# Gap Analyses for the Great Salt Lake Basin Integrated Plan

Document no: 230913163905_011540c7
Version: Draft

Utah Division of Water Resources
Work Plan for the Great Salt Lake Basin Integrated Plan
November 14, 2023

# Gap Analyses for the Great Salt Lake Basin Integrated Plan

| | | | |
|---|---|---|---|
| **Client name:** | Utah Division of Water Resources | | |
| **Project name:** | Work Plan for the Great Salt Lake Basin Integrated Plan | | |
| **Document no:** | 230913163905_011540c7 | **Project no:** | W7Y52500 |
| **Version:** | Draft | **Project manager:** | Jeff Den Bleyker |
| **Date:** | 2BNovember 14, 2023 | **Prepared by:** | Jacobs Engineering Group Inc.<br>Hansen Allen & Luce |
| **File name:** | UtahWRe_GSLBIP_GapAnalysesReport_DRAFT_2023-10-XX | | |

## Document history and status

| Version | Date | Description | Author | Checked | Reviewed | Approved |
|---|---|---|---|---|---|---|
| Draft | 11/14/23 | Gap Analyses Report | Jacobs Engineering<br>Hansen Allen & Luce | | | |
| | | | | | | |
| | | | | | | |


**Jacobs Engineering Group Inc.**

6440 S. Millrock Drive
Suite 300
Holladay, UT 84121
United States

T +1385.474.8500
www.jacobs.com

# Contents



# Tables

## Figures

# Acronyms and Abbreviations

| | |
|---|---|
| °C | degree(s) Celsius |
| ANN | artificial neural network |
| ASR | aquifer storage and recovery |
| AWQMS | Ambient Water Quality Monitoring System |
| BDA | beaver dam analog |
| BMP | best management practice |
| BRBWBTG | Bear River Basin Water Budget Technical Group |
| BYU | Brigham Young University |
| DDW | Division of Drinking Water |
| DNR | Utah Department of Natural Resources |
| DWQ | Utah Division of Water Quality |
| DWR | Utah Division of Wildlife Resources |
| EPA | U.S. Environmental Protection Agency |
| ERC | equivalent residential connection |
| ET | evapotranspiration |
| FFSL | Division of Forestry, Fire and State Lands |
| GSL | Great Salt Lake |
| GSLAC | Great Salt Lake Advisory Council |
| GSLBIP | Great Salt Lake Basin Integrated Plan |
| GSLEP | Great Salt Lake Ecosystem Program |
| GSLIM | Great Salt Lake Integrated Model |
| GSLSAC | Great Salt Lake Salinity Advisory Committee |
| H.B. | House Bill |
| HCR | House Concurrent Resolution |
| HSPF | Hydrologic Simulation Program-FORTRAN |
| IWAA | Integrated Water Availability Assessment |
| JBRPM | Joint Bear River Planning Model |
| JRBWBTG | Jordan River Basin Water Budget Technical Group |
| LAI | leaf area index |
| LID | low-impact development |
| LiDAR | light detection and ranging |
| M&I | municipal and industrial |
| NPS | Nonpoint Source |
| NRCS | Natural Resources Conservation Service |
| NWIS | National Water Information System |
| PET | potential evapotranspiration |
| PET/P | potential evapotranspiration to precipitation |
| PM | particulate matter |
| PWS | Public Water System |

| | |
|---|---|
| RAPID | Routing Application for Parallel computation of Discharge |
| S.B. | Senate Bill |
| SNOTEL | SNOpack TELemetry |
| SWE | snow water equivalent |
| SWMM | Storm Water Management Model |
| TMDL | total maximum daily load |
| UDAF | Utah Department of Agriculture and Food |
| UGS | Utah Geological Survey |
| ULBWBTG | Utah Lake Basin Water Budget Technical Group |
| UPDES | Utah Pollutant Discharge Elimination System |
| USFS | U.S. Forest Service |
| USGS | U.S. Geological Survey |
| USU | Utah State University |
| UU = | University of Utah |
| VIC | Variable Infiltration Capacity |
| WET | whole effluent toxicity |
| WMA | Waterfowl Management Area |
| WRBWBTG | Weber River Basin Water Budget Technical Group |
| WRe | Utah Division of Water Resources |
| WRi | Utah Division of Water Rights |
| WRI | Watershed Restoration Initiative |

# 1. Introduction and Overview

## 1.1 Background

The State of Utah and its partners have and are already completing significant work to manage and protect the resources of Great Salt Lake (GSL) and manage water resources throughout GSL's watershed. This work collectively serves as an important foundation to achieve the goal and objectives of the Great Salt Lake Basin Integrated Plan (GSLBIP). House Bill (H.B.) 429 requires the Utah Division of Water Resources (WRe) to complete "a synthesis of available information literature, and data, and an assessment of scientific, technical, measurement, and other informational needs…" for the GSLBIP. This report outlines the methods and results of gap analyses completed to meet this requirement. The gap analyses, and thus this report, were organized around the six building blocks of the Work Plan identified in H.B. 429 *Great Salt Lake, Water Supply, Water Demand, Watershed Management, Water Quality, and Stormwater Management* (Figure 1-1).

**Figure 1-1. Six Building Blocks of the Work Plan for the Great Salt Lake Basin Integrated Plan**


## 1.2 Purpose and Scope

The goal of the GSLBIP gap analysis was to inform development of the Work Plan for the GSLBIP. The gap analysis would identify previous and parallel efforts in the GSL watershed, eliminate redundancies, and capitalize on opportunities relevant to developing the GSLBIP. The gap analysis was intended to identify efforts that can most efficiently and effectively allow for better decisions, and further our ability to answer the goal and core question of the GSLBIP: How do we build a resilient water supply for GSL and all water uses in its watershed? The gap analysis was intended to identify the strengths of current programs, gaps in available resources, and opportunities for capacity development as they relate to answering key technical questions relevant to the GSLBIP. The gap analysis will provide a baseline against which future progress can be compared.

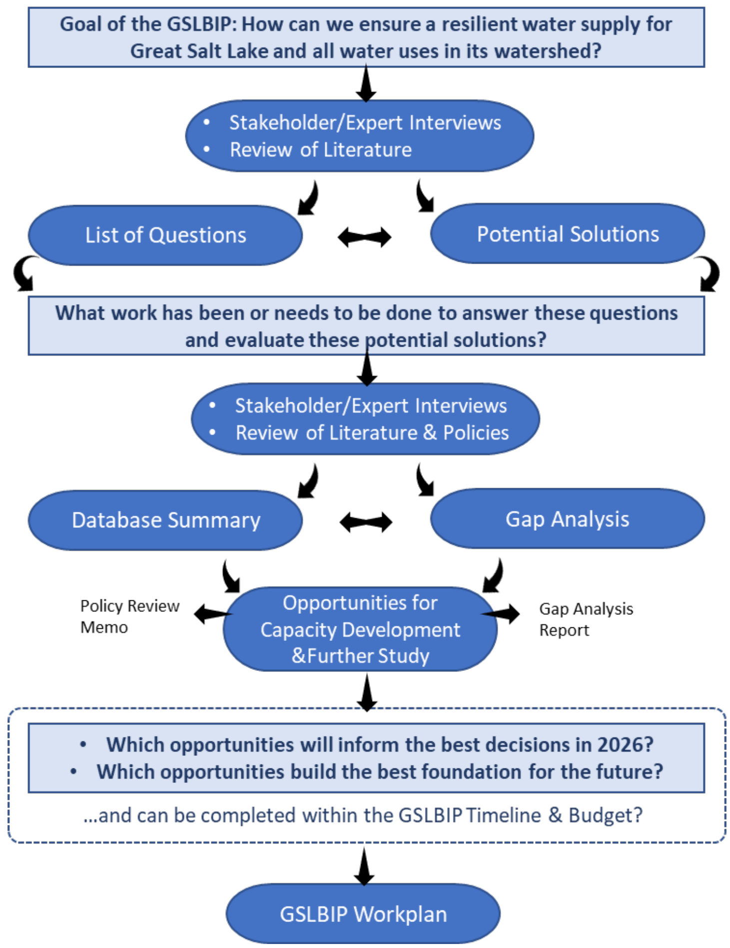
It is important to note that the gap analysis was not meant to serve as a formal literature review, nor was it intended to serve as an exhaustive inventory of every activity associated with each building block. The gap analysis was not intended to evaluate individual management activities or their efficacy, recognizing that the various initiatives (for example, research studies, resource management plans, monitoring efforts, regulatory programs, funding opportunities) planned or underway in the GSL watershed were not undertaken with the GSLBIP in mind. Finally, this gap analysis was not intended to present a prioritized implementation plan for the GSLBIP. A subsequent prioritization of the gaps and proposed areas for capacity development was completed to further inform the GSLBIP work plan.

## 1.3 Methods

Figure 1-2 illustrates the approach taken to synthesize available information, identify gaps in available resources, and identify opportunities for capacity development and further study. The approach focused efforts on that which was most relevant to accomplishing the goal of the GSLBIP and was organized around the six building blocks of the Work Plan identified in H.B. 429 *Great Salt Lake, Water Supply, Water Demand, Watershed Management, Water Quality, and Stormwater Management* (Figure 1-1).

Technical questions posed by various stakeholders, experts, and studies were identified and organized for each of the six building blocks and contrasted against potential solutions recommended by previous studies. The technical questions provided a broad "bottom-up" view of the work stakeholders and experts have completed and have been considering; the potential solutions provided a "top-down" view of examples of what the GSLBIP work must be able to address. The combination provided an opportunity to make deliberate decisions about what work would best 1) inform decisions to be made by 2026, 2) build a foundation for the future, and 3) be completed within the prescribed timeline and budget for the GSLBIP.

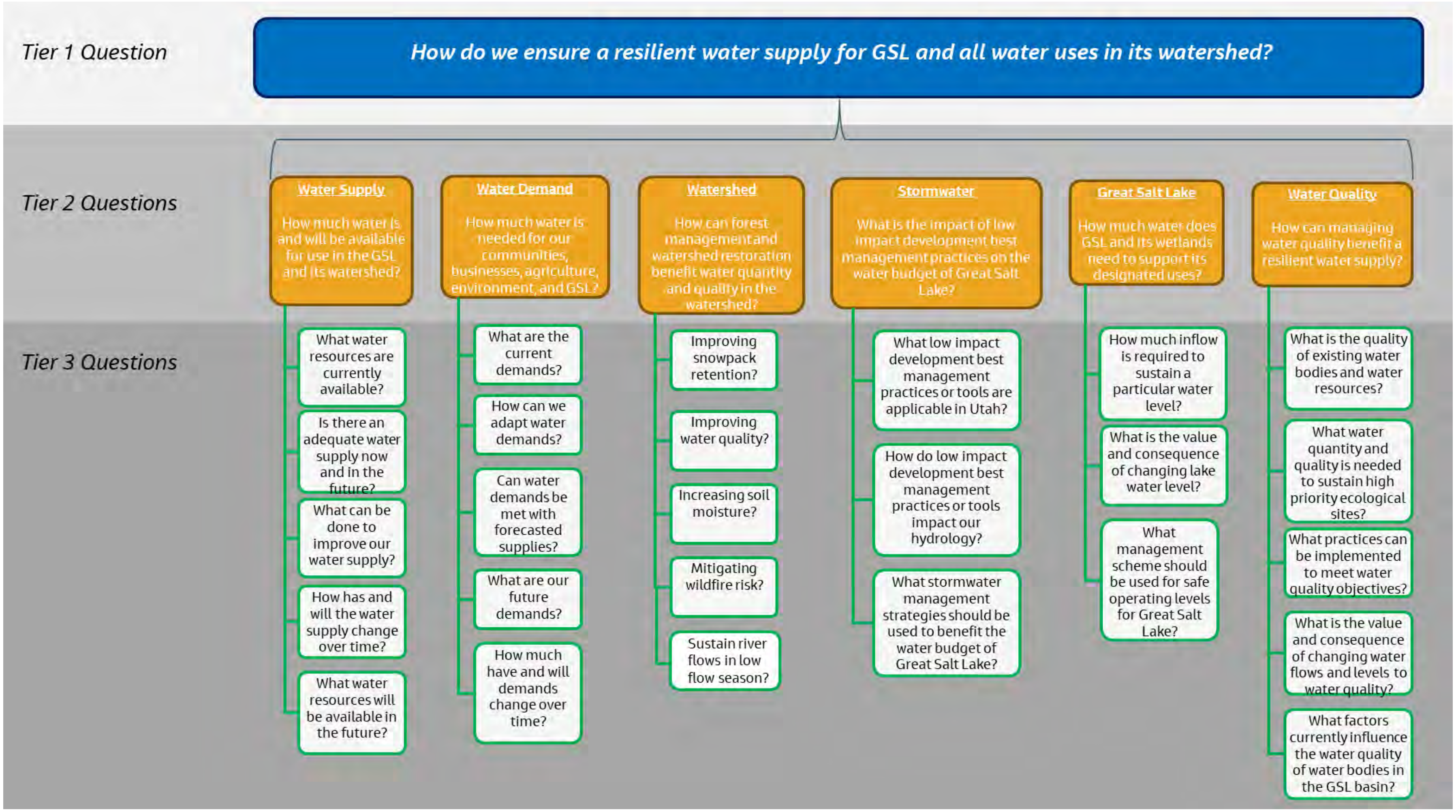
**Figure 1-2. Approach to Identify and Document Gaps in Available Resources and Proposed Areas for Capacity Development**




### 1.3.1 Technical Questions

A list of technical questions was first identified to summarize known questions that people have now, or may ask in the future, as they seek to address challenges in the system. The list of identified technical questions (refer to Section 2.2) is extensive and is intended to be comprehensive in recognition of the complex and interconnected nature of water, policy, and stakeholders in the GSL Basin. The technical questions were organized as a series of nested questions or tiers for each of the six building blocks (Figure 1-3).

**Figure 1-3. Study Question Hierarchy for the GSLBIP Work Plan**




*Note: The requirements of H.B. 429 and WTR 13-01 were organized as Tier 2 and 3 questions addressing each of the six building blocks (Tier 2 questions) from H.B. 429. The Tier 3 questions were further subdivided, based upon interviews and a literature review, into additional tiers of questions that sequentially provide more and more detail and form the intended hierarchy. All work relevant to the GSLBIP must point to and contribute to answer higher tier questions and ultimately contribute to achieving goal of the GSLBIP (Tier 1).*

Each tier of the technical questions aims to iteratively unpack the questions in the tier above with the Tier 1 question for all building blocks being the goal of the GSLBIP:

***How do we build a resilient water supply for GSL and all water uses in its watershed?***

The requirements of H.B. 429 and the U.S. Bureau of Reclamation's WTR 13-01 were organized as Tier 2 and 3 questions addressing each of the six building blocks (Tier 2 questions) from H.B. 429. The Tier 3 questions were further subdivided, based upon interviews and a literature review, into additional tiers of questions that sequentially provide more and more detail and form the intended hierarchy. All work relevant to the GSLBIP must point to and contribute to answer higher tier questions and ultimately contribute to achieving goal of the GSLBIP (Tier 1).

### 1.3.2 Gap Analyses

The consultant team conducted a series of stakeholder interviews and workshops to identify current and completed initiatives as well as future priorities within each of the six building blocks. Stakeholders were asked to identify known gaps with regard to the technical questions as well as critical questions that should be answered as part of the GSLBIP. Knowledge gained from interviews, workshops, and a review of available literature was organized in a database and linked to the technical questions (Jacobs 2023b). Many questions were found to already be answered in whole or in part. Remaining unanswered questions were identified as potential gaps in the gap analysis. These results were summarized in the project database. The database enabled the consultant team to quickly query the database to identify "who is working on what," redundancies and parallel efforts, and the remaining unanswered questions. It should be noted that technical stakeholder meetings were aimed at shaping the technical formulation of the GSLBIP work plan as a means to augment the stakeholder situational assessment (The Langdon Group 2023).

The gap analyses completed for each of the six building blocks are summarized in subsequent sections of this report. The gap analyses were shared with various participating experts and agencies to help validate results and are intended to be updated as the GSLBIP progresses. They do not in and of themselves prioritize new technical analyses.

## 1.4 How to Use this Document

Subsequent sections of this report are organized into each of the six building blocks. Each section includes a series of tables organized around the Tier 3 questions for the individual building block. Each table is organized into three columns and multiple rows. The three columns are: Strengths of Current Programs and Resources, Gaps in Available Resources, and Proposed Area of Capacity Development. The rows in each table were organized by category; no prioritization is implied.

The content in each column is presented in a bulleted list. In some cases, the proposed area of capacity development may relate directly to a gap. In other cases, however, the identified gap may be based on review of multiple initiatives, and the proposed area of capacity development may incorporate several gaps. For this reason, it may not always be appropriate to link the proposed area of capacity development to a single gap.

The proposed areas of capacity development are followed by a short statement in bracketed blue text, for example, [STUDY]. This formatted text is intended to provide an indication of how the proposed area of capacity development might be accomplished or implemented.

— [TASK] Implies that the opportunity may be incorporated into an ongoing activity.
— [STUDY] Implies that the opportunity may likely be a new and independent activity.

— [PROGRAM DEVELOPMENT] Implies that the opportunity will include multiple activities that are potentially completed by multiple organizations.

It is acknowledged that not all unanswered technical questions can or should be answered as part of the GSLBIP. Ultimately, prioritization of the unanswered questions and proposed areas of capacity development should revolve around improving certainty and allowing decision makers to make better decisions (Figure 1-2). Prioritization of those questions that are initially unanswered will promote an effective work plan and achieving the goal of the GSLBIP.

# 2. Great Salt Lake Gap Analysis

This section outlines the results of the gap analysis completed for the GSL building block of the GSLBIP. The results of this gap analysis will inform the Work Plan for the GSLBIP.

## 2.1 Tier 3 Technical Questions

This GSL gap analysis was framed around answering the following Tier 3 GSL questions (refer to Figures 1-3 and 2-1):

- How much inflow is required to sustain a particular water level? (Table 2-1)
- What is the value and consequence of changing the lake water level? (Table 2-2)
- What management scheme should be used for safe operating levels for GSL? (Table 2-3)

The complete list of GSL technical questions can be found in Section 2.2.

**Figure 2-1. Tier 3 Questions for the Great Salt Lake Gap Analysis**

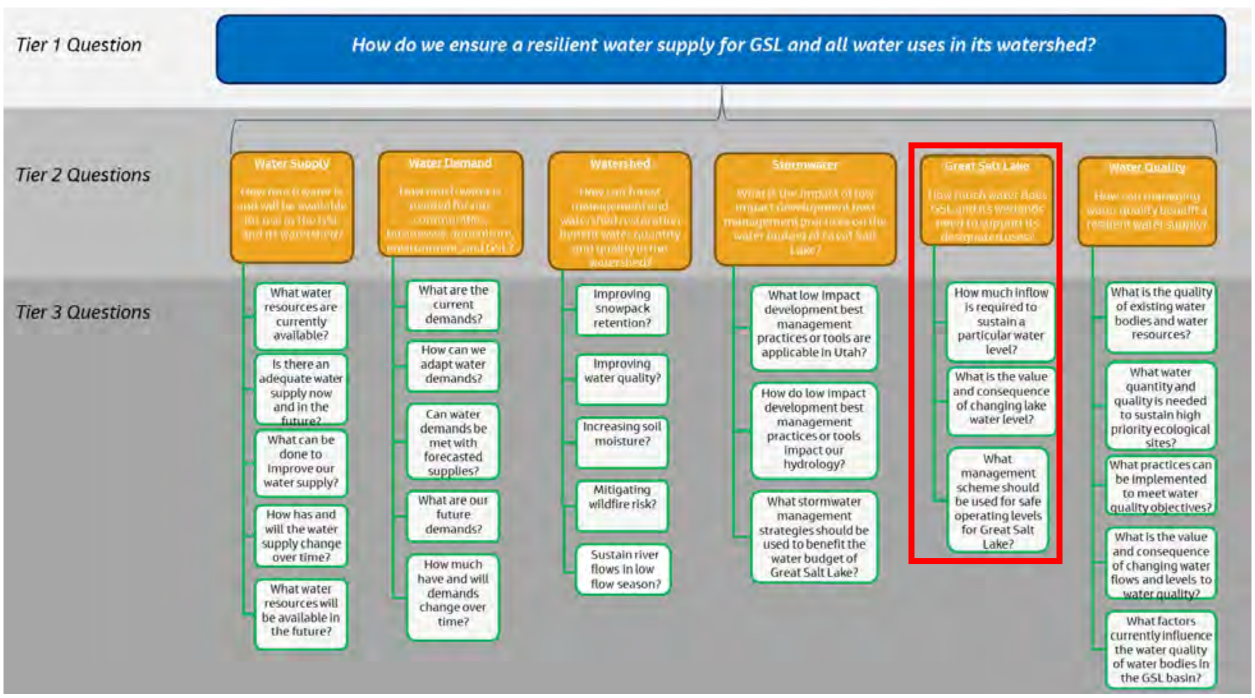


**Table 2-1. How Much Inflow Is Required to Sustain a Particular Water Level?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ USGS maintains a significant historical record of water levels in both Gilbert Bay (1847 to present, USGS Site ID: 1001000) and Gunnison Bay (1966 to present, USGS Site ID: 10010100) of GSL.<br>▪ The USGS maintains a significant historical record of surface water inflow at (Note: additional USGS gages are upstream of these):<br>- Bear River near Corinne, Utah (1949 to present): USGS Site ID 10126000<br>- Weber River near Plain City, Utah (1907 to present): USGS Site ID 10141000<br>- Goggin Drain near Magna, Utah (1963 to present): USGS Site ID 10172630<br>- Farmington Bay Outflow at Causeway Bridge (2003 – to present):USGS Site ID 410401112134801<br>▪ The USGS recently funded a study to evaluate and implement methods to measure flow from Bear River Bay into Gilbert Bay and in the lower Jordan River prior to where it bifurcates into the various wetlands (USGS Saline Lakes Ecosystem IWAAs). Both locations will help understand how much water is actually getting to GSL.<br>▪ Some monitoring and analysis of minor surface water inflows to GSL have been completed, but they are limited in scope and time period (for summaries, refer to CH2M HILL 2012, 2016; Jacobs 2019a, 2020, 2021). More recently, the UGS began a 2-year study in 2022 with The Nature Conservancy to measure surface water and groundwater inflows to the GSL Shorelands Preserve in Farmington Bay (Kirby 2022).<br>▪ Annual diverted flow volume from GSL to mineral extraction industry evaporation ponds is reported to the Utah Division of Water Rights. Additional industrial water use data is found at WRe's Open Water Data website.<br>▪ The State Engineer's office and USGS Saline Lakes Ecosystem IWAAs are currently completing a gap analysis of flow measurement systems on GSL tributaries.<br>▪ FFSL funds $500,000 per year of GSL research via the GSL Technical Team (Hot Topics Grants) to support data collection, investigation of critical issues and resources, and provide management tools. | ▪ Farmington Bay and Bear River Bay water levels are typically assumed to be the same as in Gilbert Bay. Flow through their outlets is often controlled by water levels in Gilbert Bay, the hydraulic properties of the outlets, and upstream inflow into these waterbodies. There is little to no water level data record in these waterbodies that could be used to help develop hydraulic relationships to predict flow rates through these outlets or how water levels in these waterbodies and thus water surface area could change.<br>▪ Surface water inflows from major tributaries to the open water of GSL may be overstated:<br>- Historical data describing surface water inflows to GSL are largely for locations a significant distance upstream of the GSL meander line, thus, they do not account for water diverted or consumed between these gage sites and GSL meander line.<br>- Depending upon lake water levels, surface water inflows may need to travel a significant distance across mudflats from the meander line to the open water of GSL. The quantity of water lost to evaporation and infiltration is largely unknown and has not been often considered. The Farmington Bay Outflow gage and the proposed Bear River Bay Outflow gage may be exceptions to this.<br>▪ Surface water inflows from minor tributaries to GSL are poorly understood. Flow data for numerous small tributaries are sparse and cover only short and unsynchronized periods. Most data are associated with past flood control and water quality studies; many were not completed with GSL in mind. note: The State Engineer's office and USGS Saline Lakes Ecosystem IWAAs are currently completing a gap analysis of flow measurement systems on GSL tributaries.<br>▪ Water management in managed impounded wetlands has been effective per defined goals. However, little to no historical or current water level and flow measurements and recordings throughout these systems are available to describe available inflows, resulting conditions in wetlands, and resulting outflows to GSL.<br>▪ Monitoring and reporting of diversions by the mineral extraction industry is completed monthly and annually. There are no return flow data available. | ▪ Install water level gages in Farmington Bay and key locations in Bear River Bay (such as in Willard Spur and "trapezoid") to better understand the hydrology of these bays and develop flow exchange relationships at causeways. [TASK]<br>▪ Invest in a coordinated program (with State Engineer's office and USGS) to quantify and account for inflows at all significant (> 1,000 acre feet per year) surface water tributaries and discharge locations to GSL. [PROGRAM DEVELOPMENT]<br>▪ Complete the following:<br>- Gap analysis<br>- Develop standard protocol for measuring and reporting flow data<br>- Build gage and telemetry infrastructure<br>- Construct data management and analytics systems<br>- Ongoing operations and maintenance<br>▪ Investigate interaction of surface water and groundwater in GSL's mudflats and their impact upon infiltration, water storage, evaporative loss, and formation and maintenance of surface crust. Determine the quantity of surface water inflow from tributaries and wetlands that contributes to GSL open water. [STUDY]<br>▪ Invest in updated flow control and measurement systems for managed wetlands along GSL's shoreline. [PROGRAM DEVELOPMENT]<br>- Incorporate data into developing a water balance for each system and water optimization plans for managed wetlands.<br>- Optimize water management for multiple objectives such as maximizing habitat value and water quality and minimizing evaporative losses and invasive species.<br>▪ Monitor diversions and return flows (at daily time interval) from the mineral extraction industry to inform the water and salt balance of GSL. [TASK] |
| **Reporting** | ▪ The GSL Strike Team completed the *Great Salt Lake Policy Assessment* in 2023 that included an analysis of available models and data to provide an assessment of challenges and opportunities for the State of Utah to address low water levels in GSL.<br>▪ The USGS GSL Hydro Mapper (USGS n.d.a) water data dashboard provides easy access to key attributes such as GSL water levels and flow data for primary surface water tributaries. | ▪ Data are typically collected by different organizations in independent efforts, with different goals, objectives, and methods.<br>▪ There is no central database and repository of hydrologic data for GSL. The USGS GSL Hydro Mapper dashboard (USGS n.d.a) was developed to begin to consolidate this information and provide easy access to available data.<br>▪ Aside from the USGS GSL Hydro Mapper (USGS n.d.a), and as presented at individual meetings, there is no regular report or summary of GSL inflows and water levels typically included in summaries of Utah's water resources. | ▪ Consider expansion of the USGS GSL Hydro Mapper dashboard (USGS n.d.a) as an optimized and central public launching point for GSL research and data. [TASK]<br>▪ All state and federal summaries of the region's water resources should include deliveries of inflow to GSL and GSL water levels and volume. [TASK] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Modeling** | ▪ There is a long history of the USGS, UGS, WRe, and USU working to develop water and salt balance models of GSL (starting in the 1980s) that evaluate how lake water levels are influenced by changes in inflow, climate, and lake bathymetry (refer to USGS in Jacobs 2023a for a summary of models).<br>▪ The FFSL, USGS, and WRe have been working with the GSLSAC updating the GSLIM to evaluate how lake water levels and salinity could fluctuate based upon different inflow and climate scenarios and configurations of the new Union Pacific bridge berm.<br>▪ FFSL, USGS, WRe, USU, and GSLSAC have been collecting field data and developing a computational fluid dynamics model and ANNs to represent flow through the new Union Pacific bridge connecting Gilbert Bay and Gunnison Bay (Dutta et al. 2021; Rasmussen et al. 2021). The ANNs are intended for use in lake water and salt balance models to improve estimates of changing lake level. FFSL invested additional monies in 2022 into improving both monitoring and modeling of flow through this bridge (USU and USGS FY23 Hot Topics Grants).<br>▪ New studies and models by USGS and UGS are updating our understanding of groundwater inflows from the watershed into GSL (preliminary estimates available from UGS/USGS model to be completed in 2025).<br>▪ FFSL invested in 2023 into research to better understand spatial distribution and temporal variability of regional recharge and groundwater inflows to GSL (UU FY24 Hot Topics Grants).<br>▪ FFSL developed new surface elevation models (that is, topographic contours) of GSL's shoreline with LiDAR in 2016. $1.8M was recently appropriated to UGS to use LiDAR to develop a new bathymetric and topographic map of lakebed of GSL. This is anticipated to be completed in 2025.<br>▪ USGS was funded by the GSLAC in 2023 to combine FFSL's 2016 shoreline topographic maps with the 2003 USGS bathymetry map. | ▪ Observed discrepancies in lake bathymetric data in near-shore zones have made it difficult to accurately characterize the surface area and volume of GSL's open water, the exposed mudflat area along its shoreline, habitat characteristics of the shoreline, and flow characteristics of surface water on the GSL mudflats.<br>▪ There has been significant uncertainty regarding groundwater inflows to GSL, and more specifically, from each river basin and into different habitats around GSL. Preliminary and unpublished results from UGS indicate that groundwater inflows may be much higher than previously thought. We must better understand this important source of inflow to GSL.<br>▪ While modeling of the new Union Pacific bridge is an exception, our understanding of flow exchanges between bays is highly dependent upon discrete flow measurements. Very little is understood about flow through causeway fill.<br>▪ Evaporative losses from the open water, mudflats, and wetlands of GSL are only estimates at this time and have historically been used as the variable to adjust while calibrating the GSL water budget. | ▪ Accelerate development of the new GSL Basin groundwater model in development by USGS to provide updated estimates of groundwater inflow by January 2025. [TASK] This includes the following:<br>- Develop a long-term groundwater monitoring program around GSL to validate the GSL groundwater model and monitor for changes. [PROGRAM DEVELOPMENT]<br>- Monitor shallow groundwater levels in GSL mudflats and correlate with surface soil crust characteristics and potential for dust emissions. [STUDY]<br>▪ Develop stage and storage relationships for:<br>- GSL open water (currently being completed by USGS) [TASK]<br>- GSL's impounded wetlands [TASK]<br>▪ Further develop the USU model of the new Union Pacific bridge to evaluate potential future flow control configurations. [TASK]<br>▪ Develop flow relationships for all causeway openings. [STUDY]<br>▪ Invest in quantifying precipitation onto and evaporative losses from the open water, mudflats, and wetlands of GSL (minimum of 5 years). [STUDY] This includes:<br>- Eddy covariance stations to measure ET<br>- Continuous monitoring of climate and lake water temperature and salinity conditions<br>- Research to correlate remote sensing data to field measurements; predict evaporative losses from available climate data<br>▪ Update water and salt balance of the GSLIM with new information. [TASK]<br>▪ Accelerate the current update of the GSL bathymetric map and its shoreline by UGS and USGS. [TASK] |
| **GSL Mudflat Hydrology** | ▪ New studies of GSL inflows and water level are being completed by the State Engineer and USGS Saline Lakes Ecosystem IWAAs.<br>▪ DWQ completed a detailed water budget for Willard Spur in 2011–2013 (CH2M HILL 2016).<br>▪ North Davis Sewer District completed a detailed water budget for areas of Ogden Bay and Farmington Bay in 2018–2020 (Jacobs 2019a, 2020, 2021).<br>▪ UGS, DWR, and The Nature Conservancy are completing a new study of GSL wetlands, shoreline hydrology, and groundwater interactions at the GSL Shorelands Preserve in Farmington Bay. This study is measuring surface water and groundwater inflows, mapping wetland vegetation, and estimating ET to develop a detailed water budget over a 2-year period. This work began in 2022 and is still in progress (Kirby 2022). FFSL recently invested additional monies into this work as part of its FY24 Hot Topics Grants. | ▪ Observed discrepancies in lake bathymetric data in near-shore zones have made it difficult to accurately characterize mudflat hydrology and its influence on the habitat of and inflow to GSL.<br>▪ Runoff volume from precipitation on mudflats is not well understood (that is, runoff versus infiltration).<br>▪ Interaction of surface water and groundwater along the shoreline and its influence upon inflows to and storage within GSL is poorly understood. | ▪ Accelerate the current update of the GSL bathymetric map and its shoreline by UGS and USGS. [TASK]<br>▪ Complete a detailed hydrologic analysis of GSL mudflats to develop relationships between inflow, precipitation, runoff, and infiltration that can be used in modeling efforts. [STUDY]<br>▪ Evaluate the feasibility, impacts and benefits of redirecting precipitation that accumulates on the playa of the West Desert to GSL. [STUDY]<br>▪ Update mapping of vegetation along GSL shoreline, identify areas with invasive species and previous restoration, and link to available hydrology. [TASK]<br>▪ Update mapping of microbialites (mapping of location, area and elevation) along the GSL shoreline and link to bathymetry. Develop a summary of microbialite coverage versus lake level. [TASK] |

