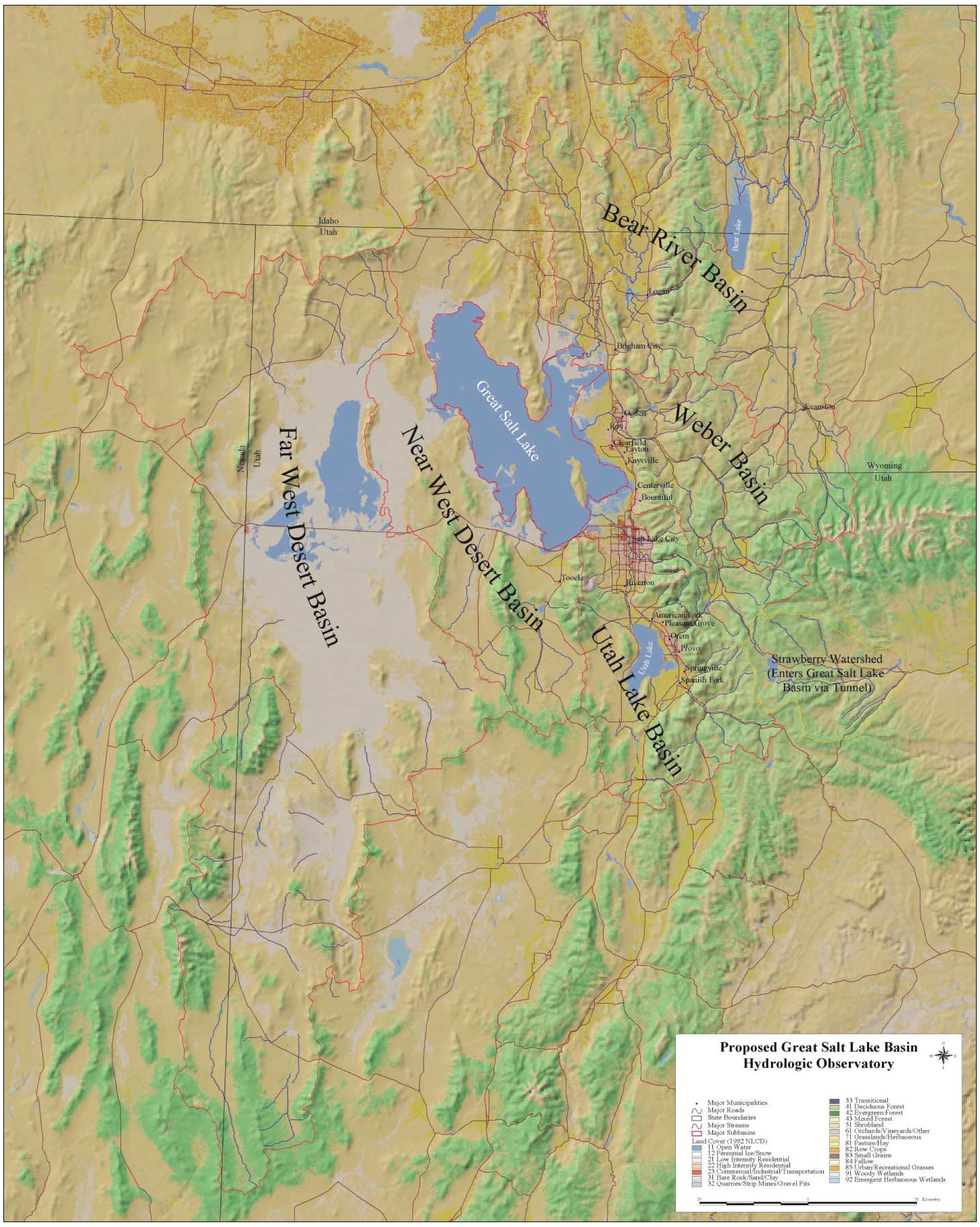
