depth at the Vineyard monitoring location in Utah Lake from 2022-2024 shown as an example of the strong linear fit between depth and natural log PAR. While the relationship is linear, the slope of the line varies by date.

As noted above, PAR thresholds of 8 and 45 $\mu\text{mol m}^{-2} \text{s}^{-1}$ were identified as the minimum light requirements for the establishment of low light-tolerant and low light-sensitive macrophyte species in Utah Lake. Using the light attenuation coefficient (K_d), we predicted the depths at which these PAR thresholds were reached for each observation collected between March and November, excluding winter months outside of the growing season.

To assess the likelihood of maintaining sufficient light for macrophyte growth, we used logistic regression models in several ways. First, we converted PAR into a binary variable at each depth from 0.3 to 2.0 meters for every survey, in 0.1-meter increments. Each depth-point was classified (Yes or No) based on whether it met or fell below the target PAR threshold (8 or 45 $\mu\text{mol m}^{-2} \text{s}^{-1}$). This allowed us to use the logistic model output to estimate the probability of meeting light requirements across depths and time. Next, we aggregated these binary outcomes by month, calculating the probability that the target PAR was met in at least 75% of surveys (i.e., three out of four days) for each depth. This monthly summary enabled us to visualize seasonal trends in light availability and identify if periods of time exist when macrophyte growth conditions were unfavorable.

Finally, we used logistic regression models to statistically evaluate the combined influence of turbidity and chlorophyll a concentration on the probability of maintaining the target PAR thresholds. Specifically, we identified the combinations of these water quality parameters required to meet the 8 and 45 $\mu\text{mol m}^{-2} \text{s}^{-1}$ thresholds 75% of the time at each depth. These modeled thresholds were then compared to observed water quality conditions in Utah Lake, providing insight into the feasibility of macrophyte establishment under current environmental conditions and comparisons of the limiting factors (i.e. algal or non-algal turbidity).

3.0 RESULTS

Light attenuation followed a log-normal decay patterns for all samples in Utah Lake and was well explained by linear regression. The PAR by water depth relationship was strong within surveys, with mean R^2 from linear regression of 0.96 (sd = 0.07). While within surveys PAR was strongly related to depth, across surveys and sites K_d was variable with a mean K_d of 3.45 (sd = 1.7, 10th and 90th percentile = 1.76 and 5.34). This suggests that there is temporal (Figure 3) and/or spatial variability of K_d that is likely explained by water quality parameters.

Linear mixed-effects models (LMMs) revealed that both algal (chlorophyll-a) and non-algal turbidity (typically suspended sediment) significantly contributed to explaining variation in K_d , with p-values < 0.001. In a multiple regression framework, fixed suspended solids (FSS) and volatile suspended solids (VSS) provided slightly stronger explanatory power for K_d than turbidity and chlorophyll-a, with R^2 of 0.46 to 0.39. However, when accounting for random effects of site and month in the LMMs, the conditional R^2 values for turbidity and chlorophyll a slightly exceeded those for FSS and VSS (0.55 to 0.53), suggesting improved model performance when spatial and temporal variability were considered in the LMM framework (Figure 4). Given that turbidity and chlorophyll-a are more commonly measured and widely interpretable water quality parameters and still explained a substantial portion of K_d variability when accounting for site and month, we selected these variables for subsequent analyses.

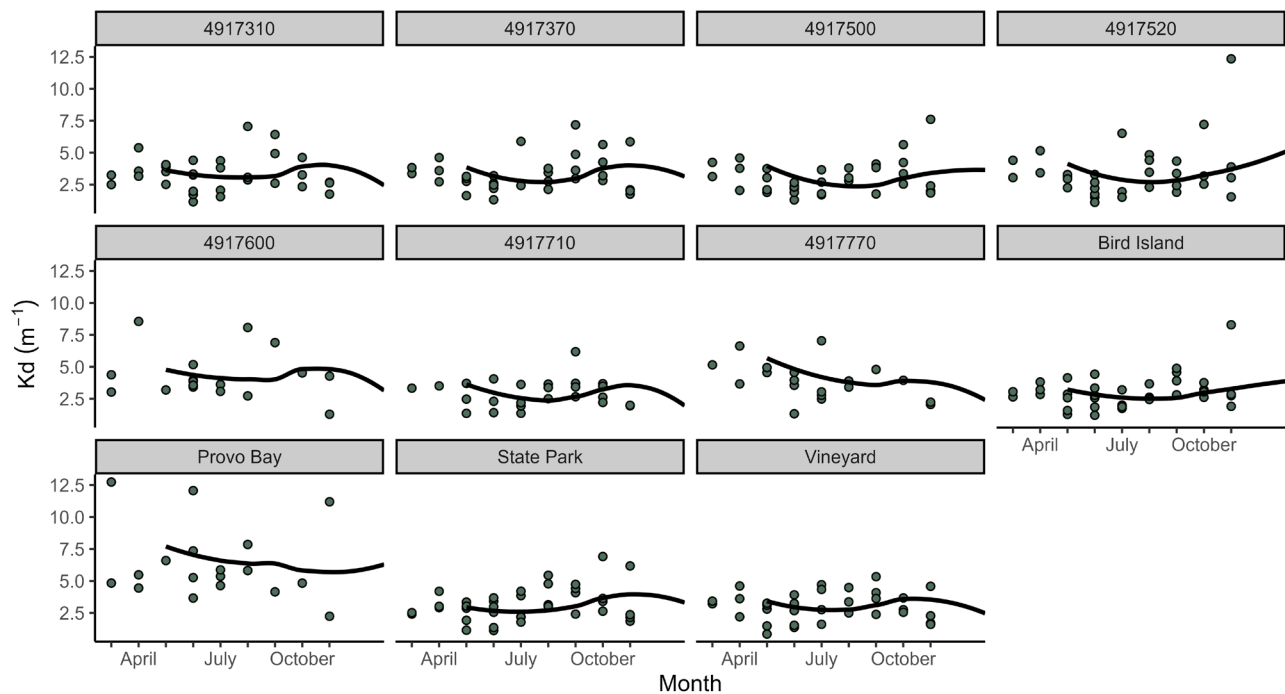


Figure 3. Light attenuation coefficient shown for each site in Utah Lake by month (numeric value on x-axis). Bouy sites used in the shear stress analysis are labeled by name, while all other sites are labeled by Utah DEQ site ID.

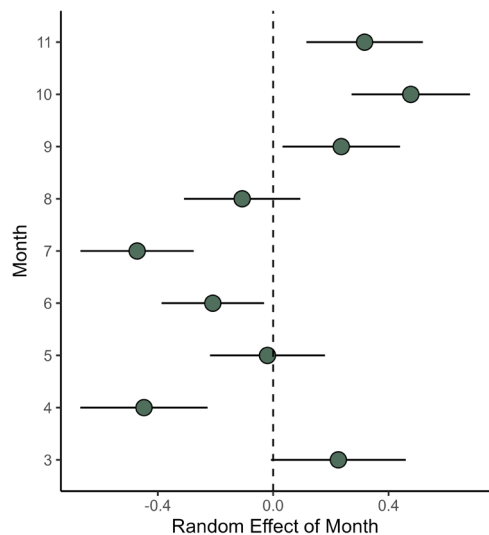


Figure 4. Linear mixed effect model random effects showing the effect of month on the light attenuation coefficient (K_d). Smaller value indicates smaller y-intercept, which means light intensity reaches zero at a shallower water depth.

Although month alone was a relatively weak predictor of K_d and its influence was difficult to interpret visually (see Figures 3), incorporating month as a random effect in the linear mixed-effects model significantly improved model performance (χ^2 test, $p < 0.001$, Figure 4). This suggests that while month may not have a consistent fixed effect across all observations, it contributes meaningfully to explaining variability in K_d when accounting for site-specific differences. Plotting the random effects of month revealed a nonlinear seasonal pattern in light attenuation. Generally, K_d random effects were highest—indicating greater light penetration—during the early spring and fall, and lowest—indicating reduced light availability—during mid-summer (Figure 4). Interestingly, April deviated from this seasonal trend, exhibiting K_d values more typical of mid-summer months. This anomaly underscores the complexity and variability of seasonal light dynamics in the system, likely influenced by episodic events such as algal blooms, sediment resuspension from wind driven events, or others.

Logistic regression models effectively captured the relationship between depth and the probability of meeting PAR targets, revealing thresholds for light availability in the water column. The models estimated a 50% probability of achieving a PAR of $8 \mu\text{mol}/\text{m}^2/\text{s}$ at 1.68 meters, while the higher PAR threshold of $45 \mu\text{mol}/\text{m}^2/\text{s}$ was only met with a 50% probability at a shallower depth of 1.16 meters. These thresholds suggest that low light-sensitive macrophytes (e.g., *Potamogeton pectinatus*) are likely to establish in waters shallower than 1 meter, whereas low light-tolerant species (e.g., *Ceratophyllum demersum*) may establish and persist at greater water depths.

To more fully utilize the logistic regression model, we predicted the probability of meeting PAR targets at every 0.1-meter depth increment between 0.3 and 2.0 meters. Each survey was represented across 16 depth intervals, allowing for a detailed 0.1-meter incremental depth analysis (Figure 5, top panels). To examine temporal trends, we summarized these predictions by month, calculating whether the PAR target was met in at least 75% of surveys in each month, representing the ability to maintain suitable light conditions on three out of four days (Figure 5, bottom panels).

The monthly summary of light attenuation revealed a steep transition zone in PAR availability. For the $8 \mu\text{mol}/\text{m}^2/\text{s}$ threshold, the probability of meeting the target PAR on 75% of days began to decline sharply around 1.2 meters, while for the $45 \mu\text{mol}/\text{m}^2/\text{s}$ threshold, this decline began around 0.75 meters. These inflection points highlight the depth ranges where small changes in water clarity can significantly impact macrophyte habitat suitability. Month had minimal influence on the depth-light transition zone (Figure 5, $p = 0.17$ and $p = 0.82$), suggesting that depth and observed water clarity measurements are sufficient explanations of the dominant drivers of light availability for macrophyte growth.

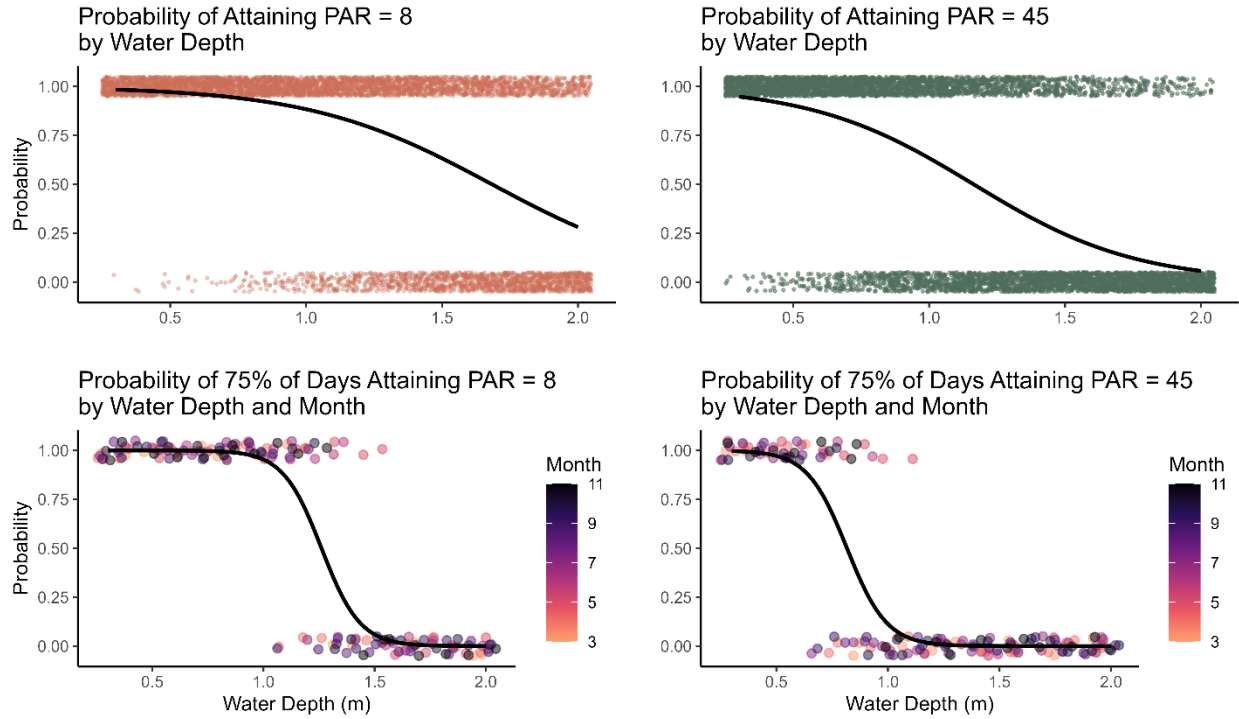


Figure 5. Logistic regression fits showing the probability of reaching the target PAR of 8 (left) and 45 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (right) where each survey is predicted at depth from 0.3 to 2.0 meters at 0.1 m intervals (top). Each depth interval is then summarized by month and determined if the PAR targets were met 75% of the time (1 = Yes, 0 = No).

The final logistic regression model developed incorporated water quality parameters, turbidity and chlorophyll-a, to predict whether PAR targets of 8 and 45 $\mu\text{mol m}^{-2} \text{s}^{-1}$ were met at various depths ranging from 0.3 to 2.0 meters. These models performed well, with both turbidity and chlorophyll-a emerging as significant predictors across all models (p-values ranging from <0.001 to 0.03). Model performance, assessed using Area Under the Curve (AUC), was strong with values ranging from 82.8% to 92.6% indicating high predictive ability. To visualize the model outputs, we used the logistic regression equations to estimate the probability of meeting each PAR target at several depth intervals. We then plotted only the combinations of turbidity and chlorophyll-a that resulted in a $\geq 75\%$ probability of achieving the target PAR for each depth. These threshold contours were overlaid with a scatterplot of observed turbidity and chlorophyll-a measurements collected concurrently with PAR surveys ($n = 316$) to contextualize the predictions within the actual range of water quality conditions in Utah Lake (Figure 6).

The resulting density plots revealed a predictable consistent pattern: as depth increases, the combinations of turbidity and chlorophyll-a required to meet PAR targets become more restrictive. This is visually represented by contour lines shifting downward and to the left in the plots (Figure 6), indicating that lower concentrations of both parameters are necessary to maintain adequate light availability at greater depths. While depth alone is a strong predictor of whether PAR targets are met, it offers limited utility for water quality management. In contrast, using the logistic regression models based on water quality parameters provides insights into how management interventions could improve light attenuation from algal and non-algal turbidity to support macrophyte re-establishment.

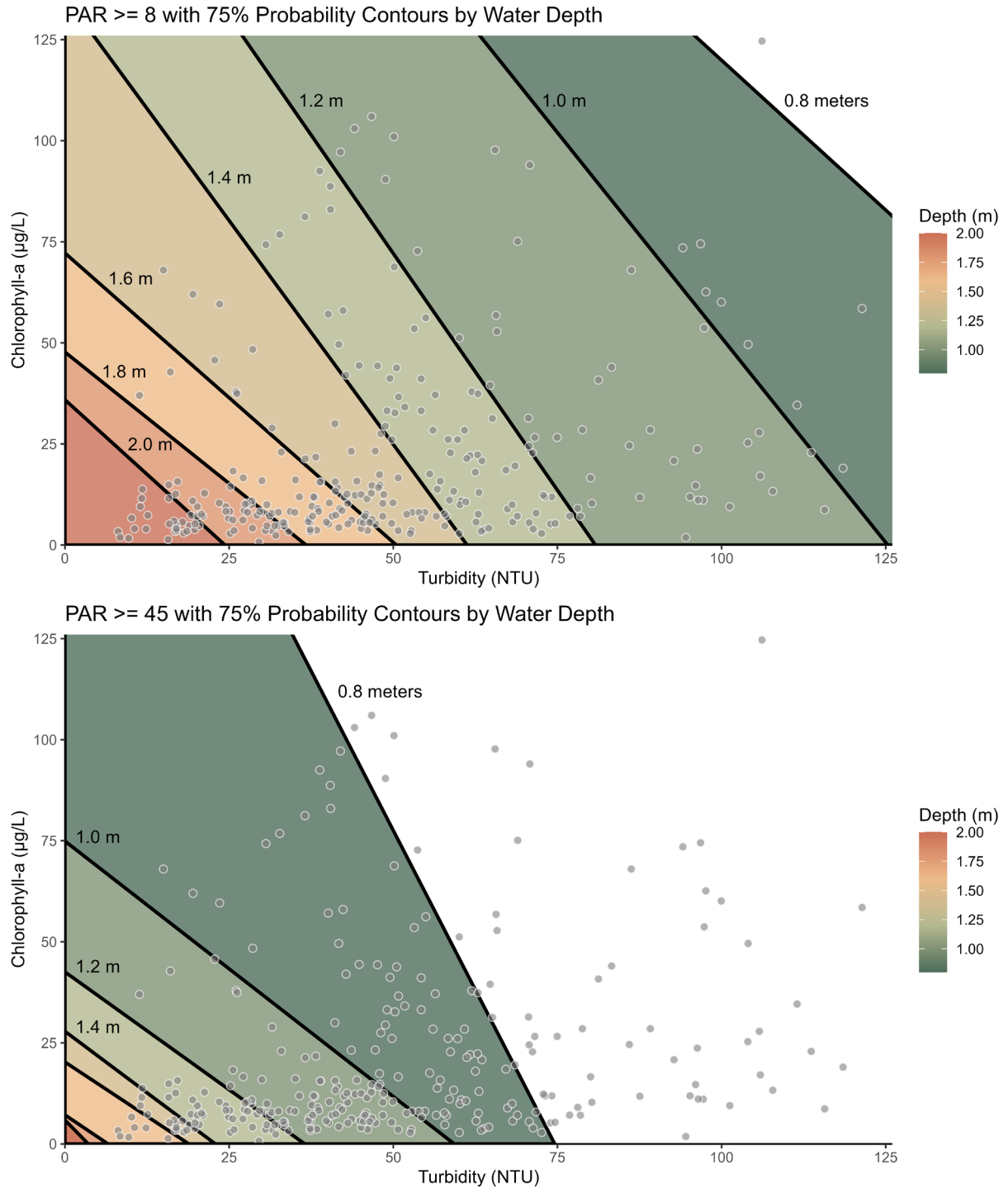


Figure 6. Probability of attaining PAR targets by depth, 75% or higher (black lines and green-to-red shaded contours), based on turbidity and chlorophyll a concentration taken concurrently with PAR profiles (grey circles). If shaded contour covers most grey circles, then observed water quality conditions in Utah Lake typically support PAR at that depth. Labels for contours 1.6-2.0 meters depth are not shown on the lower plot (PAR ≥ 45) for clarity.

Among the two predictors, turbidity emerged as more influential than chlorophyll-a in determining whether PAR targets were met (Figure 6). The two variables are not entirely independent, as chlorophyll-a contributes to turbidity through light scattering by algal cells. Still, observed turbidity levels in Utah Lake more frequently exceeded the thresholds required to meet PAR targets at depths greater than 1.0 meter. Another important consideration is growth of epiphytic algae, which at high nutrient concentrations can grow on the surface of SAV and inhibit macrophyte growth. Thus, while lower chlorophyll-a concentrations may not be strictly necessary to achieve water clarity needs for SAV growth, reducing nutrients and water column primary production are needed to avoid epiphytic growth. These findings suggest that reducing both algal and non-algal turbidity would have the greatest impact on improving light penetration and macrophyte restoration in Utah Lake.

Such improvements are essential for enabling widespread and sustained colonization of macrophytes, particularly those requiring higher light intensity. Given the influence of chlorophyll-a and turbidity on water clarity in Utah Lake, we further investigated the relative contributions of algal and non-algal suspended solids in Utah Lake. Using the same monitoring stations where PAR data were collected and calculated the ratio of volatile suspended solids (VSS) to total suspended solids (TSS) to quantify the relative amount of organic material suspended in the water column (0–1 scale).

We included the marina samples for this analysis to provide some comparisons between the main basin and bays in Utah Lake. While chlorophyll-a and turbidity are commonly used indicators in water quality monitoring programs in Utah and elsewhere, their units are not directly comparable. Turbidity is measured in nephelometric turbidity units (NTU), which reflect light scattering by suspended particles, whereas chlorophyll-a is measured in micrograms per liter and represents the concentration of photosynthetic pigment, serving as a proxy for algal biomass. However, chlorophyll-a only accounts for the chloroplast component and not the entire algal biomass. TSS represents the total concentration of suspended solids in water, while VSS quantifies the organic fraction, including algal and other organic material. Both TSS and VSS are measured in milligrams per liter (mg/L), allowing for direct comparison. This makes the VSS:TSS ratio a suitable metric for assessing the composition of suspended solids.

The VSS:TSS ratio in Utah Lake exhibited spatial variability, with median values varying by location (Figure 7). Specifically, the main basin exhibited the lowest median VSS:TSS ratio at 0.13 (interquartile range: 0.11–0.37), while marinas and bays showed higher median values of 0.23 (0.17–0.31) and 0.24 (0.15–0.37), respectively. These values indicate that, on average, approximately 13–24% of the suspended solids in the lake are composed of algal biomass or other organic particulate matter. Elevated VSS:TSS ratios were observed in the bay regions, with Provo Bay exhibiting the highest median ratio of 0.36, suggesting that up to 36% of suspended solids in this area are organic in origin. In contrast, sites in the main basin tended to have lower VSS:TSS ratios, with most median values falling below 0.15. Goshen Bay (station 4917600) also displayed relatively low VSS:TSS ratios, aligning more closely with main basin conditions than with those observed in Provo Bay (Figure 7).

Among main basin sites, the highest VSS:TSS ratio was recorded at station 4917770, located near the mouth of Provo Bay. This suggests a potential hydrologic influence from Provo Bay on adjacent main basin waters. Marina sites exhibited intermediate VSS:TSS ratios, falling between those observed in bay and main basin environments. Although marinas shared some VSS:TSS similarities with main basin sites, they were excluded from the PAR analysis due to their limited suitability for macrophyte restoration. This exclusion is justified by the need to maintain navigational access and the likelihood of periodic dredging to ensure sufficient water depth for recreational watercraft, which diminishes their macrophyte restoration potential.