Notes:

ANN = artificial neural network
DWQ = Utah Division of Water Quality
DWR = Utah Division of Wildlife Resources
WRe = Utah Division of Water Resources
ET = evapotranspiration
FFSL = Division of Forestry, Fire and State Lands
FY = fiscal year
GSL = Great Salt Lake
GSLAC = Great Salt Lake Advisory Council
GSLIM = Great Salt Lake Integrated Model
GSLSAC = Great Salt Lake Salinity Advisory Committee
ID = identification
IWAA = Integrated Water Availability Assessment
LiDAR = light detection and ranging
UGS = Utah Geological Survey
USGS = U.S. Geological Survey
USU = Utah State University
UU = University of Utah

**Table 2-2. What Is the Value and Consequence of Changing the Lake Water Level?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Planning** | ▪ The 2013 GSL Comprehensive Management Plan is an excellent resource documenting the organizational infrastructure, resources, condition, and strategies for managing GSL and its resources as water levels change (DNR FFSL 2013a).<br>▪ The 2013 GSL "lake level matrix" describes GSL elevation-specific resource characteristics for water levels ranging from 4188 to 4213+ feet (National Geodetic Vertical Datum 1929).<br>▪ The GSLEP, led by the DWR, provides leadership in monitoring, studying, evaluating, and making management recommendations that influence the aquatic and avian resources dependent upon GSL's changing water levels.<br>▪ The GSLAC, with support from FFSL and DWQ, provides leadership and connection for stakeholders as it monitors and assesses changing conditions in the lake and provides recommendations to the State of Utah.<br>▪ A new GSL Commissioner was appointed in 2023 to oversee decisions that influence the water levels of GSL (H.B. 491).<br>▪ WRe was tasked in 2022 by the Utah Legislature (H.B. 429) to complete this GSLBIP and evaluate how much water is required by GSL.<br>▪ Planning efforts that have contemplated the consequence of low lake levels include:<br>- GSLEP's ongoing development of a dynamic ecosystem model<br>- GSLSAC's research and evaluation of berm options<br>- *Assessment of Potential Costs of Declining Water Levels in Great Salt Lake* (ECONorthwest 2019)<br>- *Consequences of Drying Lakes around the World* (AECOM 2019)<br>- Evaluation of impacts on GSL water levels from changes in climate and in its watershed using GSLIM (Jacobs 2019b). | ▪ Recent low water levels in GSL are unprecedented, thus there is very little data and only an early understanding of how low lake water levels affect GSL's resources and watershed.<br>▪ The 2013 GSL Comprehensive Management Plan was last updated in 2013 when lake levels and conditions were significantly different. Recent low lake levels have made management of the lake's resources extremely challenging. FFSL must address each management decision with very little guidance.<br>▪ The GSLAC's Economic Significance Study of the GSL to the State of Utah was completed in 2012. While it has been updated to incorporate inflation, the economy in and around GSL has changed significantly.<br>▪ *Definition and Assessment of Great Salt Lake Health* was completed in 2012 when lake levels and conditions were significantly different (SWCA Environmental Consultants 2012).<br>▪ DWQ's *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) and Core *Component 2: Strategic Monitoring and Research Plan* (DWQ 2014c) were last updated in 2014. Consistent with all other plans, the extent in the decline of water levels and recent rise in lake salinity were not anticipated.<br>▪ The GSLAC's *Assessment of Potential Costs of Declining Water Levels in Great Salt Lake* study was completed in 2019. A new robust analysis should be completed of potential costs of dust mitigation, loss of habitat, and the means to increase inflows to GSL. | ▪ Update the 2013 GSL Comprehensive Management Plan. FFSL is beginning this in late 2023. [PROGRAM DEVELOPMENT] The Comprehensive Management Plan should:<br>- Evaluate and document the benefits and impacts of changing lake water levels upon GSL's uses and watershed. Clearly define vulnerabilities and risks<br>· Update the *Definition and Assessment of Great Salt Lake Health* study to characterize current condition. [STUDY]<br>· Develop a new long-term GSL salinity management plan. [STUDY]<br>· Develop a new dust emissions risk assessment to evaluate potential health and ecosystem risks from dust emissions. [STUDY]<br>· Evaluate effects of water level on aquatic ecology (GSLEP ecology model) [TASK] and avian ecology (GSLEP bioenergetics study) in conjunction with new water budget. [TASK]<br>· Update the Economic Significance of GSL to the State of Utah study. [STUDY]<br>· Update the GSL Level Matrix and GSL Salinity Matrix. [STUDY]<br>· Develop a new GSL dust monitoring and control plan to identify potential risks from and define a proactive implementation and monitoring plan, with associated costs, to control dust emissions. [STUDY]<br>- Provide clear objectives and protocol for managing GSL resources and uses. Clearly define performance metrics. Link management actions to salinity and water levels.<br>· Update the *A Great Salt Lake Water Quality Strategy*. [STUDY]<br>· Update the *Great Salt Lake Mineral Leasing Plan and Record of Decision* as part of updating the GSL Comprehensive Management Plan (DNR FFSL 2013b). [STUDY]<br>· Integrate a new GSL water optimization plan (refer to Table 2-3) and managed wetland water optimization plans (refer to Table 2-1). [STUDY]<br>· Update the *Assessment of Potential Costs of Declining Water Levels in Great Salt Lake* study. [STUDY]<br>▪ Complete and implement the GSLBIP. [PROGRAM DEVELOPMENT] |
| **Salinity** | ▪ UGS, USGS, DWR, and DWQ have and continue to develop a significant historical dataset of abiotic and biotic conditions and ecological resources for GSL.<br>▪ GSLSAC, led by FFSL and DWQ, provides leadership in monitoring and studying salinity dynamics and developing and recommending strategies for managing the salinity of GSL as conditions change, with specific details as follows:<br>- GSLSAC developed a 2019 research plan and has drafted an updated research plan.<br>- GSLSAC has been developing protocol for measuring, monitoring, and reporting salinity and developing recommendations and protocol for managing the berm at the new Union Pacific bridge.<br>- GSLSAC developed a salinity matrix to illustrate the influence of salinity upon GSL resources and uses.<br>▪ GSLSAC developed a successful strategy to modify an underwater berm at the new Union Pacific bridge to reduce the north-to-south transfer of salt into Gilbert Bay in 2022 and then again to raise the water level and dilute the in situ salt in Gilbert Bay in 2023. | ▪ The following key questions are still being investigated by GSLSAC:<br>- What is the salt load from surface water and groundwater sources? Have we adequately accounted for all salt loads into and transfers within the lake?<br>- What is the total salt mass of GSL, including deposits in the North Arm and shoreline evaporation basins?<br>- How is water and salt exchanged between the GSL bays?<br>- What are site-specific salinity impacts upon microbialites, phytoplankton, brine shrimp, brine flies, birds, and industry? What ranges of salinity allow them to thrive? How does that change with increasing or decreasing salinity?<br>- What is the source and dynamics of the observed deep brine layer in the South Arm?<br>▪ A long-term salinity management plan for GSL does not exist. | ▪ Implement and maintain a robust abiotic and biotic monitoring program that includes all GSL bays, coordinate efforts with numerous agencies and organizations. [PROGRAM DEVELOPMENT]<br>▪ Continue USGS funding for monitoring salt loads from surface water inflows to GSL. [TASK]<br>▪ Continue implementation of groundwater quality monitoring and modeling of groundwater inflows to GSL (UGS and USGS). [TASK]<br>▪ Quantify salt loads from groundwater sources. [STUDY]<br>▪ Consolidate salinity databases into one database maintained and accessible by all, linked to the USGS GSL Hydro Mapper (USGS n.d.a) and coordinated with the database being developed by the USGS Saline Lakes Ecosystem IWAAs. [TASK]<br>▪ Increase monitoring of water levels in each bay and frequency of flow measurements at each causeway opening. [PROGRAM DEVELOPMENT]<br>▪ Develop a salt mass balance for each of the GSL bays that can be used in the lake water and salt balance model (GSLIM) to forecast changes in salinity. [STUDY]<br>▪ Develop hydrodynamic model of South Arm to better understand mixing of freshwater inflows and lake and mixing of upper and deep brine layers. [STUDY]<br>▪ Develop hydraulic models of each of the causeway openings that can be used to evaluate how changes in inflow and water level influence conditions in each bay, and incorporate these results into the lake water and salt balance model (GSLIM). [PROGRAM DEVELOPMENT] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Salinity continued** | | | ▪ Complete studies to update the GSL Salinity Matrix with site-specific data (such as for birds, brine flies, microbialites). [STUDY]<br>▪ Define the mechanism(s) by which a deep brine layer forms and is maintained in Gilbert Bay. [STUDY]<br>▪ Develop a long-term GSL Salinity Management Plan that identifies appropriate thresholds for changes in lake uses and recommends management actions to optimize salinity in GSL's different bays. [STUDY] |
| **Ecology and Water Quality** | ▪ UGS, USGS, DWR, and DWQ have and continue to develop a significant historical dataset of abiotic and biotic conditions and ecological resources for GSL.<br>▪ The Sageland Collaborative Migratory Shorebird Survey is being completed at 189 sites around GSL in the spring and fall from 2021-2023. This collaborative effort has received funding from numerous groups and intends to better understanding shorebird use around GSL, identify factors that influence their abundance, and better sustain populations into the future.<br>▪ DWR has a Brine Shrimp Harvest Model that it uses to manage the commercial brine shrimp harvest and understand the demographics throughout the year for brine shrimp (Belovsky et al. 2011).<br>▪ DWR has contracted with Dr. Gary Belovsky to develop a Pelagic Ecosystem Model which is intended to provide the State with impacts to the ecosystem as a whole including birds (eared grebes). This incorporates hydrology, nutrients, phytoplankton, and brine shrimp data that has been collected since 1994.<br>▪ DWR has contracted with Dr. Gary Belovsky to develop a Benthic Ecosystem Model that focuses on microbialites and brine flies and how they respond to temperature, salinity, and food. These two models will be linked to provide projections to the ecosystem based on management actions and decisions.<br>▪ The brine shrimp industry works very closely with DWR to monitor, manage, and regulate GSL's brine shrimp harvest.<br>▪ FFSL invested in 2022 into measuring the resiliency of microbialite cyanobacteria at GSL (Westminster University FY23 Hot Topics Grant).<br>▪ FFSL invested in 2023 into monitoring brine fly dynamics at GSL (Westminster University FY24 Hot Topics Grant).<br>▪ FFSL invested in 2023 into the Intermountain West Shorebird Survey at GSL (Sageland Cooperative FY24 Hot Topics Grant).<br>▪ FFSL invested in 2023 into research of revegetation methods for disturbed wetlands around GSL during drought years (USU FY24 Hot Topics Grant).<br>▪ FFSL continues to make significant investments into mapping, monitoring and removing phragmites from around GSL.<br>▪ DWQ's *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) and *Core Component 2: Strategic Monitoring and Research Plan* (DWQ 2014c) outline important guidelines, monitoring, and research efforts that have been critical in evaluating and protecting GSL water quality. | ▪ Coordination among the numerous ongoing sampling and monitoring programs at GSL has vastly improved, but there is still some overlap and inconsistencies in methods. There is no common database for this information.<br>▪ The following key questions are still being investigated by the GSLEP:<br>- How will microbialites, phytoplankton, brine shrimp, brine flies, and birds be influenced by changing water levels and salinity?<br>- How are seasonal and annual bird populations and their use of GSL (including food sources and habitat) changing with changing inflows, water levels, and salinity?<br>- How should inflows be managed to optimize GSL avian use?<br>▪ GSLEP's new dynamic ecosystem model has its own algorithms to evaluate changes in inflow to and water levels in GSL. These may be different than those used in GSLIM.<br>▪ DWQ's *A Great Salt Lake Water Quality Strategy* reflected very different lake conditions and, as with other plans, did not anticipate record low lake water levels and increasing salinity.<br>▪ The chemistry of GSL's water is unique and often requires investigation, research, and development of custom field and laboratory techniques and protective and management criteria. Historic low water level conditions have only made this more challenging as conditions become more extreme.<br>▪ Avian flu and botulism have been prevalent at GSL. | ▪ Coordinate, update and integrate ongoing monitoring programs being implemented by USGS, DWQ, DWR, and others. [TASK]<br>▪ Consolidate databases into one database coordinated with the database being developed by the USGS Saline Lakes Ecosystem IWAAs. [TASK]<br>▪ Complete studies to update the GSL salinity matrix with site-specific data (such as for birds, brine flies, microbialites). [STUDY]<br>▪ Accelerate GSLEP's bioenergetics study and address links of water and food for both waterfowl and shorebirds. Integrate GSLEP's research with that of USGS Saline Lakes Ecosystem IWAAs. [TASK]<br>▪ Expand bird population surveys to assess critical habitats and links to available water. Integrate GSLEP's research with that of the ongoing Intermountain West Shorebird Survey and USGS Saline Lakes Ecosystem IWAAs. [STUDY]<br>▪ Invest in research into brine fly dynamics at GSL to understand their role in the food web and sensitivity to lake water levels and salinity.<br>▪ Develop water optimization plans for all managed wetland areas that address habitat, hydrology, and water quality requirements for the wetlands within the context of GSL. [PROGRAM DEVELOPMENT]<br>▪ Accelerate development of GSLEP's ecosystem model and link to the lake water and salt balance model (GSLIM) for use in the GSLBIP.<br>▪ Update the 2014 A Great Salt Lake Water Quality Strategy. [STUDY]<br>▪ Update the 2014 Great Salt Lake Strategic Monitoring and Research Plan. [STUDY] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Wetlands** | ▪ DWQ began a Farmington Bay Ecosystem Characterization Program in 2004 to begin to understand how water quantity, water quality, and ecology interact in the impounded and sheetflow wetlands of Farmington Bay.<br>▪ DWQ, Wasatch Front Water Quality Council, DWR, UGS and many others have completed significant research into evaluating GSL wetland conditions.<br>▪ EPA completed *Alternative Futures Analysis of Farmington Bay Wetlands in the Great Salt Lake Ecosystem* (Sumner et al. 2010) to evaluate alternative future conditions under different management scenarios.<br>▪ DWQ developed multi-metric indices in 2006–2013 to evaluate the condition of impounded and sheetflow wetlands of GSL.<br>▪ FFSL is investing $800,000 per year into monitoring, research, and control of *Phragmites* around GSL and throughout its watershed. This ongoing program has been very successful as it has controlled the spread of this invasive species, restored native habitat and vegetation, and reduced the consumptive use of water by this plant species.<br>▪ UGS and DWQ have partnered to develop data, tools, and methods to monitor and assess the condition and water quality of wetlands (UGS and DWQ 2017). This work has continued through fiscal years 2020–2022 to include development of an integrated database of chemistry and biological data, refinement of GSL wetland assessment methods for all major wetland classes, and assessment of condition (Downard 2020). | ▪ Most research that has been completed has been to monitor and assess the condition of wetlands and their value for bird habitat. Understanding the associated wetland hydrology has typically been a secondary or tertiary objective or was identified as a recommendation from these studies.<br>▪ There is little to no historical or current measurement and recording of water levels and flows throughout GSL wetlands systems to describe their available inflows, resulting conditions in the wetlands, and resulting outflows to GSL.<br>▪ Water management goals are typically tied to optimizing habitat and food resources for specific guilds of birds. There is a growing effort to incorporate objectives for water quality, invasive species, downstream habitat, and water for GSL, but these efforts should be advanced and integrated.<br>▪ The value of shoreline wetlands in maintaining the shallow groundwater table in and minimizing dust emissions from GSL's mudflats is poorly understood. | ▪ Incorporate monitoring of hydrology (including groundwater flux) into future wetland habitat and water quality studies. [TASK]<br>▪ Invest in updated flow control and measurement systems for managed wetlands along GSL's shoreline. Coordinate with GSLAC's new "projects project" to identify these needs. [PROGRAM DEVELOPMENT]<br>▪ Develop water balance and water optimization plans for managed wetlands to optimize water management for multiple objectives such as maximizing habitat value and water quality and minimizing evaporative losses and invasive species. [PROGRAM DEVELOPMENT]<br>▪ Complete a detailed hydrological analysis of GSL wetlands complexes to develop relationships between inflow, precipitation, ET, infiltration, and outflow that can be used in modeling efforts. [STUDY]<br>▪ Water for wetlands should be an important component of a GSL water optimization plan (refer to Table 2-3). [TASK]<br>▪ Develop strategic plans to protect additional wetlands along the shoreline of GSL. [STUDY] |
| **Dust Emissions** | ▪ Increasing research since 2015 to characterize GSL as a source of dust found in the metropolitan area of the Wasatch Front, the Wasatch mountain range, and the Uinta mountain range. Research has identified GSL as an important source of dust, has begun to understand the chemical composition of this dust, and has documented the effects of dust on snowmelt.<br>▪ An increasing awareness and engagement of the populace in understanding air quality and dust specifically.<br>▪ FFSL invested in 2022 into research to assess the vulnerability of northern Utah communities to dust from GSL playas (USGS FY23 Hot Topics Grant).<br>▪ The 2023 Utah Legislature passed H.B. 220 to complete an emissions inventory in the counties surrounding GSL with the intent that it can become the basis for an air pollutant reduction plan.<br>▪ The Division of Air Quality received $285,379 from the EPA in 2023 to deploy 40 PM10 and PM2.5 particulate matter sensors in northern Salt Lake County.<br>▪ The Dust^2 cluster is a network of six interconnected projects that are evaluating potential airborne dust risks to water quality, the water supply, soils and environment, and the population in the intermountain west. This program received $5.2M in funding from the National Science Foundation: Collaborative Research: Network Cluster: Dust in the Critical Zone from the Great Basin to the Rocky Mountains. | ▪ Although dust emissions are increasingly considered a significant risk when lake water levels are low, sources, composition, loading, risks, and mitigation options are only recently beginning to be understood.<br>▪ While we are beginning to identify the sources of dust from GSL mudflats, we are only beginning to understand the conditions or mechanisms that cause dust emissions to occur. We do not understand how these are linked to lake water levels or the shallow groundwater table.<br>▪ We are only beginning to understand dust dispersal within the GSL watershed and potential risks to human health, the water supply, and the environment. PM10 samplers in the region are not sufficiently dense or sampled frequently enough to capture all dust events at the frequency, duration, and in the locations when and where they occur.<br>▪ We do not know the historical or current GSL dust emission loads or how they could change with changing climate and lake water levels. We do not have adequate information to distinguish GSL dust loads from other sources, such as mining, construction, agriculture, or surrounding desert areas.<br>▪ We do not have thresholds to determine health and ecosystem risks.<br>▪ We have not begun to consider potential strategies to reduce dust emission loads from GSL. We do not know the potential costs or how much water might be required solely for dust mitigation. | ▪ Synthesize work to characterize GSL dust emissions to focus future efforts. [STUDY]<br>▪ Implement a robust monitoring program to characterize spatial and temporal dust composition in Tooele, Salt Lake, Davis, Weber, and Box Elder counties. How much and where is the dust going? [PROGRAM DEVELOPMENT]<br>▪ Implement a robust monitoring program to characterize active dust emissions from GSL (ground-based monitoring, unmanned aerial vehicle, video). [PROGRAM DEVELOPMENT]<br>▪ Characterize dust emissions by mapping exposed mudflats, characterizing their surfaces and hydrology, modeling wind conditions, and estimating emission loads. [STUDY]<br>▪ Develop a new dust emissions risk assessment to establish important thresholds and evaluate potential health and ecosystem risks from dust emissions. [STUDY]<br>▪ Plan potential mitigation efforts, including an evaluation of soil suitability, water availability, and stakeholder needs, concerns, and efforts. Consider and select dust control measures. Identify requirements for water and how this may impact the GSL water budget. [STUDY]<br>▪ Develop a GSL dust monitoring and control plan to identify potential risks from and define a proactive implementation and monitoring plan, with associated costs, to control dust emissions. Identify potential water requirements for inclusion in the GSL water optimization plan. [PROGRAM DEVELOPMENT] |
| **Mineral Extraction** | ▪ The 2013 *Great Salt Lake Mineral Leasing Plan and Record of Decision* (DNR FFSL 2013b) was prepared to document existing and future potential mineral leasing activities (DNR FFSL 2013a). It is slated to be updated in 2023.<br>▪ H.B. 513 was passed by the Utah Legislature in 2023 to incentivize non-depletive methods for mineral extraction from GSL and consider the fair market value of GSL leases and space utilization of GSL mineral leases.<br>▪ The UGS and others have developed a significant dataset describing the mineral resources and their dynamics in GSL.<br>▪ FFSL invested in 2023 into research to identify GSL's sources of Lithium (USGS FY24 Hot Topics Grant). | ▪ Diversions from GSL are reported in monthly time intervals on an annual basis. Return flows to GSL are not reported.<br>▪ Impacts from diversions from GSL are poorly understood, thus can become a source of controversy.<br>▪ Benefits of mineral extraction to the lake's system have not been fully quantified. | ▪ Quantify diverted water and exported salt and return flows (and salt mass). [PROGRAM DEVELOPMENT]<br>▪ Quantify and update characterization of GSL mineral resources. [STUDY]<br>▪ Develop strategy for implementation of H.B. 513. [STUDY] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|

Notes:

DWQ = Utah Division of Water Quality
DWR = Utah Division of Wildlife Resources
WRe = Utah Division of Water Resources
EPA = U.S. Environmental Protection Agency
FFSL = Division of Forestry, Fire and State Lands
FY = fiscal year

GSL = Great Salt Lake
GSLAC = Great Salt Lake Advisory Council
GSLBIP = Great Salt Lake Basin Integrated Plan
GSLEP = Great Salt Lake Ecosystem Program
GSLIM = Great Salt Lake Integrated Model
GSLSAC = Great Salt Lake Salinity Advisory Committee

H.B. = House Bill
IWAA = Integrated Water Availability Assessment
$PM_{10}$ = particulate matter of diameter 10 microns or less
$PM_{2.5}$ = particulate matter of diameter 2.5 microns or less
UGS = Utah Geological Survey
USGS = U.S. Geological Survey
USU = Utah State University

**Table 2-3. What Management Scheme Should Be Used for Safe Operating Levels for Great Salt Lake?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Connections** | ▪ Our greatest strength is possibly the proven ability of GSL stakeholders to connect and collaborate to solve very difficult and conflicting challenges. Successes over the long-term have largely been due to the vision, commitment, innovation, and passionate efforts of the numerous individuals who began to coordinate and leverage their resources and efforts around a common goal: to protect GSL and its resources. The GSLAC played an essential role in accomplishing this.<br>▪ The eastern shoreline of GSL is largely managed and protected collaboratively by various governmental and non-governmental organizations as open space.<br>▪ The Utah Legislature passed H.B. 307 in 2023 to form Utah Water Ways to optimize the use of water.<br>▪ The GSL Technical Team serves an important role in linking researchers, promoting collaboration, and advising the State of Utah regarding GSL technical topics. | ▪ The biggest challenge is the lack of connection to and the sense of value of GSL felt by both the populace and decision makers for GSL's watershed. That is compounded by the unique nature of GSL, which often requires custom approaches to monitoring, research, and management. The challenge is perceived as too great to address. | ▪ Augment Utah Water Ways to educate people about how their water use is connected to and provides value at GSL. [TASK]<br>▪ Implement an integrated collaborative strategy to develop and implement the GSLBIP. [PROGRAM DEVELOPMENT] |
| **Organizational Infrastructure** | ▪ Numerous state and federal agencies have incorporated GSL into their mission and activities. At present, GSL's resources and cooperation are a testament to the extensive individual and collective efforts by these agencies.<br>▪ A new Great Salt Lake Commissioner was appointed in 2023 to oversee decisions that influence GSL water levels (H.B. 491). | ▪ Recruitment and retention of state personnel with the required expertise is challenging.<br>▪ Monitoring and management of GSL's resources has often been completed with a very limited budget. This, in combination with GSL's unique characteristics, has generally created a management paradigm that has had to be reactionary and respond to crises as they emerge.<br>▪ There are numerous agencies that have various responsibilities and objectives that include elements of GSL and its resources. Objectives and efforts are difficult to coordinate and are at times in conflict with each other. Ongoing lake management, monitoring, and research efforts are often funded via numerous different sources with different longevity conditions requiring agency staff to focus significant time and resources to simply maintain minimum funding rather than other duties.<br>▪ Until the creation of the Great Salt Lake Commissioner position in 2023, there was no one leader or agency with the responsibility of coordinating and overseeing the work of the numerous state agencies who protect and manage GSL resources and uses.<br>▪ There is no central database and repository of literature. | ▪ Provide adequate funding to retain agency personnel, complete required monitoring and research, and develop a proactive and strategic management footing. [PROGRAM DEVELOPMENT]<br>▪ Identify a continuing funding source for GSL management activities. [PROGRAM DEVELOPMENT]<br>▪ Identify a continuing funding source for GSL monitoring activities. [PROGRAM DEVELOPMENT]<br>▪ Complete a comprehensive review of objectives, roles, and responsibilities for agencies working at GSL to enhance symbiosis and effectiveness. [STUDY]<br>▪ Develop a central database and literature repository for GSL. [PROGRAM DEVELOPMENT] |
| **Programs and Planning** | ▪ DWR established the GSLEP to manage GSL avian and aquatic communities. This work includes ongoing monitoring and research and active regulation of the brine shrimp industry. Key contributions include:<br>- GSLEP facilitates a quarterly Technical Advisory Group meeting to discuss changing conditions, research, and management actions.<br>- GSLEP funds ongoing monitoring and research of GSL abiotic and biotic parameters.<br>- GSLEP funded the development of a brine shrimp harvest model to ensure a sustainable brine shrimp population.<br>- GSLEP funded the development of a GSL ecosystem model to better understand the dynamics and interrelationships of GSL's aquatic and avian communities.<br>▪ The GSLAC was formed in 2010 in recognition of challenges posed by changing lake conditions to advise on the sustainable use, protection, and development of GSL. GSLAC has since completed and participated in numerous studies to inform management of water and GSL:<br>- Completed the 2012 *Definition and Assessment of Great Salt Lake Health* to define, assess, and identify critical future stresses to GSL' health (SWCA Environmental Consultants 2012).<br>- Completed the 2012 *Economic Significant of Great Salt Lake to the State of Utah* to document the total state economic activity tied to uses of GSL (Bioeconomics 2012).<br>- Commissioned development of GSLIM in 2015 to aid resource managers and policymakers in understanding how changes in GSL's watershed might impact the lake and its uses. An evaluation of alternative future scenarios was completed with GSLIM in 2019. | ▪ Recent low water levels in GSL are unprecedented, thus there is very little guidance on how to manage GSL's resources at these water levels. Key management documents are useable but dated and do not contemplate today's historic low water levels:<br>- 2013 *Great Salt Lake Comprehensive Management Plan* and Record of Decision (DNR FFSL 2013a)<br>- 2013 Great Salt Lake Level Matrix<br>- 2013 *Great Salt Lake Mineral Leasing Plan and Record of Decision* (DNR FFSL 2013b)<br>- 2012 *Definition and Assessment of Great Salt Lake Health* (SWCA Environmental Consultants 2012)<br>- 2012 *Economic Significant of Great Salt Lake to the State of Utah* (Bioeconomics 2012)<br>- 2014 *A Great Salt Lake Water Quality Strategy* (DWQ 2014a)<br>▪ A management plan is needed to integrate the activities of the different research programs and agencies with jurisdiction over GSL resources.<br>▪ A management plan is needed to optimize water use at GSL among its shoreline wetlands, mudflats, shoreline, and open water habitats to address numerous objectives. | ▪ Update the Great Salt Lake Comprehensive Management Plan and develop its components (refer to Table 2-2). [PROGRAM DEVELOPMENT]<br>▪ Evaluate opportunities to develop habitat management plans for 23-21-5 lands. [STUDY]<br>▪ Develop a GSL water optimization plan that accomplishes the following: [PROGRAM DEVELOPMENT]<br>- Develop a detailed water budget for GSL and its wetlands for current, which considers future conditions using the lake water and salt balance model (GSLIM).<br>- Develop and implement strategies to quantify inflows into, diversions out of, and transfers of water within GSL.<br>- Update flow control structures at all managed wetlands to enable optimization of available water.<br>- Evaluate options to optimize flow control at wetlands and causeways to optimize salinity, aquatic and avian resources, industrial uses, and dust emissions.<br>- Develop water optimization plans for all managed wetlands.<br>- Develop a GSL ecology model and complete avian bioenergetics study.<br>- Develop a GSL salinity management plan.<br>- Develop a dust emission risk assessment and dust control and monitoring plan. |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| Programs and Planning continued | - Compiled an extensive list of potential strategies to increase or maintain water delivery to Great Salt Lake in 2017 (SWCA Environmental Consultants 2017).<br>- Completed the 2019 *Assessment of Potential Costs of Declining Water Levels in Great Salt Lake* (ECONorthwest 2019).<br>- Completed the 2019 study documenting *Consequences of Drying Lake Systems around the World* (AECOM 2019).<br>- Evaluated 12 priority *Water Strategies for Great Salt Lake, Legal Analysis and Review of Select Water Strategies for Great Salt Lake*, to address declining water levels in Great Salt Lake in 2020 (ClydeSnow and Jacobs 2020).<br>- Completed the 2020 water *Conservation Impacts Study* (Bowen Collins & Associates 2020) and 2020 water reuse study (DEQ 2021) to evaluate benefits from different water management strategies.<br>- The GSLAC, FFSL, and DWQ facilitated the HCR 10 steering group in 2020, which made Recommendations to Ensure Adequate Water Flows to Great Salt Lake and Its Wetlands.<br>- Funded development of the USGS Great Salt Lake Hydro Mapper (USGS n.d.a) in 2021 to assist decision makers with up-to-date information on GSL conditions.<br>▪ FFSL completed the 2013 *Great Salt Lake Comprehensive Management Plan and Record of Decision* (DNR FFSL 2013a), which documents the organizational infrastructure, resources, condition, and strategies for managing GSL and its resources as water levels change. FFSL is updating the Comprehensive Management Plan starting in late 2023.<br>▪ FFSL completed the 2013 *Great Salt Lake Mineral Leasing Plan and Record of Decision* (DNR FFSL 2013b) provides guidance for managing the mineral resources of GSL. FFSL is updating the Mineral Leasing Plan starting in late 2023 as part of its update of the Great Salt Lake Comprehensive Management Plan.<br>▪ DWQ completed the 2014 *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) to identify potential risks and the 2014 *Core Component 2: Strategic Monitoring and Research Plan* (DWQ 2014b) to identify and develop an active research and monitoring program.<br>▪ FFSL and DWQ formed GSLSAC in 2018 to provide recommendations to the State regarding GSL monitoring, research, and salinity management:<br>- GSLSAC meets almost monthly to discuss changing conditions, research, and management recommendations.<br>- GSLSAC developed a 2019 research plan and has drafted an updated research plan.<br>- GSLSAC has been developing protocol for measuring, monitoring, and reporting salinity and developing recommendations for managing the berm at the new Union Pacific bridge.<br>- GSLSAC developed a salinity matrix to illustrate the influence of salinity upon GSL resources and uses.<br>▪ The Utah Legislature passed HCR 10 to form the HCR 10 Steering Group in 2020 to evaluate and recommend strategies for ensuring adequate inflow to GSL and its wetlands.<br>▪ The USGS Saline Lakes Ecosystem IWAAs was initiated in 2022 to create a science strategy to monitor and assess the hydrology of saline lakes in the Great Basin (including GSL) and the migratory birds and other wildlife dependent upon their habitat.<br>▪ The Utah Legislature passed H.B. 410 in 2022 to initiate the Great Salt Lake Watershed Enhancement Trust with $40M. Its stated purpose is to retain or enhance water flows to GSL and conserve, protect, and restore wetlands by engaging stakeholders and communities in partnership. Together they will complete assessments and studies and leverage available funding.<br>▪ The GSL Strike Team was formed in late 2022 to provide the Utah Legislature with a synthesis of available information, a focus upon the most important questions, and recommendations for preserving GSL. | ▪ Aging infrastructure, limited personnel, and little flow data have made it difficult to optimize water use along the shoreline of GSL.<br>▪ Water management within GSL has until recently been completed passively if considered at all. Efforts at DWR's waterfowl management areas and modification of the berm at the new Union Pacific bridge have demonstrated how decision makers can optimize the available water in GSL to benefit the system as a whole.<br>▪ Quantification of water into and diverted from GSL has been very limited, making consideration of management decisions difficult.<br>▪ Monitoring, modeling, and control of flow through causeways is limited.<br>▪ Access to GSL, especially at historic low lake levels, has been difficult to both control and provide.<br>▪ Rapid increases in the demand for lithium have significantly increased interest in developing this resource in GSL. Much is to be learned about the source, quantity, and economics of lithium in GSL. New rules for extraction of lithium from GSL are only now being developed.<br>▪ The value of land within the meander line and along the shoreline of GSL is very difficult to determine. | ▪ Incorporate the GSL water optimization plan into the Great Salt Lake Comprehensive Management Plan.Identify water users willing to lease water for use at GSL. Develop quantification methods to distribute this water to then intended use at GSL. Coordinate with the GSL Watershed Enhancement Trust. **[PROGRAM DEVELOPMENT]**<br>▪ Evaluate the feasibility, benefits, and impacts of using improved dikes and causeways (such as the Union Pacific causeway) to partition GSL as a means of protecting GSL beneficial uses at low lake levels. **[PROGRAM DEVELOPMENT]** |

Notes:

DWQ = Utah Division of Water Quality
DWR = Utah Division of Wildlife Resources
FFSL = Division of Forestry, Fire and State Lands
GSL = Great Salt Lake

GSLAC = Great Salt Lake Advisory Council
GSLBIP = Great Salt Lake Basin Integrated Plan
GSLEP = Great Salt Lake Ecosystem Program
GSLIM = Great Salt Lake Integrated Model

GSLSAC = Great Salt Lake Salinity Advisory Committee
H.B. = House Bill
HCR = House Concurrent Resolution
IWAA = Integrated Water Availability Assessment
USGS = U.S. Geological Survey

## 2.2 Building Block Technical Questions

*How do we ensure a resilient water supply for GSL and all uses in its watershed?*

How much water does GSL and its wetlands need to support its designated uses?