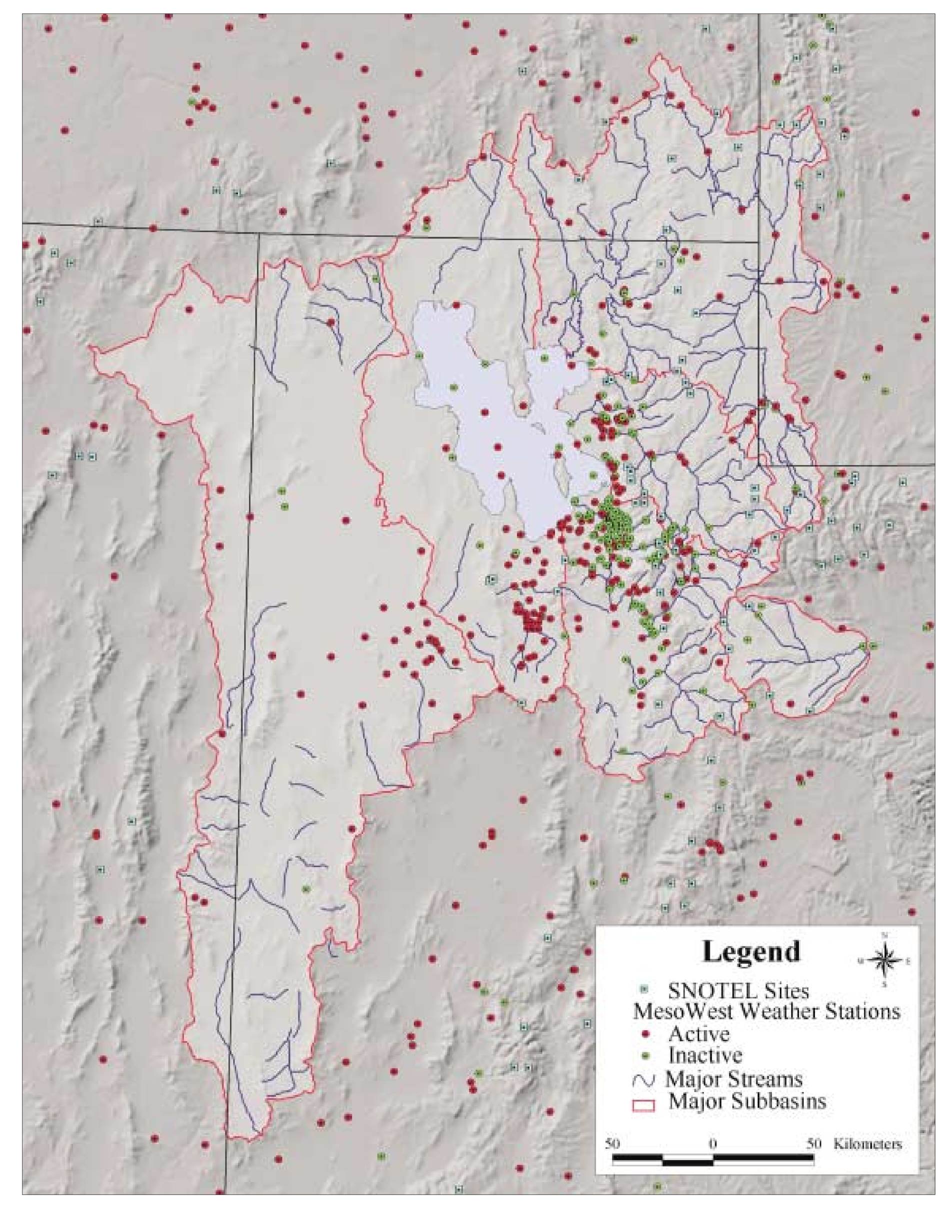
Great Salt Lake Basin