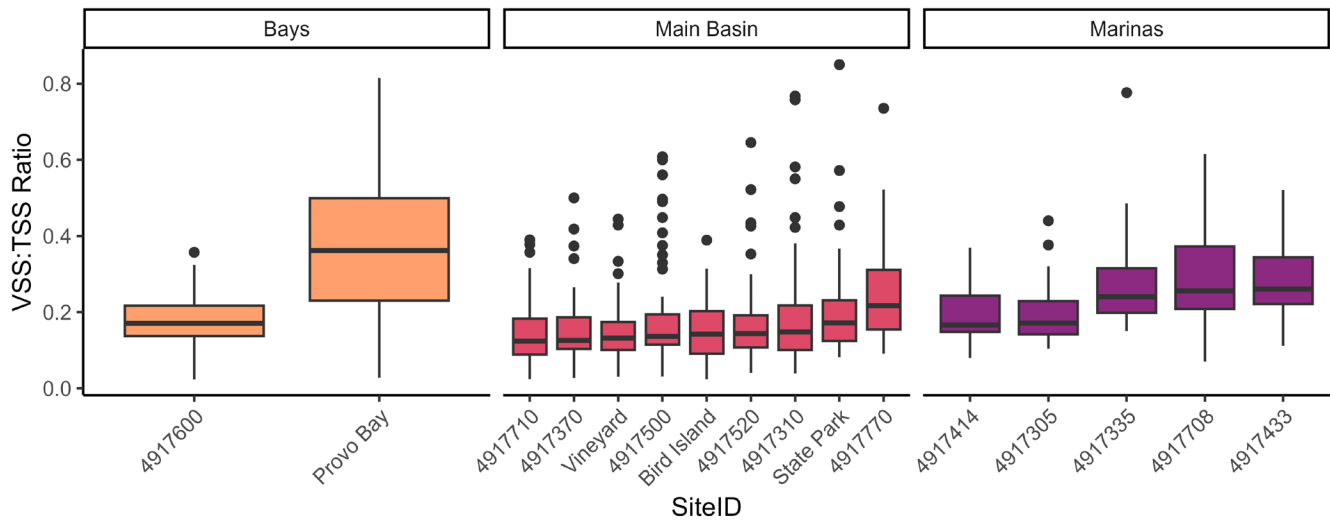


Figure 7. Boxplot of volatile suspended sediment (VSS) to total suspended sediment (TSS) ratios in Utah Lake. Ratios are calculated from samples collected at the same location (Site ID) and same day and group by location in Utah Lake for visual comparison (Bays, Main Basin, Marinas). Buoy locations used in shear stress analysis are labeled by name while all other sites are labeled by Utah DEQ numeric site IDs.

Although logistic regression analysis identified turbidity as the primary factor limiting light penetration in Utah Lake (Figure 6), turbidity associated with episodic algal bloom events may exert a disproportionately strong influence on light availability. Elevated VSS:TSS ratios can occur under two distinct conditions: (1) during algal bloom events, when VSS concentrations are high due to increased organic material, and (2) during periods of low TSS concentrations, likely associated with calm, dry weather conditions that minimize wind-driven resuspension of benthic sediments and external sediment loading from tributaries.

The VSS:TSS ratio exhibited a moderately strong positive relationship with chlorophyll a (linear regression $R^2 = 0.12$, $p < 0.001$), and a weaker negative relationship with turbidity ($R^2 = 0.05$, $p < 0.001$, Figure 8). These relationships suggest that although both mechanisms contribute to variability in the VSS:TSS ratio, elevated algal biomass is likely the dominant driver of high ratios (Figures 7 and 8). Under bloom conditions, increased algal biomass can substantially reduce light penetration, thereby inhibiting the establishment and growth of aquatic macrophytes. While overall reductions in turbidity would improve light conditions (resuspended benthic sediments), targeted management of algal blooms may also yield improvements in light availability, thereby enhancing the potential for macrophyte recovery and restoration.

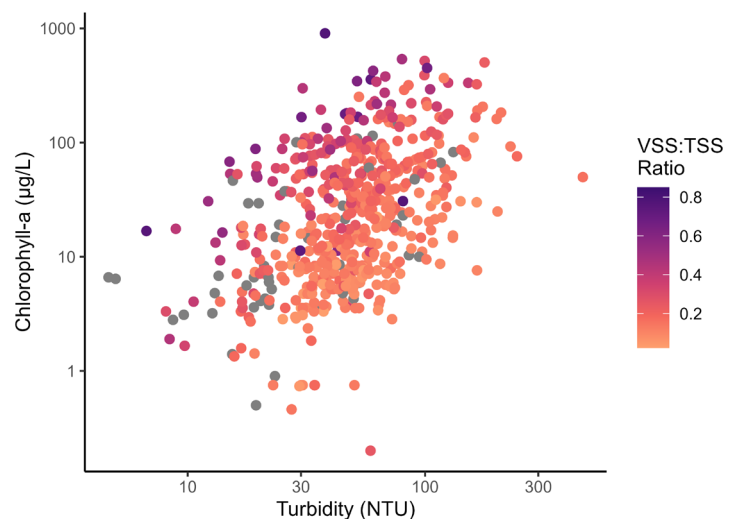


Figure 8. Scatter plot of chlorophyll-a and turbidity showing VSS:TSS ratio as color coding for each point

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UTAH LAKE STUDY



Appendix F Wind and Shear Stress Memorandum

To:	Jacobs Team
From:	Tetra Tech: Kateri Salk, Mike Shupryt, Kristen Parry, Rene Camacho, Mehdi Armandei
Date:	July 23, 2025
Subject:	Wind and Shear Stress

The Utah Division of Forestry, Fire, and State Lands along with the Department of Water Quality are conducting a study to determine how to enhance various benefits associated with Utah Lake, including:

1. Improving the clarity and quality of the water in Utah Lake
2. Conserving water resources around Utah Lake
3. Removing invasive plant and animal species, including phragmites and carp from Utah Lake
4. Restoring and improving the littoral zone and other plant communities in and around Utah Lake

This memo addresses wind and wave action and their effects on sediment resuspension, applicable with items #1 and #4 above. The shallow nature of Utah Lake encourages conditions that frequently entrain sediments into the water column, which creates highly turbid conditions that inhibit light penetration as well as instable substrate conditions, both of which could inhibit the restoration of submerged aquatic vegetation. The analysis described below addresses:

- The relationship between wind, wave action, and shear stress on the sediments
- The critical shear stress value above which sediments are resuspended into the water column
- Conditions under which critical shear stress is exceeded over time and space
- Whether there are any locations in the lake where shear stress is gentle enough to support macrophyte and mollusk communities

SUMMARY OF MAJOR FINDINGS

- Shear stress was calculated by the Environmental Fluid Dynamics Code (EFDC) model in Utah Lake, and analyses were supplemented with statistical analysis of monitoring data.
- Shear stress was largely driven by wind-wave action, with a small component also affected by lake currents. The major drivers of shear stress in Utah Lake are wind speed and direction as well as water depth. On average, low water years tended to have higher shear stress in shallow, nearshore areas than high water years, whereas deeper open water locations tended to have fairly consistent shear stress across years.
- Shear stress was significantly correlated with turbidity in Utah Lake, supporting the idea that wind-driven sediment resuspension is a major driver of reduced water clarity in the lake.
- Critical shear, the shear stress value that would be sufficient to entrain sediments into the water column, was typically exceeded on less than 10% of modeled days, with nearshore sites and shallow water years experiencing higher frequencies of critical shear exceedances. This finding indicates that wind conditions in the lake are sometimes, but not usually, sufficient to entrain sediments into the water column. High levels of turbidity on days where critical shear is not exceeded are likely driven by slow particle sinking from previous sediment resuspension events and/or phytoplankton-driven turbidity.
- Critical shear was higher in Provo Bay than in the main basin, likely due to the wind sheltering effect and low fetch of the bay. Sediment resuspension is less likely to occur in Provo Bay than in the main basin at equivalent wind velocities, also supported by observation of lower levels of non-algal turbidity in Provo Bay.

METHODS

Legend

Utah Lake Grid
Average Depth (m)

0.10	0.26
0.26	0.57
0.57	0.92
0.92	1.30
1.30	1.63
1.63	1.89
1.89	2.11
2.11	2.33
2.33	2.54
2.54	2.81

EFDC Model Grid

0 1.25 2.5 5 7.5 10 Miles
0 2 4 8 12 16 Kilometers

UT TETRA TECH

EFDC, NASA, NGA, USGS, FEMA, County of Utah, Utah Geological Survey, Center for Earth and Technology, University of Utah, Utah State Office of Water Management, EPA, NOAA, USGS, USGS

A two-way passage of information between EFDC and SWAN was established using Python and Fortran scripts (Figure 2). The sequence of steps to implement the linkage is as follows:

1. EFDC Execution Step
2. EFDC-SWAN Linkage Step
3. SWAN Execution Step
4. SWAN-EFDC Linkage Step
5. Execution Step

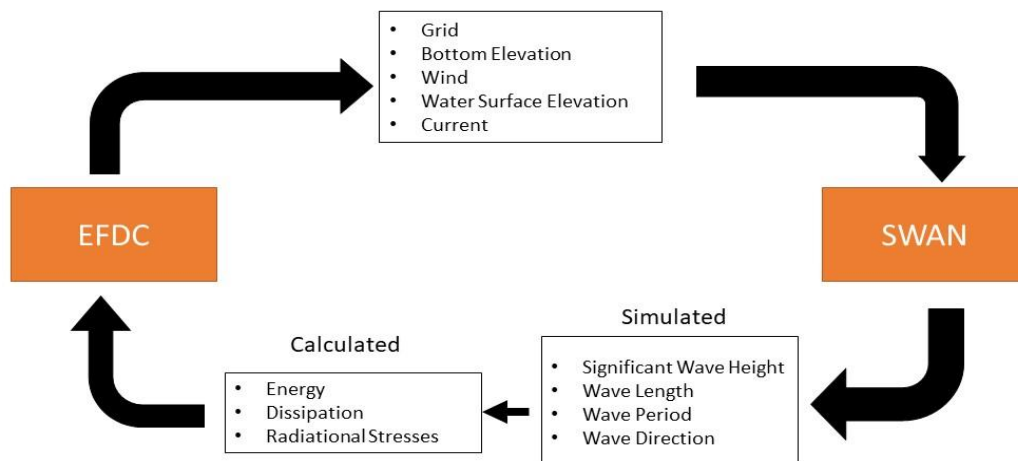


Figure 2. Conceptual model of the linkage between EFDC and SWAN.

The model was run on all grid cells over the simulated period. For analysis purposes, model output was generated for 17 sites that are monitored regularly by UDWQ to enable comparison of model output data with monitoring data (Figure 3, Table 1). Model output for wind speed, water depth, current shear stress, and wave shear stress was generated for each location.

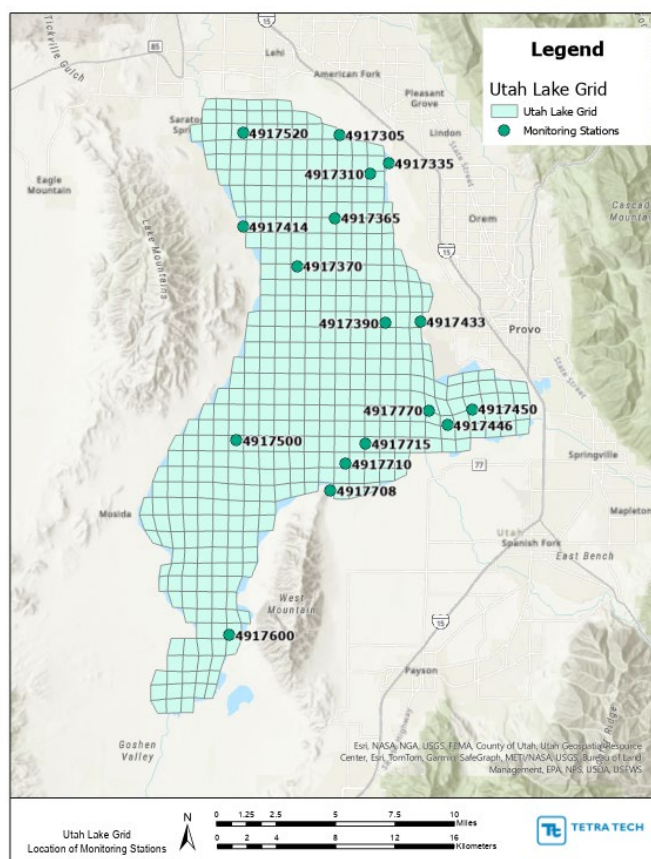


Figure 3. Locations of monitoring stations.

Table 1. Description of stations monitored by UDWQ.

Station ID	Station Location/Description
4917390	Utah Lake 1 Mi West of Provo Boat Harbor
4917715	Utah Lake 1 mile southeast of Bird Island
4917500	Utah Lake 3 Mi WNW of Lincoln Beach
4917365	Utah Lake 2 miles west of Vineyard
4917370	Utah Lake 1 Mi East of Pelican Point
4917520	Utah Lake 2 Mi E of Saratoga Springs #12
4917310	Utah Lake 0.5 Mi W of Geneva Discharge #15-A
4917710	Utah Lake 1 Mi Ne of Lincoln Point #03
4917770	Utah Lake Outside Entrance to Provo Bay
4917450	Utah Lake at Middle of Provo Bay
4917600	Utah Lake Goshen Bay Southwest End
4917433	Utah Lake SP at Marina
4917335	Utah Lake at Lindon Marina Beach NE of Launch Ramps
4917305	Utah Lake at American Fork Marina Near Boat Ramp
4917414	Utah Lake Saratoga Springs Marina Boat Ramp
4917708	Utah Lake at Lincoln Marina (Beach)
4917446	Utah Lake Entrance to Provo Bay

RESULTS

Wind varied substantially from 0 m/s to a maximum of over 15 m/s over the simulated period (Figure 4). The EFDC model applied wind speed, direction, and other weather parameters from two weather stations located at Provo Airport (KPVU) and on the western shore of Utah Lake (UTLAK). Water depths varied substantially across time and space (Figures 5 and 6).

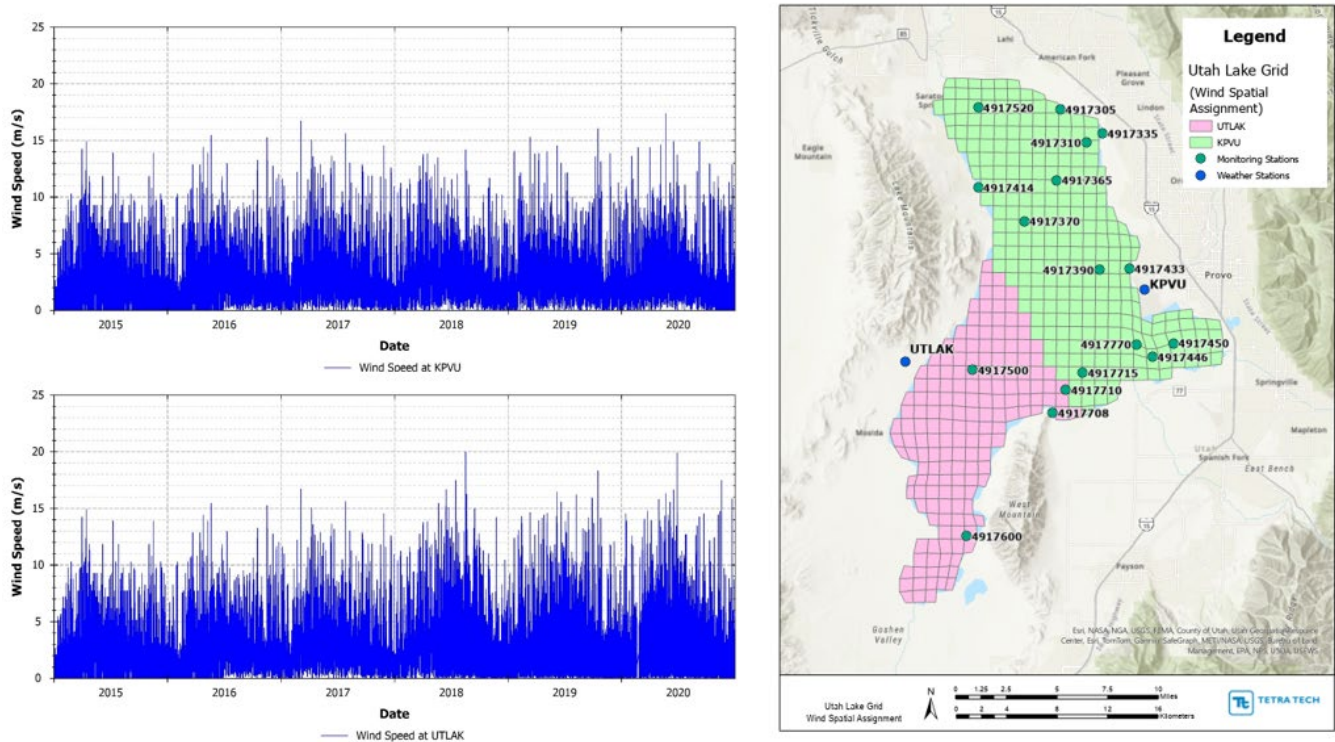


Figure 4. Wind time series over the simulation period for two weather stations. Green cells used wind input from weather station KPVU (Provo Airport) and pink cells used wind input from weather station UTLAK (western shore of Utah Lake).

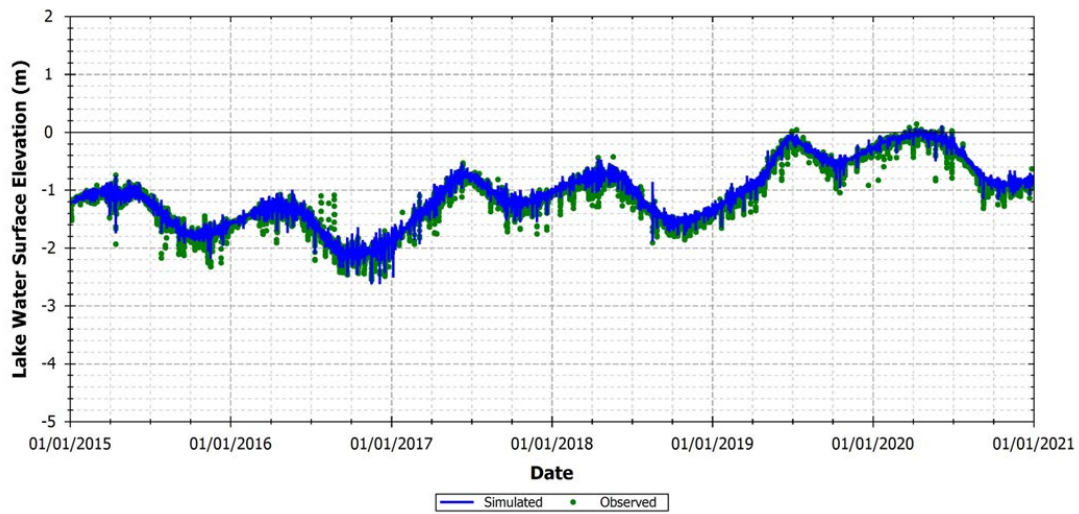


Figure 5. Utah Lake surface elevation throughout the simulated period. An elevation of 0 indicates the compromise elevation (4,489 ft).

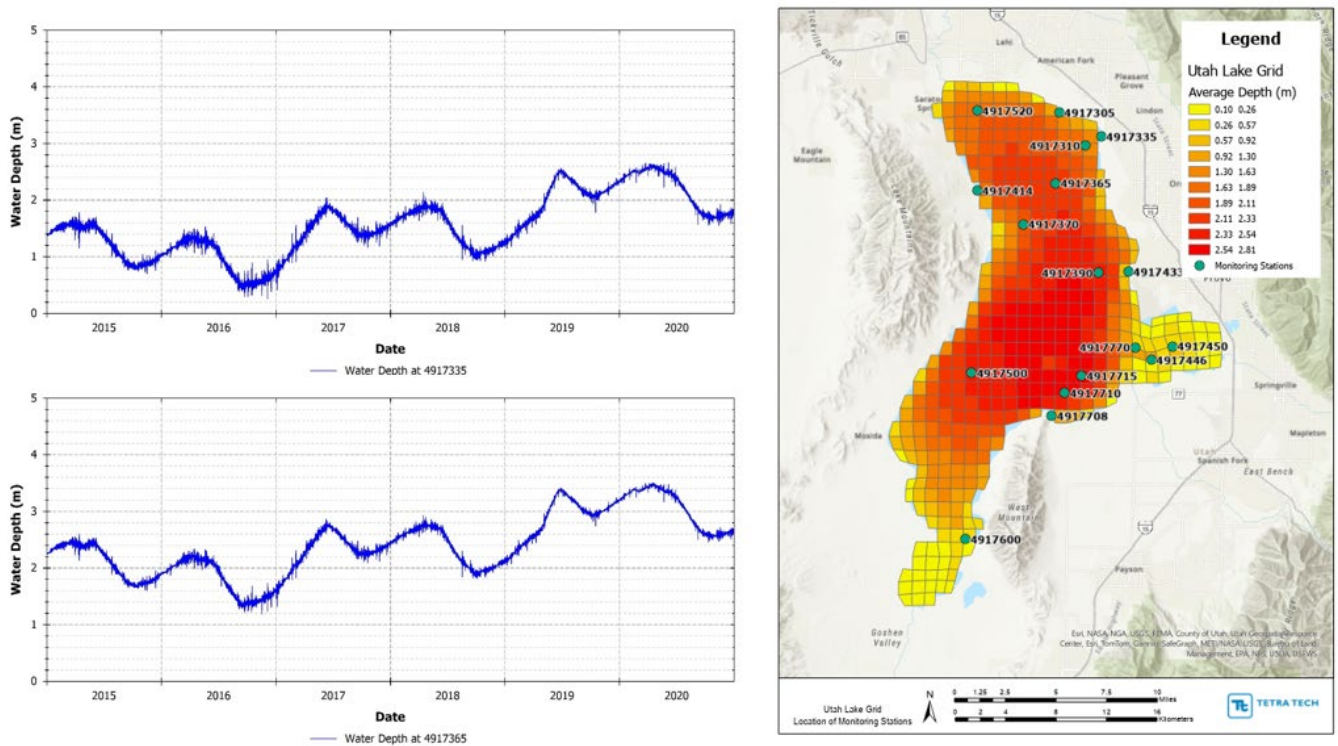


Figure 6. Water depth at stations 4917335 (Lindon Beach) and 4917365 (Vineyard).

Two types of shear stresses were calculated, one driven by advective flow, the other from wind induced waves. The monthly average of the air temperature shows that from December through February, the temperatures are near or below zero. During those months it was assumed Utah Lake is covered by ice, therefore those data were removed (Figure 7).

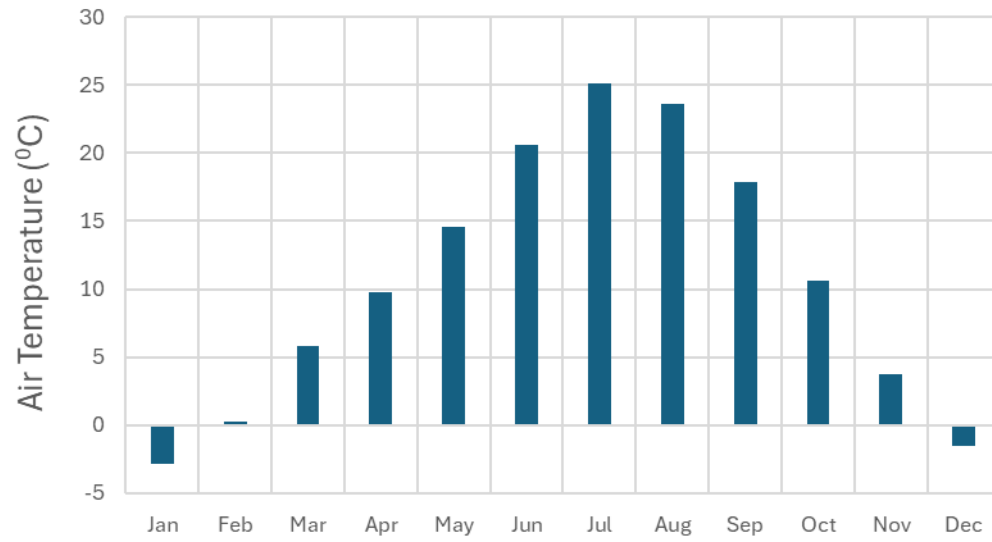


Figure 7. Utah Lake air temperature (°C) by month.