- How much inflow is needed to sustain a particular lake level?
  - What is the water budget for GSL and its associated wetlands?
    - What are the inflows?
      - What are inflows from on-lake precipitation?
        - How much precipitation does GSL receive?
          - How do we differentiate precipitation into wetlands, mudflats, and open water?
          - How do we characterize present/future climate conditions relating to precipitation?
        - How much inflow is from runoff from mudflats?
      - What are the Bear River basin inflows?
          - What are the groundwater inflows from the Bear River basin?
          - What are the surface water inflows from Bear River Bay?
          - How much surface water enters the open water of Gilbert Bay?
          - How much surface water enters the mudflats of Gilbert Bay at Union Pacific Causeway?
          - How much surface water enters the "the trapezoid" of Bear River Bay (below Compass Minerals bridge, Bear River Bay plus Compass Minerals))?
          - How much surface water enters the mudflats of Bear River Bay "proper" (Promontory Mtns, north wetlands, Willard Spur)?
            - How much surface water enters the mudflats of Bear River Bay "proper" from western shoreline (Promontory Mountains)?
            - How much surface water enters the mudflats of Bear River Bay "proper" from the north wetland complexes (public shooting rounds and Bear River Migratory Bird Refuge)?
              - How much water enters the north wetland complexes flowing into Bear River Bay "proper" (surface and groundwater)?
            - How much surface water enters the mudflats of Bear River Bay "proper" from Willard Spur?
              - How much water enters the mudflats of Willard Spur from the Bear River basin (Bear River Migratory Bird Refuge and Willard/Perry)?
                - How much water enters the Bear River basin wetland complexes flowing into Willard Spur (surface and groundwater)?
              - How much water enters the mudflats of Willard Spur from the Weber River basin (Willard Bay, Harold Crane Waterfowl Management Area (WMA), plus misc)?

      - How much water enters the Weber River basin wetland complexes flowing into Willard Spur (surface and groundwater)?

- What are the Weber River basin inflows? (Little Mountain to Antelope Island Causeway)
  - What are the groundwater inflows from the Weber River basin?
  - What are the surface water inflows from the Weber River Basin?
    - ✓ How much surface water enters the open water of Gilbert Bay (via Ogden Bay and Ogden Spur)?
    - ✓ How much surface water enters the mudflats of Ogden Bay?
      - How much water enters the Ogden Bay WMA complexes (surface and groundwater)?
    - ✓ How much surface water enters the mudflats of Ogden Spur?
      - How much water enters the Howard Slough WMA complexes (surface and groundwater)?
      - How much water enters the misc. wetland complexes between Howard Slough WMA and Antelope Island causeway (surface and groundwater)?
- What are the Utah Lake/Jordan River basin inflows?
  - What are groundwater inflows from the Utah Lake/Jordan River basin inflow?
  - What are the surface water inflows from Farmington Bay into Gilbert Bay?
    - ✓ How much surface water enters the open waters of Gilbert Bay?
    - ✓ How much water enters the mudflats of Gilbert Bay at Antelope Island Causeway?
    - ✓ How much surface water enters the mudflats of Farmington Bay?
      - How much water enters the Farmington Bay wetland complexes from the lower Jordan River (surface and groundwater)?
      - How much water enters the Farmington Bay wetland complexes from the Surplus Canal (surface and groundwater)?
      - How much water enters the Farmington Bay wetland complexes from the east shoreline (surface and groundwater)?
  - What are the surface water inflows from the Goggin Drain System into Gilbert Bay?
    - ✓ How much surface water enters the open water of Gilbert Bay?
    - ✓ How much surface water enters the mudflats of Gilbert Bay?
      - How much water enters the Goggin Drain north wetland complexes (surface and groundwater)?
      - How much water enters the Goggin Drain south wetland complexes (surface and groundwater)?
  - What are the surface water inflows from Lee Creek system into Gilbert Bay?
    - ✓ How much surface water enters the open water of Gilbert Bay?
    - ✓ How much surface water enters the mudflats of Gilbert Bay?
    - ✓ How much water enters Lee Creek wetland complexes (surface and groundwater)?
  - What are surface water inflows from the Salt Lake County southshore system into Gilbert Bay?
    - ✓ How much surface water enters the open water of Gilbert Bay?
    - ✓ How much surface water enters the mudflats of Gilbert Bay?

            - ✓ How much water enters the Salt Lake County southshore system wetland complexes (surface and groundwater)?

    - What are the West Desert basin inflows?
        - ➢ What are groundwater inflows from the Rush/Tooele valleys?
        - ➢ What are the surface water inflows from the Rush/Tooele Valleys?
        - ➢ What are groundwater inflows from the northern GSL desert?
        - ➢ What are the surface water inflows from the northern GSL desert?
        - ➢ What are groundwater inflows from the Curlew Valley?
        - ➢ What are the surface water inflows from the Curlew Valley?

- o What are the outflows?
    - What are outflows to groundwater? Assumed to be none?
    - What is lost to evaporation?
        - ➢ What are the evaporation rates?
            - ✓ How do we characterize present/future climate conditions relating to evaporation?
            - ✓ How do we characterize present/future climate conditions relating to air temperature?
            - ✓ How do we characterize present/future climate conditions relating to water temperature?
            - ✓ How do we adjust for salinity?
        - ➢ What is the surface area of different areas of the lake?
            - ✓ What is the surface area of the open water? How does it change with lake level?
                - ✦ in the North Arm?
                - ✦ in the South Arm?
                - ✦ in Bear River Bay?
                - ✦ in Farmington Bay?
            - ✓ What is the surface area of the mudflats? How does it change with inflow and lake level?
                - ✦ in the North Arm?
                - ✦ in the South Arm?
                - ✦ in Bear River Bay?
                - ✦ in Farmington Bay?
            - ✓ What is the surface area of the different vegetation classes of wetlands? How does it change with inflow and lake level?
                - ✦ in the North Arm?
                - ✦ in the South Arm?
                - ✦ in Bear River Bay?
                - ✦ in Farmington Bay?
            - ✓ What is the surface area of the constructed evaporation basins?
                - ✦ in the North Arm?
                - ✦ in the South Arm?
                - ✦ in Bear River Bay?

- o What are the flow exchanges between bays?

- How can we best represent flow through the Union Pacific Causeway for North Arm/South Arm?
    - Old breach, new bridge, seepage
- How can we best represent flow through the Compass Minerals bridge for Bear River Bay/Trapezoid?
- How can we best represent flow through the Union Pacific Causeway for Bear River Bay Trapezoid/Gilbert Bay?
- How can we best represent flow through the Antelope Island Causeway bridge for Farmington Bay/Gilbert Bay?
- How can we best represent flow through the Antelope Island Causeway culvert for Farmington Bay/Gilbert Bay?
- How can we best represent flow through the Antelope Island Southern Causeway for Farmington Bay/Gilbert Bay?

- What are the lake's storage characteristics?

- Surface water
  - What is the bathymetry that defines the lakebed, in-lake and wetland structures, and surface water for the open water, mudflats, and wetlands of the lake?
  - What is the water elevation?
    - in the North Arm?
    - in the South Arm?
    - in Farmington Bay?
    - in Bear River Bay?
    - in the shoreline wetland impoundments?
  - How does storage change with water level?
    - in open water?
    - on mudflats?
    - in wetlands?
  - Groundwater
    - How much pore space is available for storage in the mudflats at different lake levels and wetland conditions?
  - How will water levels change with changing inflows?
    - What scenarios should be evaluated?
- What is the value and consequence of changing lake water level?
    - What are the beneficial uses of the lake?
    - What are the ecological uses?
    - What are the recreational uses?
    - What are the industrial uses?
  - How will water quality change with fluctuating water levels?
    - How will salinity change with fluctuating water levels?
- What is the salt mass of Great Salt Lake?
  - What is the salt mass in the water column of each bay of Great Salt Lake?

    - What is the salt mass in the upper brine layer?
    - What is the salt mass in the deep brine layer?
    - What are the dynamics of the upper and deep brine layers?
  - How much salt is stored in the North Arm salt crust? Thickness?
  - How much salt is stored in the evaporation basins?
- What is the salt load into Great Salt Lake?
  - What is the salt load from the various surface water inflows into each of the bays of Great Salt Lake?
  - What is the salt load from groundwater into each of the bays of Great Salt Lake?
- How is salt exchanged between bays of Great Salt Lake?
  - Through the Union Pacific causeway?
    - Between the North Arm and South Arm?
    - Between Bear River Bay and Gilbert Bay?
    - Through the Antelope Island causeway?
- How does salinity impact beneficial uses?
  - How will water temperature change with fluctuating water levels?
  - How will nutrient concentrations change with fluctuating water levels?
- What are the nutrient loads into each bay of Great Salt Lake?
- What are the in-lake nutrient cycling processes?
- Are there external factors that regulate nutrient concentrations in the lake's water column?
  - How will other contaminant concentrations change with fluctuating water levels?
- Will contaminants previously contained within the deep brine layer be released at low lake levels?
  - How do discharges into GSL disperse into the lake?
    - How will the ecology change with fluctuating water levels?
  - How will the ecology of the open waters change with fluctuating water levels?
    - How will the aquatic food chain change?
    - How are phytoplankton impacted by changing water levels? And other microbiology?
  - What is the lake's species composition and population dynamics?
    - What is their role in the food chain?
      - What is their value in the aquatic food chain?
      - What is the consequence if they decline?
  - What role do water temperature, salinity, and nutrients play?
  - What are their linkages to the lake's aquatic food chain?
  - What is their productivity at different water levels? Salinity?
  - How will microbialite structures be impacted by changing water levels?
    - What are microbialites? What is their function?
    - What is their role in the food chain?
    - What is their value in the aquatic food chain?
    - What is the consequence if they decline?

- — What is the status of microbialites located in Great Salt Lake?
- — Where are they located? Spatially? Elevation? Size? Density?
- — What is their condition?
- — Are they diverse in structure/composition? Are they all the same?
- — What regulates their productivity?
- — How are they impacted by salinity?
  - o Do microbialites need to be submerged to live? By how much water? Frequency?
- — What is their productivity at different water levels? Salinity?
- — How are brine flies impacted by changing water levels?
- — What is their life cycle?
- — What is their role in the food chain?
- — What is their value in the aquatic food chain?
- — What is the consequence if they decline?
- — What is the status of brine flies located in Great Salt Lake?
- — Where are they located? Spatially? Elevation? Size? Density?
- — What is their condition?
- — Are they diverse in species per location? Are they all the same?
- — What regulates their productivity? Reproductive success?
- — How are they impacted by salinity?
- — How does a changing water level affect their life cycle?
- — What is their biomass at different water levels? Salinity?
- — How are brine shrimp impacted by changing water levels?
- — What is their life cycle?
- — What is their role in the food chain?
- — What is their value in the aquatic food chain?
- — What is the consequence if they decline?
- — What is the status of brine shrimp located in Great Salt Lake?
- — Where are they located? Spatially? Elevation? Size? Density?
- — What is their condition?
- — Are they diverse in species per location? Are they all the same?
- — What regulates their productivity? Reproductive success?
- — How are they impacted by salinity?
- — How does a changing water level affect their life cycle?
- — What is their biomass at different water levels? Salinity?

▪ How does the open water habitat structure change with water level?

How does the areal extent of open water habitat change with water level?

How will microbialite habitat in the open water be impacted by changing water levels?

See aquatic food chain

How will shorebird habitat along the shoreline of the open water be impacted by changing water levels?

What is the areal extent of shoreline feeding habitat (different depths) for different birds?

How will nesting habitat change with water level?

Where do birds nest?

How do open water foraging resources change with changing water levels?

- How will bird use in the open water change with water level?
- How will food abundance change with water level?

What do different birds eat?

Where do different birds forage?

- o How will the ecology of the mudflats and playas change with fluctuating water levels?
- o How will the ecology of the unimpounded marsh complexes change with fluctuating water levels?
- o How will the ecology of the impounded wetlands change with fluctuating water levels?
- o How will the ecology of lake islands change with fluctuating water levels?

- o How will industrial use of the lake change with fluctuating water levels?
  - o What are the limiting factors for the mineral extraction industry?
    - What are the limiting water levels for each company to divert water from the lake?
    - What is the limiting salinity for each company to divert and process water from the lake?
  - o What are the limiting factors for the brine shrimp industry?
  - ➢ What are the limiting water levels for each company to access and operate on the lake?
  - ➢ What is the limiting salinity for brine shrimp production in the lake?
  - o What are the limiting factors for permitted discharges to the lake?
  - ➢ How does lake level impact the permitted discharge of waters to the lake?

Can discharges safely reach their intended receiving water body?

Does a lower lake level expose new concerns?

Does changing water level introduce new concerns for permitted discharges?

Ecological risks

Water quality

Required dilution

- o How will recreational use of the lake change with fluctuating water levels?
  - How are boating activities on the lake impacted by water levels?
    - ➢ How is motor and sail boat and small vessel access via boat ramps impacted?
  - How is nonmotorized recreation (hiking, biking and equestrian) impacted?
  - How is camping and picnicking impacted?

        - How is off-highway vehicle recreation impacted?
        - How is bird-watching impacted?
        - How is hunting impacted?
    - How are safety and resource management activities impacted by fluctuating water levels?
        - How is motor boat and small vessel access via boat ramps impacted?
        - How are sampling or monitoring sites impacted?
    - How do water levels affect Great Salt Lake's watershed?
        - How does surface area of open water of Great Salt Lake affect snow fall in the watershed?
        - How does the surface area of the exposed lakebed affect dust emissions in the watershed?
        - How does the surface area of the exposed lakebed affect salt dispersion in the watershed?
- What management scheme should be used for safe operating levels for Great Salt Lake?
    - How do we measure system performance?
    - How do we define vulnerabilities?
    - How do we define risks?
    - How can we use existing causeways in GSL as a means to manage water levels?
    - How can we use existing causeways in GSL as a means to manage water levels?
    - What water levels should be associated with management actions?

# 3. Stormwater Gap Analysis

This section outlines the results of the gap analysis completed for the stormwater building block of the GSLBIP. The results of this gap analysis will inform the Work Plan for the GSLBIP.

## 3.1 Tier 3 Technical Questions

The stormwater gap analysis was framed around answering the following Tier 3 stormwater questions (refer to Figures 1-3 and 3-1):

- What low-impact development (LID) best management practices (BMPs) or tools are applicable in Utah (Table 3-1)?
- How do LID BMPs or tools impact our hydrology (Table 3-2)?
- What stormwater management strategies should be used to benefit the water budget of GSL (Table 3-3)?

The complete list of stormwater technical questions can be found in Section 3.2.

**Figure 3-1. Tier 3 Questions for the Stormwater Gap Analysis**

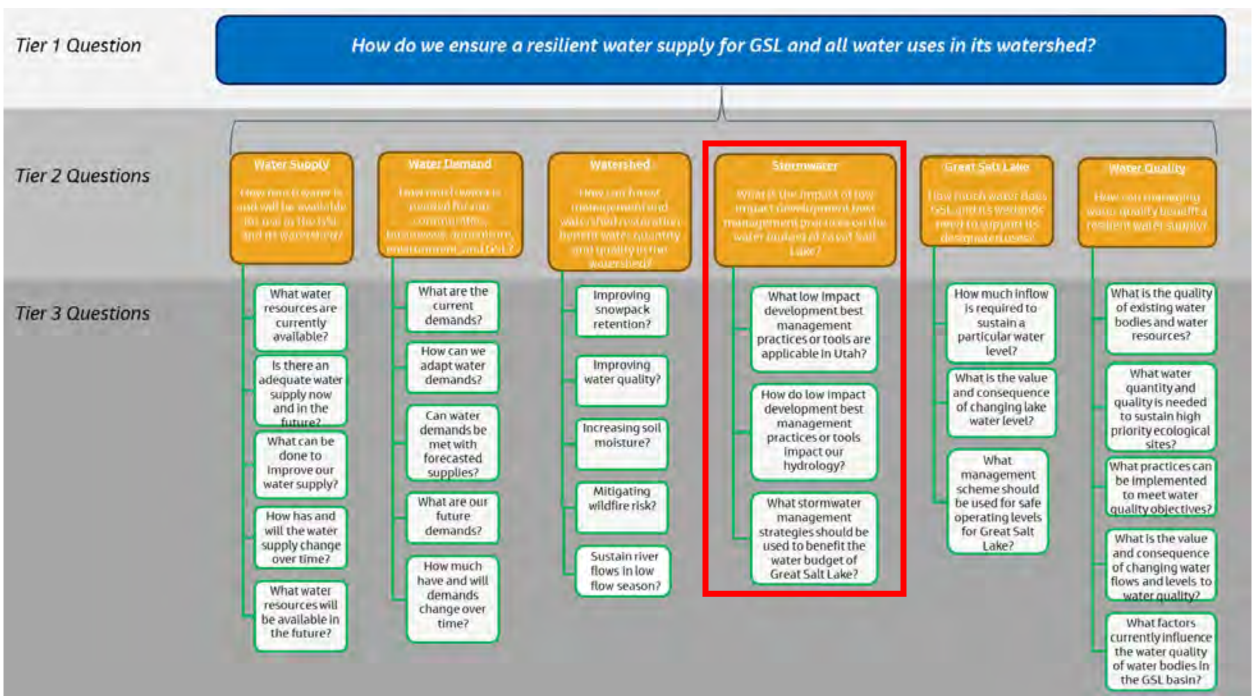


**Table 3-1. What Low-Impact Development Best Management Practices or Tools are Applicable in Utah?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Phase 1 MS4 permits require water quality monitoring data to be collected.<br>▪ In general, nationwide science has done a good job defining LID BMP effectiveness.<br>▪ DWQ has a published *A Guide to Low Impact Development within Utah* (Michael Baker International 2020). | ▪ There is a lack of long-term monitoring and maintenance data.<br>▪ There is a lack of education and experience around implementing LID among engineers. Universities are only recently implementing LID into coursework. The DWQ guide is an attempt to mitigate this weakness. | ▪ Provide trainings through continuing education and conferences. [TASK]<br>▪ Collaborate and emphasize LID and green infrastructure education at universities. [TASK] |
| **Reporting** | ▪ UPDES permittees collect and review information on projects which develop or redevelop an area greater than 1 acre. The information may also include why LID is infeasible in an area, including reasons such as high groundwater, drinking water source protection areas, soil conditions, slopes, accessibility, excessive costs, or any other justifiable constraint. | ▪ There isn't a standardized practice for permittees to receive information from developers. Rather, it is up to the permittee to record and store this information. | ▪ Study whether a mandated process or local control and flexibility yields better outcomes in developer reporting. [STUDY] |
| **Data Management** | ▪ UPDES permittees maintain an inventory of BMPs that are derived from the reporting mechanism. | ▪ This inventory is not publicly accessible to other stakeholders to help guide decisions or policies. Formats will vary, and the level of engineering analysis varies or may be absent.<br>▪ Permittees may not have complete data, particularly on older infrastructure.<br>▪ Some cities have a policy of not sharing utility information, particularly in GIS format. | ▪ Digitize the inventory and make it centrally accessible by various permittees. [POLICY/TASK] |
| **Modeling** | ▪ Groundwater models can help identify the best points for aquifer recharge, which is a component of LID applicability. | ▪ The goal of modeling is not generally to provide information about appropriate BMPs applicable to an area, but it could provide data about the comparative performance or best locations of LID techniques in Utah.<br>▪ Use of models typically requires expert understanding. | ▪ The SWMM developed by LimnoTech could provide information about the comparative performance of LID techniques in Utah. [STUDY]<br>▪ Develop GIS layers based on the models for ease of use among developers and permittees. [TASK] |
| **Metrics and Thresholds** | ▪ LID is a non-numeric standard from a water quality standpoint. Such a standard may be easier to implement and meet than a quantitative standard.<br>▪ The LID standard is quantitative from the hydrology standpoint, in that the 80th percentile storm should be retained. The standard is clear and transparently published on DWQ's website for a variety of cities. The standard may change which practices are applicable in Utah. | ▪ Meeting the standard may be more of a "check the box" approach rather than selecting the best approach from a water quality or quantity standpoint.<br>▪ Cities may attempt to meet this standard even in situations where LID is not practical due to obstacles such as high groundwater, impermeable soils, and high slopes.<br>▪ The amount of resources a permittee can dedicate will vary. | ▪ The agency should perform internal reviews periodically on the outcomes and effectiveness of the standards as written. [STUDY] |
| **Research** | ▪ DWQ has a published *A Guide to Low Impact Development within Utah* (Michael Baker International 2020).<br>▪ LimnoTech has conducted a literature review, funded by H.B. 429, on the variety and efficacy of LID stormwater techniques in arid or semiarid regions.<br>▪ Universities conduct research into LID, particularly USU and UU. | ▪ This DWQ resource may not capture the full variety of techniques used, or lack information on the efficacy specific to Utah.<br>▪ The LimnoTech literature review is not yet published.<br>▪ There is a general lack of knowledge and experience in the local engineering community related to designing cost effective LID infrastructure.<br>▪ Local monitoring data are not required or funded. | ▪ Update the guide regularly from published research, particularly from the recent LimnoT ech literature review. [STUDY] |

Notes:

BMP = best management practice
DWQ = Utah Division of Water Quality
GIS = geographic information system
H.B. = House Bill
LID = low-impact development
MS4 = municipal separate storm sewer system
SWMM = Storm Water Management Model
UPDES = Utah Pollutant Discharge Elimination System
USU = Utah State University
UU = University of Utah

**Table 3-2. How Do Low-Impact Development Best Management Practices or Tools Impact Our Hydrology?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ USGS NWIS data are available online and have been consistently collected for many years (USGS n.d.b).<br>▪ The WRi has some streamflow data available online.<br>▪ Salt Lake County tracks streamflow and data are available online.<br>▪ The USGS and WRi publish groundwater pumpage data for most populated valleys in Utah.<br>▪ Agencies within Utah track land use, land-related water use, and development status. | ▪ The USGS river gaging network does not currently include metering at GSL inflow locations on the Jordan, Weber, and Bear Rivers. "Lowest" gage points include 17th South, Plain City, and Corinne.<br>▪ Stormwater flow, volume, and quality data are often not tracked in any way. | ▪ Installation of USGS gages at GSL inflow points on the Jordan, Weber, and Bear Rivers are recommended. [TASK]<br>▪ Providing incentives for tracking stormwater flows and quality in major trunklines. [POLICY] |
| **Data Storage** | ▪ Most hydrology data are available online. | ▪ There are differences between different platforms and in the time scale of data available. | ▪ Create a centralized repository of all available data. [TASK] |
| **Modeling** | ▪ The SWMM developed by LimnoTech incorporates LID into the surface hydrology.<br>▪ Groundwater MODFLOW models are developed by the USGS and perform excellently in predicting differences in groundwater flow between various scenarios.<br>▪ The USGS is currently developing a regional groundwater flow model to more accurately quantify groundwater flow to the GSL. | ▪ This SWMM is limited to four counties (Utah, Salt Lake, Weber, Davis).<br>▪ The groundwater models have some spatial gaps, particularly in more rural areas of the state.<br>▪ The groundwater models were created at different times by different people, so the terminology and exact use of parameters within the models can vary and require expert understanding. Editing groundwater models can also be time-intensive.<br>▪ Some groundwater models may be more outdated than others.<br>▪ The USGS regional groundwater model in development has a grid size larger than the other USGS groundwater models. | ▪ The SWMM hydrology results will be unitized by area for better application to other regions of the state. [STUDY]<br>▪ In coordination with the water supply gap analysis, generally update and expand groundwater models and refine grids. [STUDY] |
| **Metrics and Thresholds** | ▪ The LID standard is to retain the 80th percentile storm depth onsite, which means that most precipitation does not reach a surface water body. It is possible to calculate the theoretical volumes retained or runoff for a given year and given impervious area. The standard closely mimics predevelopment hydrology in terms of the volumes infiltrated versus runoff volumes. | ▪ Uncertainty in variables such as the percentage of infiltration becoming effective recharge versus ET creates a challenge in defining precisely how the standard impacts hydrology. | ▪ Continued study and calibration of groundwater models specifically in areas where development is actively occurring. [STUDY] |
| **Research** | ▪ The state funded and is carrying out a study to answer how LID BMPs or tools impact GSL's hydrology.<br>▪ The USGS has studied and published groundwater data for most major, populated valleys within the GSL Basin. The link between increased groundwater pumpage and decreased environmental discharges is well known.<br>▪ UU studied the effects of LID in the Salt Lake Area on Jordan River flows (York et al. 2015). | ▪ Like all studies, LID studies on the GSL water balance are subject to specific assumptions.<br>▪ Groundwater flow is very difficult to measure and relies mostly on estimates and modeling. The exact relationship between increased aquifer pumpage, decreased aquifer pressure, and decreased environmental discharge is difficult to quantify.<br>▪ As studies age, so too does the accuracy of the results as conditions change. | ▪ Continue to fund research and update reports on a rolling basis. [POLICY] |
| **Resource Management** | ▪ The LID standards promote the use of stormwater in environmentally beneficial ways, such as increased recharge to the aquifers.<br>▪ These standards improve the water quality of streams and lakes. | ▪ Improper use of LID BMPs may result in ponding of water which is lost to evaporation and serves no beneficial use to water resources (such as recharging aquifers), although improved water quality in streams and lakes is still preserved. | ▪ Discourage the use of BMPs that do not promote effective infiltration, such as grass lined swales with no outlet. [POLICY]<br>▪ Discourage requiring grass lined swales to reduce ET demands within city standards. [POLICY]<br>▪ Specify areas where LID is unlikely to benefit aquifers and recommend alternative stormwater management practices in these areas. [STUDY/POLICY] |

Notes:

BMP = best management practice
WRi = Utah Division of Water Rights
ET = evapotranspiration
GSL = Great Salt Lake
LID = low-impact development
NWIS = National Water Information System
SWMM = Storm Water Management Model
USGS = U.S. Geological Survey
UU = University of Utah

**Table 3-3. What Stormwater Management Strategies Should Be Used to Benefit the Water Budget of Great Salt Lake?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Research** | ▪ The results of research and studies, particularly those funded by H.B. 429, will help inform stormwater management strategies. These include a literature review, bibliography, and a new study on the reasonable future development of GSL with and without LID. | ▪ Most of the H.B. 429 studies will not be published until at least November 2023.<br>▪ Results are subject to interpretation, which may lead to an incorrect understanding or application of data.<br>▪ The results are general and may not apply to particular situations. | ▪ Messaging and fact sheets should be produced to clearly and consistently interpret the results. [TASK] |
| **Resource Management** | ▪ Developers are generally responsible for cost and construction of LID BMPs. | ▪ The costs of LID BMPs versus regional stormwater treatment solutions are not well known. | ▪ Develop master plan level cost estimates for implementing LID and regional infrastructure and cost/benefit analyses. [STUDY] |

Notes:

BMP = best management practice
GSL = Great Salt Lake
H.B. = House Bill
LID = low-impact development

## 3.2 Building Block Technical Questions

*How do we ensure a resilient water supply for GSL and all uses in its watershed?*

- What is the impact of LID BMPs on the water budget of Great Salt Lake?
  - What LID BMPs or tools are applicable in Utah?
    - What LID BMPs are available?
    - What stormwater management strategies are currently being used in the GSL watershed?
    - What LID BMPs are currently being used in Utah?
    - How might LID BMPs be used in the future?
  - How do LID BMPs or tools impact our hydrology?
    - What is the hydrology within the GSL watershed?
    - What are the effects of LID BMPs on evaporation?
    - What are the relative impacts of LID BMPs upon surface water hydrology?
    - What are the relative impacts of LID BMPs upon groundwater hydrology?
    - What is the impact of LID BMPs upon inflows to Great Salt Lake?
  - What impact do various stormwater management strategies have on the water budget of Great Salt Lake?
    - What are the pros and cons of using LID BMPs in the watershed?
    - What guidance can be provided?
    - What are the costs vs benefits?

# 4. Water Demand Gap Analysis

This section outlines the results of the gap analysis completed for the water demand building block of the GSLBIP. The results of this gap analysis will inform the Work Plan for the GSLBIP.

## 4.1 Tier 3 Technical Questions

The water demand gap analysis was framed around answering the following Tier 3 water demand questions (refer to Figures 1-3 and 4-1):

- What are the current demands (Table 4-1)?
- How can we adapt water demands (Table 4-2)?
- Can water demands be met with forecasted supplies (Table 4-3)?
- What are our future demands (Table 4-4)?
- How much have and will demands change over time (Table 4-5)?

The complete list of water demand technical questions can be found in Section 4.2.