Hydrologic Observatory

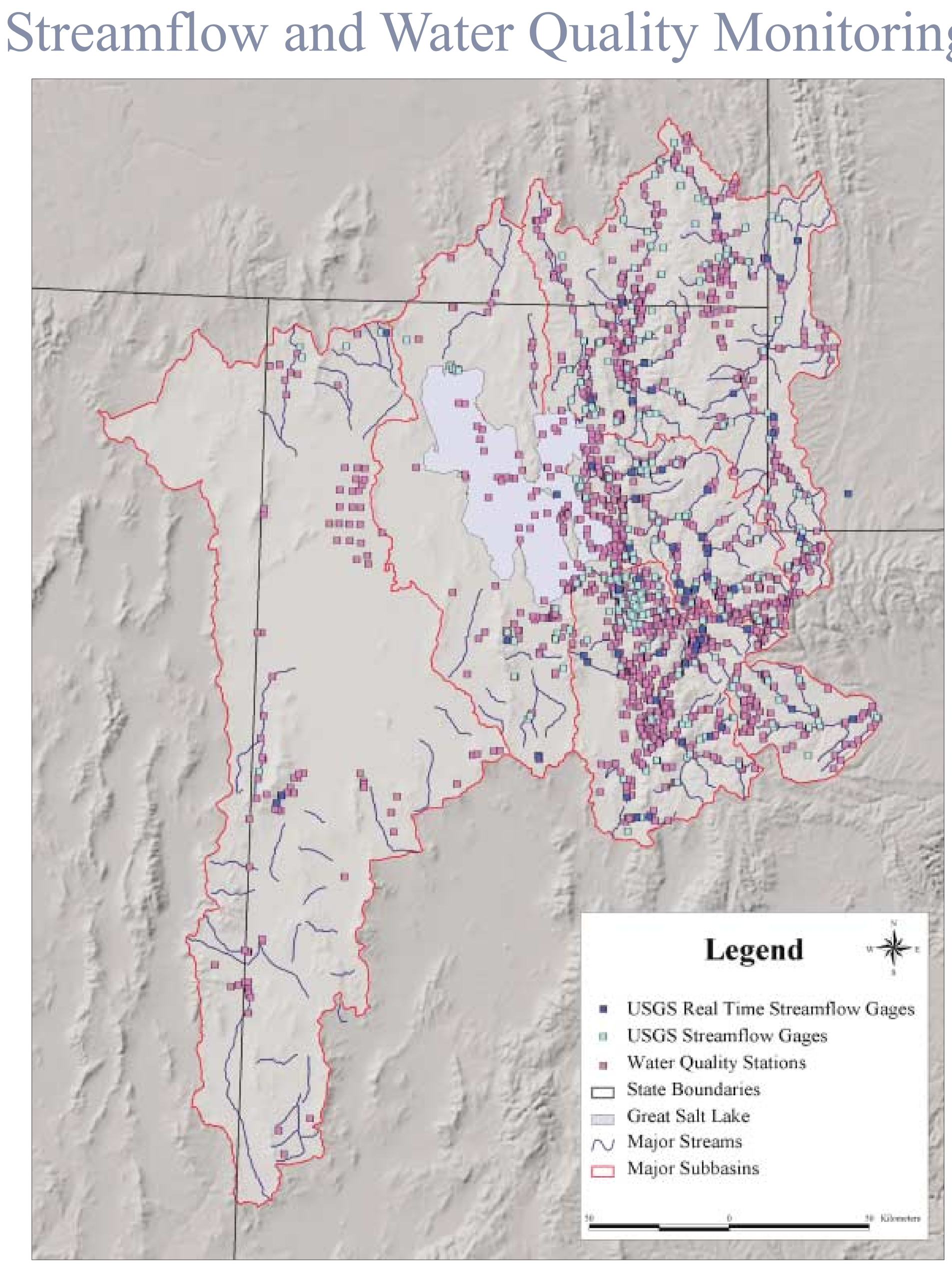
http://greatsaltlake.utah.edu



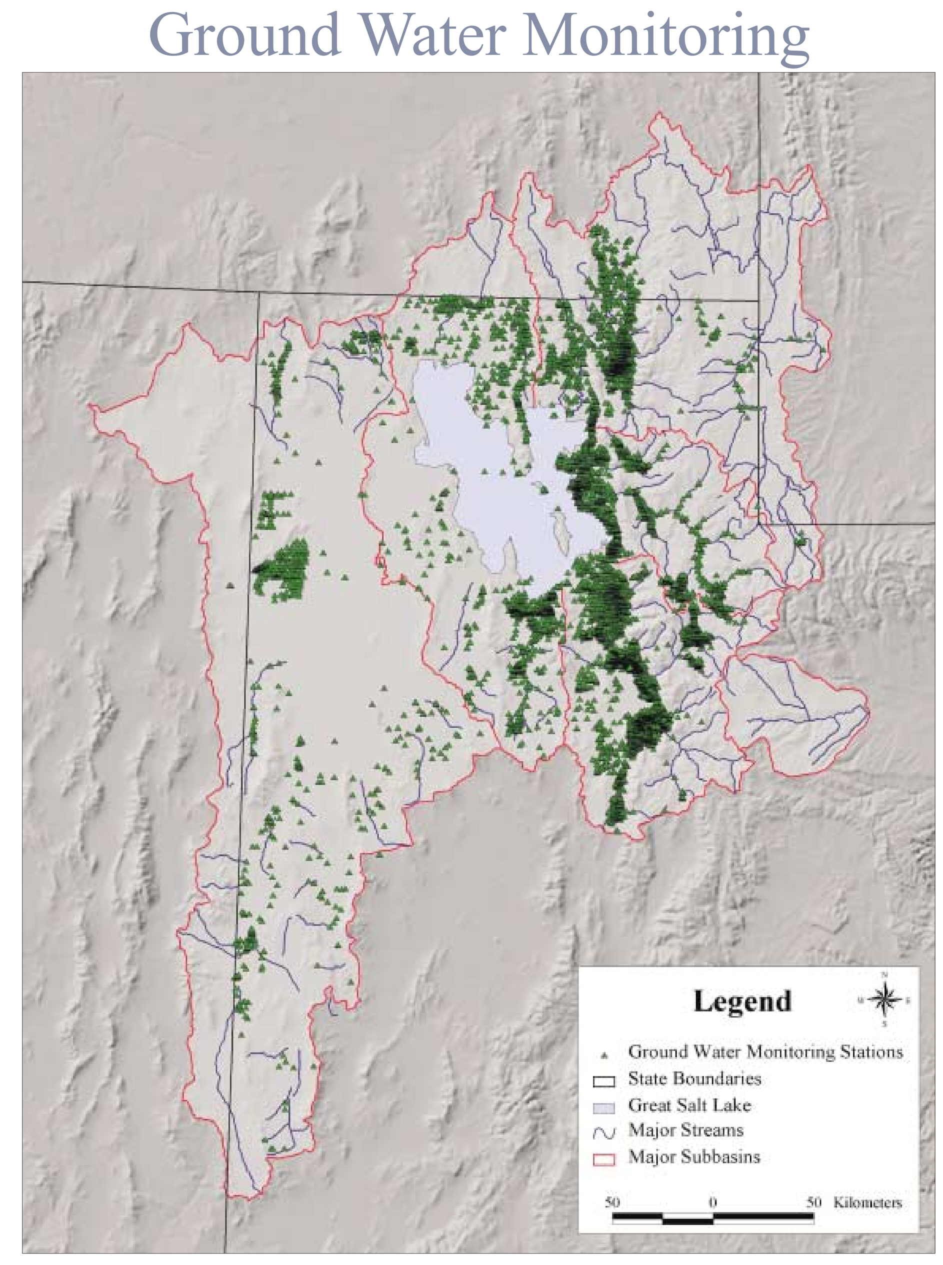
Weather and Climate Monitoring

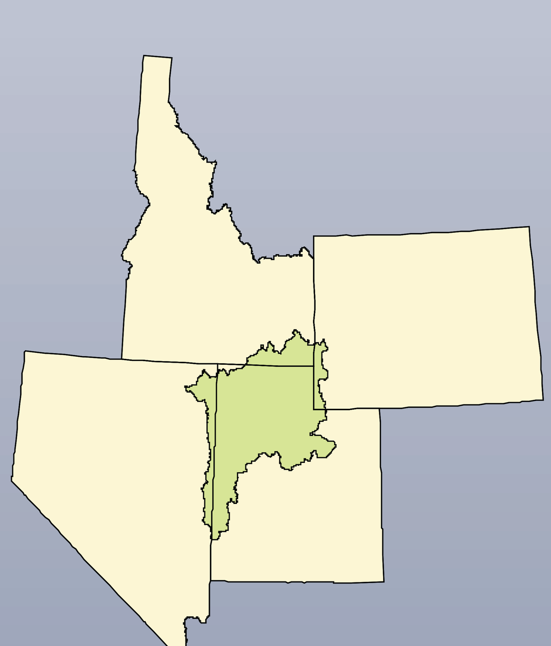


Streamflow and Water Quality Monitoring



Ground Water Monitoring





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A principal goal of CUAHSI is the development of an open community-based effort to revolutionize hydrologic science. The Great Salt Lake Basin