Wave shear stress (τ) was calculated at a sub-daily timescale for all lake grid cells across the simulated period. Figures 8 and 9 show the annual minimum, mean, and maximum wave shear values for the lowest water year (2016) and highest water year (2020) in the simulated period. Typically, wave shear was highest in nearshore areas owing to shallower depths, though these results should be interpreted with caution for areas nearest shore that are subject to drying and re-wetting due to model uncertainty. Open water locations in the main basin of the lake tended to have fairly similar shear stress in high and low water years, whereas nearshore locations tended to have higher wave shear in low water years than in high water years.

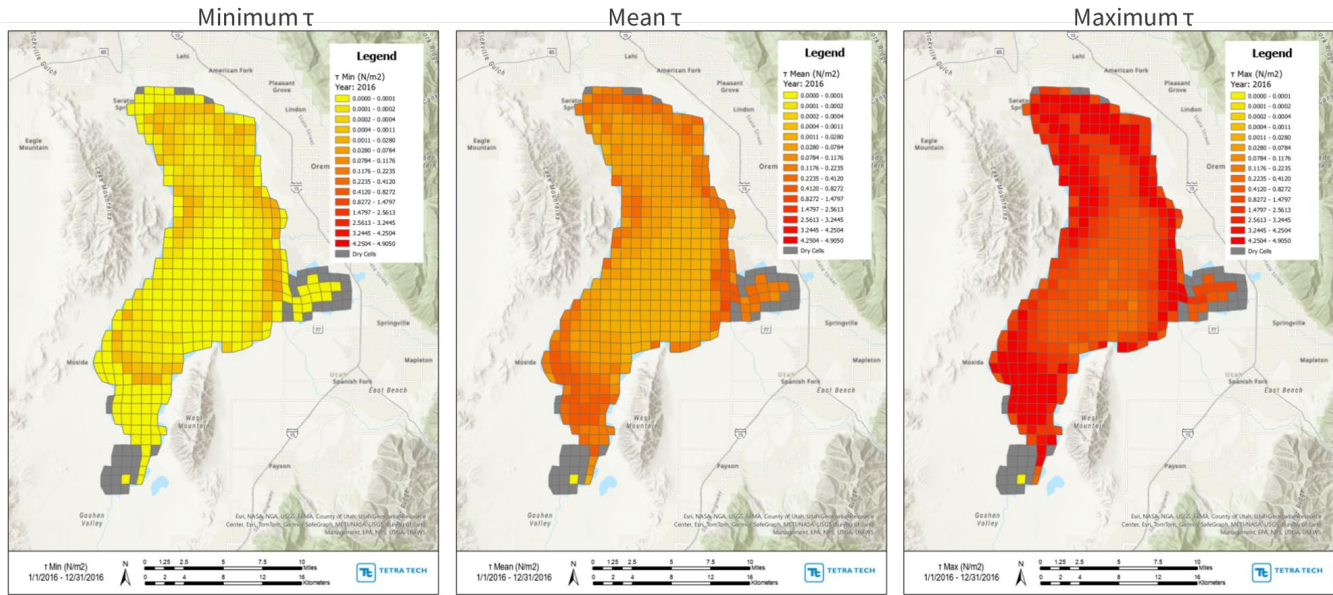


Figure 8. Wave shear stress for 2016, a low water elevation year.

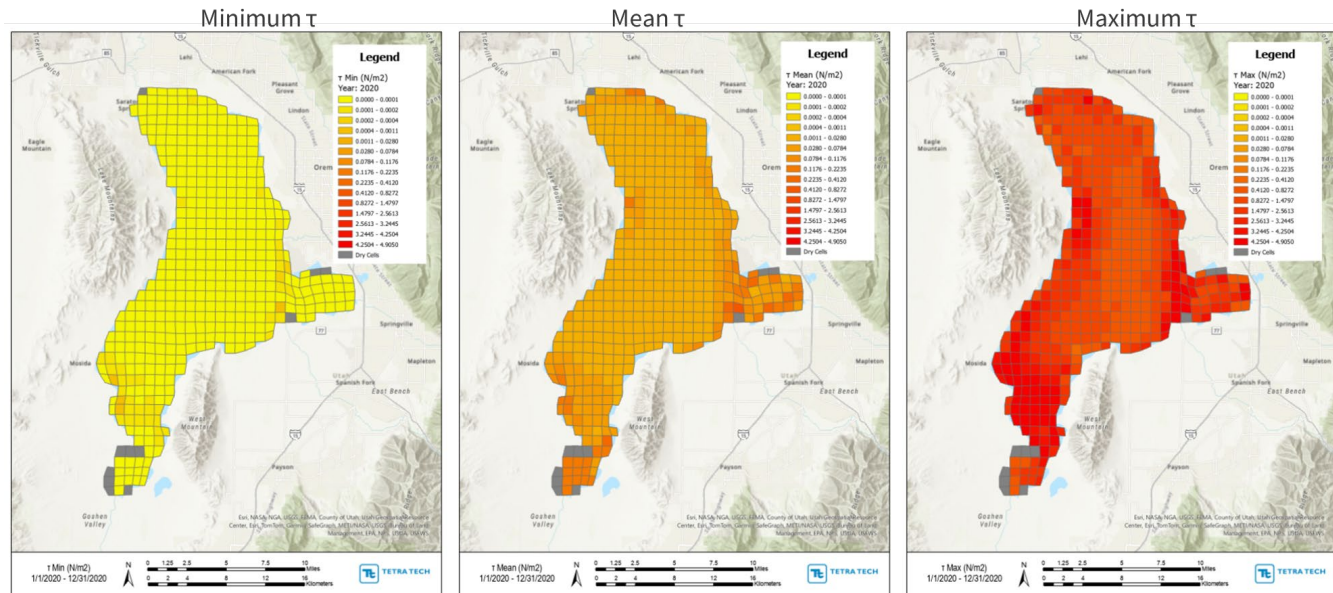


Figure 9. Wave shear stress for 2020, a high water elevation year.

Figure 10 shows simulated wave and current shear stress for two selected locations, 4917335 (Lindon Beach) and 4917365 (Vineyard). In shallow locations such as Lindon Beach, current shear is minimal and thus overall shear stress is dominated by wave action. In deeper locations such as the open water station near Vineyard, current shear is higher than in nearshore locations while wave shear remains largely consistent. Current shear made up 23.8% of overall shear across locations. However, shear stresses during extremely shallow or almost dry conditions (e.g., depth = 0.11 m) may need to be removed from the analyses (e.g., Figure 11).

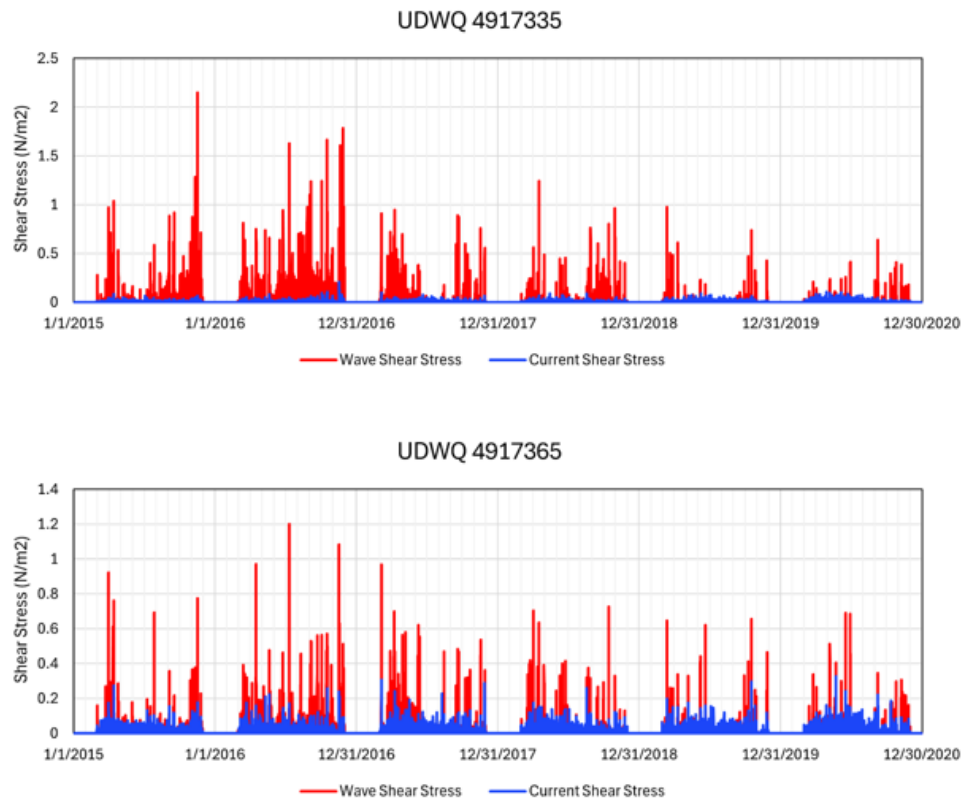


Figure 10. Wave shear (red) and current shear (blue) at stations 4917335 (Lindon Beach) and 4917365 (Vineyard).

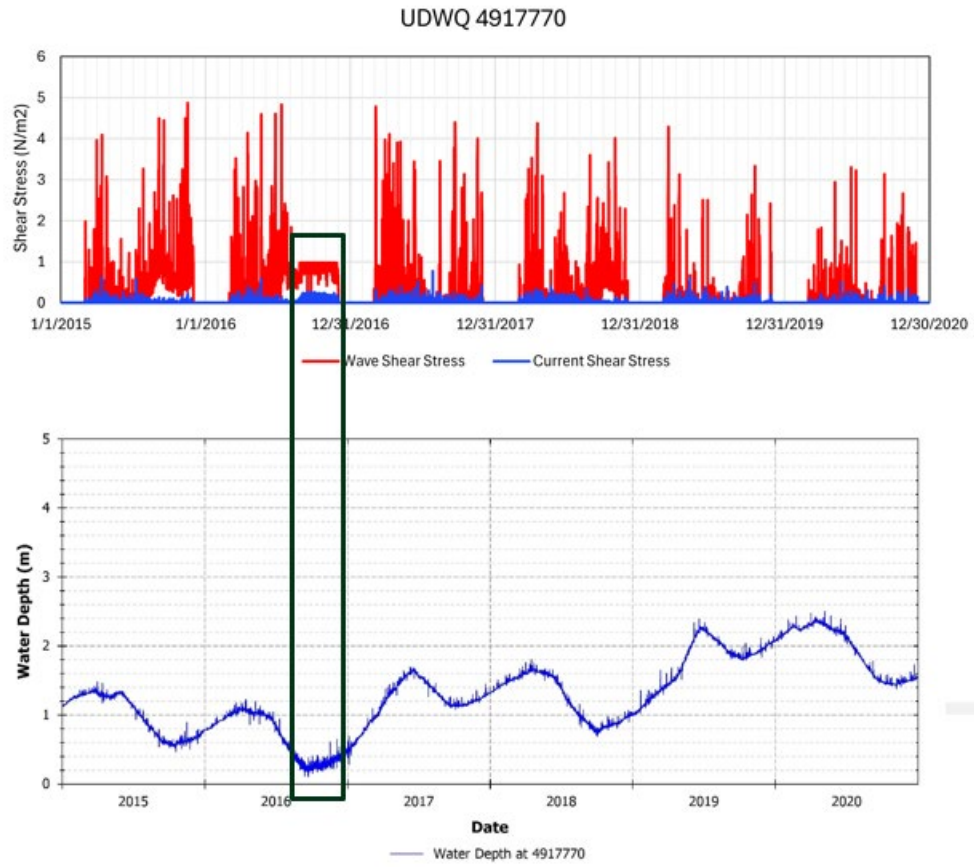


Figure 11. Implications of drying on overall estimates of shear stress at station 4917770 (entrance to Provo Bay). Top: wave shear (red) and current shear (blue). Bottom: water depth. Black box indicates a period of nearly dry condition, under which wave shear estimates are suspect.

CRITICAL SHEAR STRESS ANALYSIS

METHODS

The goal of this analysis was to determine the magnitude and relative impact of wind speed and wave action necessary to entrain bottom sediments in Utah Lake. Using physical limnological/hydrodynamic theory and statistical approaches, we calculated forces necessary to mix and entrain bottom sediments. These values can be used to estimate the number of days wind speed is sufficient to entrain bottom sediments and inform future restorations activities that can reduce shear stress to re-stabilize lakebed sediments. Using existing turbidity data from synoptic and continuous buoy samplers we developed statistical models relating total shear stress (wave plus current) from the EFDC model to observed turbidity and inorganic sediment concentration. These analyses were modeled after a 2021 study (Tetra Tech 2021) but used updated buoy data paired with EFDC model outputs and updated several statistical approaches.

Critical shear stress is the numeric threshold of total shear stress where lakebed sediment particles begin to dissociate with the benthos and can be suspended in water column. Critical shear stress was estimated using several methods including the relationship between total shear stress and observed turbidity. The EFDC model was run from 2016 through the end of 2020 and all outputs were merged with water quality data from four DEQ buoy location across Utah Lake. Critical shear stress was calculated empirically by examining the relationship between shear stress and turbidity and shear stress and fixed suspended solids (FSS). FSS is a calculated variable that is created by subtracting volatile suspended sediment (VSS) from total suspended sediments (TSS) to determine the total weight of inorganic particles suspended in water. As FSS is only the inorganic portion of TSS it should be a good representation of suspended inorganic sediments. Three different statistical techniques were used to develop breakpoints in shear stress where observed turbidity increased in the water column. We used changepoint analysis, segmented regression and classification and regression trees (CART, with bootstrapping) to estimate breakpoints in the shear stress turbidity relationship (r packages `chngpt`, `segmented`, and `rpart`, respectively). FSS measurements are collected via grab sampling and had far fewer measurements than turbidity ($n = 127$ to $4,632$) so data from the three open-water buoy locations were combined to find the threshold of total shear that led to increased FSS concentrations using CART with bootstrapping.

Lastly, we used observed data from Utah Lake to estimate parameters in an equation to compute critical shear stress (USACE 2025). The computed critical shear values from the inflection point analysis were compared with theoretical critical shear based on particle size:

$$\tau_{crit} = \theta_{crit} \times (\rho_s - \rho_w) \times g \times d$$

Where θ_{crit} is the critical Shield's parameter, g is acceleration due to gravity, ρ_s is sediment density, ρ_w is the density of water and d is median particle size. Each of these values was estimated by using literature values for and upper and lower bound (Table 2) and then randomly selecting a value between those bounds and calculating critical shear stress 10,000 times and using the average. Sediment density was calculated by correcting observed values of bulk density by porosity estimates. Instead of a range of values, bulk density was randomly selected from a distribution of values with a known mean, standard deviation, minimum and maximum values as these data were described for Utah Lake sediments (Aremu 2023).

Table 2. Shield's parameter calculating critical shear mass for Utah Lake.

	Symbol	Range	Units	Reference
Shield's Parameter	θ_{crit}	0.03 - 0.06	NA	Shields 1936
Bulk density	ρ_s	Mean = 750 -900	g/m ³	Aremu 2023
Porosity	ρ_s	0.6 - 0.82	%	Wooster et al. 2008 (sand – clay)
Water density	ρ_w	996 - 1,000	g/m ³	Calculated
Gravitational Acceleration	g	9.81	m/s ²	NA
Sediment diameter	d	0.002 - 0.005	mm	Tetra Tech 2021 (Goel pers. Comm.)

RESULTS

High turbidity was common across buoy sites, with frequent visible spikes (Figure 12, showing data through 2023). For the most part, high turbidity at a given site coincided with high turbidity at other sites. Turbidity and wind speed were positively correlated in Utah Lake (Pearson's $r = 0.60$). When departures from the turbidity-wind speed relationship occurred, they appeared to be associated with temperature, with high turbidity at relatively low wind speed occurring at low temperature and low turbidity at relatively high wind speed occurring at high temperature (Figure 13). Chlorophyll a and water temperature provided only minor explanatory power to the days where turbidity is not well predicted by windspeed (turbidity~wind speed residuals, $R^2 = 0.11$). A multiple linear regression with an interaction between wind speed and temperature, plus chlorophyll a and site indicated these variables explained 48% of variance in turbidity across sites ($df = 3,565$, $R^2 = 0.48$, $p < 0.001$).

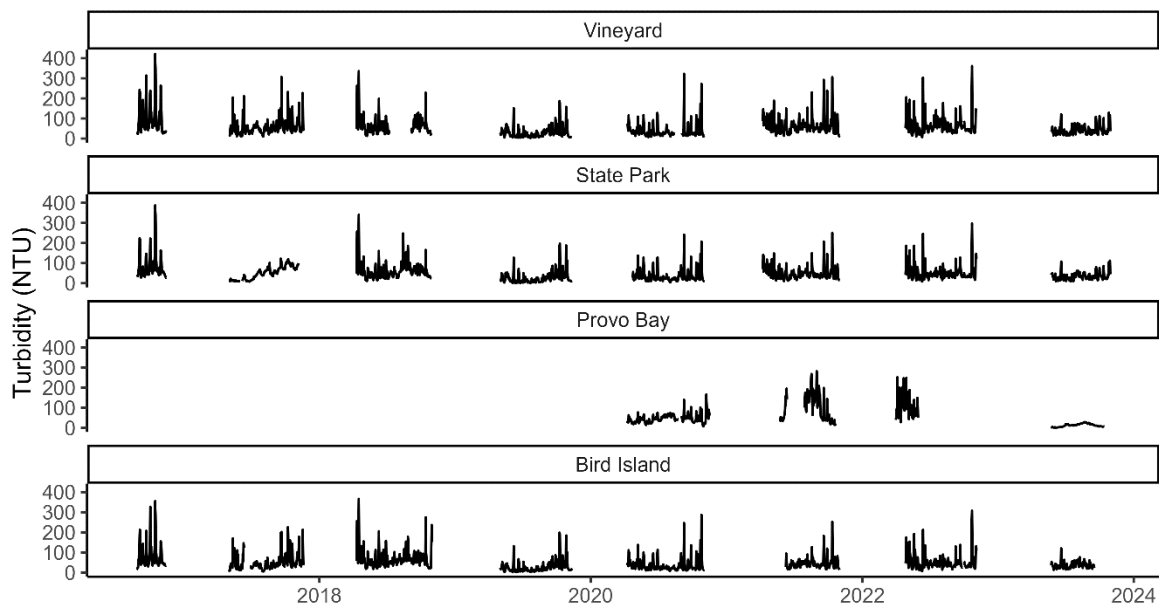


Figure 12. Time series of turbidity at buoy sites. Site codes are as follows: North = 4917365, State Park = 4917390, Provo Bay = 4917446, Bird Island = 4917715. NTU = nephelometric turbidity units. Note logged y axis.

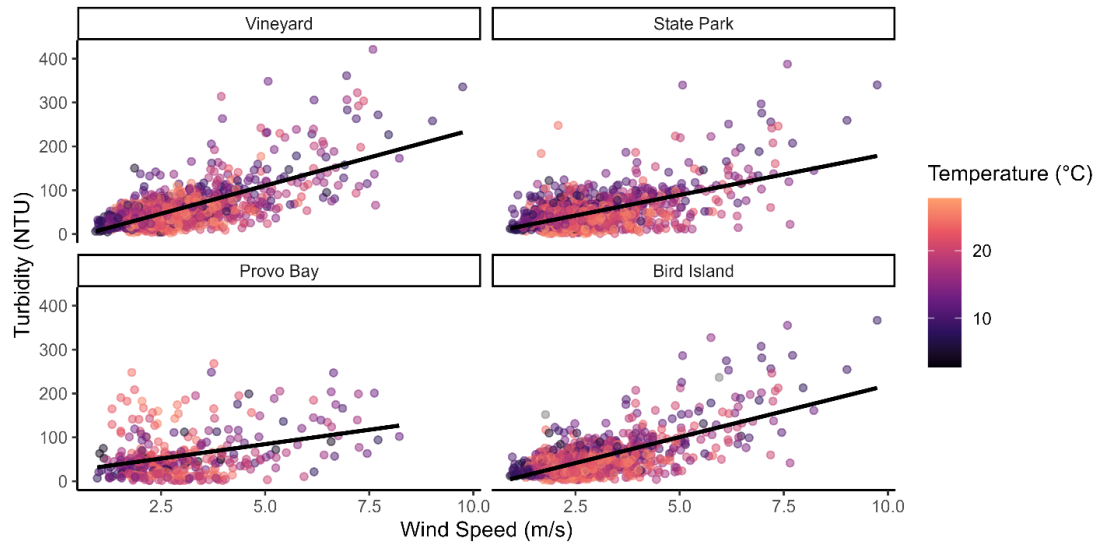


Figure 13. Relationships between wind speed and turbidity at buoy sites. Site codes are as follows: North = 4917365, State Park = 4917390, Provo Bay = 4917446, Bird Island = 4917715. NTU = nephelometric turbidity units.

Total shear stress ranged within and across the four buoy sites. Mean total shear stress was calculated as 0.020 (90th percentile = 0.003-0.047), 0.018 (0.003-0.039), 0.068 (0.0008-0.195), and 0.013 (0.002-0.030) N/m² at Vineyard, State Park, Provo Bay, and Bird Island, respectively. The three open water locations have similar depths (mean depth = 2.6-2.9m) but a slightly smaller fetch for Bird Island which likely contributes to lower shear stress (Vineyard and State Park = 10,364 m, Bird Island = 6,367 m). Provo Bay had much larger total shear estimates than the other three locations despite Provo Bay buoy location is in a bay that is more sheltered than the rest of the locations. The main difference between this location is depth in Provo Bay is much shallower (1.19 m) than the other three locations (2.6-2.9 m). Possibly, these wave shear values are not actually encountered in Provo Bay, as wave energy is dissipated by shallow underwater features not well captured by the analysis.

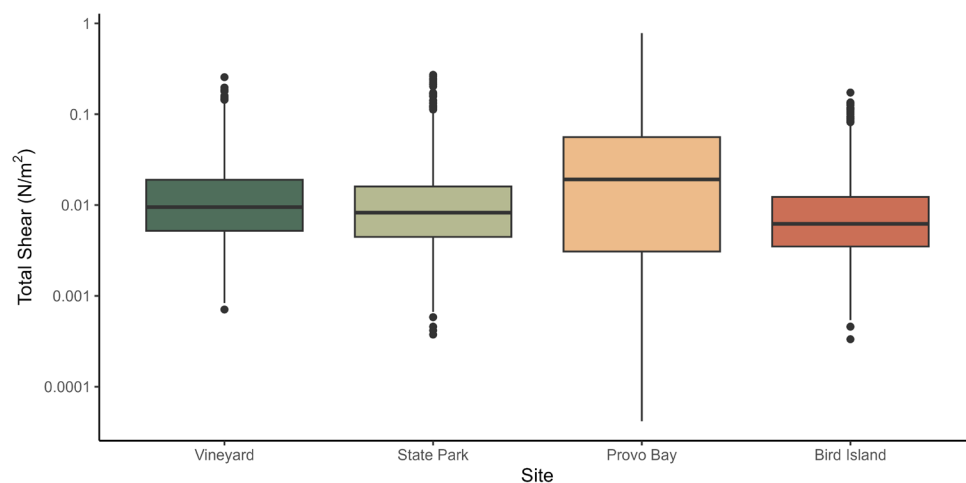


Figure 14. Distribution of wave induced shear stress at buoy sites calculated from empirical data. Site codes are as follows: Vineyard = 4917365, State Park = 4917390, Provo Bay = 4917450, Bird Island = 4917715.