**Figure 4-1. Tier 3 Questions for the Water Demand Gap Analysis**

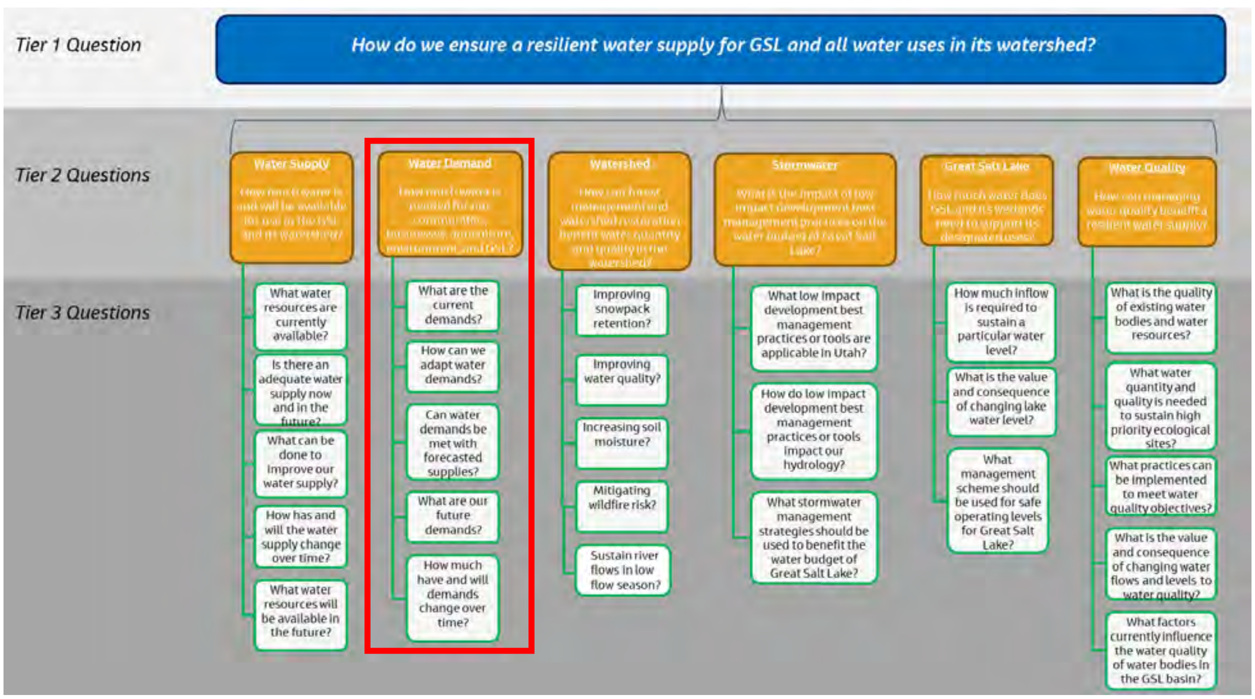


**Table 4-1. What are Current Demands?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Water use is generally measured at the point of diversion. Utah Code 73-5-4 requires water users within the state to install and maintain controlling works and a measuring device.<br>▪ Public water suppliers are required to collect and submit data on water use to the State. Accuracy of agricultural water use data has improved.<br>▪ The Utah Governor's Office supports investments in agricultural infrastructure including irrigation system metering and data storage and dissemination (Utah Governor's Office of Planning & Budget et al. 2022).<br>▪ Secondary meters are mandated to be installed by 2030.<br>▪ The Utah Governor's Office supports the expansion of secondary metering (Utah Governor's Office of Planning & Budget et al. 2022). | ▪ Water demand measurement gaps exist, particularly on small users, environmental/wildlife use, and some commercial users.<br>- Groundwater demands such as private wells and water right exchange contracts (WRBWBTG 2023)<br>- Jordan River canals diversions (ULBWBTG 2023)<br>- Mineral extraction demands are not well characterized.<br>- Oil production water demands are not well characterized; no water right or monitoring is attached to the process.<br>- WMA demands are not well understood.<br>▪ Agricultural water use is not always directly measured, and the data are less certain and less accessible than for municipal and industrial uses.<br>▪ Secondary water metering still lags, and alternative methods to measure irrigation have not scaled up (Capener et al. 2023).<br>▪ Secondary water metering may ultimately increase depletion upstream of the GSL. | ▪ Complete metering and gaging gap analysis currently in process by USU. Identify follow-on study activities. [TASK]<br>▪ Develop prioritized list of measurement installations/improvements, implement improvements. [TASK]<br>▪ Recommend evaluating gaps in canal diversion metering infrastructure on the Jordan River. [TASK]<br>▪ Recommend GSLBIP project team discuss opportunities for quantifying industrial water demands with state agencies. [TASK]<br>▪ Recommend installation of in-stream flow meters above and below waterfowl management areas and evaporative loss instrumentation to quantify management area demands. [TASK]<br>▪ Study consumptive use of industrial water. [STUDY]<br>▪ Continue to promote (enforce where applicable) point of diversion and point of use metering. [POLICY]<br>▪ Continue to refine remote sensed based methods (such as OpenET) for quantifying ET to support improved depletion quantification methods. [PROGRAM SUPPORT]<br>▪ Establish recommended methods for quantifying depletion (Wilson Water Group 2022). [TASK]<br>- Complete case studies as needed to validate and differentiate between methods. [STUDY]<br>▪ Continue funding secondary metering. [PROGRAM SUPPORT]<br>▪ Explore alternative methods, including remote sensing, for measuring irrigation. [STUDY]<br>▪ Continue to emphasize landscape modification after secondary water metering is fully implemented. [PROGRAM SUPPORT]. |
| **Reporting** | ▪ Accountability for municipal and industrial water use reporting is strong.<br>- Statutes exist for this purpose, and WRi and WRe oversee the data collection.<br>▪ Accuracy of municipal, industrial, and private water use data has improved. WRi and WRe have followed legislative and technical recommendations to improve data quality. Potable water data is very accurate and secondary water data is improving.<br>▪ Utah state-specific ET data and open-water evaporation data are compiled across the entire state. | ▪ Opportunity exists to provide data in a format that promotes public awareness (join demands to PWS boundaries in geographic information system). Increasing public awareness may promote conservation activities (utilities have had success presenting customer consumption versus neighbors).<br>▪ Current M&I water use reporting does not include associated depletions.<br>▪ More accurate spatial estimates are in development but are not yet completed, such as GridET and OpenET.<br>▪ The changing climate makes older reports inaccurate for projecting future demands. | ▪ Recommend data transparency and strategies to use data to inform and motivate the public be considered as part of the GSLBIP communication outreach plan. [TASK]<br>▪ Recommend the state provide guidance to PWSs to assist with calculating the associated depletion as part of annual water use reporting requirements (WRBWBTG 2023). [TASK]<br>▪ Quantify water leaks from M&I systems. [STUDY]<br>▪ Coordination across state agencies is recommended to identify and promote next steps in furthering ET quantification science. [TASK]<br>▪ Newer data are necessary to support estimates of ET for water surfaces, wetlands, and natural vegetation. [STUDY] |
| **Data Management** | ▪ Water demand data exist and are maintained by a number of state and federal agencies. | ▪ These data are not centrally located and in some cases can be difficult to locate due to the need to drill down through existing databases. | ▪ A common database for water demand data that is publicly available is recommended to support data accessibility and transparency. [DATABASE DEVELOPMENT]<br>▪ Recommend leveraging the common database to generate water demand visual products and dashboards (hydroinformatics) to inform stakeholders and the public of water demand conditions. [TASK]<br>▪ Recommend expansion of the central database beyond water demand and include water supply, water quality, and other data sets deemed appropriate. [TASK] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Modeling** | ▪ A number of models exist in the GSL watershed which characterize demands. A model matrix has been compiled and is included in GSLBIP Scoping Plan (Jacobs 2023c)<br>▪ WRe's Water Budget Model tracks or estimates surface and groundwater diversion, return flow, consumptive use, yield, and natural system use within Utah and the Bear River Basin for agricultural, municipal, and industrial water uses. (WRe n.d.a) | ▪ Models must be continuously updated with new data and methods.<br>▪ There needs to be an outside review of the WRe Water Budget Model/process to assess its accuracy and whether improvements would be called for. | ▪ Recommend integration of latest M&I demands, including gallons per capita per day using water use method, from PWS water use reports into GSLBIP Water Budget. [TASK]<br>▪ Conduct an outside assessment of the WRe Water Budget Model. [TASK] |
| **Research** | ▪ Utah Governor's Office supports in-stream flow strategies to protect critical habitats (Utah Governor's Office of Planning & Budget et al. 2022). | ▪ Functional flow needs for GSL watershed waterways and associated demands to support healthy fisheries and riparian habitat in the GSL watershed are not well understood. | ▪ Recommend Utah's Division of Wildlife Resources complete the functional flow study, including flow volumes and frequencies for healthy river ecosystems in the Weber River Basin, and apply lessons learned and resulting process to the Jordan and Bear River Basins of the GSL watershed. [STUDY] |
| **Programs** | ▪ Water right policy is shifting to allow more flexibility in water use, water conservation, and avoid the "use it or lose it" mentality.<br>▪ WRe maintains river basin plans for the Jordan, Weber, and Bear river basins (WRe n.d.b). | ▪ Agricultural water users may feel a need to use more water than necessary in order to avoid losing their water rights. Doing so biases the data and misuses water.<br>▪ Opportunities exist to update existing water management plans (JRBWBTG 2023). | ▪ Expand water banking to eliminate "use it or lose it" mentality and encourage voluntary water transactions for the benefit of GSL and other users. [PROGRAM DEVELOPMENT]<br>▪ Continue to shift water law policy to avoid "use it or lose it" mentality. [POLICY]<br>▪ Educate and engage producers and the public to improve understanding of water rights (Utah Governor's Office of Planning & Budget et al. 2022). [PROGRAM DEVELOPMENT]<br>▪ Update existing water use and management plans, such as the Salt Lake canal studies, Salt Lake County Water Management Plan, and the Salt Lake Valley Groundwater Management Plan. [TASK]<br>▪ Fund and assign more personnel to statewide groundwater management plan efforts. [TASK] |

Notes:

WRe = Utah Division of Water Resources
WRi = Utah Division of Water Rights
ET = evapotranspiration
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
M&I = municipal and industrial
PWS = Public Water System
USU = Utah State University
WMA = waterfowl management area

**Table 4-2. How Can We Adapt Water Demands?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Advanced metering infrastructure supports alerts and improved data resolution over past meter technologies, resulting in improved water resource management for users and providers. | ▪ Upgrading infrastructure takes time. | ▪ Educate on the benefits of advanced metering and consider programs to upgrade infrastructure. [PROGRAM DEVELOPMENT] |
| **Reporting** | ▪ Building on its statewide goal since 2000, WRe has set Regional Water Conservation Goals that capture new technologies and opportunities in specific parts of the state. | ▪ Goals were established in 2019 and achievement has not yet been measured. | ▪ A report is forthcoming in 2030. [TASK]<br>▪ Recommend integration of Regional Water Conservation Goals into GSLBIP Water Budget. [TASK] |
| **Modeling** | ▪ As mentioned in Table 4-1, statewide water models characterize water demands.<br>▪ Utah's reservoirs store water for use at all times of the year.<br>▪ River models can calculate evaporative demand from reservoirs. | ▪ There is a lack of understanding regarding how water right distribution may affect future adaptations in water demand (BRBWBTG 2023).<br>▪ There is limited exploration of how altering reservoir management strategies may impact evaporative demands. | ▪ Water right distribution rules are recommended to be investigated either within the GSLBIP Water Budget or through scenario evaluation outside of the water budget to help inform the impact water right distribution may have on future water use adaptations. [TASK]<br>▪ It is recommended that reservoir management agencies review operational strategies and resulting evaporative demands from reservoirs to identify the range in demands and how their operational decisions affect these demands. [STUDY] |
| **Metrics and Thresholds** | ▪ Some water suppliers have drought contingency plans or water shortage plans. The plans can trigger immediate, short-term water demand reductions in cases of emergencies. | ▪ The plans are effective in the short term but are not intended for long-term water sustainability. | ▪ Recommend water suppliers complete drought contingency plans if they have not done so already. [TASK]<br>▪ Develop a drought contingency plan for the GSL Basin. [STUDY] |
| **Programs** | ▪ Public water suppliers are required to have water conservation plan (*Utah Code* 73-10-32).<br>▪ Tiered rates are required for drinking water service.<br>▪ Utah has landscape conversion programs.<br>▪ Smart irrigation controllers remove the guesswork from sprinkler system operation and improve irrigation efficiency. Nathan Lunstad (DDW) and Rob Sowby (BYU) have a forthcoming paper.<br>▪ Rebates are available for water-efficient plumbing fixtures (Utah Water Savers). | ▪ Plans vary widely in scope, attitude, and effectiveness.<br>▪ Obstacles to public water suppliers implementing plans include lack of funding at the town/city level, lack of personnel at the town/city level, and immediate pressing needs taking precedence over long term planning.<br>▪ For some suppliers, the tiers are not very steep compared to other western states, calling into question how effective they are at motivating efficient use.<br>▪ Tiered rates are not required for secondary water service.<br>▪ Other options, such as volumetric allotments, may also be effective.<br>▪ The landscape conversion programs are expensive and are less accessible to smaller water suppliers. Performance is not well documented.<br>▪ Smart irrigation controllers are expensive and underused.<br>▪ Many models are available, and some are better than others.<br>▪ Anecdotally, some controllers do not adjust for weather well. There may be large differences in the quality of forecasting and data collection based on the model and brand of controller.<br>▪ How Utah incentivizes and rewards water savings has not been well documented. | ▪ Recommend water suppliers improve coupling of water conservation goals with other efforts such as land use authority coordination, water efficiency plans, and future water supply planning. [TASK]<br>▪ Consider what resources the State can offer public water suppliers to complete and implement water conservation plans. [TASK].<br>▪ Consider more innovative rate structures that combine tiered rates and allotments based on water supply conditions (Sowby and South 2023). [PROGRAM DEVELOPMENT]<br>▪ Recommend the state consider funding a study to characterize the performance of landscape conversion programs, identify where these programs are being used, and develop a strategy for improving public outreach and program availability. [STUDY]<br>▪ Collaborate with private smart irrigation controller companies to understand how they forecast weather, calculate ET, and deliver water. [TASK]<br>▪ Recommend investigating current incentives for water savings, their historical impact on water demand, and what other methods should be considered in the future (JRBWBTG 2023). [STUDY]<br>▪ Recommend investigating methods for rewarding water savings (JRBWBTG 2023). [STUDY]<br>▪ Promote rational underirrigation or turf removal. [PROGRAM SUPPORT] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Programs continued** | ▪ Water suppliers are working to control water loss.<br>▪ Utah's Governor's Office supports assisting local governments with the development of plans, ordinances, policies, regulations, and programs to link land use and water planning.<br>▪ Awareness of invasive species is growing nationwide.<br>▪ Groundwater recharge programs have a framework administered by the Division of Water Rights. Such programs may reduce evaporative losses from aboveground reservoirs and prevent consequences of aquifer depletion, such as land subsidence.<br>▪ Collaboration on water resources is increasing in Utah, as evidenced by recent legislation and public interest.<br>▪ The Bear River Compact was enacted by Congress in 1958 and amended in 1980.<br>▪ Utah's Legislature invested $200 million into agricultural water optimization programs in 2023.<br>▪ Utah's Governor's Office supports investments in agricultural infrastructure, including water optimization program projects, irrigation system automation, metering, and data storage and dissemination (Utah Governor's Office of Planning & Budget et al. 2022). | ▪ Aging infrastructure makes it difficult to keep up.<br>▪ The default residential landscape choice in Utah is turf, perhaps as a cultural expectation.<br>▪ Land use planning varies by city, making widespread reductions in nonfunctional irrigated areas difficult to achieve.<br>▪ Landscape ordinances do not always address water efficiency in new construction.<br>▪ Water districts and state agencies have no local land use authority to influence water decisions.<br>▪ Invasive species consume water that would otherwise go to GSL and other uses.<br>▪ ASR is in the very early stages in Utah, which brings specific challenges, including financial issues. ASR also changes the evaporative pathways of water, decreasing evaporation from reservoirs but also increasing ET from groundwater.<br>▪ There is currently no approved method for recharging treated wastewater effluent.<br>▪ Collaboration can be a voluntary effort and often requires a supervising agency.<br>▪ These investments will take time to realize the benefits. | ▪ Recommend state agencies consider providing support to PWSs to complete an annual water loss audit using American Water Works Association's free Water Audit Software. **[PROGRAM DEVELOPMENT]**<br>▪ Alignment between landscape design and conservation goals is recommended. Conservancy Districts and PWSs should consider promoting landscaping designs that meet their goals and provide resources for rate payers, such as a list of landscape contractors who support water-wise installations, recommended lists of drought-tolerant plants, and local suppliers that stock species listed. **[PROGRAM DEVELOPMENT]**<br>▪ Water suppliers should adopt water efficiency standards from water districts (Utah Governor's Office of Planning & Budget et al. 2022). **[PROGRAM DEVELOPMENT]**<br>▪ Water suppliers should work collaboratively with their local land use authority to reach water efficiency goals. Integration of water use and land use planning is required of most municipalities and all counties per *Utah Code* 10-9a-403 and 17-27a-401, respectively. **[PROGRAM DEVELOPMENT]**<br>▪ Maintenance of canals, rivers, and wetlands is recommended to control invasive species. **[PROGRAM DEVELOPMENT]**<br>▪ Technical stakeholders expressed interest in the viability of ASR programs and the benefits they may bring (JRBWBTG 2023). **[STUDY]**<br>▪ Study how ASR affects GSL. **[STUDY]**<br>▪ Study if recharging treated wastewater effluent is viable. **[STUDY]**<br>▪ Technical stakeholders expressed interest in the viability of conjunctive management programs and the benefits they may bring (JRBWBTG 2023). **[STUDY]**<br>▪ An analysis of future demand adaptation strategies in the Bear River Basin is recommended to clearly define what is possible considering constraints caused by an interstate river. **[STUDY]**<br>▪ Track and quantify the benefits of agricultural water optimization programs. **[STUDY]** |

Notes:

ASR = aquifer storage and recovery
BYU = Brigham Young University
DDW = Division of Drinking Water
WRe = Utah Division of Water Resources
ET = evapotranspiration
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
PWS = Public Water System

**Table 4-3. Can Water Demands Be Met with Forecasted Supplies?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ The Water Supply Gap Analysis Table 4-1 provides information about the strengths, gaps/weaknesses, and proposed areas of capacity development of current water supply programs and resources. These resources provide the supply forecast side of the data to answer this Tier 3 question. Likewise, the resources in Table 4-1 help answer the demand side of this Tier 3 question. | ▪ Refer to Water Supply Gap Analysis Table 4-1 for information on water supply and Table 4-1 for information on water demands. | ▪ Refer to Water Supply Gap Analysis Table 4-1 for information on water supply and Table 4-1 for information on water demands. |
| **Reporting** | ▪ The State has minimum sizing requirements for drinking water system demand that is a component of reporting. | ▪ Utah does not have the same level of accountability for water supply planning as it does for water demand reporting ("Reliable Water Supply: What Does it Mean?"). | ▪ A forthcoming study will provide recommendations on water policy for supply ("Reliable Water Supply: What Does it Mean?"). Continue to work with the authors to refine and implement the recommendations. [TASK] |
| **Modeling** | ▪ Utah public water suppliers have a strong culture of master planning, which is usually based on modeling and projection of future population, land use, and water use figures. | ▪ Uncertainty exists in future M&I demands and wastewater reuse, which leads to uncertainty regarding the sufficiency of future supplies.<br>▪ Growth without limits will outpace the water supply no matter what the supply is. There are few legal ways to restrict growth. Community planners may have conflicts of interest or lack expertise and technical understanding to fully address growth impacts.<br>▪ Many communities struggle to develop methodologies to forecast future water use for higher-density and more modern types of development. | ▪ It is recommended that water suppliers regularly collaborate with their local land use authority to understand the likely upcoming water demands (areas of growth). Integration of water use and land use planning is required of most municipalities and all counties per *Utah Code* 10-9a-403 and 17-27a-401, respectively. [TASK] |
| **Metrics and Thresholds** | ▪ The State has minimum sizing requirements for drinking water system demand per ERC based on actual water use. | ▪ Utah does not have comparable metrics for supply ("Reliable Water Supply: What Does it Mean?").<br>▪ Determining the link between system-specific sizing requirements and future water demand can be difficult and confusing considering the varying nature of residential and nonresidential uses. Some residential uses require very different amounts of water than others (for example, a studio apartment versus a home on a large lot).<br>▪ An ERC is a unit that varies for each water system.<br>▪ Standard water rights volumes for indoor use typically exceed actual indoor uses. Although some communities use system-specific sizing requirements, others still use standard water rights volumes. | ▪ As stated under reporting, a forthcoming study will provide recommendations on water policy for supply ("Reliable Water Supply: What Does it Mean?"). Continue to work with the authors to refine and implement the recommendations. [TASK] |
| **Programs** | ▪ As stated under modeling, Utah public water suppliers have a strong culture of master planning. Public water suppliers must demonstrate that they meet minimum sizing requirements. | ▪ Public water suppliers often share the same resource (that is, an aquifer) but often do not consider their neighbors or the finite nature of the resource during planning. This may result in an unexpected limit on the water supply side. | ▪ It is recommended that water suppliers regularly collaborate with other local suppliers and wholesalers to discuss future water development strategies and identify areas of overlap. Refer to conjunctive use management in Table 4-2. [STUDY] |

Notes:

ERC = equivalent residential connection
M&I = municipal and industrial

**Table 4-4. What Are Our Future Demands?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Utah has several sources for detailed population projections, including the Governor's Office of Management and Budget, the Kem C. Gardner Policy Institute, and the Mountain Land Association of Governments. | ▪ Any population projection is based on the best available data but is subject to forces which are outside of planners' control, such as global events, social attitudes, and market forces.<br>▪ Communities tend to want to be conservative with future demand projections and to acquire as much water as possible.<br>▪ Water use for a given population can vary widely based on how the population is housed. | ▪ Periodically update projections and consider past projections' match to actual conditions when doing so. [TASK]<br>▪ Combine populations estimates with land use models to determine how future population will be housed. [TASK] |
| **Reporting** | ▪ Reporting of current water use, particularly for public water suppliers, is strong. The online data collection portal has gone through revisions to streamline the data collection process and make it easy for public water suppliers to report their numbers. | ▪ There is no requirement for public water suppliers or municipalities to report their projected buildout populations or water demands.<br>▪ Adding another requirement to the online portal could complicate the process and confuse or frustrate public water suppliers. | ▪ Consider a rule to require reporting of buildout population and/or water demand. If a rule is not feasible, consider a study to voluntarily collect buildout populations and demands from public water suppliers. [POLICY/STUDY] |
| **Modeling** | ▪ A simple land use model, Uplan, has proven useful in the Utah County area. | ▪ These models could be applied statewide. | ▪ Combine populations estimates with land use models to determine how much agricultural land could be converted to M&I use. [TASK] |
| **Research** | ▪ The Utah Governor's Office seeks to determine and quantify the contributions that increased water use efficiencies and conservation can make on future water supplies (Utah Governor's Office of Planning & Budget et al. 2022).<br>▪ The efficiency of water use will increase through conversion of pressurized irrigation and agricultural use to drinking water or wastewater reuse.<br>▪ Climate change is often considered when forecasting future water supplies.<br>▪ Utah public water suppliers have a strong culture of master planning. | ▪ Growing technology industry water demands (for example, data centers, chip manufacturing) are not well characterized.<br>▪ Future agricultural water demands are uncertain and impacts due to a changing climate and land use conversion are unclear.<br>▪ Future environmental water demands and impacts due to a changing climate are unclear.<br>▪ The data from master plans are usually kept at the city level and are not actively shared with neighboring cities or the state. Sometimes multiple cities plan on using the same water source without coordination, particularly groundwater.<br>▪ It can be difficult for PWSs to forecast the effects agriculture to M&I conversions will have on water demands. Additionally, it is unclear how the change in water use will affect groundwater aquifers and return flow through wastewater treatment plants. | ▪ Recommend GSLBIP project team discuss opportunities for quantifying industrial water demands with state agencies. [TASK]<br>▪ Recommend past efforts be reviewed and a new study be initiated as needed to identify the combined impacts efficiency programs will have on future water demands. [STUDY]<br>- Investigate the impact of future changes to state water use regulations. [STUDY]<br>- Investigate the impacts of increased efficiency on depletion upstream of GSL. [STUDY]<br>▪ Study the effects of climate change on agricultural and environmental water demands. [STUDY]<br>▪ Plan to accommodate a wide range of possibilities. [TASK]<br>▪ Recommend GSLBIP project team investigate latest reports on climate change impacts to future water demands and identify recommendations for incorporating data into future water demand projections across water user groups. [STUDY]<br>▪ It is recommended that water suppliers regularly collaborate with other local suppliers and wholesalers to discuss future water development strategies and identify areas of overlap. [STUDY]<br>▪ Recommend the state of Utah fund a working group to develop guidance for PWSs regarding anticipated water demand and return flow impacts resulting from agriculture to M&I conversions. [STUDY]<br>▪ Recommend available future water demand data be reviewed for inclusion/exclusion of the Bear River Development project. How will the completion of this project, or decision not to pursue it, affect statewide water demands? [STUDY] |
| **Programs** | ▪ Thanks to plumbing codes, water conservation, and other factors, per capita municipal and industrial water demands are trending down, both in Utah and throughout the West (Richter 2022). | ▪ There will be a point of diminishing returns. | ▪ Recommend tiered rate structures be implemented by PWSs to encourage water conservation. [PROGRAM DEVELOPMENT]<br>▪ End subsidization of water through property taxes and recommend users pay the true cost of water. [PROGRAM DEVELOPMENT] |

Notes;

GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
M&I = municipal and industrial
PWS = Public Water System

**Table 4-5. How Much Have and Will Demands Change Over Time?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Table 4-1 provides information about the strengths, gaps/weaknesses, and proposed areas of capacity development of current water demand programs and resources. These resources provide the historical demand side of the data to answer much of this Tier 3 question. Likewise, the resources in Table 4-4 help answer the future demand side of this Tier 3 question. | ▪ Refer to Table 4-1 for information on current water demands and Table 4-4 for information on future water demands. | ▪ Refer to Table 4-1 for information on current water demands and Table 4-4 for information on future water demands.<br>▪ Compile the resources into an easy-to-understand report or other format to answer this Tier 3 question. [STUDY] |
| **Reporting** | ▪ As discussed in Tables 4-1 and 4-4, reporting of water use data is overall strong with some areas for improvement.<br>▪ Records have been kept for many years, allowing for trend analysis to be performed. | ▪ Areas for improvement of reporting are identified in Tables 4-1 and 4-4.<br>▪ Previous data may be inaccurate due to limitations in measuring equipment and record keeping, particularly the older the records are. | ▪ It is recommended that existing and future water use reporting data be used to trend changes in total demand and demand per capita day using the state-adopted water use method to identify trends and variables that may be influencing those trends (for example, public outreach related to drought). [STUDY] |
| **Modeling** | ▪ As discussed in Table 4-4, changing climate is often considered in future supply. | ▪ Impacts a changing climate will have on future water demands of all types are not well understood. | ▪ As discussed in Table 4-4, recommend GSLBIP project team investigate latest reports on climate change impacts to future water demands and identify recommendations for incorporating data into future water demand projections across water user groups. [STUDY] |
| **Research** | ▪ As discussed in Table 4-2, Utah's Legislature invested $200 million into agricultural water optimization programs in 2023. Utah's Governor's Office supports investments in agricultural infrastructure, including water optimization program projects, irrigation system automation, metering, and data storage and dissemination (Utah Governor's Office of Planning & Budget et al. 2022). | ▪ The impact agricultural optimization programs have had on agricultural depletion is not well understood. | ▪ A review of agricultural optimization programs is recommended to better understand the impact these programs have had on agricultural water depletion and enable improved prediction of future agricultural depletions. [STUDY] |

Notes:

GSLBIP = Great Salt Lake Basin Integrated Plan

## 4.2 Building Block Technical Questions

*How do we ensure a resilient water supply for GSL and all uses in its watershed?*

- How much water is needed for our communities, businesses, agriculture, environment and Great Salt Lake?
  - What are our current water demands?
    - How are water demands managed in each sector and at each scale?
    - How do we characterize the current population and land use?
    - What are our current municipal water demands?
    - What are our current industrial water demands?
    - What are our current agricultural water demands?
    - What are the current water demands of environment (that is, riparian and wetland areas)?
    - What are the current water demands of Great Salt Lake?
  - How much have and will water demands change over time?
    - What have been and will be the long-term trends in population and land use?
    - How has and will climate change influence water demands?
    - What other factors have and will influence seasonal and decadal water demands (such as changes in evapotranspiration (ET), land use change, policy)?
    - What are the critical elements that would enable more accurate predictions?
    - What are the key variability drivers?
  - What are our future water demands?
    - What are our future municipal water demands?
    - What are our future industrial water demands?
    - What are our future agricultural water demands?
    - What are the future water demands of environment (that is, riparian and wetland areas)?
    - What are the future water demands of Great Salt Lake?
    - Is there a risk for an increase in water demand? Now? And in the future?
  - Can water demands be met with forecasted supplies?
    - Who evaluates this? How, where? How is the information used?
    - What are the impacts of water demands?
  - How can we adapt water demands?
    - What immediate enablers are needed to support water demand quantification activities?
    - What BMPs could be implemented to reduce human water demands?
    - What data and management resources are needed to evaluate actions?
    - What are the costs of changes?
    - What are the opportunity costs?

# 5. Water Quality Gap Analysis

This section outlines the results of the gap analysis completed for the water quality building block of the GSLBIP. The results of this gap analysis will inform the Work Plan for the GSLBIP.

## 5.1 Tier 3 Technical Questions

The water quality gap analysis was framed around answering the following Tier 3 water quality questions (refer to Figures 1-3 and 5-1):

- What is the quality of existing waterbodies and water resources (Table 5-1)?
- What quantity and quality is needed to sustain "high priority ecological sites" (per H.B. 429) (Table 5-2)?
- What factors currently influence the water quality of water bodies in the GSL Basin (Table 5-3)?
- What BMPs can be implemented to meet water quality objectives (Table 5-4)?
- What is the value and consequence of changing water flows and levels to water quality (Table 5-5)?

The complete list of water quality technical questions can be found in Section 5.2.