Hydrologic Observatory development team is highly committed to this concept of openness. It is our hope that researchers from across the United States will involve themselves and even lead aspects of the proposed observatory. Please contact us if you would like to become part of the Great Salt Lake Basin Hydrologic Observatory Team or for more information regarding the Proposed Great Salt Lake Basin Hydrologic Observatory.

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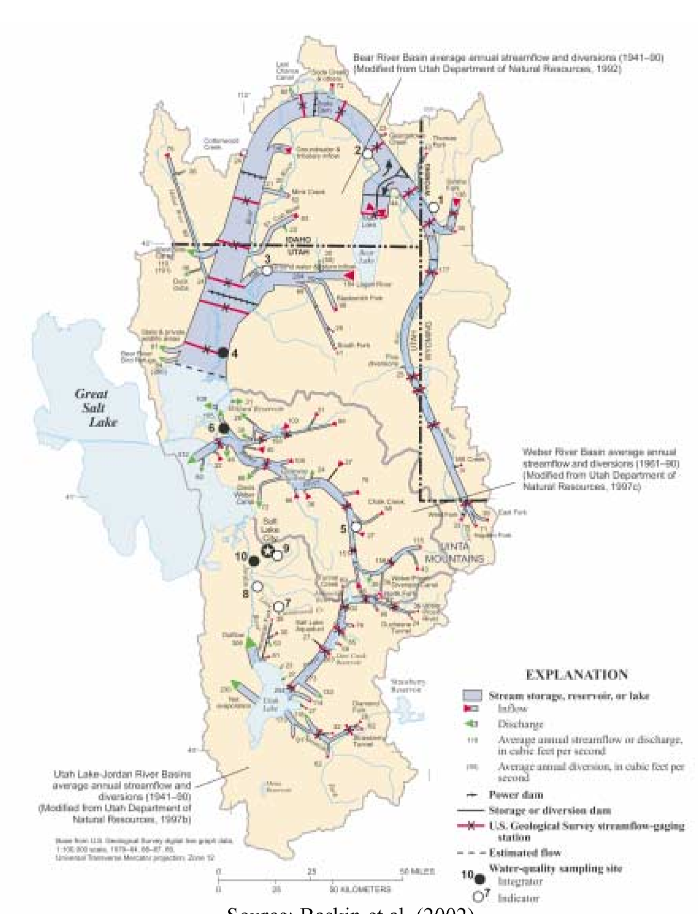