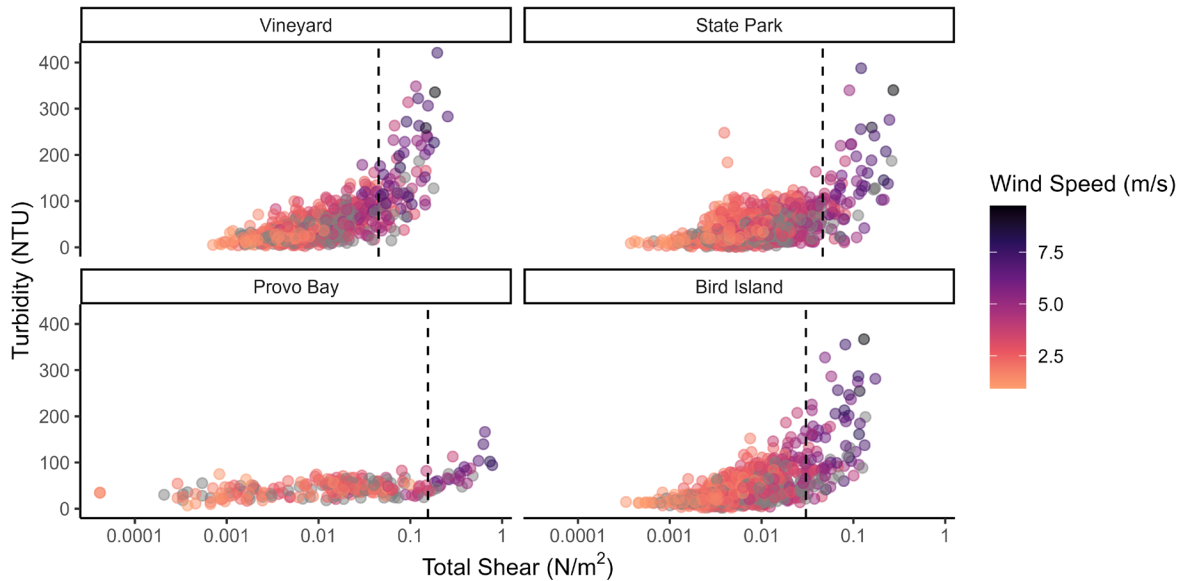


Figure 15. Wave shear and turbidity relationships in Utah Lake as they relate to wind speed. Site codes are as follows: North = 4917365, State Park = 4917390, Provo Bay = 4917446, Bird Island = 4917715. The dashed vertical line on each panel represents the mean critical shear value.

Total shear stress exhibited a positive correlation with turbidity and the site-specific model fit for total shear stress and temperature was better than the results for the wind speed and temperature model for explaining variation in turbidity ($R^2 = 0.46$ - 0.66 to $R^2 = 0.07$ - 0.53 ; Figure 15). Total shear explained 46-66% of variance in turbidity across sites, but it is clear there are sources of unexplained variance. A potential explanation for the model fit is the presence of an inflection point. At high wave shear, sediments are entrained into the water column, resulting in a positive correlation between wave shear and turbidity. At low wave shear, however, the shear is not high enough to entrain sediments but there may be residual sediment in the water column that has not settled to the bottom, resulting in a flat relationship between wave shear and turbidity. The inflection point of this relationship is referred to as critical shear (Wang, Wang, and Wang 2010).

Each of the statistical and theoretical breakpoints for critical shear stress was averaged to calculate critical shear stress, incorporating the benefits and drawbacks of each approach into an ensemble mean value (Table 3). The theoretical breakpoint for Provo Bay resulted was a value (0.40) that exceeded the reported range of values for lakebed sediments (0.009 to 0.25 N/m^2 , Chao et al. 2008). For this reason, the theoretical critical shear stress for Provo Bay was not included in further calculations and reporting. Mean critical shear values were calculated as 0.045, 0.046, 0.156, and 0.030 N/m^2 for the North, State Park, Provo Bay, and Bird Island buoy sites, respectively. Given how close these inflection points are to one another for the three open water sites, it might be reasonable to assume that critical shear values across the open water portions of the lake are consistent although observed wind induced shear stress varies by location (Figure 15).

Table 3. Critical shear stress values from each analysis and mean critical shear stress for each site.

	Vineyard	State Park	Provo Bay	Bird Island
Turbidity ~ Wave Shear: Changepoint	0.015	0.017	0.161	0.007
Turbidity ~ Wave Shear: Segmented Regression	0.049	0.037	0.206	0.026
Turbidity ~ Wave Shear: Bootstrapped CART	0.065	0.080	0.233	0.034
FSS ~ Wave Shear: Bootstrapped CART	0.023	0.023	0.023	0.023
Shields Equation	0.073	0.074	NA	0.062
Mean (N/m²)	0.045	0.046	0.156	0.030

The mean critical shear values calculated from statistical analysis of turbidity and FSS fall within this reported range from Chao et al. (2008) of 0.009 to 0.25 N/m². The critical shear stress estimate from the theoretical equation is within this range but usually a higher value than the statistically derived breakpoints. This at least suggests some discrepancies between the approaches. As several of the variables in the theoretical critical shear stress equation are estimated from literature values, the inflection point approach may be less accurate in the absence of detailed Utah Lake sediment data (e.g. sediment density vs bulk density).

Critical shear stress values fall above the 75th percentile of total shear stress estimates at all four buoy locations (Figure 16). Critical shear was exceeded for 10% of samples at the Vineyard site, 8% of samples at the State Park site, 12% of samples at Provo Bay and 10% of samples at the Bird Island site. Together, these data suggest that wind conditions in the lake are sometimes, but not usually, sufficient to entrain sediments into the water column (typically wind speeds above 3-4.5 m/s depending on site; Figure 17). Maps of EFDC output indicate that nearshore areas are more likely to than offshore areas and low water years are more likely than high water years to experience sediment resuspension due to shallower water depths (Figure 18).

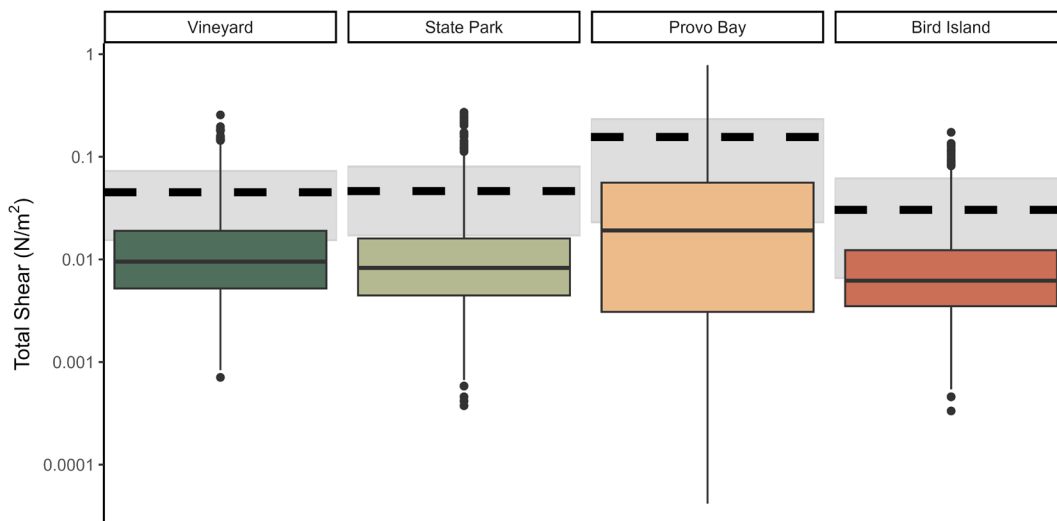


Figure 16. Observed wave shear for each of the four buoy sites compared to mean critical shear stress estimates (dashed black line) and range of critical shear stress estimates (grey background box).

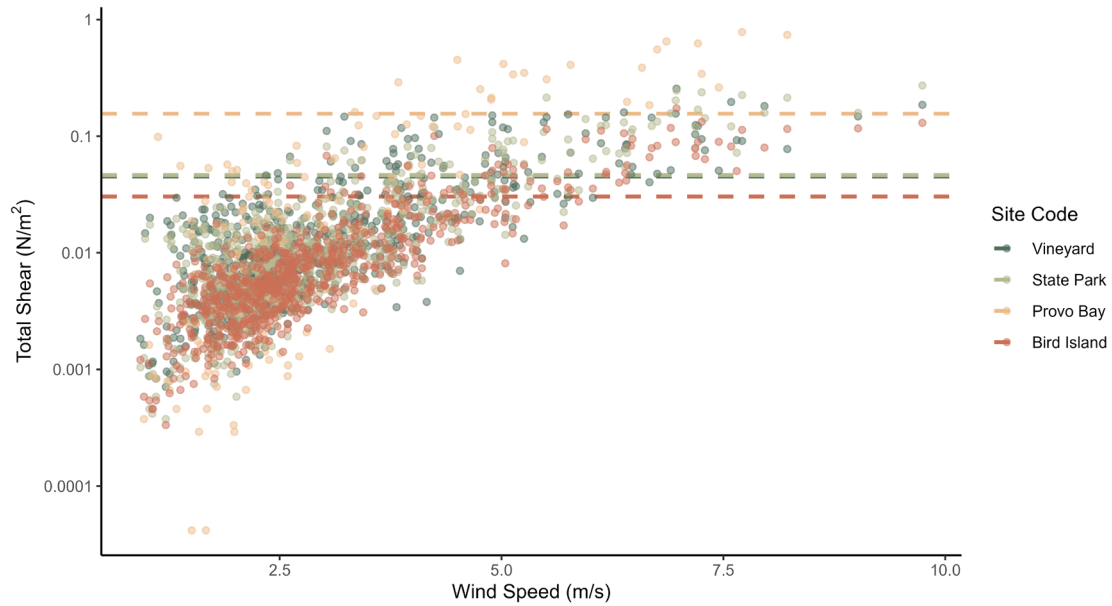


Figure 18. Wave shear and windspeed relationships for each of the four buoy locations. Dashed lines represent mean critical shear stress for each location

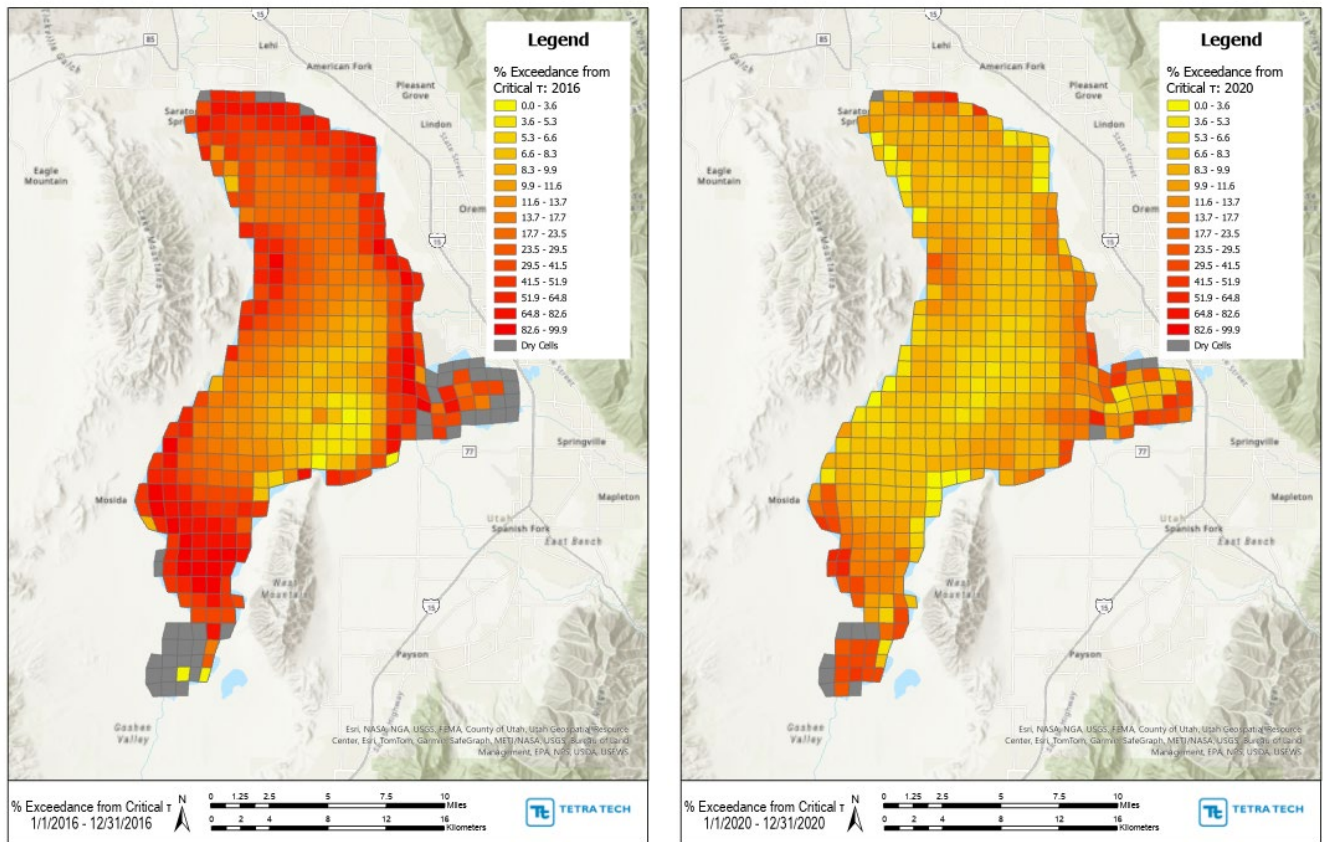


Figure 17. EFDC model output depicting the percent of time critical shear is exceeded for a low water year in 2016 (left) and a high water year in 2020 (right).

Relative Shear Stress (RSS) was calculated as daily total shear stress divided by critical shear stress for each of the four locations. An RSS value of ≥ 1 indicates the total shear stress on that day was sufficient to entrain bottom sediments. Typically, high turbidity values were associated with days where $\text{RSS} \geq 1$. On days when RSS is < 1 , turbidity is typically lower but may occasionally still exceed 100 NTU (Figure 19). Given the small particle size of sediments, the observation of moderate turbidity on days when wave shear is low may be a function of slow particle sinking rates, the effects of carp bioturbation, and/or phytoplankton induced turbidity. These findings suggest that while average conditions in the lake are not sufficient to retrain sediments into the water column, high wind events occurring on a relatively small subset of days drive sediment resuspension events that may be maintained after windy conditions subside.

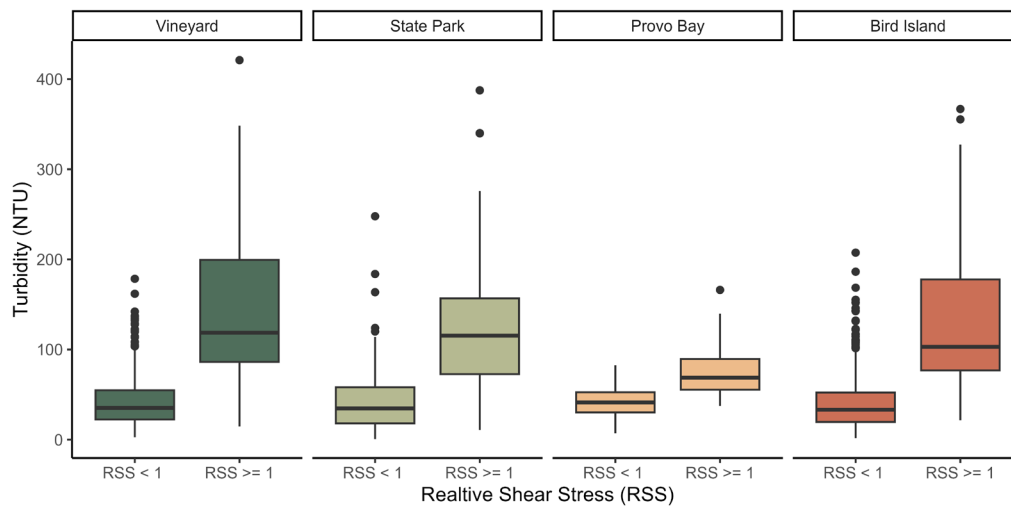


Figure 19. Observed turbidity at the four buoy locations on days when daily wave shear stress exceeds critical shear stress ($\text{RSS} \geq 1$) versus days when daily wave shear stress is below critical shear stress ($\text{RSS} < 1$).

Finally, to statistically evaluate patterns of wave induced shear stress on turbidity in Utah Lake we created a linear mixed effects model using site and month as random variables. Total shear alone explained 34% of the variation in turbidity (Marginal R^2) but including site and month increased explanatory power to 46% (Conditional R^2). State Park and Provo Bay had significantly less turbidity for the same amount of wave induced shear stress than the other sites, with only State Park being significant (Figure 20). As mentioned before, this may be due to somewhat different sediment characteristics in Provo Bay (Aremu, 2023) or that wave induced shear stress was over-estimated in the more sheltered Provo Bay but the possible mechanisms at the State Park location is uncertain. May through July also produced less turbidity relative to wave induced shear stress than the other months while September-November and April produced more turbidity relative to shear stress. The mid-winter months are not estimated due to lack of monitoring data, but some of this time is certainly ice covered in Utah Lake. The findings of less turbidity per unit of wave induced shear stress in mid-summer is unclear at this point, there may be some stabilizing effect of macrophyte growth or benthic algae although neither of these are not widely reported across the lake (as discussed in Tetra Tech 2021). Restoration activities meant to decrease shear stress and/or stabilized sediments (e.g. physical break walls, macrophyte restoration) would reduce the amount of resuspended non-algal turbidity in the lake.

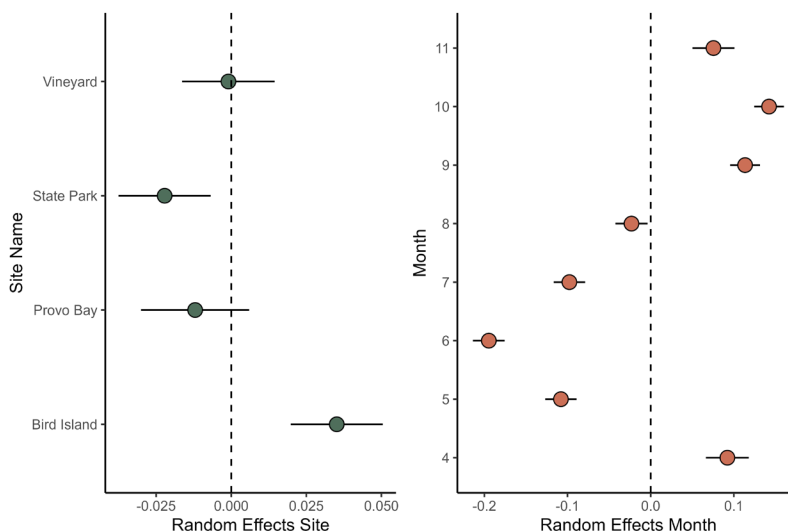


Figure 20. Relative impact of random variables in the linear mixed effects models. Variables with values and confidence interval completely above of below zero (dashed line) are considered significant.

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Appendix G

Scope of Work: Numerical Model Development to Support Revegetation Efforts

Appendix G. Scope of Work: Numerical Model Development to Support Revegetation Efforts

G.1 Introduction

This appendix outlines the numerical modeling scope of work to support the preliminary design of the pilot project proposed at Goose Point in Utah Lake and to serve as a blueprint for how other locations in Utah Lake could be evaluated for enhancement activities. Based on the feasibility level assessment of current and wave climate, three innovative conceptual options were developed and presented in the *Draft Utah Lake Study Report*; these options aim to create a robust carp-free enclosure while fostering a clearer and healthier aquatic environment for natural protection at Goose Point.

The proposed conceptual options must be designed to withstand extreme wave and current conditions over the intended economic life of the pilot project, which is estimated to be between 5 and 10 years. To achieve this, anticipated current speeds and wave heights near and around Goose Point must be calculated. This information will support the design of suitable materials, particularly in relation to the strength of netting materials and the design of anchors used to secure the nets and floating boom to be anchored to the lakebed.

G.2 Modeling Methodology

A coupled hydrodynamic and spectral wave model is proposed to determine current and wave conditions that occurred during high and low water stages recorded in Utah Lake. Results from this modeling effort will be input to design of pilot project elements.

The Danish Hydraulic Institute's MIKE 21 hydrodynamic model with flexible mesh will be used to develop the lake wide hydrodynamic model. The flexible mesh approach enables varying mesh resolutions, with finer resolutions assigned to areas of interest to resolve bathymetric and topographic details, as well as flow details, more effectively. The model simulates wind- and tide-induced water levels and currents. The flood and dry states are included in the model to simulate flooded boundaries automatically and accurately, making it suitable for inland flooding applications.

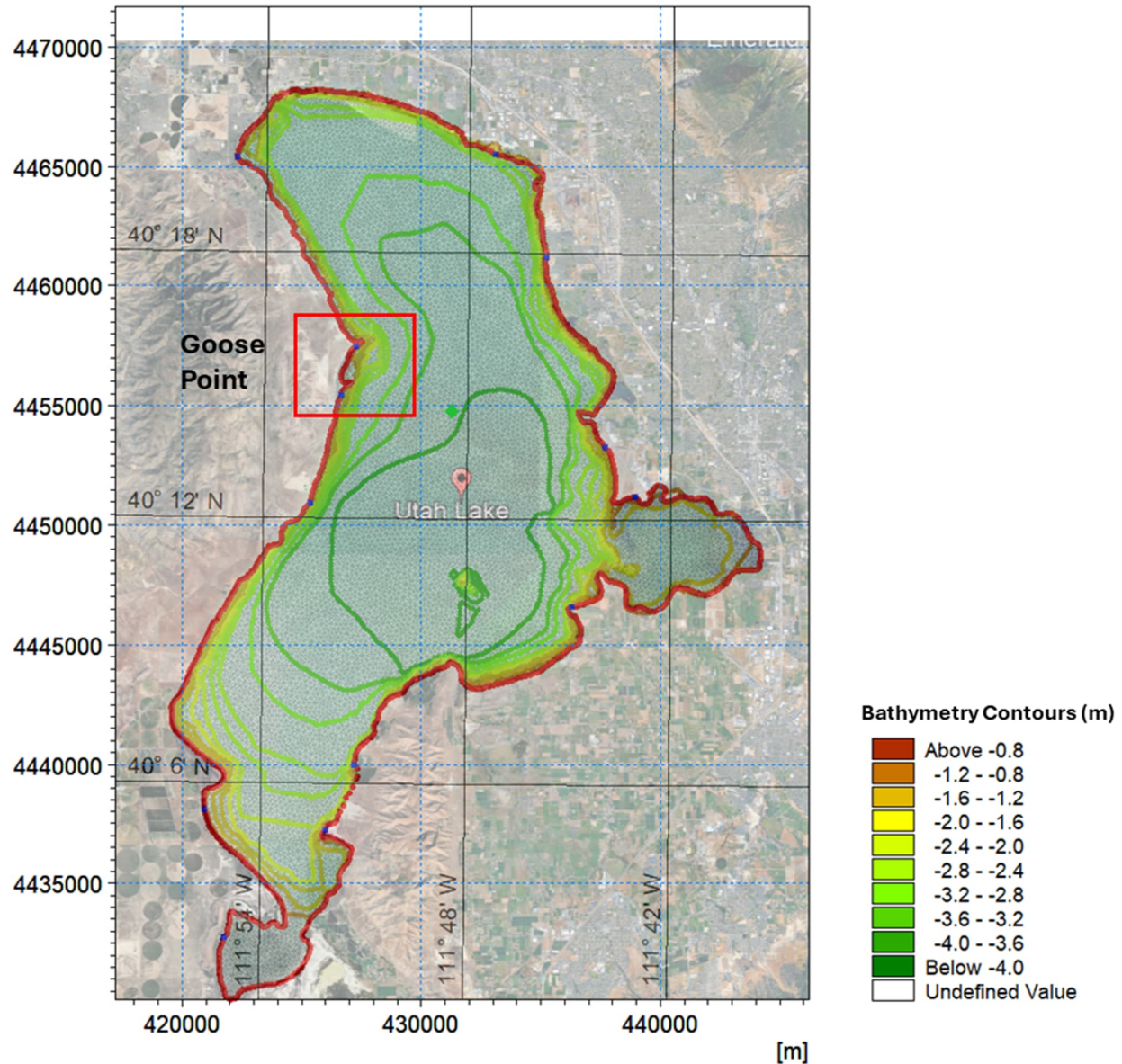
In coupled mode with the hydrodynamic model, spectral wave transformation modeling will also be conducted using same software's Spectral Wave Flexible Mesh module. This model is a third-generation phase-averaged spectral wind-wave model based on an unstructured mesh. It simulates the growth, decay, and transformation (including refraction, shoaling, diffraction, and dissipation due to wave breaking and bottom friction) of both wind-generated and swell waves as they move from offshore to nearshore. Due to absence of site specific current speed and wave height measurements, numerical model will be executed with default parameters without any parameter calibration.