**Figure 5-1. Tier 3 Questions for the Water Quality Gap Analysis**

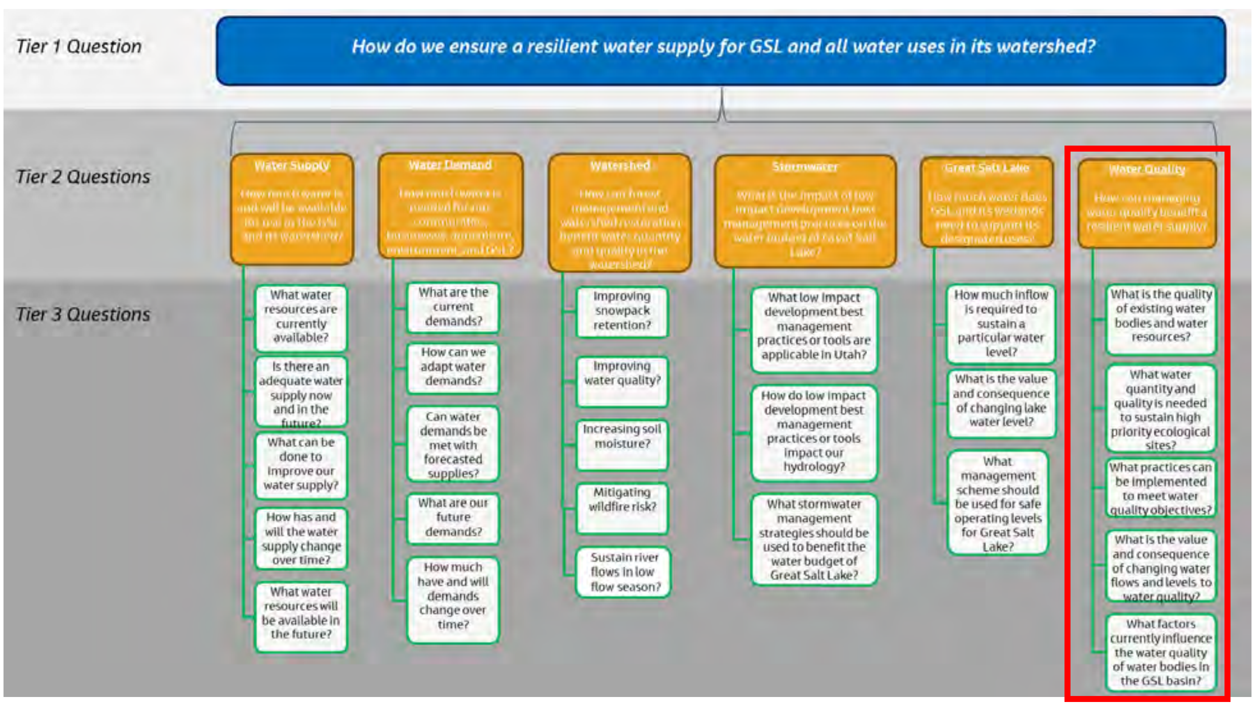


**Table 5-1. What is the Existing Quality of Water Bodies and Water Resources?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ DWQ's *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) provides a roadmap for management of GSL and balanced decision making on issues affecting the Lake. DWQ is currently revising this document with an expected completion date of 2023. This revision will reflect additional areas of program development, including criteria development, monitoring, including program specific data gaps and needs. In addition, DWQ hope to reflect and support the goals and objectives of the GSLBIP in the strategy.<br>▪ USGS has an extensive water chemistry and discharge monitoring program throughout the GSL Basin. Funded in conjunction with DWQ and FFSL, the USGS also maintains water quality sondes on select waterbodies in the GSL Basin that continuously record select parameters on a high-frequency basis.<br>▪ DWQ has an extensive statewide monitoring program that revolves between basins. DWQ collects biological, physical, and chemical data to meet the objectives of the Clean Water Act. DWQ's *Elements to Utah's Monitoring and Assessment Program, 2020-2030* (DWQ 2020) outlines DWQ's statewide monitoring strategy. Additionally, DWQ funds and manages a Cooperative Monitoring Program that expands DWQ's monitoring capabilities by leveraging agency partner resources. There are many satellite monitoring programs that operate in the Basin and many in conjunction with DWQ.<br>▪ DWQ maintains a *Quality Assurance Program Plan for Environmental Data Collection from Ambient Waters* for statewide monitoring efforts (DWQ 2023).<br>▪ DWQ's GSL Monitoring Program establishes standardized sampling and analytical methods to be used on GSL.<br>▪ The DWQ/USGS *Quality Assurance Project Plan for the Great Salt Lake Baseline Sampling Plan* (DWQ 2014a) for GSL provides an excellent example of a collaborative and organized approach to data collection.<br>▪ The DWQ/USGS *Workplan for Ongoing Monitoring of Great Salt Lake Water Quality to Inform Management of the New Breach* was developed and funded in conjunction with FFSL in 2022 (DWQ 2022) to support ongoing discussions with the GSLSAC.<br>▪ GSLSAC developed standard operating procedures for measuring water density and calculating the salinity of GSL waters (GSLSAC 2020)<br>▪ Trout Unlimited and others manages high-frequency data loggers throughout the state. Most common parameters being collected from high-frequency data loggers is temperature, followed by specific conductance, dissolved oxygen, and pH. Trout Unlimited data are available on DWQ's Utah High Frequency Data Dashboard.<br>▪ UGS funds and manages a statewide wetland monitoring program.<br>▪ Municipal water providers perform routine monitoring on high quality waters that could provide important planning and benchmark information for the GSLBIP.<br>▪ The dataset associated with the iUtah project can be used to explore how factors such as population growth, climatic variability, land use change, and human behavior affect the sustainability of water resources. | ▪ Shared, GSL Basin-specific water quality sampling objectives have not been defined outside of the DWQ/USGS *Quality Assurance Project Plan for the Great Salt Lake Baseline Sampling Plan* (DWQ 2014a). Most water quality samples in the Basin are collected in support of a variety of different monitoring objectives, depending on the scope and goal of the project and/or program initiating the sampling.<br>▪ A broader plan and purpose is needed to form a complete understanding of the data gaps (temporal and spatial) that pertain to water chemistry data in the GSL Basin.<br>▪ With the exception of additional monitoring afforded to headwater streams (Category 1 waters), modelling (Utah Lake and Watershed) and wasteload allocations, traditional monitoring programs are not typically oriented to forecasting water quality conditions or identifying trends. A majority of DWQ's monitoring is more focused on identifying and resolving water quality impairments.<br>▪ With some exceptions where annual monitoring is routinely performed, DWQ collects water quality grab samples based on a 6-year rotating basin schedule, which is inadequate to fully assess water quality, since it misses inter-annual variability (dry vs. wet year) and important sites and constituents. In addition, trend analysis is not feasible without routine data collection at long-term sentinel sites.<br>▪ Capacity and capability by laboratories for the analysis of GSL water quality chemistry and biota is extremely limited and relies upon a small set of out-of-state labs and analysts.<br>▪ Many existing USGS gages are not equipped to measure water quality attributes such as temperature and dissolved oxygen.. | ▪ As part of the GSLBIP, develop a cooperative GSL Basin Water Quality Sampling Plan [PROGRAM DEVELOPMENT]. The following sub-bullets would all be accomplished under the umbrella GSL Basin Water Quality Program:<br>- Define GSL (and GSL Basin) water quality goals. Shared goals provide a baseline against which to measure current conditions, future trends, and data gaps. For example, water quality goals may consist of a certain level of beneficial use attainment in the GSL Basin, fishable/swimmable goals, or other important thresholds defined for GSL and the watershed. Not all waterbodies have numeric criteria, so establishing other thresholds will be important. [TASK]<br>- Conduct a water quality data gap analysis. An outcome of the study would be the identification of temporal and spatial gaps that need to be filled to evaluate current conditions as they compare to water quality goals. [STUDY]<br>- Establish water quality monitoring objectives. Water quality monitoring objectives help ensure that data collected can be used to measure progress against goals. Potential monitoring objectives include: filling data gaps and monitoring trends over time. [TASK]<br>- Define representative monitoring locations and water quality parameters to measure progress on GSL Basin water quality goals. Establish a networks of sentinel sites that are monitored on a more frequent basis. [STUDY].<br>- Develop sampling and analysis plan to standardize data collection efforts. Reference the existing DWQ/USGS *Quality Assurance Project Plan for the Great Salt Lake Baseline Sampling Plan* (DWQ 2014a). [TASK]<br>- Expand the GSL DWQ/USGS Sampling Program into the Basin. Continue to integrate other monitoring programs where feasible to improve efficiency and reduce redundancies. For example, leverage DWQ's Cooperative Monitoring Program when considering integration of efforts among other resource management agencies. This Basin-scale monitoring program would coordinate, track, and manage data collected to answer the specific gaps that are continually identified as research progresses. [TASK]<br>- Establish reporting guidelines for the program so that water quality conditions within the GSL Basin can be easily referenced by agency partners and stakeholders. [TASK]<br>- Collaboratively discuss and evaluate laboratory capacity needs, analytical reporting requirements, and limitations. |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Reporting** | ▪ DWQ's biannual Integrated Report contains a summary of the categorical condition of Utah's waters in the context of their designated beneficial uses.<br>▪ UGS recently compiled a groundwater quality database around GSL, and consequently we have a better sense of what groundwater quality data is available and where (Kirby et al. 2019). | ▪ Water quality reporting could be improved by using a statistical approach rather than the current census approach.<br>▪ There is a lack of data and information related to water quality conditions in a large area surrounding GSL corresponding to 'undefined' Assessment Units (DWQ-defined watershed areas). The Integrated Report provides a foundation for assessing waters of the state but there may be unmonitored and unassessed water bodies that play a role in understanding water quality as it relates to the GSL water budget and water quality conditions in the watershed. The lack of surface water quality data represents a gap that could be filled to form a more complete understanding of water quality conditions in the GSLBIP study area.<br>▪ The UGS groundwater quality data compilation effort (Kirby et al. 2019) only pertains to the area in the immediate vicinity of GSL. | ▪ Based on pre-established reporting guidelines (defined by the GSL Basin Monitoring Program) prepare regular GSL Basin water quality reports to the GSL Commissioner with an aim to enable agency partners and stakeholders to easily reference water quality conditions within the GSL Basin. Evaluation of data against defined water quality thresholds as well as long-term trend analysis would be included in the report [TASK]<br>▪ Add current salinity values to the USGS HydroMapper website. |
| **Data Management** | ▪ The USGS HydroMapper is an excellent resource for real-time water data. The interactive map platform is intuitive and easy to use. DWQ has coordinated internally and with USGS to lay the groundwork to get all the baseline data stored in AWQMS included in HydroMapper. Furthermore, all AWQMS data should be accessible and just needs to be funded through USGS to make the connection.<br>▪ DWQ and cooperator water chemistry data and information are housed in the AWQMS database.<br>▪ DWQ's GSL Data Explorer offers interactive, map-based water chemistry results on GSL.<br>▪ USGS NWIS database is extensive and contains historic data for water chemistry and water level data.<br>▪ USGS is now moving toward Aquarius to manage time-series data.<br>▪ DWQ's Utah High Frequency Water Quality Data Dashboard offers an interactive, map-based platform to explore high-frequency data from data loggers that are managed by Trout Unlimited. | ▪ Although both the DWQ database (AWQMS) and USGS database (NWIS) push data to the nation-wide EPA Water Quality Exchange database, these databases do not handle high-frequency data well, which complicates efforts to maintain water quality data at a single location.<br>- USGS is now switching to Aquarius to manage time-series data but it is cost prohibitive for DWQ to switch to this platform.<br>▪ USGS GSL HydroMapper water data dashboard includes the entire GSL Basin, but offers minimal water quality information (water temperature and turbidity).<br>▪ The DWQ GSL monitoring program and DWQ's GSL Data Explorer only pertain to GSL itself and not the GSL Basin. | ▪ A common interface for shared GSLBIP water quality data which is publicly available is recommended to support data accessibility and transparency. One possibility is to leverage the existing USGS HydroMapper platform and link surface water locations to the EPA WQX database that is central to both USGS and DWQ. As part of this study, multiple agencies should be convened to develop a strategy and a plan for managing data that can be readily accessed by multiple agencies. [STUDY]<br>▪ Develop criteria and requirements for a central data repository so that GSL water quality data can be readily accessed by interested stakeholders. Potential criteria include the ability to manage high-frequency data and the ability to present information spatially in an interactive map-based arena. [STUDY]<br>▪ Based on findings of the study, develop a central repository for water quality data so that multiple agencies can access standardized information. [DATABASE DEVELOPMENT]<br>▪ Establish shared GSL Basin water quality data management/data storage protocols if a statewide platform does not exist. [TASK] |
| **Modeling** | ▪ Several water quality models have been developed in the GSL Basin that help evaluate scenarios and/or predict water quality conditions (for example, the Jordan River HSPF model) and the Utah Lake Watershed Model).<br>▪ Refer to GSL Table 2-1 modeling row for discussion of GSL modeling efforts, including salinity modeling and configurations of the Union Pacific bridge berm. | ▪ A water quality model at the GSL Basin scale does not exist. | ▪ Based on the Functional Flow Study, define minimum and functional stream flow volumes that can potentially be included in resource management plans, gage performance against, and test water budget 'what if' scenarios. For more information, refer to Water Supply and Water Demand sections of this report.<br>▪ Help push the DWQ Functional Framework Study forward. The Functional Flows Framework will include: (1) quantification of which hydrologic attributes are most important to GSL and upstream waters, (2) models of the natural flow regime for all streams in the GSL watershed, (3) measures or estimates of existing conditions (4) an evaluation of links between water quality and quantity, and (5) recommendations for using the framework to inform BMPs in the GSL watershed. Task #2 in the Functional Flows Framework will be to develop models of the natural flow regime for all streams in the GSL Basin. DWQ hopes to work with the Division of Water Resources to establish estimates of these natural flow regimes (for example, reference flows) with the long-term aim of evaluating where hydromodification is causing or contributing to stream impairments. Functional flows will also improve the efficiency of hydrologic restoration BMPs through an increased understanding of when, where, and how much water is needed to maximize benefits to GSL or upstream rivers and waterbodies. For more information on DWQ's Functional Flow Framework, please refer to the DWQ Functional Flows Framework section of this memorandum. |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Metrics and Thresholds** | ▪ State of Utah numeric and narrative criteria offer standardized benchmarks for evaluating the quality of existing water bodies and water resources.<br>▪ DWQ has developed only one numeric water quality criteria for the GSL (selenium), but has completed studies to develop acute thresholds for various metals.<br>▪ The GSLSAC has developed a matrix for GSL that describes critical salinity ranges that influence GSL's resources and uses (GSLSAC 2021). | ▪ The hyper-saline environment of GSL presents a challenge in establishing numeric criteria for beneficial use attainment. The GSL has one (tissue-based) criterion for selenium in shorebird eggs, but water quality numeric criteria do not exist. | ▪ Work with DWQ and be kept informed on water quality standards for GSL. A potential area for involvement is to provide collaborative input if/when DWQ updates the *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) where GSL water quality standards are discussed.<br>▪ Update the GSLSAC's salinity matrix to better address avian and brine fly resources of GSL. |
| **Research** | ▪ Many excellent research projects exist that are aimed at better understanding the quality of existing water bodies and water resources. For example, the USGS IWAAs Program, the UGS wetlands program, and Forestry Fire and State Lands Hot Topics Program.<br>▪ The USGS is working on a study to quantify nutrient mass and internal nutrient cycling in GSL.<br>▪ Most of DWQ's research projects and special studies have been directed based on priorities established in the *A Great Salt Lake Water Quality Strategy* (DWQ 2014b), primarily toxics and nutrients. A core component of the *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) is the *Core Component 2: Strategic Monitoring and Research Plan* (DWQ 2014c) which identifies more than 50 important scientific questions for understanding and managing GSL water quality.<br>▪ DWQ has also performed research and special studies in response to permit changes, notably GSL minerals (heavy metals) and Willard Bay (nutrients). | ▪ Although progress has been made, research projects may be pursued in isolation without beneficial coordination with other efforts that potentially shared common goals or objectives. | ▪ Collaboratively develop and implement research and studies aimed at improving understanding of water quality conditions. Example research topics include:<br>- Explore links between water quality and water quantity<br>- Form a better understanding of links between hydrologic modification and water quality goals<br>- Identify the extent and relative risk of pollutants and other stressors to maintain beneficial uses<br>- Build GSL-specific water quality metrics, analytical tools and capacity<br>Specifically, the proposed area of capacity development is to maintain the GSLBIP Database (Jacobs 2023b) that tracks parallel efforts, policies, critical questions, and recommendations to avoid duplication of efforts, and provides transparency on "who is doing what" in the GSL Basin. **[DATABASE DEVELOPMENT]** |

**Notes:**

AWQMS = Ambient Water Quality Monitoring System
BMP = best management practice
DWQ = Utah Division of Water Quality
EPA = U.S. Environmental Protection Agency
FFSL = Division of Forestry, Fire and State Lands
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
GSLSAC = Great Salt Lake Salinity Advisory Committee
HSPF = Hydrologic Simulation Program-FORTRAN
IWAA = Integrated Water Availability Assessment
NWIS = National Water Information System
UGS = Utah Geological Survey
USGS = U.S. Geological Survey

**Table 5-2. What Water Quantity and Quality is Needed to Sustain High Priority Ecological Sites?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ A large body of water quantity and quality data exist. These data can be mined to investigate the critical question: What quantity and quality is needed to sustain high priority ecological sites? | ▪ The term "priority ecological site" has not been defined in the context of the GSLBIP. Priority ecological sites could mean different things to different stakeholders, and could include wetlands, GSL, blue ribbon fisheries, critically impaired waterbodies, headwater streams, drinking water source watersheds, impaired watersheds with a high likelihood of restoration, primary groundwater recharge zones, wildlife management areas, and so forth.<br>▪ Monitoring for water quality, water flows, and water levels may be pursued in isolation among resource management agencies without beneficial coordination with other efforts. | ▪ Per H.B. 429, develop an agreed upon definition of the term, "high priority ecological sites" and establish criteria that can be used to measure conditions and prioritize sites. [DECISION AND/OR POLICY]<br>- Based on this shared definition, evaluate the water quantity/quality data gaps [STUDY].<br>- An outcome of the study would be the identification of temporal and spatial gaps that need to be filled as part of the monitoring program. |
| **Reporting** | ▪ DWQ's biannual Integrated Report contains a summary of the overall condition of Utah's waters in the context of their designated beneficial uses. | ▪ There is a data and information gap related to the acute and chronic impacts of hydromodification on beneficial use attainment. | ▪ While completing the Functional Flow Framework, evaluate where managed flows (hydromodification) may be creating or contributing to water quality impairments with a long-term goal of developing 303(d) assessment methodology. [STUDY] |
| **Data Storage** | ▪ Refer to discussion in Table 5-1. | ▪ Refer to discussion in Table 5-1. | ▪ Refer to discussion in Table 5-1. |
| **Modeling** | ▪ Refer to discussion in Table 5-1. | ▪ Refer to discussion in Table 5-1. | ▪ Refer to discussion in Table 5-1. |
| **Metrics and Thresholds** | ▪ DWQ is working on updating their existing 2016 methodology to prioritize water quality impairments (DWQ 2016). This methodology, to be completed in April 2024, will help inform how resources are allocated for addressing water quality impairments.<br>▪ State of Utah numeric and narrative criteria provide the foundation for water quality assessment and protection of beneficial uses. | ▪ Water quantity requirements to meet designated beneficial uses (for example, minimum in-stream flows) are not defined in Utah Administrative Code.<br>▪ GSL water levels nor water quality criteria (except for selenium) are not defined in conjunction with GSL beneficial use attainment. | ▪ As part of the GSLBIP, engage with DWQ to discuss the forthcoming 303(d) prioritization process. Discuss possibly including specific criteria for prioritization that may be in alignment with GSL Basin watershed and/or water quality goals. Refer to Table 5-1 for discussion on establishing shared GSL Basin water quality goals.<br>▪ Evaluate the feasibility and efficacy of various regulatory tools that "give credit" or incentives to permittees making voluntary efforts to improve or protect water quality in the watershed and not just at the point of discharge. Example include water quality trading, water banking, market-based approaches, integrated planning, and economic/financial incentives. [STUDY]<br>▪ Ongoing investigations are necessary to define target lake level elevations that are supportive of water quality conditions associated with GSL designated beneficial use attainment. [POLICY] |
| **Research** | ▪ DWQ, USGS, UGS, and other resource management agencies have robust programs dedicated to studying ecological systems in the GSL Basin.<br>▪ DWQ, DWR, and USU are in the early stages of developing a Functional Flows Framework. This study is examining not only minimum flow requirements for wildlife, but also the critical timing of flows delivered throughout the year that support aquatic life and water quality.<br>▪ DWR and Weber Basin Water Conservancy District have discussed the potential to modify water delivery on the Weber River and whether it can be altered to maximize the local and downstream conditions for fish or other organisms. For example, using flushing spring events to remove sediment.<br>▪ The relationship between salinity, GSL water level, and beneficial uses is being investigated by the GSLSAC. | ▪ The two major knowledge gaps with regard to wetlands water quantity requirements are: (1) understanding the critical volume and timing of hydroperiods (patterns of flooding and drying over a growing season), and (2) the minimum flooding required before a wetland moves to the degraded status. UGS is working on filling these knowledge gaps. | ▪ Continue to push wetland research forward and help to prioritize research questions that are aimed at allowing resource managers to make more informed decisions. [STUDY]<br>▪ Help push the DWQ Functional Framework Study Forward (refer to discussion in Table 5-1 and in the DWQ Functional Flows Framework section of this memo). [STUDY] |
| **Resource Management** | X | ▪ Water managers do not have operational guidelines for minimum in-stream flows that protect water quality, wildlife, and habitat.<br>▪ Management objectives for impounded wetlands can be in conflict. For example, creating habitat (impoundments) often results in degraded water quality conditions if there is not an adequate water supply to flush water through the impoundments. | ▪ Help push the DWQ Functional Framework Study Forward (refer to discussion in Table 5-1 and in the DWQ Functional Flows Framework section of this memo). [STUDY]<br>▪ Determine minimum and functional stream flow volumes as well as lake-level guidelines for water managers to incorporate into their operational plans. [STUDY] |

Notes:

DWQ = Utah Division of Water Quality
DWR = Utah Division of Wildlife Resources
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
GSLSAC = Great Salt Lake Salinity Advisory Committee
H.B. = House Bill
UGS = Utah Geological Survey
USGS = U.S. Geological Survey
USU = Utah State University

**Table 5-3. What Factors Currently Influence the Water Quality of Water Bodies in the GSL Basin?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ DWQ continually performs water quality monitoring for source identification as part of the TMDL processes or for special studies.<br>▪ As part of DWQ NPS Program, water quality monitoring data are collected to measure how BMP implementation contribute to improved water quality conditions.<br>▪ As part of the UPDES program, permittees are required to provide Discharge Monitoring Reports. | ▪ Monitoring for source identification may be a site-specific activity, and the associated monitoring data could be taken out of context if used to answer other research questions.<br>▪ There is an opportunity to expand the NPS program to ensure that water quality monitoring continues after projects are implemented. | ▪ Refer to discussion in Table 5-1 regarding development of GSL Basin Water Quality Monitoring Program. Continue to integrate monitoring programs to improve efficiency and reduce redundancies. [PROGRAM DEVELOPMENT]<br>▪ Explore strategies, funding pools, and other ways to expand the NPS program. Create incentives for NPS grant recipients to continue monitoring after water quality improvement projects are implemented. Also, select a portion of implementation projects for long-term project efficacy research. [TASK] |
| **Reporting** | ▪ DWQ's biannual Integrated Report contains a summary of the overall condition of Utah's waters in the context of their designated beneficial uses.<br>▪ The pollution sources and factors that influence water quality at impaired waterbodies are evaluated during the TMDL process. A TMDL traditionally evaluates the various factors (for example, land use, pollution sources, hydrology) that influence water quality in the area of concern.<br>▪ **Stormwater:** Annual MS4 stormwater loads may be evaluated as part of the MS4 annual report to DWQ. In addition, MS4s evaluate BMP effectiveness.<br>▪ **Groundwater**: UGS and USGS have robust groundwater sampling programs, and several special studies evaluate how specific land-use practices have impacted groundwater quality (for example, septic system shallow aquifer contamination). | ▪ Within the Integrated Report framework, DWQ does not have formal 303(d) assessment methodology to evaluate which water quality impairments are due to reduced (for example, drought) versus managed flows.<br>▪ TMDLs have not been completed for all impaired waterbodies in the GSL Basin and not all waterbodies in the Basin are assessed for impairments due, in many cases, to insufficient available data.<br>▪ Annual reports from all MS4s in the Basin are not "readily available" in that they are not quickly aggregated or queried.<br>▪ Not all MS4s have the resources and capacity to conduct wet weather monitoring and calculate annual stormwater loading estimates. | ▪ Continue to push the DWQ Functional Flows Framework study forward. [STUDY]<br>▪ Evaluate the possibility of standardized, GSL basin-scale MS4 stormwater quality/quantity reporting to facilitate rapid assessment of existing conditions, make informed decisions about resource allocation, and prioritize filling gaps in understanding about stormwater impacts to GSL and its watershed. [STUDY]<br>▪ Integrate and build upon the H.B. 429 Stormwater Low-Impact Design Study into GSLBIP. Refer to Section 3 Stormwater Gap Analysis for additional information. |
| **Modeling** | ▪ The Jordan River watershed HSPF model and Utah Lake watershed model provides a means of exploring water quality conditions associated with various land uses. | ▪ The scale of the Jordan River watershed HSPF model is limited to immediate Jordan River watershed in the Salt Lake Valley. | ▪ Continue to push the Jordan River HSPF model update forward. The Jordan River HSPF model may require additional resources to calibrate and apply to loading scenarios. [STUDY] |
| **Metrics and Thresholds** | ▪ Good correlation between salinity and lake levels has been established for GSL. | ▪ GSL lake-level and water quality correlations are not well documented for water quality constituents apart from salinity. | ▪ Fund research that enables development of a long-term GSL Salinity Management Plan. For more information, refer to the GSL Building Block Gap Analysis Memorandum. |
| **Research** | ▪ DWQ, the DWR, and USU are in the early stages of developing a Functional Flows Framework. This study is examining not only minimum flow requirements for wildlife, but also the critical timing of flows delivered throughout the year that support aquatic life and water quality.<br>▪ The GSLSAC is investigating the relationship between salinity, lake level, and beneficial uses.<br>▪ **Wetlands**: The UGS wetlands monitoring program is evaluating links between water quality and wetland condition.<br>▪ The Jordan River pulse-flow experiment and the Weber pilot study begin to unpack the question of how the timing of flow delivery impacts water quality. | ▪ Water chemistry in wetlands is complex, and water quality conditions are not a reliable indicator of overall wetland condition. It is not well understood which factors influence water quality in GSL and mountain wetlands.<br>▪ At the GSL Basin-scale, we do not have a strong understanding of how surface water quality affects groundwater quality, and vice versa.<br>▪ At the GSL Basin-scale, we do not have a strong understanding how specific land-use practices and patterns of development impact water quantity and water quality. | ▪ Evaluate the effects of urban development on drinking water source areas and in sensitive watersheds to avoid or mitigate potential negative impacts. [STUDY]<br>▪ Continue to push wetland research forward and help to prioritize research questions that are aimed at allowing resource managers to make more informed decisions. [STUDY] |
| **Resource Management** | ▪ **Drinking water**: Many well-established programs (for example, SLCDPU's watershed protection program, Provo River Watershed Council, Weber River Water Conservancy District) help to ensure high-quality drinking water in several watersheds in the GSL Basin.<br>▪ DWQ's UPDES Program proactively evaluates various factors that influence water quality from point sources and establishes limits to ensure water quality standards are not violated.<br>▪ DWQs Antidegradation program ensures that degradation (pollution) by point sources is minimized and only allowed for socially, environmentally, or economically important reasons.<br>▪ The State Revolving Fund offers significant incentives for municipal wastewater facilities to invest in water quality improvement projects. | ▪ The cause/effect relationship between specific watershed management practices (for example, development practices, forest management practices, and water conveyance systems) and water quality conditions is not well documented.<br>▪ Water quality dischargers permitted under the UPDES program may only treat water to meet permitted limits. Dischargers are not incentivized to go 'above and beyond' what is required in UPDES discharge permit to address other sources of pollution in watershed.<br>▪ Additional information is needed about how the timing of flow affects water quality in specific reaches and throughout the GSL Basin (for example, DWQ's Functional Flows Framework). | ▪ Evaluate the feasibility and efficacy of various regulatory tools to "give credit" or incentives to permittees making voluntary efforts to improve or protect water quality in the watershed, and not just at the point of discharge. For example, water quality trading, water banking, regulatory market based tools, and other incentives for water quality protection. [STUDY]<br>▪ Improvements to the UPDES program could include further refinement of Interim Methods for Evaluating Use Support for GSL as well as GSL species-specific WET testing development.<br>▪ Study the water quality and water quantity effect of reuse on waterbodies within the GSL basin and the potential effect to flows to GSL. Understand the avoided costs of reduced in-stream flows. Evaluate the trade-offs and the associated costs of managing in-stream flows. Incorporate findings into decision support tools for water managers and agencies. [STUDY] |

otes:

BMP = best management practice
DWQ = Utah Division of Water Quality
DWR = Utah Division of Wildlife Resources
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
GSLSAC = Great Salt Lake Salinity Advisory Committee
iH.B. = House Bill
HSPF = Hydrologic Simulation Program-FORTRAN
MS4= municipal separate storm sewer system
NPS = Nonpoint Source
SLCDPU =
TMDL = total maximum daily load
UGS = Utah Geological Survey
UPDES = Utah Pollutant Discharge Elimination System
USGS = U.S. Geological Survey
USU = Utah State University
WET = whole effluent toxicity

**Table 5-4. What Best Management Practices Can Be Implemented to Meet Water Quality Objectives?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Resource Management** | ▪ DWQ's *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) provides a roadmap for management of GSL and balanced decision making on issues affecting the Lake.<br>▪ DNR's WRI Program is robust and extensive work has been done to implement restoration projects in watersheds throughout the state.<br>▪ The Shared Stewardship Program provides a framework for agency coordination and resource management and water providers with regard to forest health priorities and wildfire prevention.<br>▪ DWQ's NPS Program (and the associated body of literature associated with NPS pollution) identifies practices that can be implemented to improve water quality.<br>▪ The NRCS, UDAF, and local conservation districts are critical partners in promoting and implementing NPS pollution prevention practices.<br>▪ MS4s are required to implement stormwater BMPs as part of UPDES permits. The LID Stormwater Rule was adopted to address post-construction runoff quantity. | ▪ DWQ's *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) needs to be updated to reflect current conditions.<br>▪ The WRI Program may not always evaluate long-term efficacy of watershed restoration projects, and specifically, water quality and hydrologic impacts associated with implementation of watershed restoration projects.<br>▪ Water quality may not be a high priority for water managers, and in some cases perhaps might not even be considered unless it is required.<br>▪ NPS Program<br>- The NPS program is a voluntary incentive (grant) program and funds are limited. In some watersheds in the GSL basin there are challenges to voluntary participation, however, funding is the greatest limitation.<br>- Within the NPS Program, implementation of BMPs typically occurs *after* a problem has been identified and not proactively to protect water quality. It remains a challenge to proactively fund BMPs for protection of water resources. In most watersheds, BMP funding becomes available after the waterbody is listed on the 303(d) list of impaired waterbodies.<br>- In many cases, follow-up on monitoring data to evaluate efficacy of NPS projects are lacking.<br>- NPS pollution prevention is voluntary. In many watersheds it is a challenge to get voluntary participation in implementation of BMPs aimed at reducing nonpoint source pollution.<br>▪ The link between forest management BMPs and water quality/water supply is not well understood (refer to the GSLBIP Watershed Building Block Gap Analysis Memorandum) | ▪ Update the 2014 *A Great Salt Lake Water Strategy* (DWQ 2014b) with collaborative input from stakeholders involved in the GSLBIP. **[PLANNING PROJECT]**<br>▪ Evaluate the effects of forest management practices on water quality in specific areas, with an aim of identifying GSL Basin-scale best practices for forest management **[STUDY].** Refer to the GSLBIP Watershed Building Block Gap Analysis Memorandum for more information.<br>▪ Conduct a study to prioritize water quality BMPs in the GSL Basin according to land use and other location-specific factors such as groundwater recharge/discharge areas, and water quality impairment. As part of the study prioritize the various solutions that can potentially meet both water quality and water quantity objectives. Examine if and how implementation of various BMPs could present competing water use/water quality requirements. **[STUDY]** |
| **Metrics and Thresholds** | ▪ State of Utah numeric and narrative criteria offer standardized benchmarks for defining water quality objectives. | ▪ To know what BMPs can be implemented to meet water quality objectives we first need to define the water quality objectives. GSL Basin water quality objectives, apart from beneficial use attainment, have not been defined. Furthermore, not all waterbodies have numeric criteria (for example, numeric criteria largely do not exist for GSL). | ▪ DWQ is currently revising the *A Great Salt Lake Water Quality Strategy* (DWQ 2014b) with an expected completion date of end of 2023. This revision will reflect additional areas of program development, including **criteria development**, monitoring, including program specific data gaps and needs. **[STUDY]**<br>▪ Define GSL (and GSL Basin) water quality objectives. Shared goals provide a baseline against which to measure current conditions, future trends, and data gaps **[GSLBIP PROGRAM DEVELOPMENT].** Refer to discussion in Table 5-1. |
| **Data Management** | ▪ DWQ and the EPA provide excellent resources on stormwater management BMPs. | ▪ A central repository of BMP information aggregated by land use and prioritized according to GSL Basin water quality and quantity objectives does not exist. | ▪ A proposed area of capacity development is to conduct a GSL Basin BMP prioritization study (refer to the recommended study in the "Resource Management" row of this table). A subsequent proposed area of capacity development is to share the results of the study in an online database so that GSL-specific BMP information is available for water users at various levels and for various objectives. **[DATA INFRASTRUCTURE/DATABASE]** |
| **Funding** | ▪ Multiple state and federal funding opportunities exist to implement NPS pollution prevention projects and water quality BMPs throughout the state. | ▪ NPS pollution prevention is voluntary. In many watersheds it is a challenge to get voluntary participation in watershed plans and programs aimed at reducing NPS pollution.<br>▪ The cost requirements of widespread implementation of BMPs to achieve water quality objectives at the GSL Basin scale is not known. Cost requirements include capital, operational, and maintenance costs.<br>▪ Funding and technical resources are not always available for fast growing communities to promote proactive water quality protection in context of fast-paced development. | ▪ Conduct a study aimed at identifying specific barriers that prevent resource managers at various levels (for example, private landowner, municipality, state agency) from implementing BMPs to improve water quality. **[STUDY]**<br>- Based on findings of the study, develop specific strategies and financial incentives for implementation of BMPs that improve water quality and water resource conditions.<br>▪ Provide consistent guidance and funding opportunities to implement stormwater management solutions that promote water quality objectives in the GSL Basin. **[STUDY, FUNDING]**<br>▪ Identify the barriers of widely implementing the known best practices for development and growth that promote proactive water quality protection. **[STUDY]** |
| **Outreach and Education** | ▪ Water quality and water resource topics are more widely covered in the news than ever before. The public is becoming familiar with these issues. | ▪ The public may be experiencing information fatigue. Unified and consistent messaging will become more and more important moving forward. | ▪ Expand upon public education that helps people understand their role in water quality and its consequences. **[PUBLIC OUTREACH CAMPAIGN]** |