Science

The Great Salt Lake Basin is a microcosm for hydrology in the Western United States.

Rationale for Hydrologic Observatory Design

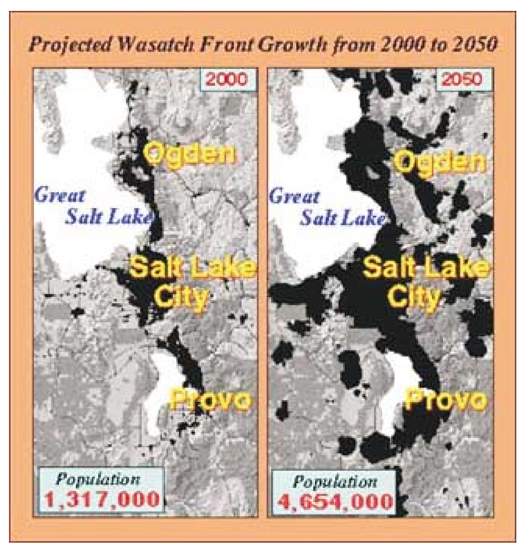
Overall the Great Salt Lake Basin is a unique location ideally suited, both physically and in terms of infrastructure, to addressing fundamental hydrologic science questions in western mountain basin systems in an open community-driven hydrologic observatory.