G.2.1 Model Mesh and Bathymetry

The model mesh having element size of about 200 meters, and bathymetry contours are shown in Figure G-1.

Figure G-1. Model Mesh and Bathymetry Contours

[m]

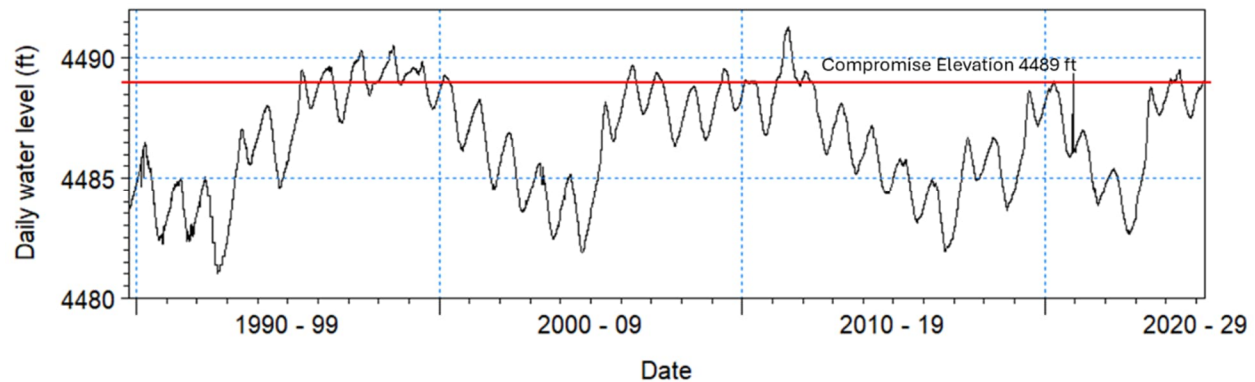


Note:
m = meter(s)

G.2.2 Water Levels and Wind

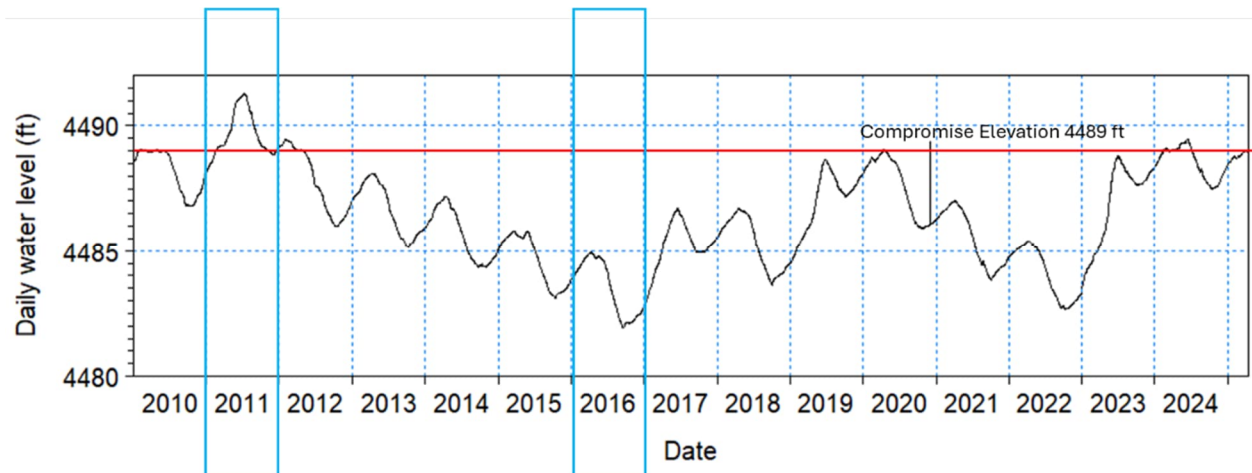
The daily mean long-term lake water levels measured from October 1989 through April 2025 exhibit variations between 4,480 feet and 4,492 feet, which are illustrated on Figure G-2. A detailed view of the low and high lake level fluctuations, along with a compromise elevation of 4,498 feet, is presented on Figure G-3. To establish a range of expected current speeds at the pilot site, two representative years, 2011 and 2016, that experienced high and low lake level conditions, respectively, were measured.

Figure G-2. Measured Long-Term Utah Lake Water Level Variation



Note:
ft = feet

Figure G-3. Zoom-in View of Measured Utah Lake Water Level Variation, 2010 through 2025



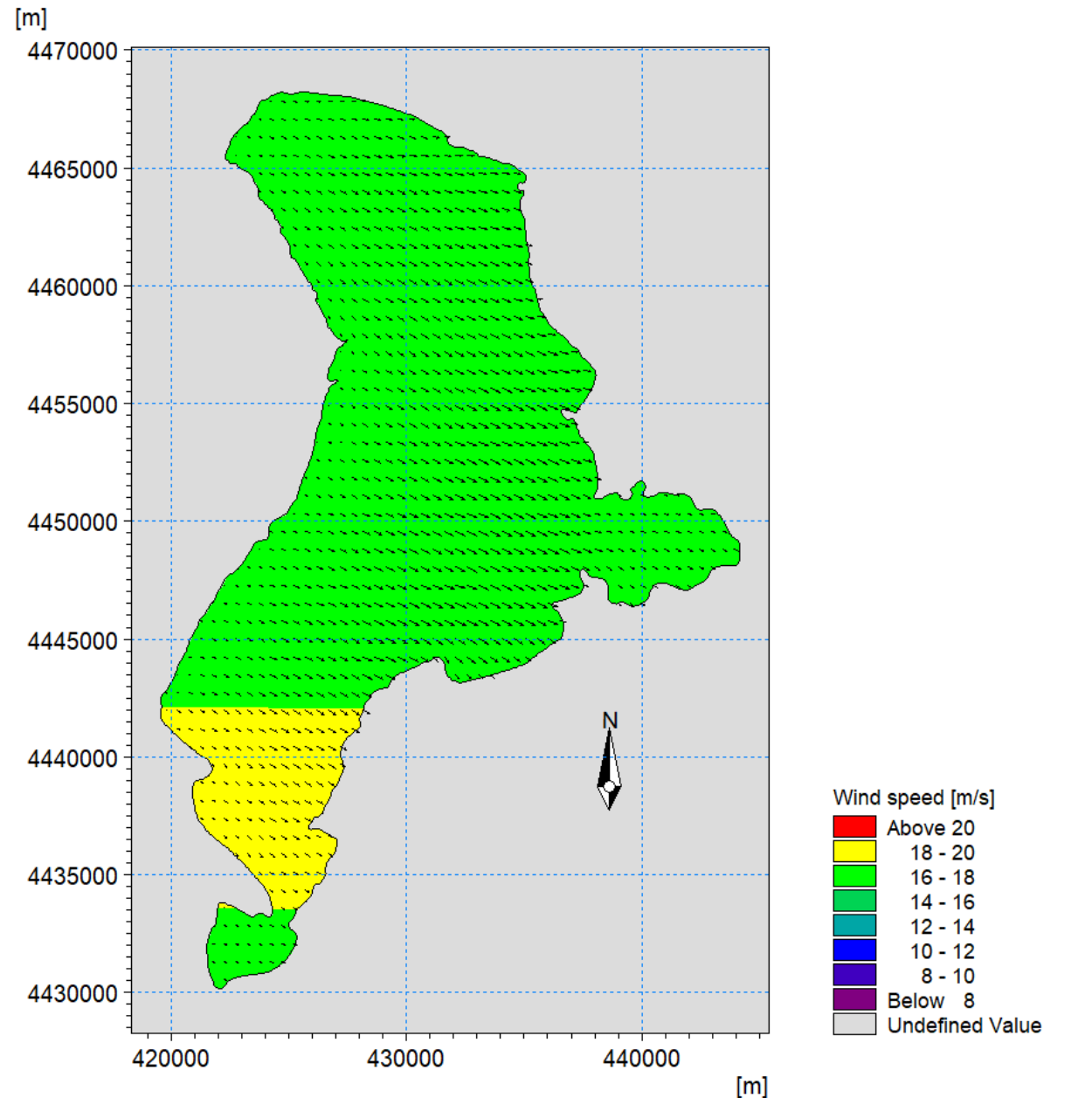
Note:
ft = feet

Wind and atmospheric pressure data from the National Oceanic and Atmospheric Administration (NOAA) Climate Forecast System Reanalysis (CFSR) will be used as external forcing to influence water levels and currents in the lake. The CFSR wind data uses a global atmospheric reanalysis that has been available since 1979 and is continuously updated in real time. Wind data are provided with an hourly temporal resolution. Data from 1980 to 2024 are accessible through NOAA, and specific years characterized by low and high water levels will be selected for the simulations. Figure G-4 illustrates a snapshot of the spatial distribution of wind speed variation across the lake surface, which is used to simulate the current climate for one month in November 2024. Wind speeds near the mainland coastline are anticipated to be generally lower compared with offshore wind speeds.

Measured wind speed and direction data from two weather stations, Provo Airport and UTLAK, are available for the years 2000 to 2020. Although wind data are reported at nonuniform time intervals, they are either recorded hourly or every 10 minutes. Wind roses

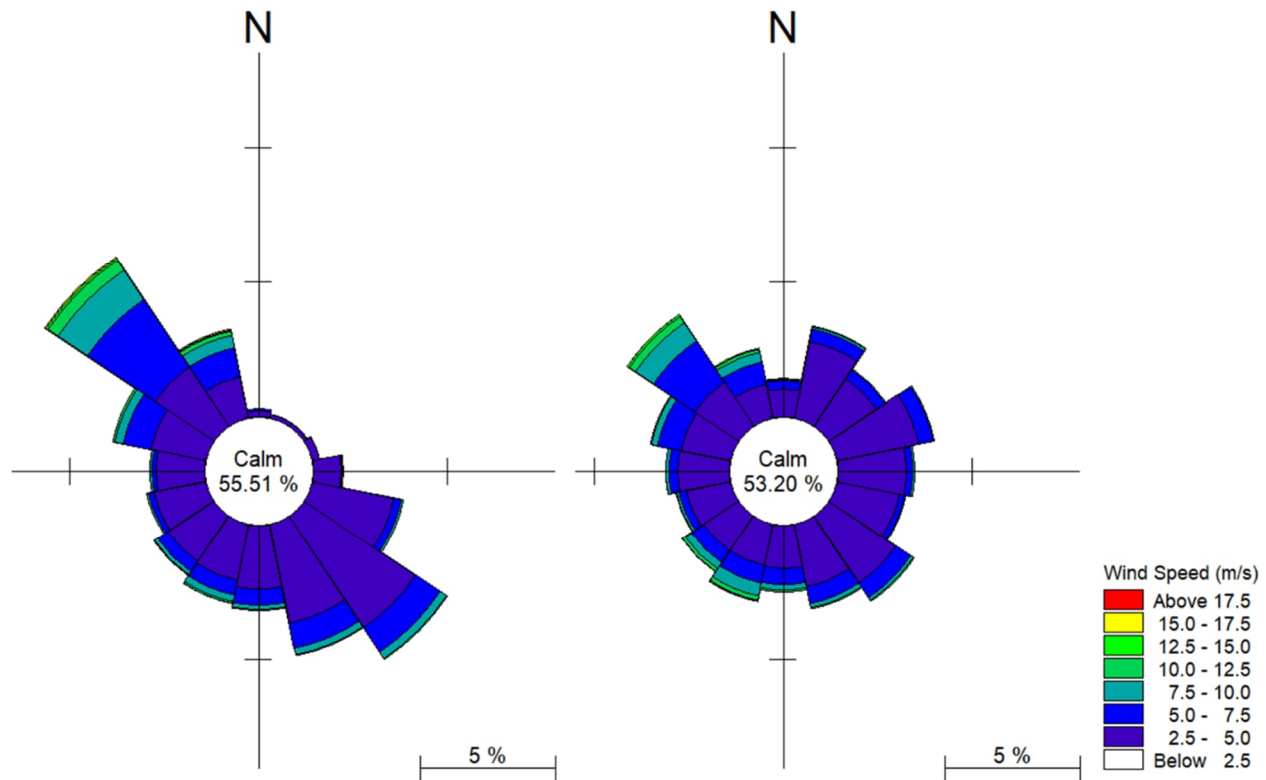
from both stations, shown on Figure G-5, indicate that wind blows from all directions. However, prevailing winds predominantly come from the northwest and southeast directions over the 20-year record period. Additionally, the wind speed is less than 2.5 meters per second (m/s), or 5 knots, approximately 50 percent of the time at both sites. Extreme value analysis will be carried out to determine extreme wind speed for 1 in 10-, 25-, and 50-year return period storm events. Results from this analysis will be input into spectral wave model to develop extreme waves at the Goose Point.

Figure G-4. Snapshot of Wind Field on Utah Lake November 27, 2024, at 05:25:00



Note:
m = meter(s)
m/s = meter(s) per second

Figure G-5. Wind Rose at KPVU (left) and UTLAK (right) Weather Stations, 2000 through 2020

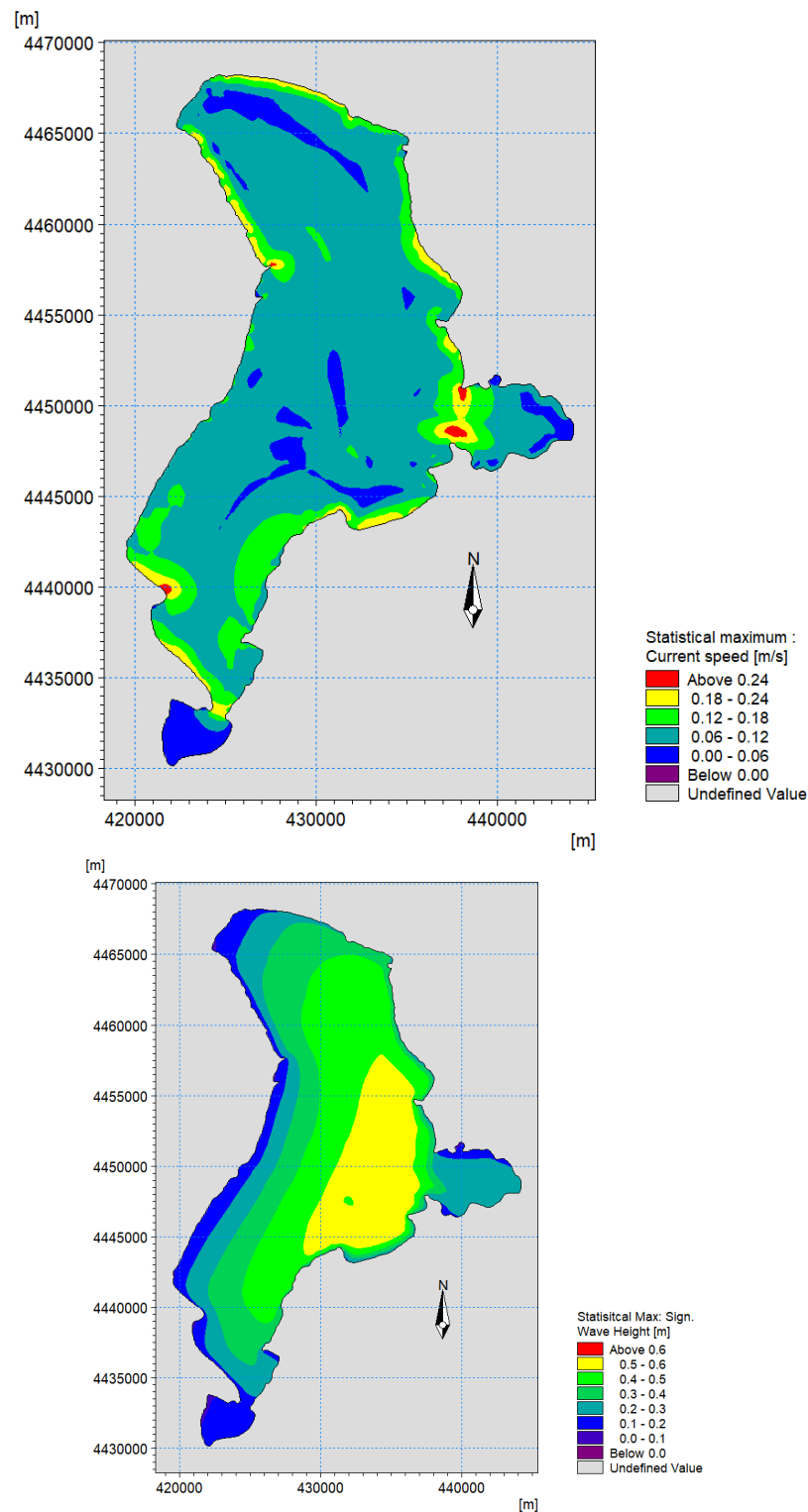


Note:
m/s = meter(s) per second

G.3 Deliverable

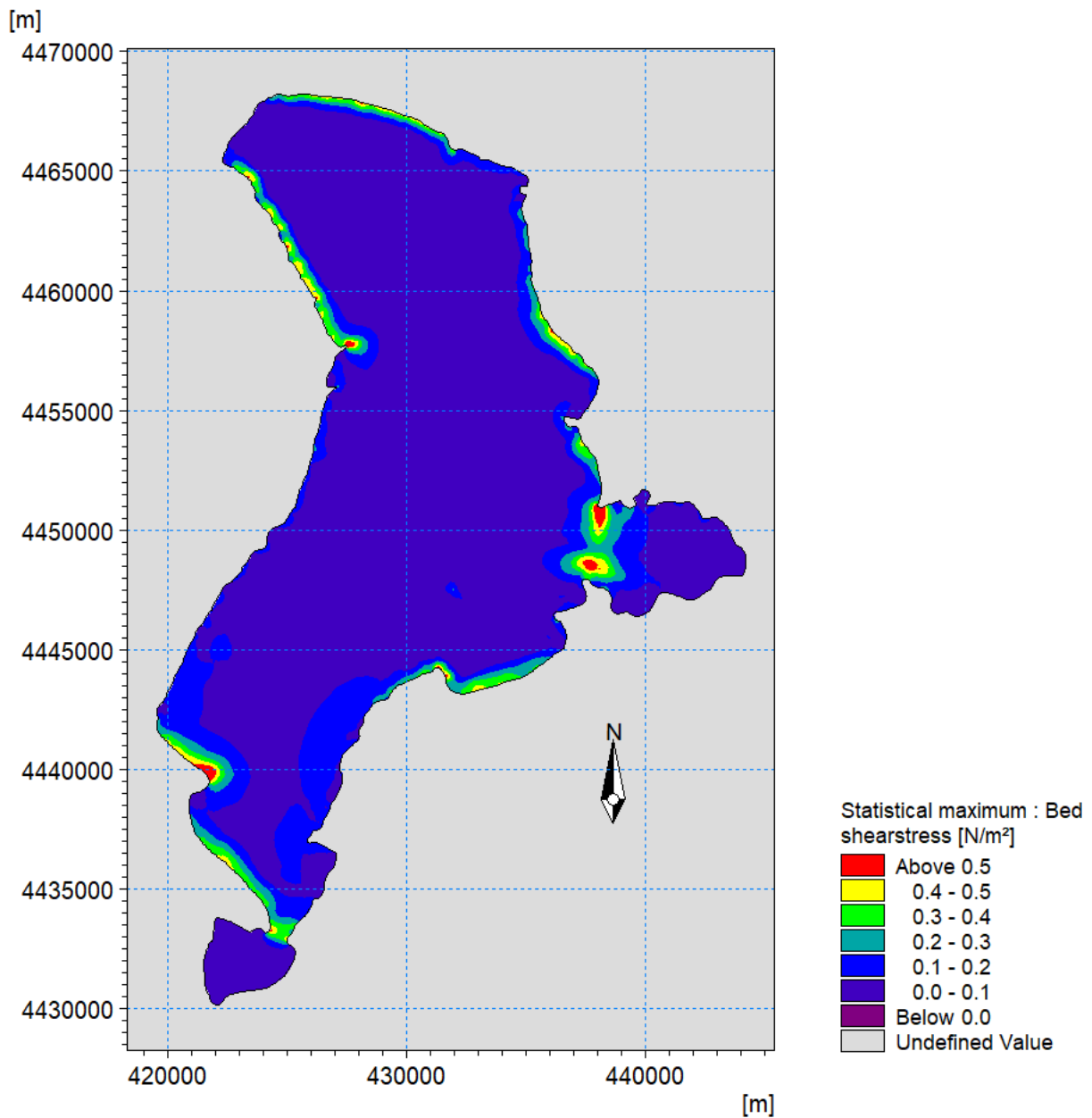
A technical memorandum on numerical modeling will be prepared that summarizes the model setup, boundary conditions, and modeling scenarios. The technical note also will include a detailed and thorough discussion of the model results the spatial distribution of maximum current and wave parameters (shown on Figure G-6). The model results will present the minimum, mean, and maximum lakebed shear stress distribution due to waves and currents. Figure G-7 illustrates a representative current shear stress map for the month of November 2024.

Figure G-6. Maximum Current (top) and Wave (bottom) Field Map, November 2024



Notes:
m = meter(s)
m/s = meter(s) per second

Figure G-7. Snapshot of Maximum Current Bed Shear Stress Map, November 2024



Notes:
m = meter(s)
m/s = meter(s) per second



Appendix H

Utah Lake and Goose Point Conceptual Revegetation Information

Appendix H. Utah Lake and Goose Point Conceptual Revegetation Information

The Goose Point pilot project is a fenced perimeter area designed to exclude carp, reduce the impacts of wind and wave action, and facilitate targeted habitat enhancements. Within this controlled setting, implemented actions will reduce or eliminate key stressors that negatively impact Utah Lake and that are critical limitations to natural habitat enhancement. The conditions in the pilot project area will be monitored over time to assess ecosystem responses. Rather than initiating large-scale enhancements across the entire lake, the pilot project will follow an iterative approach.

H.1 Existing Conditions

Goose Point is located on the western shore of Utah Lake and has three existing inundation zones within an area of low dunes that create a semiisolated, protected lagoon conditions (shown on Figure H-1).