Notes:

BMP = best management practice
DNR = Utah Department of Natural Resources
DWQ = Utah Division of Water Quality
EPA = U.S. Environmental Protection Agency
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
LID = low-impact development
NPS = Nonpoint Source
NRCS = Natural Resources Conservation Service
UDAF = Utah Department of Agriculture and Food
UPDES = Utah Pollutant Discharge Elimination System
WRI = Watershed Restoration Initiative

**Table 5-5. What is the Value and Consequence of Changing Water Flows and Levels to Water Quality?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Resource Management** | ▪ Several state water strategy reports outline specific recommendations for integrating water quality and water quantity management. Consequently, the topic has momentum and growing interest amongst regulators and policy makers. For example, the Governor's Water Strategy Advisory Team 2017 recommended state water strategy, *Utah's Coordinated Action Plan for Water* (Utah Governor's Office of Planning & Budget et al. 2022), *Water Strategies for Great Salt Lake, Legal Analysis and Review of Select Water Strategies for Great Salt Lake* (ClydeSnow and Jacobs 2020), and the Great Salt Lake Resolution (HCR-10) Steering Group (2020) *Recommended Actions to Ensure Adequate Flows to Great Salt Lake and Its Wetlands*.<br>▪ The newly formed Utah Watershed Councils provide a platform to discuss the integration of water supply and water quality concerns. | ▪ The consequences of *not* addressing water quality impairments that are caused by managed or reduced flows has not been studied. Similarly, the consequences of not maintaining sufficient water quality and water quantity at "high priority ecological sites" has not been studied.<br>▪ Efforts and studies that examine the water quantity/water quality nexus are limited in the state system. Water quality and water quantity are traditionally siloed in the State system. This is exacerbated by siloed data management systems. | ▪ Establish a mechanism of interfacing with the State Engineer's office in situations where quality is becoming impacted by reduced flows **[POLICY]**<br>▪ Provide guidance to water managers about target water flow volumes, as well as the timing of water flows throughout the year. **[STUDY]**<br>▪ Refer to Table 5-2 for more discussion. |
| **Modeling** | ▪ Several water quality models have been developed for the GSL Basin that help evaluate scenarios and predict conditions (for example, the Jordan River HSPF model and Utah Lake watershed model). These models have capability to evaluate water quality impacts from hydrologic modification of inputs.<br>▪ DWQ is working on a Functional Flow Framework. Functional flows are flow targets developed from an exercise that identifies the most ecologically critical quantities and timing to support and maintain local and downstream aquatic life. | ▪ A single, integrated water budget model for GSL (that integrates water quality) does not exist. | ▪ As part of the GSLBIP, develop a centralized water budget that incorporates water quality. For more information, refer to the modeling discussion under GSLBIP Water Supply and Water Demand gap analysis memorandums.<br>▪ Evaluate financial and other costs of not addressing water quality issues in the watershed and in GSL. **[STUDY]**<br>▪ Continue to advance DWQ's Functional Flow Framework so the results can be integrated into the GSLBIP water budget model. **[STUDY].** The Functional Flow Framework will include: (1) quantification of which hydrologic attributes are most important to GSL and upstream waters, (2) models of the natural flow regime for all streams in the GSL watershed, (3) measures or estimates of existing conditions, (4) an evaluation of links between water quality and quantity, and (5) recommendations for using the framework to inform BMPs in the GSL watershed. |
| **Data Management** | ▪ Extensive datasets exist that describe water quality and water quantity in Utah. | ▪ Water level and water quality data are often siloed in the state system, and monitoring is often pursued in isolation, which complicates the links between water quality and water quantity. | ▪ Refer to discussion in Table 5-1. |
| **Reporting** | ▪ DWQ's biannual Integrated Report contains a summary of the overall condition of Utah's waters in the context of their designated beneficial uses. | ▪ It is not known the extent to which beneficial use impairments can be attributed to human-caused changes to water flows/levels. | ▪ Establish a means of evaluating which designated beneficial uses are not supported by hydromodification (for example, develop a 303(d) assessment methodology for listing and delisting hydrologically modified streams). **[STUDY].** |

Notes:

BMP = best management practice
DWQ = Utah Division of Water Quality
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
HCR = House Concurrent Resolution
HSPF = Hydrologic Simulation Program-FORTRAN

## 5.2 Building Block Technical Questions

*How do we ensure a resilient water supply for GSL and all uses in its watershed?*

- How can managing water quality benefit a resilient water supply?
  - — What is the quality of existing water bodies and water resources?
  - — What programs are being implemented to monitor and assess water quality?
  - — By whom?
    - o Why are they evaluating water quality?
    - o What are their objectives?
    - o What is their funding source?
- Is there an opportunity integrate the efforts and staff to improve efficiency, accuracy and effectiveness of efforts?
- Where are the individual programmatic data housed?
- How is water quality currently assessed, reported, tracked, and evaluated?
  - — Numeric criteria, beneficial uses, and 303(d)/305(b) reporting
- Which water bodies are assessed? Which are not?
  - — Can we assess the water quality of undefined areas surrounding Great Salt Lake?
  - — Either in the context of the integration report or as a special report (not used for 303(d)/305(b) reporting).
- Where are these locations?
  - — Are these locations representative of conditions in the larger assessment unit area?
- What water quality monitoring data do we have and where?
  - — For groundwater?
  - — For surface water?
  - — Do we have the data at the sites we need to characterize water quality coming into the lake?
  - — What are the data gaps?
- Can the HydroMapper be updated…
  - — To show the assessment results of the undefined assessment units in the GSL basin?
  - — Locations of existing water quality monitoring points?
  - — Is there a surrogate parameter that can be used to evaluate water quality across numerous water bodies?
  - — Where are the beneficial use impairments caused by hydrologic modifications?
  - — Should the class 5 beneficial use for Great Salt Lake extend upstream?
  - — If beneficial uses are supported in the watershed, will beneficial uses in GSL be supported?
  - — Do we need to develop a GSL salinity control program? How much salinity do we need to control?
  - — Should the class 5 beneficial uses be associated with a numeric water quality standard for salinity?
- Watershed approach for evaluating water quality
  - — Can we use the U.S. Environmental Protection Agency's (EPA's) Recovery Potential Screening tool to compare watershed condition and restorability?

- EPA's National Assessment (and Utah specific) assessments? NRSA,
  - — What other tools are available ?
- Which tools would be most appropriate for use in the Great Salt Lake watershed?
  - — Could these tools provide additional information beyond the evaluation of beneficial use attainment?
  - — On a watershed scale, can we not only evaluate water quality, but predict water quality? For example, based on extrinsic factors that make a watershed sensitive or vulnerable to water 5-10uality pollution?
- What is the condition of the waters in the GSL watershed?
  - — Can water quality condition be predicted from watershed assessment?
- How are water bodies currently prioritized?
  - — For assessment?
  - — For improvement?
  - — Because they are severely degraded?
  - — Because they have a high potential for restoration?
  - — For protection?
  - — By the critical ecosystem function they support (for example, wetlands), supporting GSL recovery?
  - — Because of critical habitat?
  - — Because of how they are used by the public?
  - — Because of the economic value of protection vs restoration?
- What water quantity and quality is needed to sustain high priority ecological sites?
  - — What is a high priority ecological site?
  - — What criteria are used to define them?
    - o Rivers
    - o Riparian habitat
    - o Wetlands
    - o Lakes
    - o Groundwater? (Groundwater recharge zones?)
  - — What criteria are used to prioritize them?
    - o Rivers
    - o Riparian habitat
    - o Wetlands
    - o Lakes
    - o Groundwater? (Groundwater recharge zones?)
  - — What water quality objectives are used for each? Should be used?
    - o Rivers
    - o Riparian habitat
    - o Wetlands
    - o Lakes
    - o Groundwater? (Groundwater recharge zones?)
  - — What water quantity is required?
    - o Rivers
    - o Riparian habitat

  - o Wetlands
  - o Lakes
  - o Groundwater? (Groundwater recharge zones?)

- Where are the high priority ecological sites in the Great Salt Lake watershed?
  - — What data and mapping do we have?
  - — What is their condition?
  - — How are the high priority ecological sites ranked?
- How much water is required to sustain high priority ecological sites?
- What are the minimum required instream flows to sustain water quality and function?
  - — What methods/tools are being used in other states? What could be appropriate for Utah?
  - — What is the important timing of minimum in-stream flows?
- What are the minimum required flows to sustain water quality in wetlands and function?
- What are the minimum required flows and water levels to sustain water quality in lakes and function?
  - — What role does groundwater seepage to surface springs play in managing in-stream flows?
- What factors currently influence the water quality of water bodies in the Great Salt Lake basin?
  - — What factors currently influence water quality?
  - — How do groundwater inputs affect surface water quality?
  - — How has growth, development, water management, reduced flows impacted water quality?
  - — How does watershed management affect water quality?
- How many of current water quality impairments are influenced by managed or reduced flow?
  - — Can we distinguish between drought influence and water management influence?
    - o What are the trends in water quality?
    - o What are the barriers to improving or protecting water quality?
    - o What are the most vulnerable waters? Most impaired?
    - o How much water is required to sustain water quality in streams, wetlands, and lakes in the watershed?
  - — Or, How will water quality change with fluctuating water flow and levels?
  - — for each water body?
- How does the timing of flow affect water quality? (for example, the Jordan River flow pulse experiment)
- What BMPs can be implemented to meet water quality objectives?
  - — What practices are available to protect and improve water quality?
  - — What practices are currently being implemented to protect and improve water quality?
    - o Where are they being implemented? And by whom?
    - o by basin
  - — What are the costs for these practices?
    - o What are the costs by basin?
    - o What are the costs associated with impairments influenced by managed or reduced flow?
    - o Capital costs, maintenance costs,
  - — Have they been successful?

- Why or why not?

- What should our water quality objectives be?
- What practices should be implemented and where to protect and improve water quality?
- What BMPs could present competing water use and/or water quality interests if implemented?
  - Can flow rates be manipulated to improve water quality?
  - Can the timing of flow rates be manipulated to improve water quality?
- What is the value and consequence of changing water flows and levels to water quality?
  - What investment is required to meet water quality objectives in the watershed?
  - What investment is required to address water quality impairments influenced by managed or reduced flow?
    - What are the consequences of not addressing water quality impairments influenced by managed or reduced flow?
- What investment is required to address the impairment of high priority ecological sites influenced by managed or reduced flow?
  - What are the consequences of not addressing the impairment of high priority ecological sites influenced by managed or reduced flow?
  - What is the value of water provided to offset water quality impairments influenced by water flow or levels?
- How can we integrate water quality into water supply considerations?

# 6. Water Supply Gap Analysis

This section outlines the results of the gap analysis completed for the water supply building block of the GSLBIP. The results of this gap analysis will inform the Work Plan for the GSLBIP.

## 6.1 Tier 3 Technical Questions

The water supply gap analysis was framed around answering the following Tier 3 water supply questions (refer to Figures 1-3 and 6-1):

- What water resources are currently available (Table 6-1)?
- Is there an adequate water supply now and in the future (Table 6-2)?
- What can be done to improve our water supply (Table 6-3)?
- How has and will the water supply change over time (Table 6-4)?
- What water resources will be available in the future (Table 6-5)?

The complete list of water supply technical questions can be found in Section 6.2.

**Figure 6-1. Tier 3 Questions for the Water Supply Gap Analysis**

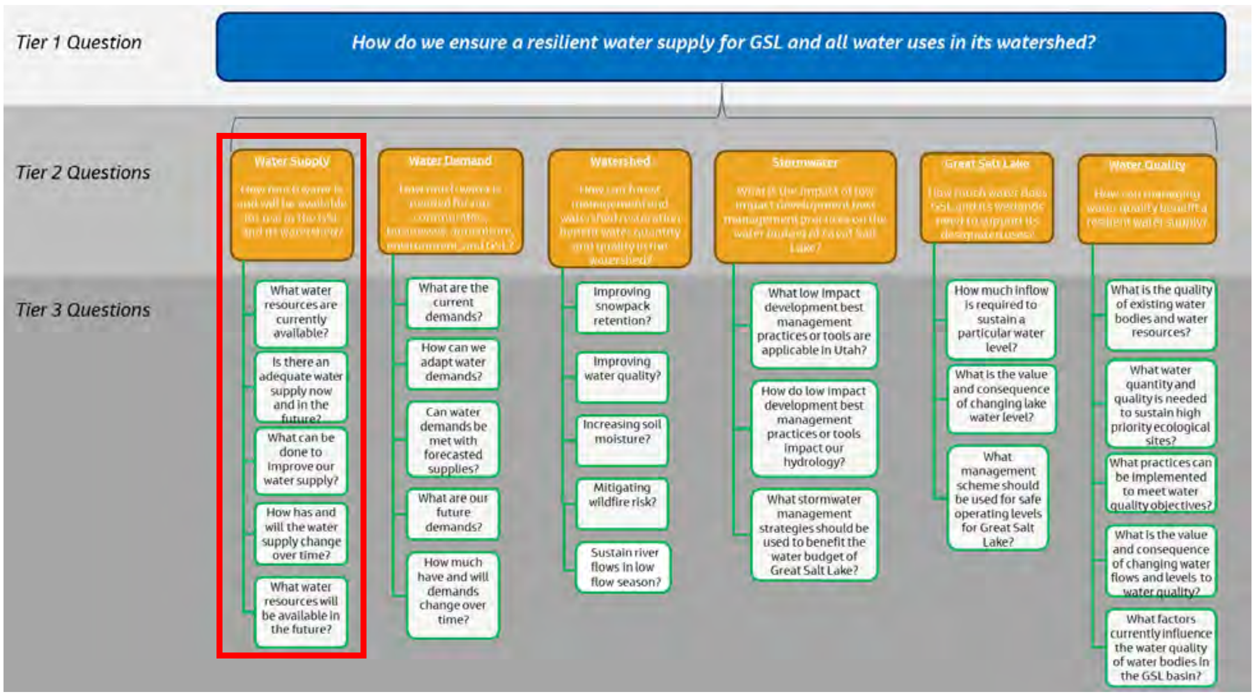


**Table 6-1. What Water Resources are Currently Available?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ USGS's NWIS data are available online and have been consistently collected for many years (USGS n.d.b).<br>▪ WRi supplements the USGS records with many independently-run streamflow sites.<br>▪ Other agencies, such as Salt Lake County Flood Control, also measure streamflow at various points.<br>▪ The NRCS operates SNOTEL and provides streamflow runoff forecasts for major rivers in the basin which are updated monthly in January through June (NRCS n.d.).<br>▪ Regulations around depletion for beneficial water use.<br>▪ Online meteorological data sources such as PRISM and DAYMET (PRISM Climate Group 2023; ORNL n.d.) provide gridded meteorological data such as precipitation.<br>▪ The National Weather Service collects precipitation data at stations throughout the basin. | ▪ Existing measurement of GSL watershed in-stream flows is not complete; data exists in different locations and measurement gaps exist.<br>▪ USGS river gaging network does not currently include metering at GSL inflow locations on the Jordan, Weber, and Bear Rivers. "Lowest" gage points include 17th South, Plain City, and Corinne.<br>▪ SNOTEL sites site coverage could be expanded.<br>▪ Correlation between snow water equivalent of snowpack and soil moisture with streamflow does not appear to be well understood based on past runoff forecasting performance (Prepare60 2020).<br>▪ There is a lack of data around return flows from industry or wastewater that are discharged to GSL.<br>▪ Gridded precipitation data represent long-term averages and corresponding precipitation variation data are less available. | ▪ Complete metering and gaging gap analysis currently in process by USU. [STUDY]<br>▪ Develop prioritized list of measurement installations and improvements, implement improvements. [TASK]<br>▪ Once measurement installations are complete, recommend incorporating measurement data into common publicly available database. [TASK]<br>▪ Installation of USGS gages and/or reactivation of inactive gages at GSL inflow points on the Jordan, Weber, and Bear Rivers are recommended. [TASK]<br>▪ Coordination with NRCS is recommended to identify gaps in SNOTEL site coverage and recommended installation locations. [TASK]<br>▪ Performance of a study that improves the correlation of snow water equivalent, soil moisture, and resulting streamflow, and enables improved forecasting models, is recommended. [STUDY]<br>▪ Consider studying or requiring that industries provide return flow information. [TASK/STUDY]<br>▪ Consider precipitation variability when documenting water resources. [TASK] |
| **Reporting** | ▪ State agencies have mapped chronic low flow reaches (WRBWBTG 2023). | ▪ Chronic low flow areas are not integrated with other state and federal water supply datasets to develop a complete picture for BMP development. | ▪ Recommend integrating low flow reach data into a common database to support GSLBIP and BMP development. [TASK] |
| **Data Management** | ▪ Water supply data exists and are maintained by a number of state and federal agencies. | ▪ These data are not centrally located and in some cases can be difficult to locate due to the need to "drill down" through existing databases. | ▪ Creation of a common and publicly available water supply database to support data accessibility and transparency is recommended. [DATABASE DEVELOPMENT]<br>▪ Recommend leveraging the common database to generate water supply visual products and dashboards (hydroinformatics) to inform stakeholders and the public of water supply conditions. [TASK]<br>▪ Recommend expansion of central database beyond water supply and include water demand, water quality, and other datasets deemed appropriate. [TASK] |
| **Modeling** | ▪ The USGS has conducted hydrogeological studies of most groundwater systems statewide, including some information about the location and magnitude of surface and ground water exchanges.<br>▪ WRi maintains several groundwater models for State of Utah.<br>▪ Groundwater models are available to assist in determining the "safe yield" of aquifers.<br>▪ WRi maintains water right distribution models that inform available water supply and are publicly accessible.<br>▪ Major tributaries to GSL have river basin models developed by various agencies.<br>▪ WRe has developed a water budget model for the GSL Basin. | ▪ A spatial understanding of water sources and exchanges between surface water and groundwater that aligns with observed flows at USGS stream gage sites is not well characterized.<br>▪ Past modeling efforts have (in some cases) had poor agreement with observed river flow measurements at USGS stream gage sites.<br>▪ Past studies have various completion dates and advancing science means that older studies in particular may not have benefitted from more recent methods.<br>▪ Spatial gaps exist in the available groundwater models for the GSL watershed.<br>▪ Safe yield of aquifers that support demands in GSL watershed are not well defined.<br>▪ Water right distribution models do not share a common format or structure.<br>▪ Not all GSL watershed rivers have water right distribution models constructed.<br>▪ Existing river basin models (such as JBRPM, WeberSim, CUPSim) were developed for specific purposes and do not have all required information to support the GSLBIP Water Budget. For example, information related to Bear River tributaries was noted as lacking in JBRPM (BRBWBTG 2023).<br>▪ Existing river basin models (such as JBRPM, WeberSim, CUPSim) were developed for specific purposes and do not have all required information to support the GSLBIP Water Budget. For example, information related to Bear River tributaries was noted as lacking in JBRPM (WRBWBTG 2023).<br>▪ Outside review of the water budget model could provide some good data and improvements for the GSLBIP. | ▪ Finalize calibration of WRe VIC and RAPID models and incorporate results into the GSLBIP Water Budget river basin modules. [TASK]<br>▪ Incorporate VIC and RAPID model results into river basin models to evaluate surface and groundwater exchanges. [TASK]<br>▪ Updated river basin models to support validation of GSLBIP Water Budget river module results. [TASK]<br>▪ Update older hydrogeological studies and models, particularly in areas with larger populations and aquifer use. [TASK/STUDY].<br>▪ Additional groundwater models should be developed to fill gaps in existing model spatial extents. [TASK]<br>▪ Existing groundwater models should be used to investigate and develop safe yield estimates in the study area. It is recommended that these estimates are added to the GSLBIP Water Budget. [STUDY]<br>▪ Future refinements to safe yield estimates should be planned that align safe yields with the respective aquifers from which water is being extracted. In some areas, groundwater is being extracted from various aquifers, and knowing each aquifer's safe yield is important to understand available water supplies for GSL watershed communities. [STUDY]<br>▪ Recommend WRi consider a common format for water right distribution models. [TASK]<br>▪ Recommend WRi complete ongoing water right distribution model development (Weber River [WRBWBTG 2023), Hobble Creek (ULBWBTG 2023), Spanish Fork (ULBWBTG 2023)) and identify any gaps for future development. [TASK]<br>▪ Existing river basin models (such as JBRPM, WeberSim, CUPSim) need to be updated or new models need to be built that leverage the past efforts of existing models to support GSLBIP Water Budget development. [TASK]<br>▪ Conduct an outside review of the water budget model. [TASK] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Research** | ▪ The Bear River, GSL's only major interstate river, has an established interstate Compact since 1958. | ▪ The Compact influences what can and cannot be done by the State with regard to the Bear River. | ▪ A careful review of the Bear River Compact (U.S. Congress 1980) is recommended to inform GSLBIP Water Budget development (BRBWBTG 2023). [TASK] |

Notes:

BMP = best management practice
WRe = Utah Division of Water Resources
WRi = Utah Division of Water Rights
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
JBRPM = Joint Bear River Planning Model
WeberSim = Weber River RiverWare model
NRCS = Natural Resources Conservation Service
RAPID = Routing Application for Parallel computation of Discharge
SNOTEL = SNOpack TELemetry
USGS = U.S. Geological Survey
USU = Utah State University
VIC = Variable Infiltration Capacity

**Table 6-2. Is There an Adequate Water Supply Now and in the Future?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Current and future water supply is evaluated in Tables 6-1 and 6-5. | ▪ Current and future water supply is evaluated in Tables 6-1 and 6-5. | ▪ Current and future water supply is evaluated in Tables 6-1 and 6-5. |
| **Reporting** | ▪ WRe is coordinating a State Water Plan work group to identify State Water Plan requirements and to quantify the state's reliable water supply considering current work being performed by BYU. | ▪ The BYU work is forthcoming. | ▪ A forthcoming study will provide recommendations on water policy for supply ("Reliable Water Supply: What Does it Mean?"). Continue to work with the authors to refine and implement the recommendations. [TASK] |
| **Modeling** | ▪ Climate change is often considered when forecasting future water supplies. | ▪ Future impacts of climate change, including changes in the current balance of rain/snow hydrology and how these impacts will affect GSL watershed storage reservoirs, related water user supplies, and remaining supplies which provide inflows to GSL are not well characterized across the watershed.<br>▪ Methods used by water managers and planners to evaluate potential impacts from climate change are not consistent, thus resulting predictions in water supply vary. | ▪ Use WeberSim and model results documented in the Weber Basin Water Conservancy District's Drought Contingency Plan (JUB Engineers, Inc. 2018) to evaluate the impacts to Weber River basin water users and the resulting inflows to GSL across the range of possible future occurrences. [STUDY]<br>▪ Develop drought contingency plans in the Jordan and Bear River Basins to better understand likely reservoir operations, impacts to river basin water users, and resulting flows to the GSL. [STUDY] |
| **Metrics and Thresholds** | ▪ The State has minimum sizing requirements for drinking water system demand. | ▪ Utah does not have the same level of accountability for water supply planning as it does for water demand reporting ("Reliable Water Supply: What Does it Mean?"). | ▪ A forthcoming study will provide recommendations on water policy for supply ("Reliable Water Supply: What Does it Mean?"). Continue to work with the authors to refine and implement the recommendations. [TASK] |
| **Research** | ▪ WRe is working with BYU to quantify the state of Utah's reliable water supply as a function of hydrology, infrastructure, and governance constraints | ▪ Functional flow needs for GSL watershed waterways are not well understood. | ▪ Complete a functional flow study, including flow volumes and frequencies for healthy river ecosystems in the Weber River Basin and apply lessons learned and resulting process to the Jordan and Bear River Basins of the GSL watershed. [STUDY] |

Notes:

BYU = Brigham Young University
WRe = Utah Division of Water Resources
GSL = Great Salt Lake
WeberSim = WeberSim = Weber River RiverWare model

**Table 6-3. What Can be Done to Improve Our Water Supply?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Reporting** | ▪ Groundwater recharge programs are subject to application and reporting requirements from WRi. | ▪ ASR programs in Utah are in the very early stages, and little data is available. | ▪ Collecting data from existing ASR projects in Utah is recommended. [TASK] |
| **Research** | ▪ The *Great Salt Lake Policy Assessment* reports water supply improvement policy options (GSL Strike Team 2023).<br>▪ WRe did a pilot study of covering/enclosing canals in Utah. | ▪ Movement from policy to reality may require collaboration, feasibility studies, or other data not yet available.<br>▪ The pilot program can be expanded, if warranted. | ▪ A review of existing importation project feasibility studies (Sowby et al. 2023) and initiation of new studies where gaps in knowledge exist is recommended. [STUDY]<br>▪ A review of existing forest management and watershed restoration feasibility studies and initiation of new studies where gaps in knowledge exist is recommended. [STUDY]<br>▪ A review of efficiency projects (in agriculture, pressurized irrigation) that may include covering canals, maintaining canals free from wetland and invasive plants, and reducing seepage is recommended. [STUDY] |
| **Programs** | ▪ The State's cloud seeding program provides an annual average of 186,700 acre-feet of additional water supply without degrading water quality from cloud seeding components (WRe 2021).<br>▪ In 2023, the Utah Legislature allocated $12 million in one-time funding and provided an annual budget of $5 million to the division. Costs for cloud seeding programs are split with local sponsors. (WRe n.d.a)<br>▪ Groundwater recharge programs have a framework administered by the WRi. Such programs may reduce evaporative losses from aboveground reservoirs and prevent consequences of aquifer depletion, such as land subsidence. | ▪ The program could be expanded. Additional research is needed for proper positioning and benefit identification.<br>▪ ASR programs in Utah are in the very early stages, which brings specific challenges, such as financial considerations. ASR also changes the evaporative pathways of water, decreasing evaporation from reservoirs but also increasing ET from groundwater. | ▪ Investigate expanding the cloud seeding program and take action if warranted. [STUDY]<br>▪ Research proper positioning of 120 additional automated cloud seeding generators. [STUDY]<br>▪ The viability of ASR programs and the benefits they may bring was expressed as an interest by technical stakeholders (JRBWBTG 2023). [STUDY]<br>▪ Study how ASR affects GSL. **[STUDY]** |

Notes:

ASR = aquifer storage and recovery
WRe = Utah Division of Water Resources
WRi = Utah Division of Water Rights
ET = evapotranspiration
GSL = Great Salt Lake

**Table 6-4. How Has and Will the Water Supply Change Over Time?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ Table 6-1 provides information about the strengths, gaps/weaknesses, and proposed areas of capacity development of current water supply programs and resources. These resources provide the historical supply side of the data to answer this Tier 3 question. Likewise, the resources in Table 6-5 help answer the future side of this Tier 3 question. | ▪ Refer to Table 6-1 for information on current water supply and Table 6-5 for information on future water supply. | ▪ Refer to Table 6-1 for information on current water supply and Table 6-5 for information on future water supply. |
| **Data Management** | ▪ WRi maintains historical water distribution records for waterways in the State of Utah (WRi 2008). | ▪ Databases are vulnerable to change over time, decay in usefulness if not maintained, and must be constantly updated.<br>▪ Diversions lack depletion data. | ▪ Continue efforts to update databases to preserve the historical record. [TASK]<br>▪ Add depletion data when available. [TASK] |
| **Modeling** | ▪ Climate change is often considered when forecasting future water supplies.<br>▪ The *Great Salt Lake Policy Assessment* (GSL Strike Team 2023) reports that over the long term, slight increases in expected precipitation will likely be overwhelmed by increases in temperature and evaporation.<br>▪ EPA streamflow projections (EPA n.d.) include late 21st century projections (2071–2100) based on five models from Coupled Model Intercomparison Project Phase 5 (CMIP5) dataset (WCRP n.d.), all using RCP 8.5.<br>▪ Virtually any model (for example, river basin, groundwater) can be used in “what if” analysis to simulate different future patterns of drought and wet cycles and differing severity of droughts. | ▪ Investigation of projected water supplies in the GSL watershed that incorporate the latest climate change science is ongoing.<br>▪ It is unclear if these data are integrated into State or local planning.<br>▪ “What if” analyses could be expanded with time and funding investments. | ▪ Finalize calibration of WRe VIC and RAPID models and evaluate the range of possible future water supply outcomes for the GSL watershed. [TASK]<br>▪ Compare VIC and RAPID model results against other projections such as EPA’s streamflow projections (EPA n.d.). [TASK]<br>▪ Recommended cropping patterns and crop types for various future regimes (such as longer growing seasons or fewer water supplies) could be beneficial to farmers. [TASK]<br>▪ Investigate whether streamflow projections are incorporated into State and local planning, and integrate the projections if not. [TASK]<br>▪ Modeling past and possible future drought cycles is recommended to inform drought impacted water supplies (WRBWBTG 2023). [TASK] |
| **Programs** | ▪ Some water suppliers have completed Drought Contingency Plans (JUB Engineers, Inc. 2018). | ▪ A basin-wide drought contingency plan is needed to coordinate water use in critically dry periods. | ▪ All water suppliers should complete Drought Contingency Plan. [TASK]<br>▪ Complete a basin-wide drought contingency plan. [TASK] |
| **Research** | ▪ As mentioned in Table 6-1, the NRCS operates SNOTEL and provides streamflow runoff forecasts for major rivers in the basin which are updated monthly in January through June (NRCS n.d.). | ▪ Recent inaccuracies in streamflow forecast results show the need for improved understanding in variables impacting available water supplies<br>- Low soil moisture led to lower than expected runoff in 2021, resulting in over reporting in expected streamflow volumes.<br>- Increased temperatures (Udall and Overpeck 2017) have led to a reduction in available water supplies in the Colorado River Basin. | ▪ An evaluation of the correlations between variables such as soil moisture and temperature and observed water supplies is recommended to provide better information about future available water supplies. [STUDY] |

Notes:

WRe = Utah Division of Water Resources
WRi = Utah Division of Water Rights
EPA = U.S. Environmental Protection Agency
GSL = Great Salt Lake
NRCS = Natural Resource Conservation Service
RAPID = Routing Application for Parallel computation of Discharge
SNOTEL = SNOpack TELemetry
VIC = Variable Infiltration Capacity