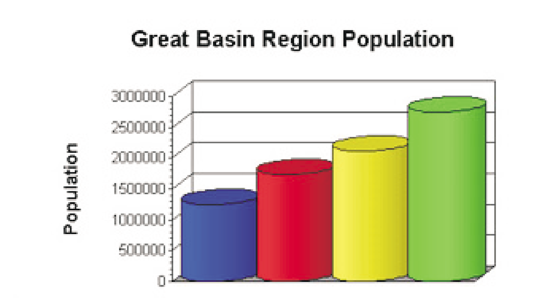
Nowhere in the United States is the societal importance of water more evident than in the arid west, where rapid population growth and limited water resources converge to reach near-crisis level during periods of drought.



Source: Baskin et al. (2002)

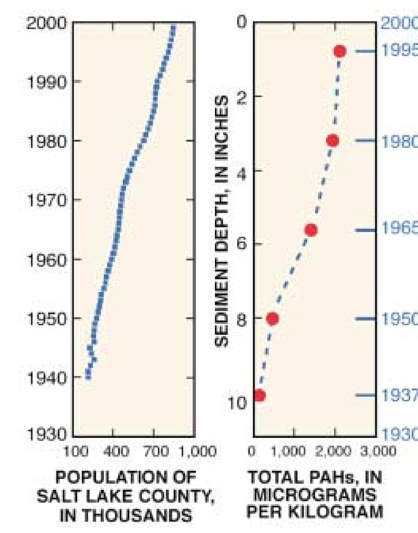
The Great Salt Lake Basin is tractable as a hydrologic observatory because it is closed and the lake serves as an integrator. Extremes in topography, climate, geology, ecology, and land use are captured in a compact area, allowing the overall system to be represented by a nested sampling design. The vast majority of inflow to the lake is contributed by the three major subwatersheds to the east, and characterization of the major fluxes in the basin can be accomplished with high density monitoring to the east of the lake with lower density monitoring to the west.





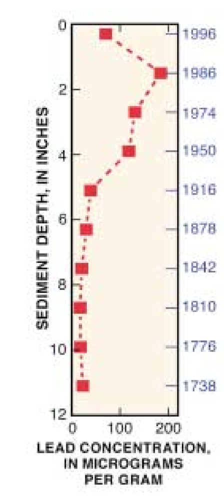
POP 1970	1246993
POP 1980	1738448
POP 1990	2117218
POP 2000	2742716

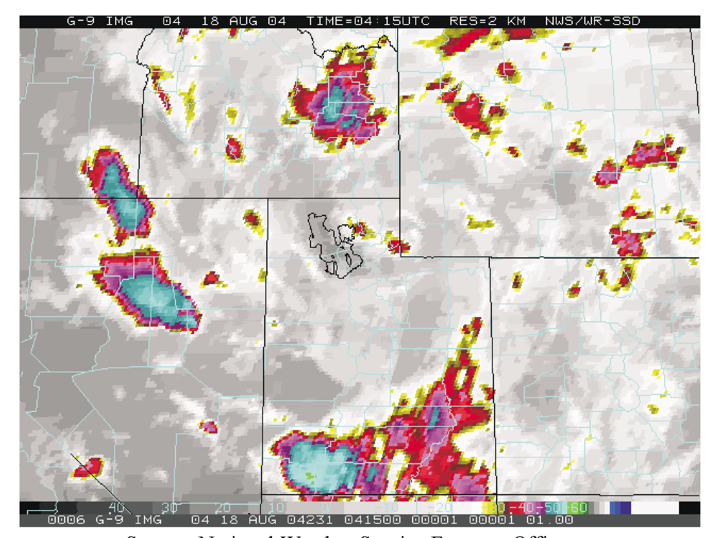
Located in one of the fastest-growing areas in the United States, the Great Salt Lake Basin provides the opportunity to observe climate and human-induced land-surface changes affecting water availability, water quality, and water use. These attributes reflect the changing relationship between people and water across the globe and make the Great Salt Lake Basin a microcosm of contemporary water resource issues and an excellent site to pursue interdisciplinary and integrated hydrologic science.