H.2 Preliminary Design

Data collection to date at Goose Point has been preliminary and largely been a desktop effort in addition to some field reconnaissance. Data collection has included vegetation mapping, assessment of hydrologic conditions and the hydraulic connection to Utah Lake, information on soil types, elevation survey, and calculations of exclusion materials and appropriate species. The Goose Point project will consist of the following:

- Construct carp exclusion.
- Provide a range of elevations within a variety of hydrologic conditions to promote diversity of wetland vegetation: wet meadow (WM), emergent vegetation (EV), submerged aquatic vegetation (SAV).
- Allow some nonplanted areas within the carp enclosure to observe passive plant/habitat reaction to the protected conditions.
- Plant some wetland areas with plants appropriate for design hydrology.
- Plant slopes above wetland with riparian trees and shrubs and stabilize any disturbed areas.
- Provide access to the approximately 100-acre site via boat or on foot.

Figure H-1. Goose Point Pilot Project and Plant Community Inundation Zones





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Planting will be conducted within the SAV, EV, and WM zones (and within riparian areas disturbed through construction). The conceptual layout for the planting plan and wetland zones are shown on Figure H-1. The project could be divided into the following four areas:

- Area 1: SAV, EV, and WM plantings within the carp enclosure; eliminate disturbance from carp with possible reduction of wave action and suspended sediment. Area 1 would be planted with three community types in target inundation zones. Planting could incorporate a variety of plug/pot species and those species planted in larger sod mats (EV only). Target species would be installed and monitored to determine species inundation preference and competitive ability to establish and spread. Sod mats and plugs or pot plant material would be installed to observe the outcome of different planting techniques and spacing most appropriate for in large area habitat enhancements. Abiotic conditions within the enclosure would be monitored to track conditions within the carp exclusion. Abiotic factors of interest might include water depth and timing, presence and absence of algae, Secchi disk results, water clarity, water temperature, and wildlife observations (for example, invertebrates, fish, mollusks, avian, mammal use).
- Area 2: No planting reference area within the carp enclosure; eliminate disturbance from carp and possible reduction of wave action and suspended sediment. A portion of the enclosure would not be planted to allow passive regeneration to occur within WM, EV, and SAV inundation zones. These areas would be monitored to compare the passive regeneration results within the carp enclosure area. Abiotic conditions within the enclosure would be monitored to track conditions within the carp exclusion. Abiotic factors of interest might include water depth and timing, presence and absence of algae, Secchi disk results, water clarity, water temperature, and wildlife observations (for example, invertebrates, fish, mollusks, avian, mammal use).
- Area 3: SAV, EV, and WM plantings outside the carp enclosure (planting control); no control of carp or wave disturbance effects on plantings outside of enclosure in the Area 3 (planting control location). Area 3 would be planted with three community types in target inundation zones. Planting could incorporate a variety of plug/pot species and plantings in larger sod mats. Target species would be installed and monitored to determine species inundation preference and competitive ability to establish and spread. Sod mats and plugs or potted plant material would be installed to observe the outcome of different planting techniques and spacing most appropriate for large area habitat enhancements (no reduction of stressors). Abiotic conditions within the enclosure would be monitored to track conditions within the carp exclusion. Abiotic factors of interest might include water depth and timing, presence and absence of algae, Secchi disk results, water clarity, water temperature, and wildlife observations (for example, invertebrates, fish, mollusks, avian, mammal use).
- Area 4: Reference area/no planting outside the carp enclosure (reference site); no control of carp or water disturbance outside of enclosure, no planting of native plant material. Area 4 is the reference site outside of the enclosure where no planting or stressor reductions would occur and should reflect typical Utah Lake conditions without intervention. This area would be monitored to compare the reference conditions associated with passive regeneration results with no stressor reduction/outside of the carp enclosure area. Abiotic conditions would be monitored. Abiotic factors of interest might include water depth and timing, presence and absence of algae, Secchi disk results, water clarity, water temperature, and wildlife observations (for example, invertebrates, fish, mollusks, avian, mammal use).

H.3 Basis of Design

The main objectives of the Goose Point pilot project basis of design are as follows:

- Establish approximately 100 acres of SAV, EV, and WM wetlands at Goose Point.
- Establish conditions to promote lake hydrology and surface water mixing within the project and Utah Lake.
- Establish SAV native species in areas that are always inundated with 1 foot to 3 feet of inundation.
- Establish EV wetland vegetation, including native sedges, bulrushes, and shallow water aquatic plants along the lower banks that are inundated from 0 to 3 feet of water.
- Establish upper WM wetland in areas that have seasonal inundation with water levels fluctuation between 1 foot above and below the ground surface; the WM may include woody shrub and tree species, potentially including willow, alder, dogwood, cottonwood, and others in slightly higher areas of the WM zone.
- Establish herbaceous, shrub, and tree species in any disturbed riparian areas adjacent to Goose Point, potentially including willow, alder, dogwood, cottonwood, and others.

Potential preliminary vegetation success criteria may include the following targets:

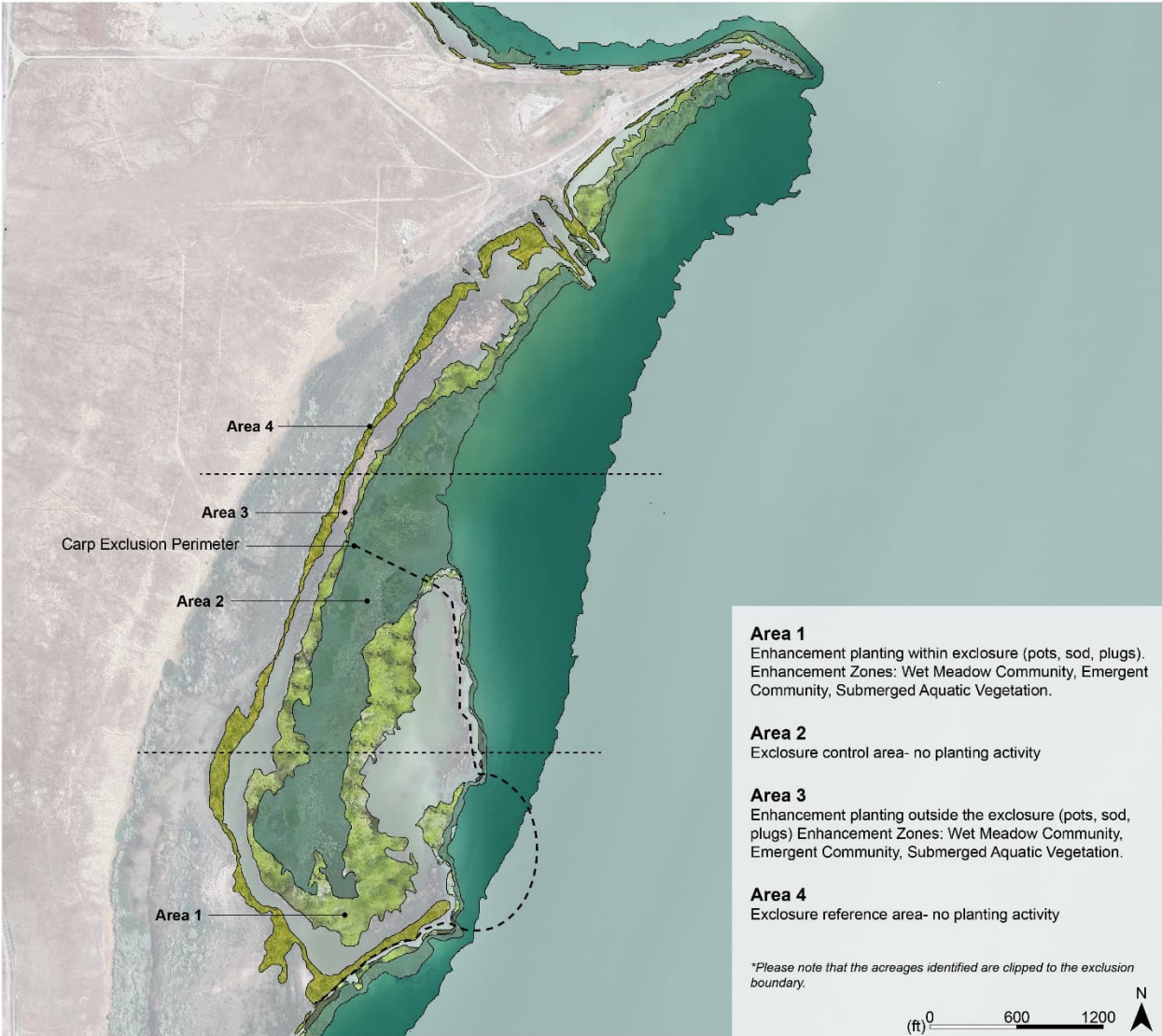
- Native species cover is at least 60 percent (Year 5).
- Invasive species cover is no more than 10 percent by Year 3 and in all subsequent years through Year 5.
- Bare substrate represents no more than 20-percent cover.
- By Year 3 and thereafter, at least six different native species are established in the EV, WM, and SAV zones.

Emergent WM and SAV vegetation will be installed either as plug or containerized material or as wetland sod installed per the manufacturer's specification. WM areas will be interseeded with native forb and grass mix if conditions are appropriate. Riparian and upland buffer plantings will be in the form of canes and live cuttings or containerized material and installed at a density of 10 feet on center. Disturbed soils will be seeded with a native seed mix. The conceptual layout for the planting plan and wetland zones are shown on Figure H-2.

H.4 Species Selection

Planting will be conducted within the SAV, EV, and WM zones (and within riparian areas disturbed through construction). Table H-1 provides a preliminary species planting list by planting zone. The acreage of each planting zone is estimated based on field evaluation and inundation depth analysis provided in the site suitability analysis. Plants were selected based on suitability for varying hydrologic conditions in Utah Lake, desirability for habitat restoration quality, and propensity for rapid establishment. Goose Point has been treated for *Phragmites* control in 2014 and 2023 (FFSL et al. 2025). Limited invasive species control will initially be required (Year 1). However, invasive species will be managed and included in the long-term maintenance plan.

Figure H-2. Goose Point Pilot Project Conceptual Layout





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Table H-1. Utah Lake Habitat Enhancement Plant List by Community Type

Common Name	Latin Name	Facultative Rating ^[a]
<i>Emergent Community Species List</i>		
Hardstem bulrush ^[b]	<i>Schoenoplectus acutus</i>	OBL
Alkali bulrush ^[b]	<i>Bolboschoenus maritimus</i>	OBL
Broadleaf cattail	<i>Typha latifolia</i>	OBL
Seaside arrowgrass	<i>Triglochin maritima</i>	OBL
Water sedge	<i>Carex aquatilis</i>	OBL
Spikerush ^[b]	<i>Eleocharis palustris</i>	OBL
Swamp milkweed	<i>Asclepias incarnata</i>	OBL
Broadleaf arrowhead	<i>Sagittaria latifolia</i>	OBL
Nodding beggartick	<i>Bidens cernua</i>	OBL
Giant bur reed	<i>Sparganium americanus</i>	OBL
Three-square bulrush ^[b]	<i>Schoenoplectus americanus</i>	OBL
Broadfruit bur reed	<i>Sparganium eurycarpum</i>	OBL
Nebraska sedge	<i>Carex nebrascensis</i>	FACW
Arctic rush	<i>Juncus arcticus</i>	FACW
Water sedge	<i>Carex aquatilis</i>	OBL
Coyote willow	<i>Salix exigua</i>	FACW
Joe-pye weed	<i>Eutrochium maculatum</i>	FACW
Water ragwort	<i>Senecio hydrophilus</i>	OBL
<i>Submerged Aquatic Vegetation Species List</i>		
Common waterweed	<i>Elodea canadensis</i>	Submerged
Duckweed	<i>Lemna minor</i>	Free-floating
Northern or Shortspike watermilfoil	<i>Myriophyllum sibiricum</i>	Submerged
Mosquito fern	<i>Azolla microphylla</i>	Free-floating
Longleaf pondweed	<i>Potamogeton nodosus</i>	Submerged and floating
Leafy pondweed	<i>Potamogeton foliosus</i>	Submerged
Sago pondweed	<i>Stuckenia pectinata</i> [<i>Potamogeton pectinatus</i>]	Submerged
broadleaf pondweed	<i>Stucknia striata</i> [<i>Potamogeton latifolius</i>]	Submerged
Spiral ditchgrass	<i>Ruppia cirrhosa</i>	Submerged
Stinkgrass/muskgrass/Stonewort	<i>Chara</i> sp.	Submerged
Southern water nymph	<i>Najas guadalupensis</i>	Submerged
Horned pondweed	<i>Zannichellia palustris</i>	N/A
White crow-flower	<i>Ranunculus aquatilis</i>	N/A



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Common Name	Latin Name	Facultative Rating ^[a]
<i>Wet Meadow Species List</i>		
Fremont cottonwood	<i>Populus fremontii</i>	FAC
Boxelder	<i>Acer negundo</i>	FAC
Coyote willow	<i>Salix exigua</i>	FACW
Nebraska sedge	<i>Carex nebrascensis</i>	FACW
Baltic rush	<i>Juncus balticus</i>	FACW
Saltgrass	<i>Distichlis spicata</i>	FAC
Pickleweed	<i>Salicornia rubra</i>	FACW
Joe-pye weed	<i>Eutrochium maculatum</i>	FACW
Pickleweed	<i>Salicornia rubra</i>	FACW
Arctic rush	<i>Juncus arcticus</i>	FACW
Water sedge	<i>Carex aquatilis</i>	OBL
foxtail barley	<i>Hordeum jubatum</i>	FACW

^[a] Facultative rating: FAC = facultative; FACW = facultative wetland = OBL = obligate

^[b] Preferred highly competitive species for fluctuating water levels.

N/A = not applicable

H.5 Timing

Wetland and riparian plantings are planned for early in the growing season as soon as the Utah Lake water surface elevation (WSE) begins to drop and hydrology is favorable to access the site (July). The plant installation will be conducted after the enclosure is constructed and all carp are removed. The order of plant installation may begin in the deepest location for SAV and work upslope to shallower locations (EM) and WM communities. The WM community will follow the dropping WSE to promote plant establishment and moist soils. The final community type to be planted would be the WM plantings and riparian plantings to restore any disturbed areas. This progression will minimize disturbance of installed materials throughout the planting process.

H.6 Work Plan

Construction activities will be conducted within the boundaries of the existing site limits. Figure H-1 shows the general design of the pilot project which will include areas of WM, EV, and SAV plantings within the enclosure (Area 1), passive regeneration within the enclosure-control (Area 2), plantings outside the enclosure (Area 3), and a reference area outside of the enclosure (Area 4). Construction of the Goose Point habitat enhancement area will occur subject to any in-water work window restrictions and during low water typically observed in July through October. Construction of the enclosure will begin prior to low water with the expectation that planting will commence in July. The plant installation will be conducted after the enclosure is constructed and all carp are removed.

Wetland and riparian plantings are planned for early in the growing season as soon as Utah Lake WSE has begun to drop and hydrology is favorable to access the site (July). The plant

installation will be conducted after the enclosure is constructed and all carp are removed. The order of plant installation may begin in deepest location for SAV and work upslope to shallower locations (EV) and WM communities. Final community type to be planted would be the WM plantings and riparian plantings to restore any disturbed areas. This progression will minimize disturbance of installed materials throughout the planting process. Planting zones are based on the inundation ranges targeted for each of the wetland community types.

H.7 Maintenance

Goose Point habitat enhancement will include maintenance activities throughout Years 1 through 5. Maintenance activities could include irrigation (Years 1 through 3; WM up to every 2 weeks if needed in the growing season), invasive species control (Years 1 through 5; quarterly), removal and monitoring of algal growth in the enclosure (Years 1 through 5; monthly), monitoring and removal of carp within the enclosure (Years 1 through 5; monthly). Following are additional considerations for site maintenance:

- Provisions for replanting if plant mortalities are high and to include reseeding bare areas
- Provisions for implementing other maintenance recommendations in an annual report.

H.8 Phase 1 Goose Point Monitoring Considerations

Monitoring Utah Lake responses to pilot project habitat enhancement is critical to refining and expanding the Utah Lake habitat enhancement. Monitoring methods are designed tailored to address specific concepts of expected ecosystem recovery under reduced pressures from carp and sedimentation (if possible) that will inform future actions and refine large-scale restoration methods at Utah Lake. Ecosystem and Utah Lake vegetation response to carp removal can be tested within the pilot carp enclosures. The effects of reducing wind/wave-driven sediment resuspension on ecosystem dynamics can be tested by choosing project areas that are relatively protected from wind/wave-related sediment resuspension and considering the wave reductions provided by the enclosure materials. Monitoring considerations are provided in Table H-3 with the objective to monitor, test, and understand the potential for reestablishing wetland and SAV habitats at Utah Lake.

H.9 Project Goal

The primary goal of the Goose Island pilot project is to establish native wetland vegetation along the Utah Lake littoral zone, focusing on developing WM, EV, and SAV communities to enhance and expand Utah Lake habitat, ecological function, and recreational use.

H.10 Monitoring Objectives

The following specific, measurable, and time-bound objectives guide ecological monitoring at Goose Point. These objectives are designed to inform and support large-scale habitat enhancement by evaluating natural constraints and interactions between restoration actions and existing lake conditions. Monitoring efforts are organized into five key categories:

- Passive vs. active habitat enhancement
- Plant material selection
- Invasive species management
- Environmental conditions
- Wildlife utilization

Each category contributes to understanding the dynamics of habitat restoration and supports adaptive management strategies.

H.11 Monitoring Categories and Protocols

This section summarizes each monitoring category and its protocols:

- Passive vs. active habitat enhancement
 - Objective: Compare passive enhancement (no plantings within carp exclosures) with active enhancement (plantings within carp exclosures) and compare results within the exclosure with control plantings outside of the exclosure (with carp access)
 - Frequency: Annually
 - Monitoring method: Line intercept, species survival, species vigor, photo points, and drone camera footage
 - Purpose: Assess vegetation establishment and habitat development under different restoration approaches
- Plant material selection
 - Objective: Monitor establishment, spread, and inundation tolerance of WM, EV, and SAV species
 - Frequency: Annually (late summer to early fall)
 - Monitoring method: Line intercept, species survival, species vigor, inundation depths, photo points, drone camera footage
 - Purpose: Evaluate species performance and inform future planting strategies
- Invasive species
 - Objective: Monitor and manage the presence and spread of invasive plant species within the pilot project area
 - Frequency: Quarterly, as needed, with regular assessments
 - Monitoring method: Line intercept, general observation and percent vegetative cover, inundation depths, photo points, drone camera footage
 - Purpose: Prevent ecological degradation and support native species dominance
- Environmental conditions
 - Objective: Track key abiotic factors:
 - o Water clarity and depth (Secchi disk readings)
 - o WSE
 - o Temperature
 - o Soil saturation
 - o Algal presence
 - Frequency: Monthly during the growing season
 - Monitoring method: Data plots within each wetland community type, inundation depths and reported WSE, Secchi disk readings, soil saturation observation and depth to groundwater within 24 inches, drone camera footage
 - Purpose: Understand environmental drivers of vegetation success and habitat quality

- Wildlife utilization
 - Objective: Document wildlife presence and behavior:
 - o Nesting activity
 - o Invertebrates and mollusk populations
 - o Fish occurrence
 - o Habitat preferences by season and location
 - Frequency: Quarterly
 - Monitoring method: Pedestrian survey, photos, global positioning system observation locations
 - Purpose: Evaluate habitat use and biodiversity response to restoration efforts

In summary, Goose Point pilot project monitoring should include the following elements:

- Establishing permanent sample plots in each of the planting areas
- Establishing permanent photographs points in each of the planting areas
- Documenting annually vegetation, hydrology, and soils in each sample plot
- Photodocumenting annually the site from established photograph points
- Identifying maintenance concerns and recommending remediation for them

Further, invasive species will be removed by hand pulling or spot hand spraying using approved wetland herbicides in accordance with relevant state and U.S. Environmental Protection Agency regulations for application and use in wetlands and near water bodies.

H.12 Goose Point Uncertainties

Numerous variables and points of uncertainty will need to be resolved before implementation of the Goose Point Pilot Project, including the following:

- Anticipated surface water levels at the Goose Point site and for Utah Lake. Water levels at Utah Lake are unpredictable and may delay planting or increase the planting schedule based on Utah Lake draw down and water management. If Utah Lake operations change, and the water levels raised or lowered in a manner not seen historically, then the water level in the wetlands could be impacted, which could, in turn, affect plant growth, site access, and plant establishment. Falling water levels may be most significant in establishing WM community type.
- Dewatering. An appropriate approach for dealing with uncertainty associated with construction dewatering needs to be developed if in-water planting is not possible.
- Exclosure construction and water circulation. Because of the uncertainty about how the carp exclosure will function and whether it will decrease surface water exchange with the larger Utah Lake and support algal bloom within the perimeter, exclusion and interior conditions will need to be monitored closely following installation.
- Plant establishment. Replanting and reseeding may need to be conducted because of attrition, climate, or predation.
- Temporary irrigation for establishing WM (and upland/riparian) community. The risk of replanting will be greatly reduced with an irrigation system to compensate for drought year weather or even for a normal precipitation year to provide a predictable and longer season with ideal soil moisture. Although the plants were selected to be able to generally tolerate these conditions, they are not likely to do so until they are well

established, which usually takes a minimum of 2 years; this can be accomplished with a temporary aboveground irrigation system that would be dismantled when the watering period is completed.

- Goose Point construction will likely require a nationwide permit from the U.S. Army Corps of Engineers for temporary or permanent impacts associated with constructing the project. A nationwide permit will require compliance with the Endangered Species Act and the State Historic Preservation Office (SHPO) Section 106. SHPO compliance will typically requires cultural survey and determination of effect to historic properties.
- To support the Utah Lake Study, and specifically the habitat enhancement component, necessary staffing and budgetary resources need to be identified. This requirement includes determining full-time equivalent positions and funding requirements and establishing a robust management structure. Collaboration among agencies and engagement with the legislature are critical to ensure that these resources are secured and effectively deployed.

H.13 Staffing and Level of Effort

The Goose Point habitat enhancement monitoring should include monthly (six events during growing season), quarterly (four events), and annual (one event) monitoring events depending on the monitoring category (passive vs. active habitat enhancement, plant material selection, invasive species management, environmental conditions, or wildlife utilization). Table H-3 provides conceptual levels of staff effort and general schedule to collect field data, map, analyze, and summarize results for the pilot project for habitat enhancement.

Table H-3. Estimated Labor Hours for Pilot Project Habitat Enhancement Monitoring; Field-Data Collection, Mapping, and Results

Category	Number of Events per Year	Staff (days per total hours)	Total Staff Level of Effort per Year (hours)
<i>Quarterly Monitoring</i>			
Invasive species	3 (spring, summer, fall)	Field: 1 staff/1 day 10 hours Mapping and results: 40 hours	150
Wildlife utilization	4 (spring, summer, fall, winter)	Field: 2 staff/1 day 20 hours each Mapping and results: 40 hours	240
<i>Monthly (growing season May through October; 6 events)</i>			
Environmental conditions	6	Field: 2 staff/2 days 40 hours each Mapping and results: 40 hours	480
<i>Annual Monitoring (1 event late summer)</i>			
Passive vs. active habitat enhancement	1 (summer)	Field: 4 staff/5 days 40 hours each Mapping and results: 80 hours	280
Plant material selection	1 (summer)	Field: 4 staff/5 days 40 hours each Mapping and results: 80 hours	280

H.14 Reference

Utah Division of Forestry, Fire and State Lands, Utah County, and the Utah Lake Authority. 2025. Phragmites aerial spraying spatial data. Provided July 14, 2025.