**Table 6-5. What Water Resources Will Be Available in the Future?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection** | ▪ As current water supplies are expected to be available in some form in the future, Table 6-1 provides information about the strengths, gaps/weaknesses, and proposed areas of capacity development of current water supply programs and resources. | ▪ Refer to Table 6-1 for information on current water supply. | ▪ Refer to Table 6-1 for information on current water supply. |
| **Modeling** | ▪ Chapter 6 of the *Water Resources Plan* (RWe 2021) summarizes Bear River Development Act allocations, which total 220,000 acre-feet (DNR 2021). | ▪ The impacts of the Bear River Development is not well defined. | ▪ Potential impacts of the Bear River Development Act are recommended for inclusion in the GSLBIP Water Budget and studies related to future water supply projections for the Bear River. [TASK]<br>▪ A careful review of the Bear River Compact (U.S. Congress 1980) is recommended to inform GSLBIP Water Budget development (BRBWBTG 2023). [TASK] |
| | ▪ As mentioned in Table 6-1, major tributaries to GSL have river basin models developed by various agencies. | ▪ Current river basin models do not support validation of GSLBIP Water Budget climate change scenario results.<br>▪ A water supply forecast model from Utah Lake to the Jordan River does not currently exist. | ▪ Incorporate common data library into river basin models, including the latest water demand information. [TASK]<br>▪ Incorporate VIC and RAPID model results into river basin models. [TASK]<br>▪ Recommend building a water supply forecast model from Utah Lake to the Jordan River and incorporating into the GSLBIP Water Budget. [TASK] |
| | ▪ As mentioned in Table 6-1, WRe has developed a water budget model for the GSL Basin. | ▪ Development of the GSLBIP Water Budget is needed to support evaluation of climate change scenarios, including historic patterns, short- and long-term projections, and contingencies for reversal of climate change trends.<br>▪ A reliable season to season or long-term water supply and precipitation model does not exist for the entire GSL Basin. | ▪ Incorporate VIC and RAPID model results and common data library into GSLBIP Water Budget to evaluate climate change impacts to water supply and how these impact the GSL and users in the watershed. [TASK]<br>▪ Recommend building a reliable season to season or long-term water supply and precipitation model does not exist for the entire GSL Basin and incorporating into the GSLBIP Water Budget. [TASK] |
| | ▪ As mentioned in Table 6-1, groundwater models developed by the USGS and archived by WRi are available to assist in determining the “safe yield” of aquifers. | ▪ A quantitative groundwater inflow model which incorporates impacts related to human development and climate change does not exist. | ▪ Recommend USGS complete current development of the GSL Regional Flow Model. [TASK] |
| | ▪ The Utah Lake Jordanelle Exchange Model contains the Weber-Provo Diversion. | ▪ It is unclear if the Weber-Provo Diversion is modeled in WeberSim. Diverted water from the Weber to the Provo impacts the broader water budget, these impacts are not fully characterized. | ▪ Recommend WeberSim be updated to include the Weber-Provo Diversion if not included. [TASK]<br>▪ A consolidated effort among the basins (Weber and Utah Lake) is recommended to understand the impacts of Weber-Provo diversion management decisions on available basin water supplies and downstream impacts to GSL (WRBWBTG 2023; ULBWBTG 2023). [STUDY] |
| **Research** | ▪ Water from the Colorado River is imported to the GSL Basin to meet M&I and agricultural needs, much of which is undepleted and flows to Utah Lake. | ▪ Potential impacts to the GSL related to a curtailment on the Colorado River are not well known (ULBWBTG 2023). | ▪ Recommend studying the potential impacts to the GSL related to a curtailment on the Colorado River. [STUDY] |

Notes:

WRe = Utah Division of Water Resources
WRi = Utah Division of Water Rights
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
M&I = municipal and industrial
RAPID = Routing Application for Parallel computation of Discharge
USGS = U.S. Geological Survey
VIC = Variable Infiltration Capacity
WeberSim = Weber River RiverWare model

## 6.2 Water Quality Building Block Technical Questions

*How do we ensure a resilient water supply for GSL and all uses in its watershed?*

- How much water is and will be available for use in the Great Salt Lake watershed?
  - What water resources are currently available?
    - How is water supply currently measured, reported, and evaluated in each sector and for each service area, river sub-basin, basin, and overall watershed??
    - What is the current, assumed reliable surface water supply? What is the portfolio?
    - What is the current, assumed reliable groundwater supply (safe yield)? What is the portfolio?
  - How has and will the water supply vary over time?
    - What have been and will be the long-term trends in "natural" water availability, reliability? What has been available for human use?
    - How has and will climate change influence water availability?
    - What other factors have and will influence seasonal and decadal water availability (such as changes in ET, upstream storage requirements, land use change)?
    - What are the critical elements that would enable more accurate measurement?
    - What are the critical elements that would enable more accurate predictions?
  - What water resources will be available in the future?
    - What will be our future reliable and range of available surface water supply? What is the portfolio?
    - What will be our future reliable and range of groundwater supply? What is the portfolio?
    - Is there a risk for a reduction in water supply? Now? And in the future?
  - Is there an adequate water supply now and in the future?
    - What are the impacts from an inadequate water supply?
  - What can be done to improve our water supply?
    - What immediate enablers are needed to support water supply quantification activities?
    - Are there any supply side BMPs that should be considered as part of the assessment? Note: most are tied to demands but some may better inform supplies available to system users.
    - What actions can be taken?
    - What data and management resources are needed to evaluate actions?
    - What are the costs of changes?
    - What are the opportunity costs?

# 7. Watershed Gap Analysis

This section outlines the results of the gap analysis completed for the watershed building block of the GSLBIP. The results of this gap analysis will inform the Work Plan for the GSLBIP.

## 7.1 Tier 3 Technical Questions

The watersheds gap analysis was framed around answering the following Tier 3 watersheds questions (refer to Figures 1-3 and 7-1):

- How can forest management and watershed restoration benefit water quantity and quality in the watershed by:
  - Improving snowpack retention (Table 7-1)?
  - Increasing soil moisture (Table 7-2)?
  - Sustaining river flows in low flow season (Table 7-3)?
  - Mitigating wildfire risk (Table 7-4)?
  - Improving water quality (Table 7-5)?

The complete list of watershed technical questions can be found in Section 7.2.

**Figure 7-1. Tier 3 Questions for the Watershed Gap Analysis**

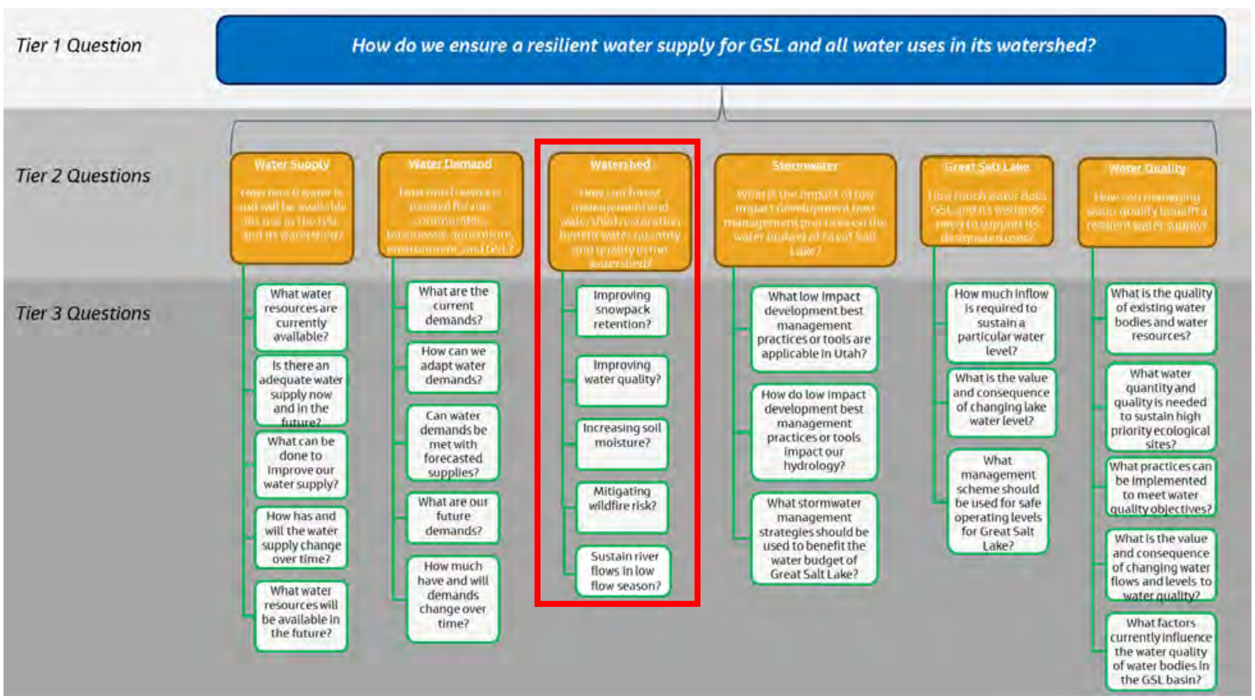


**Table 7-1. How Can Forest Management and Watershed Restoration Benefit Water Quantity And Quality in the Watershed By Improving Snowpack Retention?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection and Monitoring** | ▪ The NRCS SNOTEL program operates a network of snow depth and SWE gages around the state, making data available freely online. The SNOTEL program provides real-time data and long-term trends in snow depth and SWE.<br>▪ OpenET provides satellite-based estimates of ET. | ▪ The existing SNOTEL network is a great database of snowpack data, but additional sites are needed to provide greater resolution into snowpack variability at different aspects, elevations, and geographies.<br>▪ While OpenET is a great source of ET data, it does not provide PET as an output.<br>▪ An aridity dataset is lacking to support modeling of snowpack and the potential result of forest treatments on snowpack. | ▪ Coordination with NRCS is recommended to identify gaps in SNOTEL site coverage and recommended installation locations. [TASK]<br>▪ Shared Stewardship, WRe, and water agencies should work with NRCS to provide funding, develop, and manage additional SNOTEL sites. [PROGRAM]<br>▪ Aridity estimates should be made to support modeling of snowpack within the basin. WRe should lead the development of a pixel-based dataset of aridity in Utah based on climate data and modeling, similar to the Utah Wildfire Risk Explorer. In this context aridity can be defined as the ratio of PET/P. [TASK]<br>▪ Investigate whether ET (estimated by OpenET) can be used as a proxy for PET. [TASK] |
| **Research** | ▪ Research has shown that as much as 30% of snowfall can be intercepted by the forest canopy and then sublimated back into the atmosphere, preventing it from accumulating on the ground as snowpack (MacDonald and Stednick 2003).<br>▪ Removing forest canopy decreases interception rates and increases the amount of snow that accumulates on the forest floor, but it also increases the rate of snowmelt and can increase sublimation from accumulated snow.<br>▪ The importance of forest structure and the spatial arrangement of trees to maximize snow accumulation, retention, and streamflow has been recognized in recent forest hydrology research (Goeking and Tarboton 2020; Sun et al. 2018). However, no 'one size fits all' approach can be implemented everywhere.<br>▪ Research has shown that the canopy edge effect and forest density are key to maximizing snow accumulation and snow retention in forests where canopy removal has taken place.<br>▪ In general, treating north-facing slopes is the best way to simultaneously maximize SWE and minimize snowmelt rate (Troendle and Olsen 1994; MacDonald and Stednick 2003).<br>▪ SWE is generally greater in aspen than coniferous forest, but this may be offset by greater ET losses in aspen forest (LaMalfa and Ryle 2008). | ▪ Research is mixed on whether canopy removal results in increased water yield. Mechanisms for reduced streamflow include increased water use by vegetation regrowth, increased sublimation and evaporation of exposed snowpack, and increased soil evaporation from reduced canopy shade. There is a body of literature on the subject, but there is a lack of experiments within the GSL Basin.<br>▪ Understanding of aridity and recommended forest treatments is very site-specific and may need to be investigated on a higher resolution and site-specific basis.<br>▪ A pixel-based dataset (including a map) of aridity throughout the basin based on climate data and modeling to support statewide mapping to inform locations for forest thinning to increase water yield. In this context, aridity can be defined as the ration of PET/P. | ▪ How potential ET will change in the future should be estimated, and a dataset of predicted aridity under various climate change scenarios should be developed. WRe could lead this effort. [TASK]<br>▪ While there is a body of literature to draw from in the western United States, additional studies should be implemented to measure the effect of forest treatments (thinning) and forest composition on snowpack in the GSL Basin. Studies should consider variables such as aspect and elevation. [TASK]<br>▪ Future studies should explicitly report quantitative forest density (for example, in terms of LAI, basal area per acre, or canopy cover percentage), quantitative disturbance effects (for example, reduction in LAI, area affected), scale of assessment (for example, stand, hillslope, or catchment), annual precipitation, annual maximum SWE, and magnitude of hydrologic change, as well as results of statistical significance tests (Goeking and Tarboton 2020). [TASK]<br>▪ NRCS should experiment with using imagery and spectral data to understand and monitor snowpack depth (for example, cornice formation). [TASK]<br>▪ WRe should characterize the relationship between GSL lake level and dust on snow deposition in the watershed to document a potential correlation between lake level and rate of snowpack melting. [TASK] |
| **Policy** | ▪ 2017 State Water Strategy recommends managing and restoring watershed to decrease transpiration, increase runoff, and protect water quality (Governor's Water Strategy Advisory Team 2017).<br>▪ The creation of watershed councils throughout the state may facilitate the pursuit of watershed management projects, such as those aimed at increasing snowpack.<br>▪ Existing funding programs to help identify and fund projects to improve snowpack retention include the DWQ Nonpoint Source Grants (Federal 319 grant funding) and the DNR WRI. | ▪ 2017 State Water Strategy recognizes changes in snowpack hydrology as a threat to stream flows and water rights. | ▪ Watershed councils should engage with landowners within the watersheds in addition to Shared Stewardship to pursue research and implementation of watershed management projects to improve snowpack retention. [PROGRAM] |

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Management** | ▪ Snowpack retention is recognized as critical to water supply, including surface water and groundwater. The amount of water stored in snowpack is an important indicator of water yield (Schnorbus and Alila 2004).<br>▪ Snowpack is recognized as providing Utah's largest storage reservoir (95% of the state's water supply; Julander and Clayton 2018).<br>▪ Snowpack may be further reduced as GSL dries up, due to the potential reduction in the lake effect snowfall and an increase in dust on snow. Snowmelt could accelerate by approximately 7 to 17 days due to increased dust deposition (ECONorthwest 2019; Lang et al. 2023).<br>▪ The WRe Weather Modification Program produces a 5% to 12% increase in snowpack in seeded areas (WRe 2021). | ▪ Wildfire mitigation and forest treatment efforts generally do not consider water quantity and quality in treatment design.<br>▪ Forest thinning could result in the unintended consequence of decreased SWE, soil moisture, and streamflow.<br>▪ A management and coordination gap may exist around watershed management to maximize snowpack retention. Shared Stewardship is focused on wildfire prevention, and while WRe funds some snowpack augmentation work (Weather Modification Program), coordination around watershed management for water quantity is lacking.<br>▪ A lack of funding and staff resources employed towards forest and watershed management may be impeding the implementation of coordinated management strategies throughout the watershed.<br>▪ Landowners and land managers may not be aware of forest and watershed management and watershed restoration strategies that can help retain snowpack.<br>▪ A standardized process for identifying, planning, and implementing projects that ensures coordination amongst key stakeholders.<br>▪ Additional funding was allocated in 2023 for one-time ($12M) funding and an annual budget of $5M to support the Weather Modification Program. | ▪ Forest management should be performed for multiple benefits (including water supply, wildfire mitigation, and wildlife habitat) to increase opportunity to attract funding and leverage investments for greater collective impact. All land and forest management agencies and property owners should consider this. **[PROGRAM]**<br>▪ Shared Stewardship should consider maximizing SWE in their programs and treatments; however, site-specific analysis is likely required because forest treatments could decrease water yield in arid climates. More planning and coordination with partner agencies are needed with Shared Stewardship. Water managers (water conservancy districts), and other stakeholders should be involved in forest treatment project planning, and hydrologic modeling should be completed as part of the planning process for forest treatment projects. Shared Stewardship should facilitate this coordination. Refer to the Lake Tahoe West Restoration Partnership as an example. **[PROGRAM]**<br>▪ WRI should fund the development of a toolbox for landowners and land managers with different options and methodologies for increasing snowpack retention. **[TASK]**<br>▪ In areas of Utah where average winter temperature is below 1°C, a moderately dense forest cover should be maintained to maximize snow retention, particularly in south-facing slopes where they provide solar shading (Lundquist et al. 2013). **[PROGRAM]**<br>▪ In areas of Utah where average winter temperature is more than 1°C, a sparser forest cover should be maintained to optimize snow retention by providing solar shading with minimal longwave radiation emittance. **[PROGRAM]** |

Notes:

°C = degree(s) Celsius
DNR = Utah Department of Natural Resources
DWQ = Utah Division of Water Quality
WRe = Utah Division of Water Resources
ET = evapotranspiration
GSL = Great Salt Lake
LAI = leaf area index
NRCS = Natural Resources Conservation Service
PET = potential evapotranspiration
PET/P = potential evapotranspiration to precipitation
SNOTEL = SNOpack TELemetry
SWE = snow water equivalent
WRI = Watershed Restoration Initiative

**Table 7-2. How Can Forest Management and Watershed Restoration Increase Soil Moisture?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection and Monitoring** | ▪ NRCS manages a network of soil moisture measurement probes (SCAN) and data are freely available online. Increased SWE and snow retention generally leads to greater soil moisture and infiltration.<br>▪ Soil moisture is key to managing for streamflow and water yield. Recent empirical data have proven this as dry soil conditions have played a large role in influencing low water yield through spring runoff. | ▪ The coverage of the soil moisture monitoring network is limited and insufficient to provide an in-depth understanding of soil conditions and watershed health throughout the basin. Additional sensors in all sub-watersheds and at various aspects and elevations are necessary to fully understand and track soil moisture dynamics.<br>▪ Understanding of aridity and recommended forest treatments is very site specific and may need to be investigated on a higher resolution and site-specific basis.<br>- There is not a "one size fits all" approach to forest treatments to increase soil moisture that could be implemented basin wide.<br>▪ There is a lack of coordination amongst all key stakeholders in the planning and implementation of watershed and forest projects. In some cases, the objective to increase soil moisture may not be included in the project planning and design. | ▪ Support the NRCS and identify funding to expand the soil moisture monitoring (data collection) network. [PROGRAM]<br>- Soil moisture sensors should be installed in all tributary watersheds, at multiple aspects and elevations, to provide comprehensive understanding of (and data describing) soil moisture dynamics within the watershed.<br>▪ Research efforts to document results should be coordinated between different agencies, including Shared Stewardship, WRI, and UGS, and research on watershed restoration and forest management should focus on multiple outcomes, such as wildfire mitigation, snowpack, soil moisture, water quality, and low flow season flows. This could take the form of a cooperative watershed management research program. [PROGRAM]<br>▪ Continue to implement stream, floodplain, and meadow restoration projects using beaver dam analogs and other methods to raise the water table and slow the movement of water downstream. [PROGRAM]<br>- Develop a study to document the effect of these restoration tactics on soil moisture. Multiple studies could be implemented to consider variables such as aspect, elevation, and surrounding vegetation composition on the effectiveness of treatments. [TASK] |
| **Research** | ▪ Research has shown that the canopy edge effect and forest density are key to maximizing snow accumulation and snow retention (and therefore soil moisture) in forests where canopy removal has taken place.<br>▪ Research has shown that pinon juniper reduction increases soil water availability (Roundy et al. 2014; Roundy et al. 2020).<br>▪ Numerous research studies and projects have been implemented to investigate the effects of pinyon juniper removal. Pinyon juniper removal treatments are generally focused on increasing herbaceous vegetation growth in the understory. | ▪ There is limited understanding of the effect of forest management on soil moisture.<br>▪ A pixel-based dataset (including a map) of aridity does not exist in Utah.<br>- Aridity data are key to modeling soil moisture throughout the basin.<br>In this context aridity can be defined as the ration of PET/P. | ▪ WRI should fund research to investigate the effect of forest composition (mixed aspen and conifer forests) on soil moisture in forests. [TASK]<br>▪ Long-term studies of the effect of forest disturbance (and forest treatments) on soil moisture as soil moisture responds to disturbance may vary over long timescales.<br>- Document late-season soil moisture in response to forest treatments. This could be done as a part of research efforts to evaluate the effectiveness of forest treatment on water yield and water quality. WRe or WRI to lead and fund this effort. [TASK]<br>▪ Future studies should explicitly report quantitative forest density (for example, in terms of LAI, basal area per acre, or canopy cover percentage), quantitative disturbance effects (for example, reduction in LAI, area affected), scale of assessment (for example, stand, hillslope, or catchment), annual precipitation, annual maximum SWE, and magnitude of hydrologic change as well as results of statistical significance tests (Goeking and Tarboton 2020). [PROGRAM] |
| **Management** | ▪ Forest management and research on the effects of different forest treatments on soil moisture has progressed over the years.<br>- SWE and early season soil moisture are greater in aspen than coniferous forest but may be offset by greater ET losses in aspen forest (LaMalfa and Ryle 2008).<br>- Forest treatments (tree removal) have the potential to increase soil moisture, but this can be undone by increases in surface soil moisture losses and ET from understory vegetation that may colonize and increased shortwave radiation.<br>- The importance of forest structure and the spatial arrangement of trees to maximize snow accumulation, retention, and streamflow has been recognized in recent forest hydrology research (Goeking and Tarboton 2020; Sun et al. 2018). However, there is no "one size fits all" approach that can be implemented everywhere.<br>▪ In general, treating north-facing slopes is the best way to simultaneously maximize SWE and minimize snowmelt rate (Troendle and Olsen 1994; MacDonald and Stednick 2003).<br>▪ Restoration of streams (for example, Ogden River) and meadows through beaver reintroduction or beaver dam analogs (for example, East Canyon Creek) helps to raise the water table and increase soil moisture in adjacent areas. These restoration practices have become more accepted and implemented within the basin. | ▪ Wildfire mitigation and forest treatment efforts generally do not always take soil moisture into account in treatment design.<br>▪ Forest thinning could result in the unintended consequence of decreased SWE, soil moisture, and streamflow. | ▪ Publicize the effect of pinyon juniper removal on shallow groundwater elevations from current UGS research (Young et al. 2013; Roundy et al. 2014). [TASK]<br>▪ Develop a toolbox for landowners and managers with different options and methodologies for land management to maximize soil moisture (USGS 2021). WRe could work with NRCS and UDAF to develop the toolbox and make it available to land managers and landowners. [TASK] |

Notes:

WRe = Utah Division of Water Resources
ET = evapotranspiration
LAI = leaf area index
NRCS = Natural Resources Conservation Service
PET/P = potential evapotranspiration to precipitation
SWE = snow water equivalent
UDAF = Utah Department of Agriculture and Food
UGS = Utah Geological Survey
RI = Watershed Restoration Initiative

**Table 7-3. How Can Forest Management and Watershed Restoration Enhance River Flows in Low-Flow Seasons?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection and Monitoring** | ▪ USGS, Salt Lake County, water agencies, and irrigation companies maintain flow gages throughout the basin.<br>▪ WRi, USU, and USGS Saline Lakes Ecosystem IWAAs are currently completing a gap analysis of flow measurement systems on GSL tributaries.<br>▪ UGS (Hugh Hurlow) Vernon BDA study is quantifying how BDAs impact streamflow. This study will help determine how or if an improved water table from BDAs impacts streamflow. | ▪ Flow (and water quality) measurement infrastructure is insufficient and nonexistent in some areas. A higher density of gages is needed to characterize water quantity and quality and particularly to ensure that water rights get delivered (shepherded) downstream.<br>▪ Long-term studies of the effect of forest disturbance on low flow season flows as low flow response to disturbance may vary over long timescales. | ▪ Future studies should explicitly report quantitative forest density (for example, in terms of LAI, basal area per acre, or canopy cover percentage), quantitative disturbance effects (for example, reduction in LAI, area affected), scale of assessment (for example, stand, hillslope, or catchment), annual precipitation, annual maximum SWE, and magnitude of hydrologic change as well as results of statistical significance tests (Goeking and Tarboton 2020). [PROGRAM]<br>▪ Increase the network of streamflow gages in the watershed, prioritizing areas such as the lower Bear River where gages are lacking, and additional water secured from consumptive water rights could be delivered to GSL. Collaborate with WRi and USU on this effort. [PROGRAM]<br>▪ Add water quality sondes to existing gaging stations (USGS gages). [PROGRAM]<br>▪ Collaborate with resource management agencies (USFS, USGS, UGS, DWQ, WRi) to increase data collection efforts for the following:<br>- Streamflow<br>- Water diversions<br>- Water quality<br>- Spectral data<br>- Soil moisture and characteristics<br>- Hyporheic exchange<br>▪ Implement studies documenting the effects of BDAs, meadow restoration, and other watershed treatments on low season flows. [TASK] |
| **Policy** | ▪ H.B. 33 allows FFSL to file for change applications under the instream flow statute to benefit preservation of the natural environment.<br>▪ S.B. 26 allows for water banking to transfer water rights from one use to another.<br>▪ H.B. 130 authorized split season and fixed time applications to encourage water sharing among users.<br>▪ The Great Salt Lake Watershed Enhancement Program was passed in 2022, authorizing $40 million to set up a trust to enhance water quantity and quality for Great Salt Lake and its wetlands.<br>- The trust could serve as a source of funding for research or implementation of projects to increase low flow season flows in streams. | ▪ There are no environmental flow requirements to ensure seasonal flows are sufficient to meet water quality standards and habitat requirements for wildlife.<br>- Existing Utah water law does not adequately address these complexities or issues of how minimum instream flows and conservation may affect water quality (Governor's Water Strategy Advisory Team 2017).<br>- The water rights framework allows streams to become degraded or go dry (or to flow extremely low) due to water diversions. | ▪ Continue to work toward updating water law in Utah to be protective of the environment and to ensure that water diversions and extractions do not degrade the environment. [PROGRAM]<br>▪ Work with the legislature to require the development of minimum flow requirements in addition to functional flows for each stream within the basin. [PROGRAM] |
| **Management** | ▪ The response of low flows to forest disturbance is related to snow accumulation, snowmelt rates, and summer ET rates (Goeking and Tarboton 2020).<br>▪ Following forest disturbance, water yield and low flows may initially increase, but then decrease over the longer term due to post-disturbance vegetation growth (and associated ET) (Perry and Jones 2017; Moore and Wondzell 2005).<br>▪ Efforts to maximize SWE and soil moisture have the potential to increase low flow season flows in streams.<br>▪ Forest disturbance (for example, clear cuts, wildfire) has the potential to increase spring flows (and overall flows in the short term) but generally results in reduced low flow season flows in the long term (Perry and Jones 2017; Moore and Wondzell 2005).<br>▪ Meadow restoration and installation of beaver dams and beaver dam analogs have the potential to increase low season flows.<br>▪ These projects have been funded by WRI, DWQ NPS grants, and mitigation projects. | ▪ Some streams in the basin are dewatered at the expense of the environment.<br>▪ Management of environmental flows needs to be done more collaboratively and involve natural resource agencies in addition to water agencies and water rights holders. | ▪ Establish environmental flows needed to maintain healthy rivers and lakes.<br>- Pursue both minimum flow targets in addition to functional flows for each water body. [PROGRAM]<br>· Functional flows will also improve the efficiency of hydrologic restoration BMPs through an increased understanding of when, where, and how much water is needed to maximize benefits to the GSL or upstream rivers and waterbodies.<br>▪ Identify minimum and functional flow needs for fish, invertebrates, other wildlife, and sediment transport. [PROGRAM]<br>▪ Use water budgets/modeling (to be developed as part of the GSLBIP) to determine how much water is needed and where. [PROGRAM] |

Notes:

BDA = beaver dam analog
BMP = best management practice
DWQ = Utah Division of Water Quality
WRi = Utah Division of Water Rights
ET = evapotranspiration
FFSL = Utah Division of Forestry, Fire and State Lands
GSL = Great Salt Lake
GSLBIP = Great Salt Lake Basin Integrated Plan
H.B. = House Bill
IWAA = Integrated Water Availability Assessment
LAI = leaf area index
S.B. = Senate Bill
SWE = snow water equivalent
NPS = Nonpoint Source
UGS = Utah Geological Survey
USFS = U.S. Forest Service
USGS = U.S. Geological Survey
USU = Utah State University
WRI = Watershed Restoration Initiative

**Table 7-4. How Can Forest Management and Watershed Restoration Mitigate Wildfire Risk?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection and Monitoring** | ▪ The Utah Wildfire Risk Explorer is a valuable tool for evaluating wildfire hazard, burn probability, and more. | ▪ The frequency and severity of future wildfires is not known.<br>▪ The WRI program may not always evaluate long-term efficacy of watershed restoration projects, and specifically, water quality and hydrologic impacts associated with implementation of watershed restoration projects.<br>- Documentation of outcomes and findings from WRI-funded projects is lacking.<br>▪ There is limited coordination around where wildfire mitigation projects need to be completed, where they have been completed, and whether they still need to be completed. | ▪ WRe should coordinate and collaborate with WRI, Shared Stewardship, and other funding agencies to develop reporting requirements and templates to communicate the findings of watershed management projects. [PROGRAM]<br>- Work with WRI to ensure the findings and results of watershed projects and studies are promoted and data are made available.<br>▪ Forest treatment projects should include hydrologic modeling to inform designs. [TASK]<br>▪ Use LiDAR imagery in forest treatment planning. [TASK]<br>- Reference cooperative work being done in the Tahoe basin.<br>▪ Increase the monitoring network, including soil moisture sensors to help track wildfire conditions. [PROGRAM] |
| **Research** | ▪ Wildfire has the potential to affect water yield. In the lower Colorado River Basin, wildfire may result in increased summer streamflow but decreased winter and annual streamflow (Biederman et al. 2022). | ▪ There is no "one size fits all" approach to forest management to mitigate wildfire risk.<br>▪ Site-specific data collection and planning are needed to inform forest treatment projects. | ▪ Pursue in-forest biochar production and dispersion as a part of forest treatment (thinning) projects. [PROGRAM]<br>- Woody residues from forest treatment, harvesting, or restoration projects can be burned at low temperatures and turned into biochar, which offers benefits for soil health and carbon emissions and even provides an economic benefit for landowners (USFS 2022). |
| **Management** | ▪ A catastrophic wildfire sterilizes soils, strips vegetation of all foliage, and leads to erosion and sedimentation that contaminates our drinking water sources and damages water treatment facilities. Damage can last for years and create conditions that reduce snowpack, runoff, and water quality and cost taxpayers millions of dollars in restoration, remediation, and repair work. This is becoming more widely recognized in the state and wildfire mitigation projects are increasing.<br>▪ Forest treatment projects such as forest thinning and fuels removal has the potential to reduce the risk of catastrophic wildfire.<br>▪ The Shared Stewardship program is a cooperative approach to managing Utah's forests, bringing together state and federal agencies to protect communities from the threat of large wildfires.<br>▪ Forest treatments (thinning and fuels reduction) can help minimize the risk of wildfire and catastrophic wildfire and can be beneficial to water quantity and quality by increasing the potential for increased SWE and soil moisture. Land management agencies are implementing forest treatment projects where feasible. | ▪ Lack of resources (staff, funding, equipment) prevent widespread implementation of forest treatment projects.<br>▪ There is not enough coordination among land and resource management agencies to ensure that efforts to mitigate fire risk are also done with the objective of increasing water quantity and quality.<br>▪ Wildfire mitigation and forest treatment efforts may not always take water quantity and quality into account in treatment design.<br>▪ Coordination among land management agencies and stakeholders could be increased and improved.<br>▪ This is a lack of timber mills to process timber in Utah, making the economics and logistics of forest thinning challenging. | ▪ Increase coordination between agencies and improve the coordinated effort to mitigate wildfire risk throughout the state. Develop a standard process for project development and implementation that ensures proper coordination and input from relevant stakeholders. [PROGRAM]<br>▪ Increase coordination to ensure that wildfire mitigation efforts also incorporate water quantity and quality in the objectives and treatment design. [PROGRAM]<br>▪ Wildfire mitigation efforts should consider the potential impacts of wildfire to water quality and supply downstream. [PROGRAM]<br>▪ Projects should include debris dams (debris flow prevention and containment) routing and storage projects, sediment storage and sink projects, and other projects to contain and/or filter fine sediments and ash before they reach sensitive water bodies. [PROGRAM] |