Due to the interest in water development of the early settlers, the basin has a rich hydrologic measurement infrastructure (precipitation, snowpack, streamflow, groundwater). Paleohydrologic research in the closed basin lakes (Bear Lake and Great Salt Lake) extends our knowledge of hydrologic processes well beyond the historical record. Analysis of the geologic record in accumulated lake sediments offers the ability to determine historic trends in lake inflow, volume and water quality.

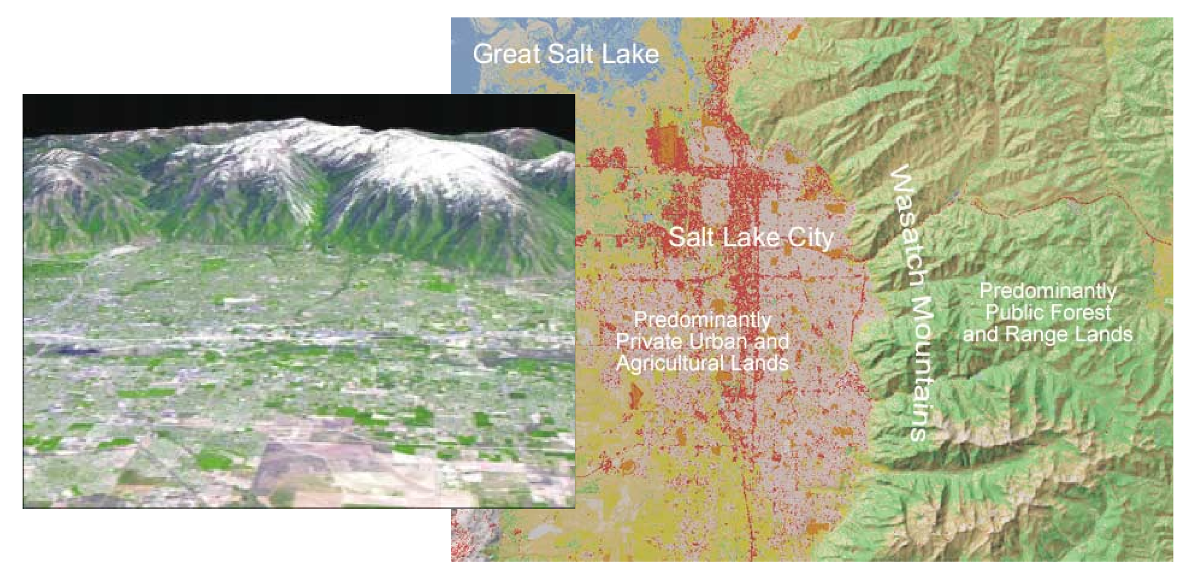
Figures: Waddell et al. (2004)