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Appendix I Proof of Concept for the Utah Lake Study Phased Enhancement Framework

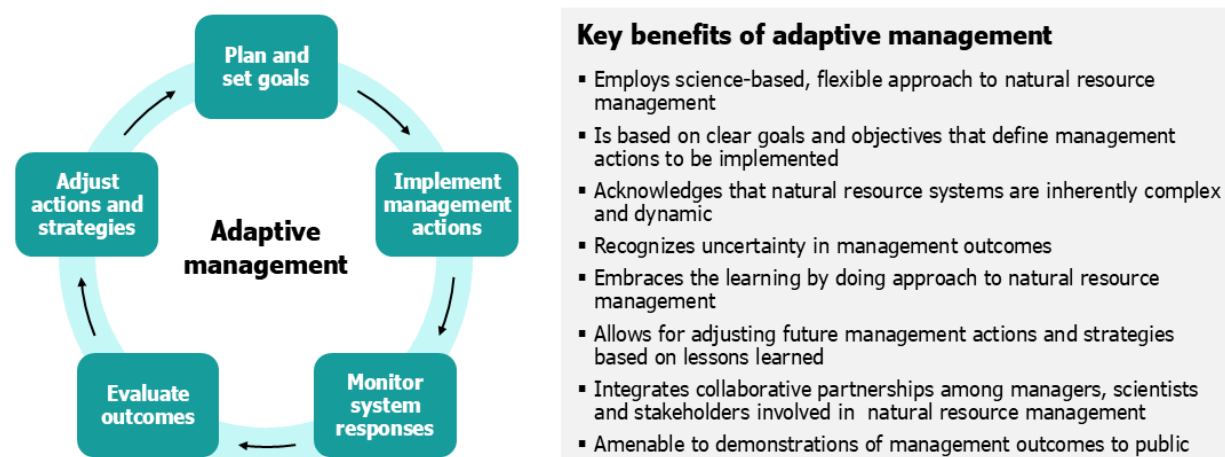
Appendix I. Proof of Concept for Utah Lake Study Phased Enhancement Framework

One framework that has become a proven success for addressing complex ecological enhancement efforts around the world is adaptive management. Concepts from the adaptive management framework inform the development of the Utah Lake Study (ULS) Phased Enhancement Framework (PEF).

I.1 What is the Framework and Why Does It Work?

Adaptive management is a phased, flexible, and systematic decision-making process for improving resource management. It focuses on learning from the outcomes of implemented management actions. Adaptive management starts with planning and setting clear and measurable management goals and objectives, followed by implementing management actions. Monitoring and evaluating outcomes from management actions is critical to advancing system understanding and adjusting future management actions and strategies based on lessons learned, all as part of an iterative learning process (Figure I-1). While many restoration efforts have been implemented, sometimes with very large investments, some fail to achieve their goals due to a lack of monitoring (Palmer et al. 2010). Robust assessments (involving monitoring) are essential for adaptive management, providing the evidence needed to guide future restoration implementation.

Figure I-1. The Adaptive Management Process and Its Primary Benefits to Natural Resource Management



A key benefit of adaptive management is that it is action-oriented and promotes flexible decision-making that can be adjusted as outcomes from management actions and other events become better understood. This process is grounded in a “learning-by-doing” approach to making more effective resource management decisions for the Utah Division of Forestry, Fire, and State Lands and helps meet the state’s environmental, social, and economic goals; increase scientific knowledge; and reduce tensions through partnerships among managers, scientists, and stakeholders, who learn together how to create and maintain sustainable resource systems (Williams et al. 2009). These same principles are applied to the PEF for Utah Lake.

I.1.1 Adaptive Management in Lake Rehabilitation

Adaptive management has been identified as an important approach to lake rehabilitation in a recent global survey of lake restoration scientists, practitioners, and policy makers representing 67 countries, including several European nations, the United States, Canada, Japan, South Korea, Australia, and New Zealand (Poikane et al. 2024). In this survey, respondents collectively highlighted various components of adaptive management as key focus areas for rehabilitation practitioners and lake managers, including the following:

- Setting clear project goals and objectives
- Identifying and targeting key stressors (termed as “pressures” in the survey) impacting lakes as part of the rehabilitation approach
- Gaining an understanding of stressor ecological response processes through empirical means, monitoring, and process modeling
- Incorporating an ability to adjust and revise targets and strategies based on knowledge gained
- Encouraging stakeholder engagement throughout the life of the project

The survey respondents highlighted these aspects of adaptive management as being critical for identifying the magnitude of the issues, drivers, impacts, costs, and benefits to guide the selection of lake rehabilitation measures (Poikane et al. 2024). Similarly, Spears et al. (2021) proposed conceptual, empirical, and process modeling approaches to support adaptive management of lakes, providing guidance on managing multiple stressors and their interactions through a learning-by-doing approach.

I.1.2 Case Study: Adaptive Restoration in Waikato (New Zealand) Lakes

A review of rehabilitation practices for improving the ecological condition of more than 70 degraded shallow lakes in the Waikato region of New Zealand identified adaptive management as an important decision-making process to address uncertainties associated with selecting and implementing specific rehabilitation practices and help fine-tune implementation protocols as part of the region’s Shallow Lakes Management Plan (Abell 2018). Many of these Waikato region lakes are subject to stressors like those observed in Utah Lake, including eutrophication from external and internal nutrient loading, high turbidity caused by the bioturbation activities of invasive carp (*Cyprinus carpio*), wind and wave resuspension of fine sediment, high phytoplankton concentrations, and degraded native macrophyte and benthic habitats. As such, many of these Waikato lakes, like Utah Lake, likely experienced a shift from a macrophyte-dominated clear water phase to their current phytoplankton-dominated turbid water state. Because of the complexity of ecological interactions from the effects of multiple stressors on Waikato lakes and uncertainties associated with ecological responses to rehabilitation actions, a lake-specific decision-making approach to selecting and implementing rehabilitation measures based on adaptive framework was proposed for managing Waikato lakes (Abell 2018).

I.1.3 Case Study: Adaptive Restoration in Malheur Lake

Malheur Lake is a large, shallow (average area is approximately 48,400 acres, average depth is approximately 1.9 feet, and maximum depth is approximately 4.1 feet) polymictic

terminal¹ lake in southeast Oregon within the Malheur Wildlife National Refuge (Pearson 2020; Pearson et al. 2022). The lake experiences large water level fluctuations (where the lake has been as large as 13,344 acres and as small as 1,236 acres) that are primarily driven by runoff from precipitation and evapotranspiration (Pearson et al. 2022). Malheur Lake once harbored one of the largest freshwater marshes in North America, serving as a habitat for migratory birds along the Pacific Flyway, a breeding area for numerous shorebird species, and a habitat for resident species (Pearson 2020).

Historically, Malheur Lake (like Utah Lake), existed in an ecologically desirable, macrophyte-dominated, clear water state, but its ecosystem health has significantly declined in recent decades following the introduction of invasive common carp and habitat degradation. Twenty-five years of carp- and wind-driven sediment resuspension has caused Malheur Lake to become a highly turbid system. The lake generally lacks submergent and emergent vegetation as a result of carp impacts, variable water levels, and turbidity-induced reductions in light penetration; further, it exhibits high phytoplankton productivity because of high levels of nutrients and harbors a depauperate fish assemblage dominated by the nonnative common carp (Pearson 2020; Wood and Smith 2022; Boos and King 2023).

Adaptive restoration has been identified as a primary approach for decision-making and addressing Malheur Lake's ecological challenges. The principal goal is to shift Malheur Lake from its current turbid phytoplankton-dominated state to a healthier, clear water, macrophyte-dominated state that can better support the diverse wildlife that depends on it (Malheur National Wildlife Refuge 2013). To realize this goal, a long-term, ongoing effort involving research, collaboration, and commitment to learning and adapting restoration practices over time is being implemented. Understanding the evolving status of Malheur Lake through ongoing monitoring and research has been identified as essential to shaping future decisions and adapting restoration strategies as lessons are learned and data gaps and uncertainties are addressed. Restoration strategies that target the primary stressors impacting Malheur Lake, including carp population management, emergent and submergent native vegetation restoration, nutrient management, and turbidity control are all components of the learning-by-doing adaptive management approach for restoring Malheur Lake, where strategies are tested and adjusted based on monitoring and evaluation of results.

Interestingly, two dry years in 2021 and 2022 caused Malheur Lake to dry up, which allowed sediments to consolidate and acquire oxygen, supporting the revegetation of plants, both native and invasive (Burns Times-Herald 2023). The desiccation of the lake also resulted in a large portion of the lake's carp population dying off. Runoff from wet years in 2023 and 2024 filled the lake back up, and the lake appears to be in a clearer water state, with sago pondweed and bulrush growing healthily and supporting large numbers of avifauna. Lake desiccation seems to have served as a reset for the system, although how conditions in the lake will change moving forward and whether the clear water state will remain are unclear. Large numbers of carp have been seen in one of the lake's tributaries, and carp populations could rebound given the large lake size. Lake management is currently mostly focused on monitoring (for example, vegetation, avifauna, and water quality) and carp control. Monitoring at Malheur Lake has demonstrated the value of monitoring and

¹A polymictic, terminal lake regularly mixes vertically and has no outlet.

adaptive management, because it has provided information on the ecological status of the lake in response to manipulations by stressors.

In summary, both Malheur Lake and Utah Lake, despite their geographical differences, face several similar environmental challenges (stressors), including water quality degradation, proliferation of invasive carp, and declining habitats and associated native biota, that have reversed both lake systems from a clear water, macrophyte-dominated state to their present turbid, algae-dominated state. Although specific details, intensity, and drivers of these issues may vary, the overarching themes of ecological disruption and the need for restoration (ecological enhancement) approaches that are implemented, tested, shaped, and refined within the framework of adaptive management are shared between these two systems.

I.1.4 Ecosystem Responses to Stressor Manipulations

Information gained by monitoring how various components of the ecosystem, for example, turbidity, benthic primary productivity (submerged aquatic vegetation [SAV]), wetland vegetation (wetland meadow [WM] and emergent vegetation [EV]), and benthic macroinvertebrates, respond to manipulations of key stressors, such as carp-driven and/or wind-/wave-driven suspended sediment, can contribute to the understanding of ecosystem dynamics under reduced stressors. Monitoring plans are designed to be objective-oriented and tailored to address specific questions or hypotheses focused on expected ecosystem recovery under reduced stressor pressures that will collectively inform the decision-making process. Biomanipulation of carp can be implemented and tested as an enhancement action in carp exclosures.

The effects of reducing wind-/wave-driven sediment resuspension on ecosystem dynamics can be tested in multiple ways, including the following:

- Choosing demonstration areas that are relatively protected from wind/wave-related sediment resuspension
- Incorporating areas within carp exclosures where strategic revegetation of the littoral zone can help naturally reduce wind/wave-driven sediment
- Using engineered solutions, such as wave breaks or groins constructed in demonstration areas, although such structures could present navigational obstacles and natural breaks using vegetation should be prioritized as a first option.

Various considerations, including the level of effort and cost and the scalability of the measures being tested, drive the implementation method choice.

I.1.5 System Uncertainty and Surprising Outcomes

The PEF explicitly recognizes that Utah Lake is a complex ecosystem under multiple stressor pressures that has undergone a regime shift from a clear water phase to its current turbid state. Utah Lake's current ecological structure and function differs fundamentally from those that characterized the lake during its previous clear water phase. For example, the lake has experienced loss of keystone species such as Bonneville cutthroat trout and native mollusks, including unionid mussels, clams, and gastropods, that have been replaced by common carp, other nonnative fish species, and pollution-tolerant benthic invertebrates. Native macrophytes, which historically helped consolidate and anchor the sediment, have largely been replaced by invasive plants such as *Phragmites*, and benthic periphyton have been greatly reduced (Jacobs 2025). The ways that this altered ecosystem responds to

enhancement actions will likely involve uncertainties and surprising outcomes (refer to Section 5.1.1 in the ULS in which this appendix is included for examples of hypothetical scenarios with surprising outcomes) that cannot necessarily be anticipated at the outset. The PEF's approach to implementing and testing the outcomes of enhancement actions will help address the uncertainty and unpredictability inherent in this complex, altered ecosystem and contribute useful information about the effectiveness of various interventions that can later be implemented on a larger scale.

I.1.6 Engineering Design

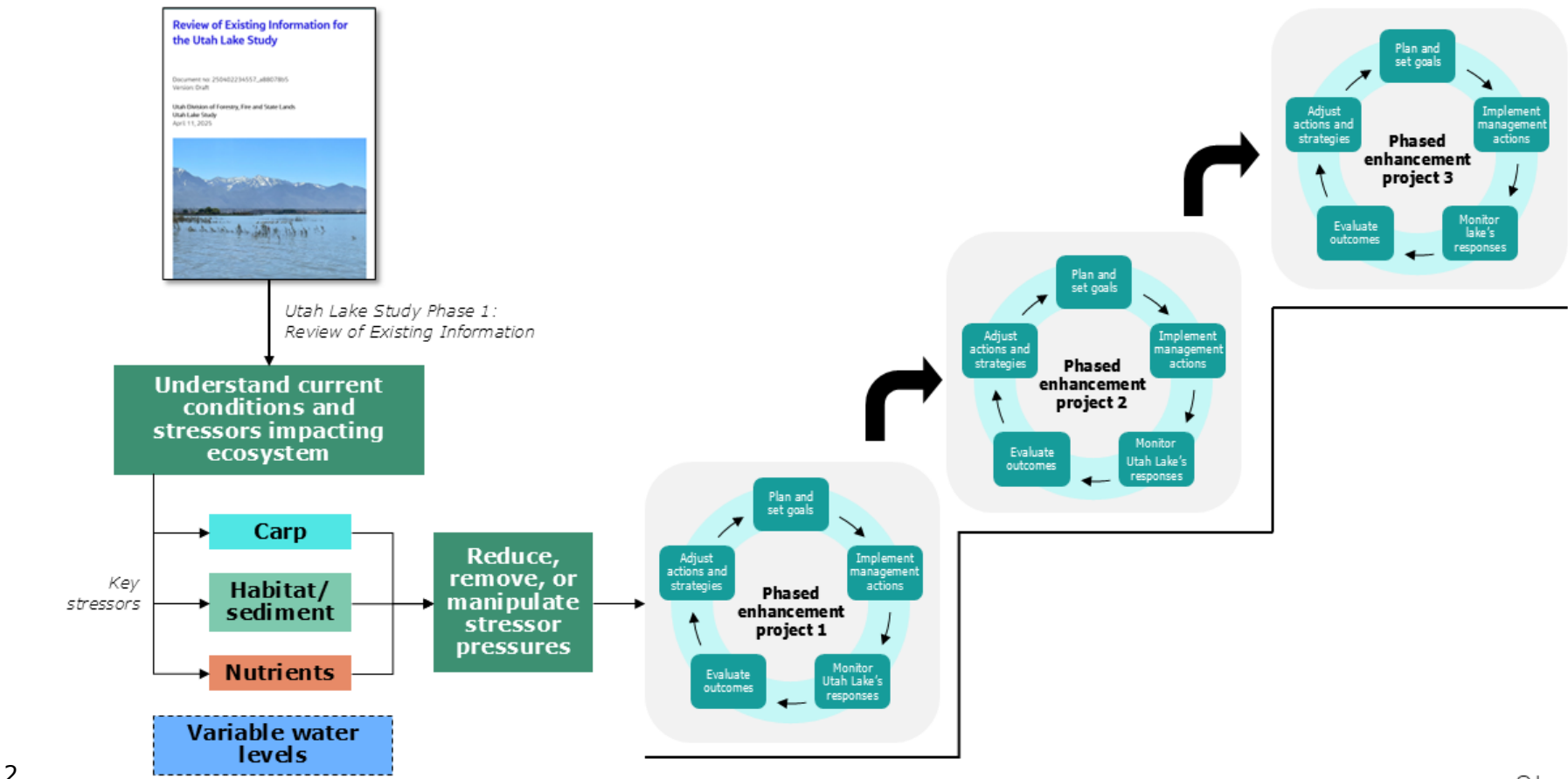
The PEF provides important practical information on engineering solutions and designs for implementing enhancement actions in Utah Lake. For example, a pilot carp enclosure will require robust fencing that prevents the entry of large carp into the enclosure and can withstand the impacts of wind, wave, and ice action (Appendix C provides more details). The enclosure design will also have to accommodate access for monitoring activities within the enclosure as well as maintain the mixed uses of the lake outside of these areas. Engineering specifications and deployment methods for such barriers can be developed, implemented, and refined in smaller pilot areas, rather than the far costlier option of direct large-scale implementation. Engineering wind-/wave-reducing solutions, like submerged reefs or wave breaks, or nature-based solutions, such as strategically located plantings of native vegetation, can likewise be tested first in smaller pilot areas, making the enhancement program more cost efficient by avoiding the risk of large-scale design failures.

I.1.7 Successful Methods for Ecosystem Recovery

The learning-by-doing approach is at the core of the PEF. As such, the process provides a structured and iterative framework that can accommodate testing various enhancement actions (for example, removing carp, reducing wind-/wave-driven sediment, planting native vegetation, and seeding with native plant species) to identify successful methods for ecosystem recovery and adapting future strategies based on information gained from enhancement outcomes. This learning-by-doing approach wherein enhancement actions are implemented as pilot or demonstration projects differs vastly from "trial and error" or traditionally rigid lake management approaches, because it is objective driven; can incorporate hypothesis testing; includes objective-oriented monitoring, data analysis, and evaluation; and accommodates the adaptation of future enhancement strategies based on information learned. Adapting future strategies could, for example, involve modifying existing methods, discontinuing those that do not work, and introducing new approaches. In this way, lake managers, practitioners, and stakeholders can progressively improve their understanding of the lake's dynamics under enhancement actions and iteratively increase the likelihood of achieving successful large-scale lake enhancement outcomes. Most importantly, this approach minimizes the risk of high costs associated with failures in implementing large-scale (lake-wide) enhancement actions.

Figure I-3 shows the PEF proposed for Utah Lake as a series of steps necessary for PEF development and execution, including implementing and learning from enhancement actions, to improve the ecological health and promote beneficial uses at Utah Lake.

1 **Figure I-3. Utah Lake Study Phased Enhancement Framework**



2
3 Note: Phased enhancement Projects 1 through 3 illustrate the iterative learning-by-doing process and do not suggest the number of ULS project pilots or demonstrations.

I.1.8 Pilot Project Justification

The ULS began with a review of existing information, which provided an understanding of existing conditions within Utah Lake (Section 2.1 of the ULS Report), information needs that need to be addressed to implement enhancements and improve the lake's condition (Section 2.2 of the ULS Report), and, importantly, the primary stressors affecting Utah Lake (Figure I-4):

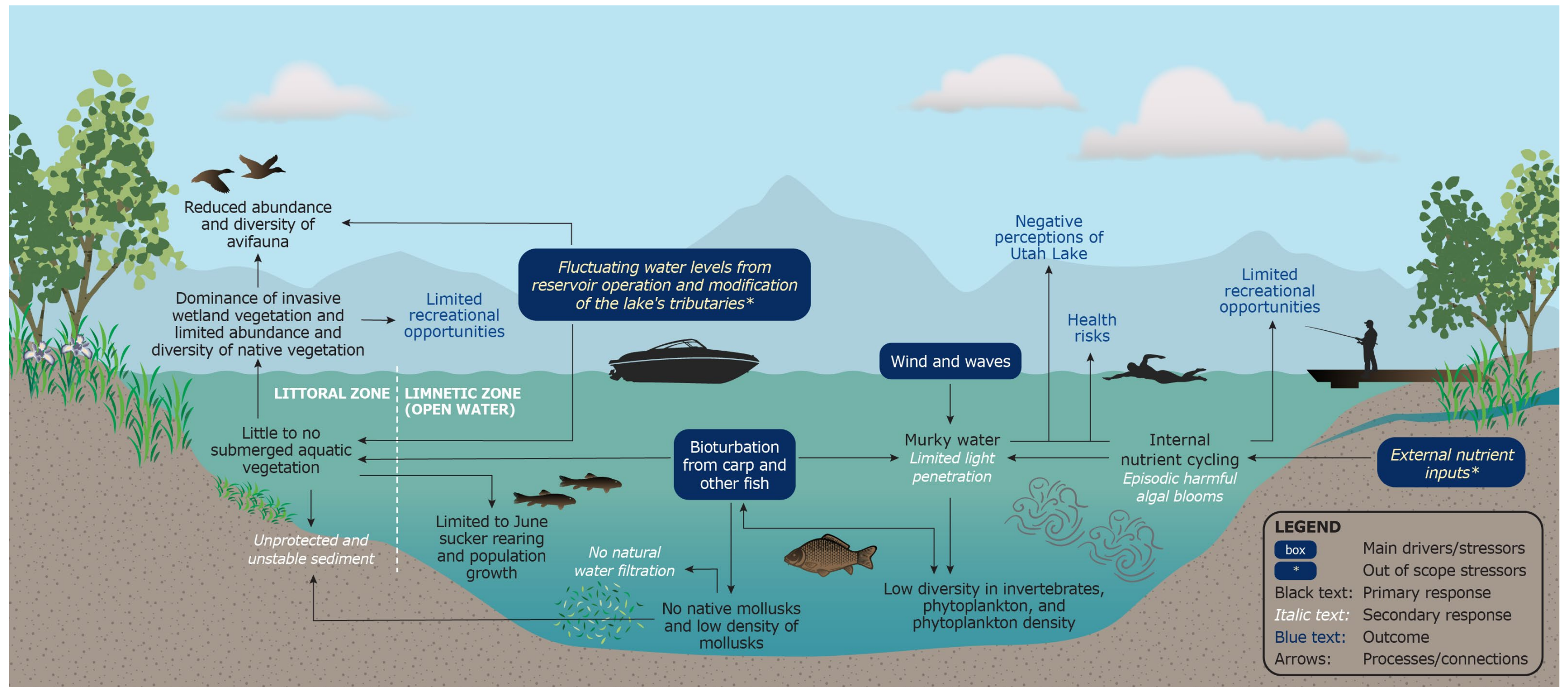
- Carp
- Wind and wave sediment resuspension (turbidity)
- Nutrients
- Degraded habitat
- Variable water levels

The PEF targets the removal, reduction, and/or manipulation of certain primary stressors affecting Utah Lake, implemented as phased enhancement actions at select pilot or demonstration sites in the lake (refer to Section 5.1.2.3 of the ULS Report for additional details). For example, a relatively small-scale pilot project can first be conducted at Goose Point (Figure I-3; phased enhancement project 1). Based on the information gained from that site and lessons learned, implementation can then progressively occur at larger scale demonstration sites in Goshen Bay (Figure I-3; phased enhancement project 2), then Provo Bay (Figure I-3; phased enhancement project 3), as necessary (refer to Section 5.1.2.3 of the ULS Report for additional information). Various enhancement actions, such as removal or reduction of carp, reduced wind-/wave-induced turbidity, and native plant revegetation efforts, can be tested within these phased enhancement areas to evaluate the lake's responses to stressor manipulations and evaluate various methods for ecosystem recovery.

The common carp is a widely reported nuisance fish in the United States, and its negative direct and indirect effects on water quality, native aquatic vegetation, native fish, and macroinvertebrates have been well studied. Likewise, carp in Utah Lake have played a significant role, directly and indirectly, in the degradation of the lake's water quality, loss of native macrophyte abundance, and composition and decline of macroinvertebrate richness and diversity. Carp are an important contributing factor for Utah Lake's degradation from a clear water phase to a turbid water phase (Jacobs 2025). For example, carp directly consume and reduce macrophyte cover but also uproot or damage macrophytes while foraging; their impacts on certain species of SAV, such as *Chara aspera* and *Stuckenia pectinata* (syn. *Potamogeton pectinatus*), in Utah Lake can be devastating (Miller and Crowl 2006). Carp foraging behavior directly increases turbidity through resuspension of sediments. The loss of sediment anchoring macrophytes leads to wind-/wave-induced increases in sediment resuspension that in turn reduces light availability for SAV establishment. Sediment resuspension also increases the nutrients in the water column that would otherwise remain sequestered in sediment (Miller and Crowl 2006). Disruption of the sediment layer and benthic primary production can also negatively affect benthic invertebrates and the zooplankton community by disrupting benthic habitat and zooplankton refugia (Miller and Crowl 2006; King et al. 2023).