Notes:

WRe = Utah Division of Water Resources
LiDAR = light detection and ranging
SWE = snow water equivalent
WRI = Watershed Restoration Initiative

**Table 7-5. How Can Forest Management and Watershed Restoration Benefit Water Quality?**

| Program Areas | Strengths | Gaps | Opportunities |
|---|---|---|---|
| **Data Collection and Monitoring** | ▪ USGS has an extensive water chemistry and discharge monitoring program.<br>▪ DWQ has an extensive monitoring program that revolves between basins. DWQ's *Elements to Utah's Monitoring and Assessment Program, 2020-2030* (DWQ 2020) outlines DWQ's monitoring strategy. Additionally, DWQ manages a Cooperative Monitoring Program that expands DWQ's monitoring capabilities by leveraging agency partner resources. Many satellite monitoring programs operate in the Colorado River Basin, many in conjunction with DWQ. | ▪ Water quality data is limited, both spatially and temporally.<br>- DWQ collects water quality grab samples based on a 6-year rotating basin schedule, which makes long-term trend analysis unfeasible.<br>- Not all areas in the GSL Basin are assessed; therefore, monitoring data are lacking in some areas.<br>▪ The WRI program may not always evaluate long-term efficacy of watershed restoration projects, and specifically, water quality and hydrologic impacts associated with implementation of watershed restoration projects.<br>- Documentation of outcomes and findings from WRI-funded projects is lacking.<br>- Monitoring data is not always collected or made available. | ▪ Establish water quality monitoring objectives. Water quality monitoring objectives help ensure that data collected can be used to measure progress against goals. Potential monitoring objectives include filling data gaps and monitoring trends over time. [PROGRAM]<br>▪ Increase the network of water quality and streamflow gages in the watershed. [PROGRAM]<br>- Adding water quality monitoring stations instrumented with water quality probes could help increase the temporal resolution of available data.<br>▪ Assess all areas of the basin for their water quality and achievement of beneficial uses. [PROGRAM]<br>▪ Add water quality sondes to existing gauging stations (USGS gages). [TASK]<br>▪ DWQ could provide consistent guidance and funding opportunities to implement stormwater management solutions that promote water quality objectives in the basin. [PROGRAM] |
| **Policy** | ▪ Stormwater regulations help to minimize degradation of water quality.<br>▪ The Salt Lake Stormwater Coalition and the Davis County Stormwater Coalition provide excellent resources to help prevent stormwater pollution.<br>▪ The Recommended State Water Strategy outlines specific recommendations for integrating water quality and water quantity management (Governor's Water Strategy Advisory Team 2017). Consequently, the topic has momentum and growing interest among regulators and policymakers.<br>▪ The newly formed watershed councils provide a platform to discuss the integration of watershed management, water supply, and water quality concerns.<br>▪ DWQ's nonpoint source program (and the associated body of literature associated with nonpoint source pollution) provides a means of understanding what factors influence water quality, and what BMPs can be implemented to achieve water quality goals. There is state and federal funding available to implement nonpoint source pollution prevention projects throughout the state.<br>▪ DNR's WRI program is robust and has funded extensive restoration projects in watersheds throughout the basin, including stream restoration projects. | ▪ Utah's water quantity and quality can no longer be thought of separately. Each facet affects the other, and there is a growing and urgent need for our state water policy to address them conjunctively.<br>▪ Stormwater regulations and systems do not entirely prevent or properly filter discharge of contaminants into waterbodies. | ▪ As Utah plans for its water future, it is critical to better integrate water quality and quantity into planning and management. [PROGRAM]<br>- DWQ should encourage and facilitate widespread pursuit of integrated watershed planning with permittees throughout the basin. |
| **Management** | ▪ Management of forests for forest health (and minimizing the risk of catastrophic wildfire) is generally protective of water quality in downstream streams and lakes.<br>▪ The Utah Grazing Improvement Program provides grant funding for ranchers and producers to implement improvements and restoration on their lands to protect watershed health (among other things).<br>- The Three Creeks Grazing, LLC is a great example of an innovative approach to grazing and watershed management.<br>- Forest and range management helps to minimize erosion and maximize filtration of pollutants, stabilization of streambanks, and shading of streams. This helps to prevent sedimentation, minimize turbidity, and minimize heating of water temperatures.<br>▪ NRCS and local conservation districts are critical partners in promoting and implementing nonpoint source pollution prevention BMPs.<br>▪ Reintroduction of beavers or the installation of beaver dam analogs can help to preserve water quality by raising the water table, restoring meadow floodplain habitats, and filling in incised eroding channels. Beaver reintroduction and beaver dam analogs have become more widely accepted and implemented in Utah. | ▪ The linkage between watershed BMPs and water quality/water supply is not definitively understood. For example, forest management and beaver dam analogs and their associated (quantitative) impacts on water supply and water quality are not well documented.<br>▪ Watershed improvement or restoration projects are generally pursued in response to water quality impairments and not proactively to avoid potential future impairments. | ▪ WRe should work with partners (DWQ, NRCS, and others) to develop a GSL-specific BMP database (handbook) for water users and land managers at various levels and for various objectives. [TASK]<br>- A toolbox-type of resource could be extremely beneficial for managers to reference and draw from.<br>- Watershed managers and groups (watershed councils) should develop projects from the toolbox and pursue funding for implementation.<br>▪ Evaluate the effects of forest management practices on water quality in specific areas, with an aim of identifying basin-scale best practices for forest management. [PROGRAM]<br>▪ Develop and implement studies analyzing the effects (on water quality and quantity) of BDAs, meadow restoration, and other watershed treatments. [PROGRAM] |

Notes:

BDA = beaver dam analog
BMP = best management practice
DNR = Utah Department of Natural Resources
DWQ = Utah Division of Water Quality
WRe = Utah Division of Water Resources
GSL = Great Salt Lake
NRCS = Natural Resources Conservation Service
USGS = U.S. Geological Survey
WRI = Watershed Restoration Initiative

## 7.2 Building Block Technical Questions

*How do we ensure a resilient water supply for GSL and all uses in its watershed?*

- How can forest management and watershed restoration benefit water quantity and quality by?
  - — Improving snowpack retention?
    - o What are past, current, and future snowpack retention characteristics in the watershed?
      - What are the past, current, and future characteristics/conditions? By basin?
      - What tools and/or data are we using to measure snowpack retention?
      - What are the trends? Key drivers for change?
      - What are the benefits from and potential to improve snowpack retention?
      - What are the risks for and impacts of declining snowpack retention?
      - What is the relationship of snowpack retention to water quantity and quality?
    - o What existing programs are in place that are working to improve snowpack retention?
      - What were their objectives?
      - What were their methods?
      - What were lessons learned?
      - Where have and are these being implemented?
      - What were their funding sources?
      - How can these programs be better coordinated?
      - Are there programs/projects that could benefit multiple objectives (for example, forest thinning to improve snowpack retention, minimize water use by trees, and to reduce the risk of wildfire)?
      - Are there any programs and/or projects that have been identified but have yet to be implemented and tested?
    - o How can snowpack retention be improved in the Great Salt Lake watershed?
      - How should objectives be defined? What metrics should be used?
      - What measures should be implemented? Where?
      - How should investments be prioritized?
      - How do we monitor, track, report, and evaluate success?
      - What is the return on investment?
  - — Increasing soil moisture?
    - o What are past, current, and future soil moisture characteristics in the watershed?
      - What are the past, current, and future characteristics/conditions? By basin?
      - What tools and/or data are we using to measure soil moisture?
      - What are the trends? Key drivers for change?
      - What are the benefits from and potential to increasing soil moisture?
      - What are the risks for and impacts of declining soil moisture?
      - What is the relationship of soil moisture to water quantity and quality?
    - o What existing programs are in place that are working to increasing soil moisture?
      - What were their objectives?
      - What were their methods?

        - What were lessons learned?
        - Where have and are these being implemented?
        - What were their funding sources?
        - How can these programs be better coordinated?

    - How can soil moisture be increased in the Great Salt Lake watershed?

        - How should objectives be defined? What metrics should be used?
        - What measures should be implemented? Where?
        - How should investments be prioritized?
        - How do we monitor, track, report, and evaluate success?
        - What is the return on investment?

- Enhancing river flows in low flow season?

    - What are past, current, and future river flow characteristics in the watershed?

        - What are the past, current, and future characteristics/conditions? By basin?
        - What tools and/or data are we using to measure stream flow?
        - What are the trends? Key drivers for change?
        - What are the benefits from and potential to enhancing river flows in the low flow season?
        - What are the risks for and impacts of declining river flows in the low flow season?
        - What is the relationship of low flow season river flows to water quantity and quality?

    - What existing programs are in place that are working to enhancing river flows in the low flow season?

        - What were their objectives?
        - What were their methods?
        - What were lessons learned?
        - Where have and are these being implemented?
        - What were their funding sources?
        - How can these programs be better coordinated?

    - How can river flows in the low flow season be enhanced in the Great Salt Lake watershed?

        - How should objectives be defined? What metrics should be used?
        - What measures should be implemented? Where?
        - How should investments be prioritized?
        - How do we monitor, track, report, and evaluate success?
        - What is the return on investment?

- Mitigating wildfire risk?

    - What are past, current, and future wildfire risk in the watershed?

        - What are the past, current, and future characteristics/conditions? By basin?
        - What tools and/or data are we using to evaluate wildfire risk?
        - What are the trends? Key drivers for change?
        - What are the benefits from and potential to mitigate wildfire risk?
        - What are the risks from and impacts from wildfire?
        - What is the relationship of wildfire risk to water quantity and quality?

    - What existing programs are in place that are working to mitigate wildfire risk?

        - What were their objectives?
        - What were their methods?
        - What were lessons learned?
        - Where have and are these being implemented?

- What were their funding sources?
- How can these programs be better coordinated?

o How can wildfire risk be mitigated in the Great Salt Lake watershed?

- How should objectives be defined? What metrics should be used?
- What measures should be implemented? Where?
- How should investments be prioritized?
- How do we monitor, track, report, and evaluate success?
- What is the return on investment?

— Improving water quality?

o What is past, current, and future water quality in the watershed?

- What are the past, current, and future characteristics/conditions? By basin?
- What tools and/or data are we using to evaluate water quality ?
- What are the trends? Key drivers for change?
- What are the benefits from and potential to improving water quality?
- What are the risks from and impacts from water quality?
- What is the relationship of water quality to water quantity ?

o What existing programs are in place that are working to improving water quality?

- What were their objectives?
- What were their methods?
- What were lessons learned?
- Where have and are these being implemented?
- What were their funding sources?
- How can these programs be better coordinated?

o How can water quality be improved in the Great Salt Lake watershed?

- How should objectives be defined? What metrics should be used?
- How much water is required to sustain high priority ecological sites?
- What measures should be implemented? Where?
- How should investments be prioritized?
- How do we monitor, track, report, and evaluate success?
- What is the return on investment?

# 8. References

AECOM. 2019. *Consequences of Drying Lake Systems around the World*. Prepared for State of Utah, Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/activities/DWQ-2019-010002.pdf. February 15.

Bear River Basin Water Budget Technical Group (BRBWBTG). 2023. Basin Stakeholder Meeting. July 27.

Bear River Water Conservancy District, Cache Water District, Central Iron County Water Conservancy District, Central Utah Water Conservancy District, Jordan Valley Water Conservancy District, Utah Division of Water Resources, Washington County Water Conservancy District, and Weber Basin Water Conservancy District (Prepare60). 2020. *Statewide Water Infrastructure Plan*. 2nd Edition. https://prepare60.com/Content/SWIP2.pdf.

Belovsky, G., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J. Leeuwen, and D. Allen. 2011. The Great Salt Lake Ecosystem (Utah, USA): Long term data and a structural equation approach: Reply. *Ecosphere*. Vol. 2, No. 3. 16 March. pp. 1–40.

Biederman, J.A., M.D. Robles, R.L. Scott, and J.F. Knowles. 2022. Streamflow Response to Wildfire Differs with Season and Elevation in Adjacent Headwaters of the Lower Colorado River Basin. *Water Resources Research*. Vol. 58, e2021WR030687. DOI: 10/1029/2021WR030687.

Bioeconomics. 2012. *Economic Significance of the Great Salt Lake to the State of Utah*. Prepared for State of Utah, Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/Activities/DWQ-2012-006864.pdf. January 26.

Bowen Collins & Associates. 2020. *Conservation Impacts Study*. Final Draft. Prepared for Weber Basin Water Conservancy District and Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/gsl-website-docs/other-studies/DWQ-2020-021042.pdf. October.

Capener, Annelise M., Robert B. Sowby, and Gustavious P. Williams. 2023. Pathways to Enhancing Analysis of Irrigation by Remote Sensing (AIRS) in Urban Settings. *Sustainability*. Vol. 15, No. 17. August. https://www.mdpi.com/2071-1050/15/17/12676.

CH2M HILL. 2012. *A Review: Farmington Bay Hydrology and Water Management*. Final. Prepared for the Utah Department of Natural Resources, Division of Forestry, Fire, & State Lands. January.

CH2M HILL. 2016. *Hydrology Assessment of Willard Spur, Great Salt Lake, 2011-2013: Development of Water Quality Standards for Great Salt Lake*. Prepared for Utah Division of Water Quality.

ClydeSnow and Jacobs. 2020. *Water Strategies for Great Salt Lake, Legal Analysis and Review of Select Water Strategies for Great Salt Lake*. Final (Updated). Prepared for Great Salt Lake Advisory Council, Utah Department of Natural Resources, Utah Department of Environmental Quality. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/activities/DWQ-2020-017633.pdf. September 10.

Downard, B. 2020. *FY 20, FY21, and FY 22 Region 8 Wetland Program Development Grant Proposal – EPA-REG8-WPDG-20-01*.

Dutta, S., B.M. Crookston, M. Rasmussen, and E. Larsen. 2021. Predicting Flow through the Causeway of the Great Salt Lake using Hydrodynamic Simulations and Artificial Neural Networks. *Hydraulics Report No. 4450*. Final. Prepared by Utah State University, Utah Water Research Laboratory for the Utah Department of Natural Resources, Division of Forestry, Fire, & State Lands. July 31.

ECONorthwest. 2019. *Assessment of Potential Costs of Declining Water Levels in Great Salt Lake*. Prepared for Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/activities/DWQ-2019-012913.pdf. November.

Goeking, S.A. and D.G. Tarboton. 2020. Forests and Water Yield: A Synthesis of Disturbance Effects on Streamflow and Snowpack in Western Coniferous Forests. *Journal of Forestry*. pp. 172-192.

Governor's Water Strategy Advisory Team. 2017. *Recommended State Water Strategy.* Facilitated by Envision Utah. July. https://static1.squarespace.com/static/5c059ead36099b1445c1d246/t/5d0175481376fd00017313c4/1560376658209/Water+Strategy+PDF.pdf.

Great Salt Lake Resolution (HCR-10) Steering Group. 2020. *Recommended Actions to Ensure Adequate Water Flows to Great Salt Lake and Its Wetlands.* Final. December. https://ffsl.utah.gov/wp-content/uploads/GSL_HCR10Report_final_Dec2020b.pdf.

Great Salt Lake Salinity Advisory Committee (GSLSAC). 2020. *Standard Operating Procedure, Great Salt Lake Water Density Measurement and Salinity Calculation: Utah Geological Survey Open-File Report 728*. https://doi.org/10.34191/OFR-728.

Great Salt Lake Salinity Advisory Committee (GSLSAC). 2021. *Influence of Salinity on the Resources and Uses of Great Salt Lake.* Final. Prepared for the Utah Division of Water Quality and Utah Division of Forestry, Fire, & State Lands. July 27. https://ffsl.utah.gov/wp-content/uploads/GSLSAC_SalinityInfluencesRangesTM_Final_July2021.pdf.

Great Salt Lake Strike Team (GSL Strike Team). 2023. *Great Salt Lake Policy Assessment: A synthesized resource document for the 2023 General Legislative Session*. February 9. https://gardner.utah.edu/wp-content/uploads/GSL-Assessment-Feb2023.pdf.

Jacobs Engineering Group Inc. (Jacobs). 2019a. *2018 Annual Project Operating Report: Technology-based Phosphorus Effluent Limit Variance Compliance Monitoring at Great Salt Lake.* Prepared for North Davis Sewer District. February.

Jacobs Engineering Group Inc. (Jacobs). 2019b. *Phase II – GSLIM Evaluation: Great Salt Lake Integrated Model (GSLIM), An Integrated Water Resource Management Tool for the Great Salt Lake Watershed*. Prepared for Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/DWQ-2022-028692.pdf. September 26.

Jacobs Engineering Group Inc. (Jacobs). 2020. *2019 Annual Project Operating Report: Technology-based Phosphorus Effluent Limit Variance Compliance Monitoring at Ogden Spur, Great Salt Lake*. Prepared for North Davis Sewer District. February.

Jacobs Engineering Group Inc. (Jacobs). 2021. *2020 Annual Project Operating Report, Technology-based Phosphorus Effluent Limit Variance Compliance Monitoring at Outfall 001 to Farmington Bay, Great Salt Lake*. Prepared for North Davis Sewer District. February.

Jacobs Engineering Group Inc. (Jacobs). 2023a. *Model Scoping Plan: Great Salt Lake Basin Integrated Plan*. Prepared for Utah Department of Natural Resources, Division of Water Resources. September.

Jacobs Engineering Group Inc. (Jacobs). 2023b. *Great Salt Lake Basin Integrated Plan Project Database*. MS Excel Database of Existing Projects, Policies, Data gaps, and Recommendations. Available on file at Jacobs Engineering, Salt Lake City, Utah.

Jacobs Engineering Group Inc. (Jacobs). 2023c. *Great Salt Lake Basin Integrated Plan Water Budget Scoping Plan*. Available on file at Jacobs Engineering, Salt Lake City, Utah.

Jordan River Basin Water Budget Technical Group. 2023. Basin Stakeholder Meeting. July 25.

JUB Engineers, Inc.. 2018. *Drought Contingency Plan*. Prepared for Weber Basin Water Conservancy District. https://weberbasin.gov/Docs/DCP%20Executive%20Summary.pdf.

Julander, R. P. and Clayton, J. A. 2018. Determining the proportion of streamflow that is generated by cold season processes versus summer rainfall in Utah, USA. *Journal of Hydrology: Regional Studies*. Vol. 17. June. pp. 36–46. https://doi.org/10.1016/j.ejrh.2018.04.005.

Kirby, S. 2022. *Wetland Water Budget and Wetland Change Analysis for The Nature Conservancy's Great Salt Lake Shorelands Preserve*. Grant application submitted to the Utah Division of Forestry, Fire, and State Lands for FY22-FY23.

Kirby, Stefan M., Paul C. Inkenbrandt, and Andrew Rupke. 2019. *Mapping Groundwater Quality and Chemistry Adjacent to Great Salt Lake, Utah.* Open File Report 699. Utah Geological Survey. https://ugspub.nr.utah.gov/publications/open_file_reports/ofr-699/ofr-699.pdf.

LaMalfa, E.M. and R. Ryle. 2008. Differential Snowpack Accumulation and Water Dynamics in Aspen and Conifer Communities: Implications for Water Yield and Ecosystem Function. *Ecosystems*. Vol. 11. pp. 569-581.

Lang, O.T., Mallia, D., and S. McKenzie Skiles. 2023. The shrinking Great Salt Lake contributes to record high dust-on-snow deposition in the Wasatch Mountains during the 2022 snowmelt season. *Environmental Research Letters*. 18 064045.

Lundquist, J.D., S.E. Dickerson-Lange, J.A. Lutz, and C.C. Nicoleta. 2013. Lower Forest Density Enhances Snow Retention in Regions with Warmer Winters: A Global Framework Developed from Plot-scale Observations and Modeling. *Water Resources Research*. Vol. 49. pp. 6356-6370. Doi: 10.1002/wrcr.20504.

MacDonald, L.H. and J.D. Stednick. 2003. Forests and water: A state-of-the-art review for Colorado. *CWRRI Completion Report No. 196*. Fort Collins, CO: Colorado State University. https://www.fs.usda.gov/research/treesearch/59257.

Michael Baker International. 2020. *A Guide to Low Impact Development within Utah*. December 2018, Revised August 2020. Prepared for Utah Department of Environmental Quality, Division of Water Quality. https://documents.deq.utah.gov/water-quality/stormwater/updes/DWQ-2019-000161.pdf.

Moore, R. and S. Wondzell. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review. Journal of the American Water Resources Association. Vol. 41, No. 4. pp. 763-784.

Natural Resources Conservation Service (NRCS). n.d. Utah Snow Survey Program. Accessed September 2023. https://www.nrcs.usda.gov/wps/portal/wcc/home/quicklinks/states/utah.

Oak Ridge National Laboratory (ORNL). n.d. *DAYMET Daily Surface Weather and Climatological Summaries*. Accessed September 2023. https://daymet.ornl.gov.

Perry, T.D. and J.A. Jones. 2017. Summer Streamflow Deficits from Regenerating Douglas-fir Forest in the Pacific Northwest, USA. *Ecohydrology*. Vol. 10. pp. 1-13.

PRISM Climate Group. 2023. *PRISM Climate Data*. https://prism.oregonstate.edu.

Rasmussen, M., S. Dutta, B.T. Neilson, and B.M. Crookston. 2021. CFD Model of the Density-Driven Bidirectional Flows through the West Crack Breach in the Great Salt Lake Causeway. *Water 2021*. Vol. 13, No. 17, 2423.

Richter, Brian D. 2022. Decoupling Urban Water Use from Population Growth in the Colorado River Basin. *Journal of Water Resources Planning and Management*. Vol. 149, No. 2. December 15. https://ascelibrary.org/doi/10.1061/JWRMD5.WRENG-5887.

Roundy, B. A., K. Young, N. Cline, A. Hulet, R.F. Miller, R.J. Tausch, J.C. Chambers, and B. Rau. 2014. Piñon-Juniper Reduction Effects on Soil Temperature and Water Availability of the Resource Growth Pool. *Rangeland Ecology & Management*. Vol. 67, No. 5. September. pp. 495–505. https://www.sciencedirect.com/science/article/pii/S155074241450084X?via%3Dihub.

Roundy, B.A., R.F. Miller, R.J. Tausch, J.C. Chambers, and B.M. Rau. 2020. Long-term effects of tree expansion and reduction on soil climate in a semiarid ecosystem. *Ecosphere*. Vol. 11, No. 9. September. https://esajournals.onlinelibrary.wiley.com/doi/10.1002/ecs2.3241.

Schnorbus, M. and Y. Alila. 2004. Forest harvesting impacts on the peak flow regime in the Columbia Mountains of southeastern British Columbia: An investigation using long-term numerical modeling. *Water Resources Research*. Vol. 40, No. 5. May. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2003WR002918.

Sowby, Robert B. and Andrew J. South. 2023. Innovative water rates as a policy tool for drought response: Two case studies from Utah, USA. *Utilities Policy*. Vol. 82. June. https://www.sciencedirect.com/science/article/pii/S0957178723000826?via%3Dihub.

Sowby, Robert B., Gustavious P. Williams, and Andrew J. South. 2023. Estimated Energy and Emissions Impacts of Pumping Pacific Ocean Water to Great Salt Lake. *ESS Open Archive*. August 8. https://essopenarchive.org/users/582443/articles/622494-estimated-energy-requirements-for-pumping-pacific-ocean-water-to-great-salt-lake.

Sumner, R., J. Schubauer-Berigan, T. Mulcahy, J. Miner, B. Dson, C. Godfrey, and J. Blue. 2010. *Alternative Futures Analysis of Farmington Bay Wetlands in The Great Salt Lake Ecosystem*. U.S. Environmental Protection Agency, Cincinnati, OH, EPA/ 600/ R-10/ 032.

Sun, N., M. Wigmosta, T. Zhou, J. Lundquist, S. Dickerson-Lange, and N. Cristea. 2018. Evaluating the functionality and streamflow impacts of explicitly modelling forest–snow interactions and canopy gaps in a distributed hydrologic model. *Hydrological Processes*. Vol. 32, No. 13. 30 June. pp. 2128–2140. https://doi.org/10.1002/hyp.13150.

SWCA Environmental Consultants. 2012. *Definition and Assessment of Great Salt Lake Health*. Prepared for Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/Activities/DWQ-2012-006862.pdf. January.

SWCA Environmental Consultants. 2017. *Water for Great Salt Lake*. Prepared for Great Salt Lake Advisory Council. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/Activities/DWQ-2018-003349.pdf. September.

The Langdon Group. 2023. *Great Salt Lake Basin Integrated Plan: Situational Assessment Report*. Prepared for the Utah Division of Water Resources. June.

Troendle, C.A., and W.K. Olsen. 1994. Potential Effects of Timber Harvest and Water Management on Streamflow Dynamics and Sediment Transport. Sustainable Ecological Systems: Implementing an Ecological Approach to Land Management. *USDA Forest Service General Technical Report RM-247, Fort Collins, CO*. pp. 34-41.

U.S. Congress. 1980. *Public Law 96-189* (also referred to as the Bear River Compact). February 8. https://www.congress.gov/96/statute/STATUTE-94/STATUTE-94-Pg4.pdf.

U.S. Environmental Protection Agency (EPA). n.d. *Streamflow Projections Map*. Accessed September 12, 2023. https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=48dcf8ca136a49a298a60e31422d58f0.

U.S. Forest Service (USFS). 2022. Biochar Basics: An A-to-Z Guide to Biochar Production, Use, and Benefits. *Rocky Mountain Research Station Science You Can Use Bulletin*. Issue 54. May/June 2022.

U.S. Geological Survey (USGS). n.d.a. *Great Salt Lake Hydro Mapper*. Accessed September 2023. https://webapps.usgs.gov/gsl.

U.S. Geological Survey (USGS). n.d.b. *USGS Water Data for the Nation*. Accessed September 12, 2023. https://waterdata.usgs.gov/nwis.

U.S. Geological Survey (USGS). 2021. *Sagebrush conservation strategy—challenges to sagebrush conservation*. USGS Open-File Report 2020-1125. Prepared by T.E. Remington, P.A. Deibert, S.E. Hanser, D.M. Davis, L.A. Robb, and J.L. Welty. Prepared in cooperation with the Western Association of Fish and Wildlife Agencies, the Bureau of Land Management, and the U.S. Fish and Wildlife Service. https://pubs.usgs.gov/of/2020/1125/ofr20201125.pdf.

Udall, Bradley and Jonathan Overpeck. 2017. The twenty-first century Colorado River hot drought and implications for the future. *Water Resources Research*. Vol. 53, No. 3. February 17. pp. 2404–2418. https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2016WR019638.

Utah Department of Environmental Quality (DEQ). 2021. *Great Salt Lake & Water Reuse: Determining the Future of Great Salt Lake*. https://documents.deq.utah.gov/water-quality/standards-technical-services/great-salt-lake-advisory-council/activities/DWQ-2021-019529.pdf.

Utah Department of Natural Resources (DNR). 2021. *Water Resources Plan, Utah State Water Plan*. December. https://water.utah.gov/wp-content/uploads/2022/01/Water-Resources-Plan-Single-Page-Layout.pdf.

Utah Department of Natural Resources, Division of Forestry, Fire and State Lands (DNR FFSL). 2013a. *Great Salt Lake Comprehensive Management Plan and Record of Decision*. Final. March. https://ffsl.utah.gov/wp-content/uploads/OnlineGSL-CMPandROD-March2013.pdf.

Utah Department of Natural Resources, Division of Forestry, Fire and State Lands (DNR FFSL). 2013b. *Great Salt Lake Mineral Leasing Plan and Record of Decision*. Final. March. https://ffsl.utah.gov/wp-content/uploads/OnlineGSL-MLPandROD-March2013.pdf.

Utah Division of Water Resources (WRe). 2021. *Water Resources Plan*. December. https://water.utah.gov/2021waterplan/.2021.

Utah Division of Water Resources (WRe). n.d.a. *Utah's Water Budget*. https://dwre-utahdnr.opendata.arcgis.com/pages/water-budget. Accessed September 22, 2023

Utah Division of Water Resources (WRe). n.d.b. *Water Reports*. https://water.utah.gov/water-reports/. Accessed September 22, 2023

Utah Division of Water Rights (WRi). 2008. *Water Use and Streamflow Records*. September 23. https://waterrights.utah.gov/distinfo/default.asp.

Utah Division of Water Quality (DWQ). 2014a. *Quality Assurance Project Plan for the Great Salt Lake Baseline Sampling Plan.* May 1. https://documents.deq.utah.gov/water-quality/standards-technical-services/gsl-website-docs/monitoring-protocols/DWQ-2019-000447.pdf.

Utah Division of Water Quality (DWQ). 2014b. *A Great Salt Lake Water Quality Strategy*. Final. September. https://documents.deq.utah.gov/water-quality/standards-technical-services/gsl-website-docs/gsl-wq-strategy/DWQ-2019-000535.pdf.

Utah Division of Water Quality (DWQ). 2014c. *Core Component 2: Strategic Monitoring and Research Plan*. Final. September. https://documents.deq.utah.gov/water-quality/standards-technical-services/gsl-website-docs/gsl-wq-strategy/DWQ-2019-000422.pdf.

Utah Division of Water Quality (DWQ). 2016. *Prioritizing Utah's 303(d) List.* November 23. https://documents.deq.utah.gov/legacy/programs/water-quality/watersheds/docs/2016/303d-list-for%20tmdl-development.pdf.

Utah Division of Water Quality (DWQ). 2020. *Elements to Utah's Monitoring and Assessment Program, 2020-2030.* Version 2.2. September 8. https://documents.deq.utah.gov/water-quality/monitoring-reporting/DWQ-2021-018149.pdf.

Utah Division of Water Quality (DWQ). 2022. *Workplan for Ongoing Monitoring of Great Salt Lake Water Quality to Inform Management of the New Breach*. Draft. Prepared for review by the GSL Salinity Advisory Committee. September. Available on file at Jacobs Engineering, Salt Lake City, Utah.

Utah Division of Water Quality (DWQ). 2023. *Quality Assurance Program Plan for Environmental Data Collection from Ambient Waters.* Final. Revision No. 2.0. Effective August 1, 2023. https://drive.google.com/file/d/1CkjxV3WAzAh0x2ozaODc43Ad1PubyoYK/view.

Utah Geological Survey (UGS) and Utah Division of Water Quality (DWQ). 2017. *Utah's Wetland Program Plan – 2018-2023*. Version 1.0. Prepared for EPA Region 8 Wetlands Program. December.

Utah Governor's Office of Planning & Budget, Utah Governor's Office of Economic Opportunity, Utah Department of Agriculture and Food, Utah Department of Environmental Quality, Utah Department of Natural Resources, and Colorado River Authority of Utah. 2022. *Utah's Coordinated Action Plan for Water*. November. https://gopb.utah.gov/wp-content/uploads/2022/11/2022_11-Plan-for-Coordinated-Water-Action-FINAL.pdf.

Utah Lake Basin Water Budget Technical Group. 2023. Basin Stakeholder Meeting. August 2.

Weber River Basin Water Budget Technical Group. 2023. Basin Stakeholder Meeting. August 1.

Wilson Water Group. 2022. *AWOTF Case Study Final Report 2023, UCRC Phase III Report*.

World Climate Research Programme (WCRP). n.d. CMIP5 - Coupled Model Intercomparison Project Phase 5 - Overview. Archived at: U.S Department of Energy, National Nuclear Security Administration, Lawrence Livermore National Laboratory, Program for Climate Model Diagnosis and Intercomparison. Accessed August 2023. https://pcmdi.llnl.gov/mips/cmip5/.

York, Chris, E. Goharian, and S.J. Burian. 2015. Impacts of Large-Scale Green Infrastructure Implementation and Climate Change on Receiving Water Response in the Salt Lake City Area. *American Journal of Environmental Science*. Vol. 11, No. 4. pp. 278–292.

Young, K.R., B.A. Roundy, and D.L. Eggett. 2013. Tree reduction and debris from mastication of Utah juniper alter the soil climate in sagebrush steppe. *Forest Ecology and Management*. Vol. 310. pp. 777–785.