1 **Figure I-4. Utah Lake Main Stressors, Benefit Areas, and Responses**



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Carp exclosures are important tools used to evaluate lake ecosystem responses where carp are locally eliminated. When combined with methods that also reduce wind-/wave-driven sediment resuspension (either through selection of areas naturally protected from wind and wave action via wave break structures in the area or through strategically placed areas of native vegetation), carp exclosures can provide useful information on rates and trajectories of ecological recovery under reduced stressor pressures. In Lake Wingra, Wisconsin a 2.5-acre carp exclosure resulted in clearer water and increased density of aquatic macrophytes (Lathrop et al. 2013). Miller and Crowl (2006) used 49-foot by 16-foot by 4.92-foot carp exclosures combined with wave breaks (to reduce wind and wave energy near exclosures) and monitored these exclosures over a 30-day period to show that excluding carp benefited SAV in Utah Lake.

The PEF recommends a carp exclosure pilot area designed to inform the path to Utah Lake enhancements. The scale of this pilot will, however, need to be of sufficient size and duration to adequately capture ecological recovery processes while minimizing the risk of edge effects and experimental artifacts that could distort ecological realism and the extrapolation of results (Petersen et al. 2003). Exclosure size and duration must also adequately capture the range of water level variability (annual and interannual) at the site and accommodate testing multiple revegetation efforts for various macrophyte communities and other ecological manipulations, as necessary, to address various objectives (refer to Section 5.1.2.3 of the ULS Report for details on scale issues).

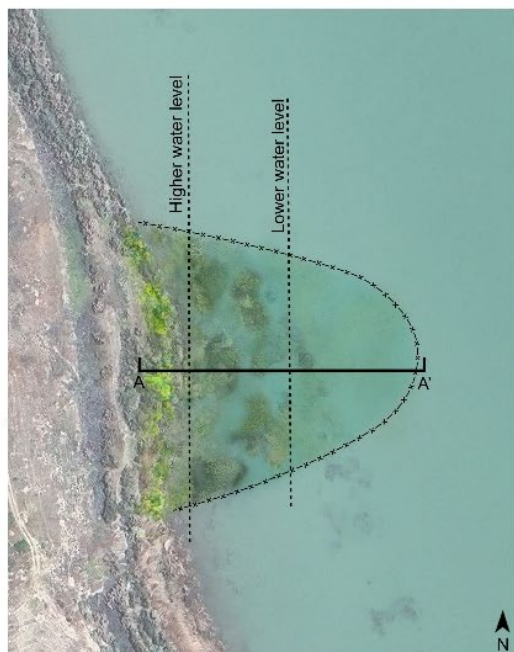
Figure I-5 presents a conceptual rendering of the exclosure. The exclosure would, thus, corral an area extending from the shoreline and into the water to a sufficient depth beyond the typical low water level observed in the lake (Figure I-5). In this manner, various types of wetland vegetation communities, such as EV, SAV, and WM, which are adapted to different inundation timings, durations, and depths, can be incorporated into the exclosure area (Figure I-5). Including a hydrological regime that can potentially support various types of wetland vegetation communities and associated ecology presents opportunities for testing various approaches and/or methods of ecological recovery within the exclosure where stressor pressures are reduced. Observations from the exclosure can further be compared, if needed, with a control area (that is, a lake area open to carp access; Figure I-5); in this way, information can be gained on ecological responses to carp removal (and reduction of suspended sediment if such measures are included in the exclosure design to minimize wind/wave-driven sediment resuspension), system uncertainty, engineering design, and successful methods for ecosystem recovery.

The proposed ULS exclosure design (Figure I-5) differs from the typically smaller exclosures that are fenced on all sides and set offshore in the lake (Miller and Crowl 2006). Such exclosures cannot meaningfully incorporate water level variations into their design. That is, when lake water levels are low, these small exclosures are at risk of being completely stranded without water; when lake levels are high, such exclosures can become inundated to depths that can drown out established plants and/or deter the establishment and growth of wetland vegetation.

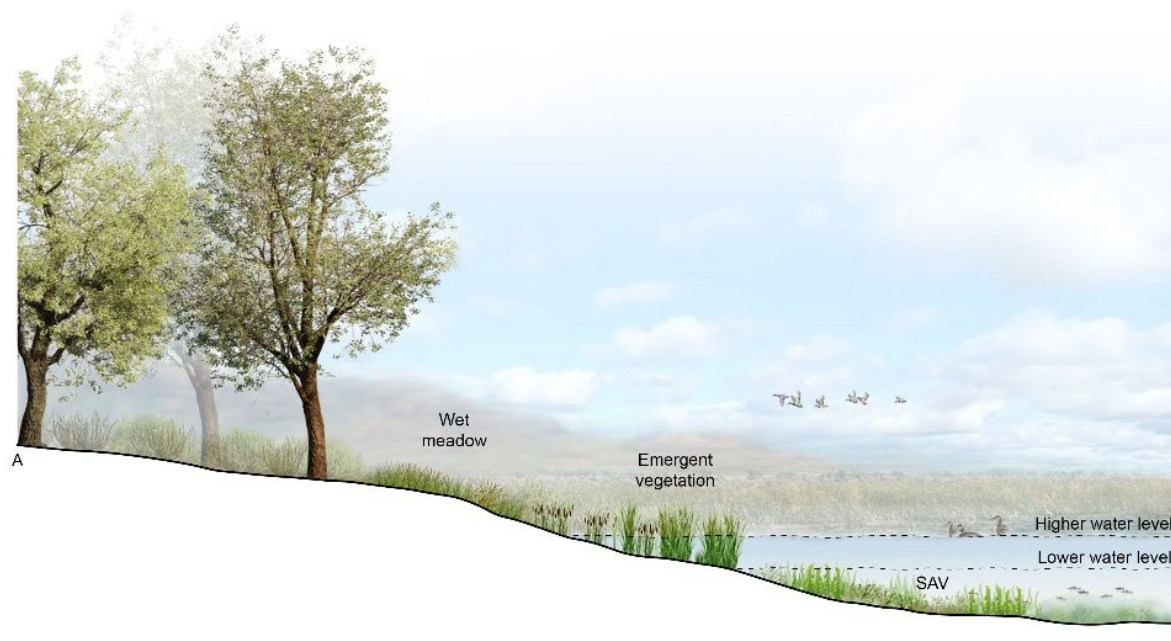


1 Figure I-5. Carp Exclosure Conceptual Plan Top View (A) and Side Elevational Profile (B)

A



B



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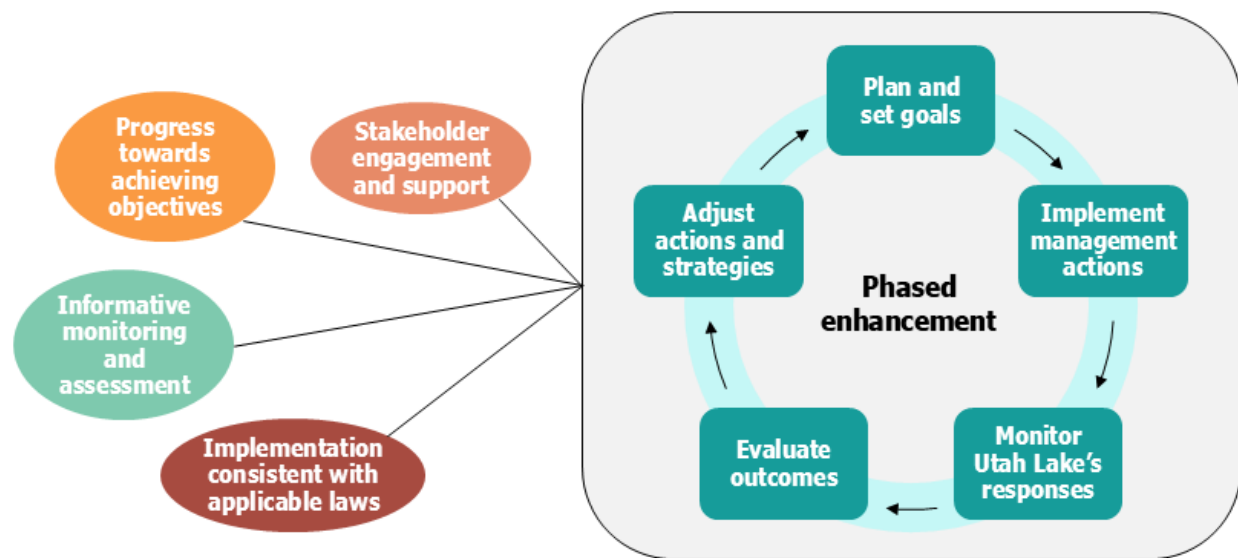
Note: Square plot markers for monitoring vegetation and other ecological parameters are illustrative of potential activities that can be conducted within the exclosure and are not meant to indicate the number and location of plots.

I.2 What are Success Factors for Phased Enhancement?

The success of the PEF proposed for Utah Lake is predicated on key criteria that have been widely recognized for the successful implementation of adaptive management plans. Williams et al. (2009) specify the following four criteria for recognizing success in adaptive management (Figure I-6), which apply to the ULS phased enhancement framework:

- Stakeholder engagement and support
- Progress toward achieving objectives
- Informative monitoring and assessment
- Implementation consistent with applicable laws

Figure I-6. Phased Enhancement Framework and Four Criteria for Its Successful Implementation

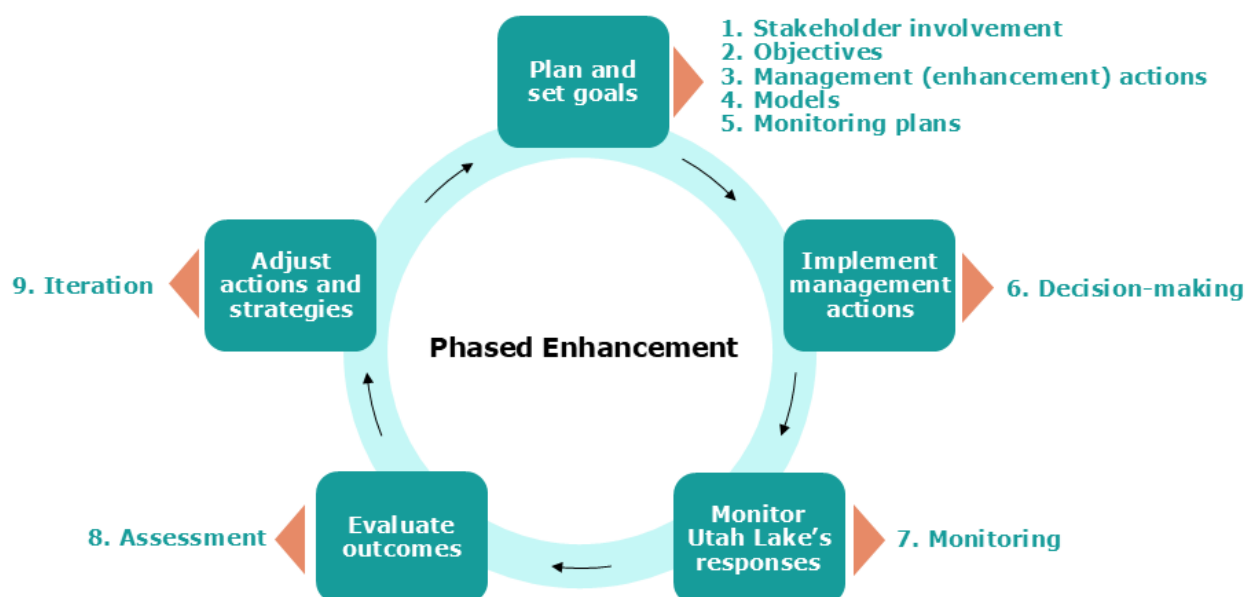


These criteria should be considered collectively as indicators of success, and all four criteria must be met over a project's lifespan for the PEF to be successful (Williams et al. 2009). For example, a PEF may not be considered fully successful if key stakeholders are not fully engaged or committed to the process or if they do not see the resource management process as legitimate (for example, water rights issues with Utah Lake are inviolable). Likewise, success may be elusive if monitoring and assessment plans are improperly designed such that objectives are not addressed, are inadequately addressed by the data collected, or are not sufficient to meaningfully inform adjustments in management practices. The four criteria for recognizing success in adaptive management, as they would apply to the PEF, are as follows:

- **Stakeholders are actively involved and committed to the overall process.** Stakeholder engagement and involvement, ideally in every step of the process (Figure I-7), is critical for the success of PEF. Stakeholder engagement throughout a project's cycle will reinforce stakeholder perceptions of phased enhancement as a legitimate process, encourage cooperation, and reduce the likelihood of conflict (Poikane et al. 2024; Williams et al. 2009). Stakeholder engagement has been identified as a critical component of the ULS and includes a diverse range of Utah Lake partners and stakeholders, including all members from the ULS Planning Team and Steering

Committee, as well as individuals from academic institutions, water management entities, local governments, and nongovernmental organizations (Jacobs 2025). The diverse range of stakeholders that are being engaged in the ULS reflects the complex system of interests surrounding Utah Lake.

Figure I-7. Operational Steps of Phased Enhancement in the Setup (Steps 1 through 5) and Iterative (Steps 6 through 9) Phases



Source: Adapted from Williams et al. 2009.

Note: Refer to Table I-1 for descriptions of the operational steps.

Close collaboration and coordination between identified stakeholders (for example, resource managers, nongovernmental organizations, scientists, engineers, and other agency personnel) during planning and goal setting, process design, monitoring and assessment, and other elements of the PEF will help build support for the process and provide a solid foundation for the learning-by-doing model of management being proposed for the enhancement of Utah Lake. It will also provide opportunities for resource managers to obtain additional information about the natural system and its response to management actions and set priorities for its management before decisions are made (Williams et al. 2009). A lack of such stakeholder involvement can quickly derail the successful implementation of the PEF (Poikane et al. 2024).

- **Progress is made toward achieving management objectives.** Clear and measurable goals and objectives lay the groundwork for guiding the decision-making process and for assessing the performance of enhancement (management) actions (Williams et al. 2009; Poikane et al. 2024) in the PEF. For example, the goal to improve the water quality of Utah Lake (one of the 10 elements of S.B. 270) would have removal of carp and evaluation of ecosystem recovery in the absence of carp as one of the objectives. Carp have been identified as one of the primary stressors affecting Utah Lake water quality by their bioturbation activities and through their impact on native vegetation. This objective drives the planning, design, and implementation of carp exclosures as pilot projects to evaluate ecosystem recovery in terms of both habitat and water quality in the absence of carp. Such pilots at scale provide insights and information on ecological recovery trajectories to be expected as IPM measures for carp are implemented lake-wide through

time and whether additional management measures, such as carp barriers, are needed, at least temporarily, in areas targeted for establishment of native vegetation. Monitoring various metrics representing the physical, chemical, and biological state within carp enclosures will be necessary to evaluate progress toward achieving this objective in this learning-by-doing approach. As such, adaptive management by design pursues management benefits as expressed in the management objectives; thus, progress toward achieving objectives is a key criterion of success (Williams et al. 2009).

Williams et al. (2009) further emphasize two scenarios for the success of adaptive management that are applicable to the PEF.

- Multiple objectives: There can be multiple objectives associated with a project. Improving an outcome associated with one objective may involve tradeoffs with outcomes associated with other objectives. When multiple objectives are identified, it is important to recognize and account for the relationships among them so that potential tradeoffs can inform decision-making.
- Dynamic objectives: The dynamic nature of the adaptive enhancement process means that objectives may change over time. As new knowledge is gained and understanding accumulates throughout a project's cycle, refinement of objectives may become necessary. Thus, adaptive enhancement needs to include not only the cyclic evaluation of project performance but also a periodic reassessment of the project objectives.

▪ **Results from monitoring and assessment are used to adjust and improve management decisions.** A successful phased enhancement program is critically dependent on effectively linking monitoring and assessment to objective-driven decision-making (Williams et al. 2009). Monitoring must be designed to measure the response of key resource parameters (for example, vegetation, water quality variables, and benthic and planktonic biota) to ecological enhancement actions (for example, carp removal, structures that reduce inorganic turbidity) to ensure success. Evaluating the outcomes of enhancement (management) actions critically depends on the collection and assessment of objective-oriented monitoring data, the results of which directly influence the decision-making process. The accumulation of understanding and subsequent adaptation of future enhancement (management) strategies thus depends on a well-designed objective-oriented monitoring program wherein scientists, resource managers, and stakeholders collaborate to assess what is known and what is being learned about Utah Lake through the implementation of enhancement actions.

▪ **Implementation is consistent with applicable laws.** Phased enhancement implementation must be consistent with applicable laws and limitations to be considered successful. Inconsistencies with applicable laws tend to detract from project objectives, create distrust among stakeholders, and may even lead to litigation (Williams et al. 2009). Attention needs to be consistently provided throughout the project's duration to confirm compliance with the laws, regulations, and policies governing Utah Lake to ensure success.

- For example, Utah Lake has been managed as a storage reservoir since the mid-1800s, with a complex system of water rights established over time. Over the past 3 decades, Utah Lake's elevation has fluctuated by an average of 3.3 feet annually, with a maximum difference of about 7 feet recorded in 2004. Such variable water level fluctuations create a challenge for resource managers, including challenges related to managing recreational access points, native plant restoration initiatives, fisheries and upland habitat improvement projects, and more

(Appendix A). However, consistent with the applicable requirement stated in lines 60 to 63 of S.B. 270, the ULS “shall respect the need to preserve water rights and interests related to water collection, storage, or delivery and projects for water collection, storage, or delivery associated with Utah Lake.”

— The ULS is sensitive to water rights issues, and the adaptive enhancement process being proposed will work within the applicable limits set by water rights. For example, the design of pilot carp exclosures will explicitly consider demarking an exclosure area that captures a large range of water levels in the lake over time so that project objectives can be tested and system responses can be measured against the backdrop of fluctuating water levels (Section 5.1.2.3 of the ULS). In this manner, objectives, such as the efficacy of restoring native vegetation in the absence of carp while the lake is undergoing water level fluctuations, can be tested and provide information on resilient plant species that can establish under such conditions.

— Finally, this success criterion is dependent largely on the success of the other three criteria, which will affect stakeholder assessments of whether a project remains in compliance with applicable laws. For example, if serious disagreements persist among stakeholders regarding the appropriateness of monitoring protocols and results, stakeholders may challenge the validity of the program’s results, which can lead to withdrawal of stakeholder support, loss of continued funding, and even litigation (Williams et al. 2009).

Success factors for these criteria can be evaluated through a series of questions that help practitioners increase the likelihood of success (Williams et al. 2009). These questions are categorized according to the operational steps of the adaptive management process as indicated on Figure I-7 and listed in Table I-1 and can serve as a checklist to verify the likelihood of phased enhancement success at Utah Lake.

Table I-1. Questions for the Operational Steps of the Phased Enhancement Process to Increase its Success Likelihood

Phased Enhancement Operational Steps	Description	Questions to Guide Successful Phased Enhancement Implementation
1. Stakeholder Involvement	Ensure that stakeholders are committed to adaptively manage the project or program for its duration.	- Has a systematic process been developed that facilitates effective participation by stakeholders? - Have agreed-upon lines of communication been established, and are their importance to successful PEFes understood? - Are stakeholders committed to and involved in the PEF, including the monitoring and assessment program? - Is the adaptive management process able to adapt to changes in stakeholder and public viewpoints?
2. Objectives	Identify clear, measurable, and agreed-upon management objectives to guide decision-making and evaluate management effectiveness over time.	- Have explicit and measurable management objectives been identified and developed? - Are the management objectives achievable and sustainable? - Have performance metrics relating to the management objectives been developed? - Has a system of monitoring and assessment relevant to the management objectives been developed and implemented so that progress in meeting the objectives can be tracked? - Have tradeoffs among management objectives been considered, and are they understood?
3. Management (Enhancement) Actions	Identify a set of potential management actions for decision-making.	- Has a range of potential management actions been developed? - Have the specific tasks to implement the management alternatives been identified? - Is the range of potential actions appropriate for the time frame wherein changes are likely to occur? - Can the set of management alternatives be adjusted through time if needed? - How are the traditional Public Trust doctrine principles incorporated into the potential management action?



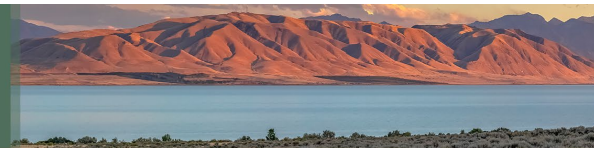
UTAH LAKE STUDY



Phased Enhancement Operational Steps	Description	Questions to Guide Successful Phased Enhancement Implementation
4. Models	Identify models that characterize different ideas (hypotheses) about how the system works and adds to the understanding of the ecological process.	- Are the hypotheses underlying the strategies for resource management expressed as testable models? - Have explicit links between management actions and resource dynamics been incorporated into the models? - Are the ecological and resource processes that drive resource dynamics understood? - Are the relevant environmental factors incorporated into the models? - Are the models calibrated with available information?
5. Monitoring Plans	Design and implement a monitoring plan to track resource status and other key resource attributes.	- Will the monitoring plan support the testing of alternative models and measurement of progress toward accomplishing management objectives? - Is it clear what monitoring data need to be collected to estimate the relevant resource attributes? - Has the level of accuracy needed been identified? - Are commitments among managers, scientists, and other stakeholders in place to sustain an ongoing monitoring and assessment program? - Will meaningful and useful data and information be available within time frames that allow for adaptive decision-making?
6. Decision-Making	Select management actions based on management objectives, resource conditions, and enhanced understanding and implement those actions.	- Is the process by which decisions will be made clear? - Are decisions at each point in time based on the current status and understanding of the resource? - Are decisions being guided by management objectives? - Are stakeholders informed and consulted before decisions are made or changed?



UTAH LAKE STUDY



Phased Enhancement Operational Steps	Description	Questions to Guide Successful Phased Enhancement Implementation
7. Monitoring	Use monitoring to track system responses to management actions.	▪ Are the analysis needs understood? ▪ Is monitoring conducted on a timely basis? ▪ Is monitoring targeted to system attributes that are useful for evaluation and learning? ▪ Are monitoring data collected and managed so that they are available and easy to access? ▪ Can the monitoring data be used to update the measures of model confidence?
8. Assessment	Improve the understanding of resource dynamics by comparing predicted versus observed changes in resource status.	▪ Have the expected impacts of alternative management strategies been evaluated? ▪ Is it clear how results are to be understood and interpreted? ▪ Have thresholds that indicate a change in management been recognized? ▪ Have the action(s) to be taken when a threshold is reached been identified?
9. Iteration	Return to Step 6 and, less frequently, to Step 1	▪ Are management actions and decisions reviewed frequently based on monitoring and assessment? ▪ Have incentives been developed to encourage experimentation and learning? ▪ Have resource management alternatives been revisited and/or modified over time? ▪ Has uncertainty related to resource dynamics and the impacts of management actions been reduced through learning over time? ▪ Are the targets identified in the performance metrics likely to be achieved within the specified time frame?

Source: Adapted and summarized from Williams et al. 2009.

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