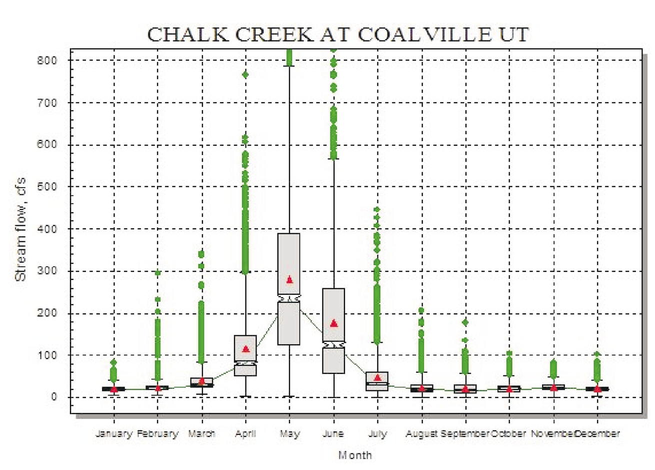


Source: National Weather Service Forecast Office

The Great Salt Lake Basin Hydrologic Observatory represents a significant advance in scale relative to scales over which hydrologic processes have previously been comprehensively measured. Furthermore, the scales over which atmospheric processes operate in the western U.S. require consideration of an area of this size.



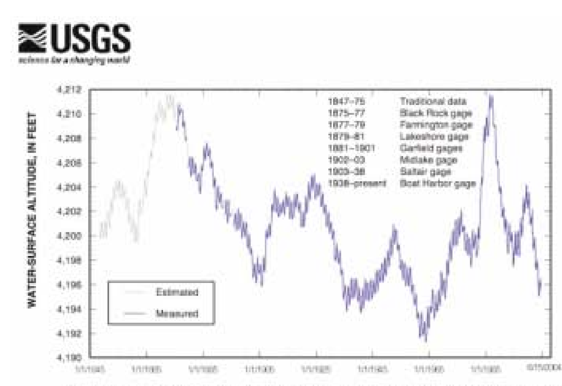
The steep topographic, climatic, and land-use gradients in the Great Salt Lake Basin provide a compactness that is unparalleled in the U.S., and that is more proximal to logistical support than any other comparable location in the U.S. For example, a 30 km transect can span from regional base-level to alpine catchment while remaining within 50 km of major research universities, an international airport, and major government agencies.



The Great Salt Lake Basin serves as a model for much of the western U.S. in that the hydrologic system is driven by snowmelt in the mountains that supplies water to the relatively arid valleys. The region is dominated by nonlinear interactions between snow deposition and loss in the mountains, streamflow, and groundwater recharge at high and mid-elevations, and evaporation from the desert floor. Few hydrologic models are able to represent the complexity of western mountain systems, making an observatory in this region critical for advancing these models.

The Great Salt Lake Basin is a closed basin system, and as such present a unique opportunity to close the water, solute, and sediment balances that is rarely possible in a watershed of a size sufficient for the study of atmospheric interactions.

Changes in the volume of the Great Salt Lake, which have been recorded since 1847, represent the integrated effects of all of the major components of the hydrologic cycle. The Great Salt Lake acts as a collector and integrator of hydrologic signals from the surrounding basin providing the opportunity to investigate fundamental hydrologic processes at scales that have been previously unexplored.



Science Themes

The input of the national hydrologic community is sought in expanding and refining the science themes and questions to develop a robust set of drivers for the Great Salt Lake Basin Hydrologic Observatory proposal.

The Great Salt Lake Basin serves as a model for much of the western United States in that the hydrology is driven by snowmelt in the mountains that supplies water to the relatively arid valleys. The region is dominated by nonlinear interactions between snow deposition and loss in the mountains, streamflow, groundwater recharge at high and mid-elevations, and evaporation from the desert floor. Important societal concerns center on:

How do climate variability and human-induced landscape changes affect hydrologic processes, water quality and availability, and aquatic ecosystems over a range of scales?

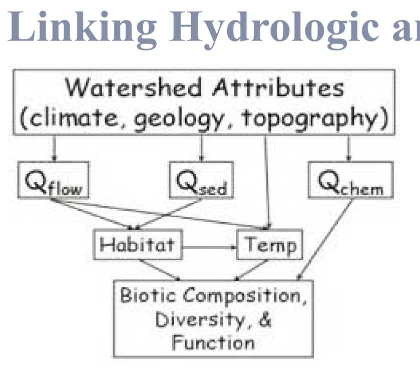
What are the resource, social, and economic consequences of these changes?

These questions cut across the following themes and are the fundamental issues that provide the thematic focus of the proposed Great Salt Lake Basin Hydrologic Observatory:

1. Water Quantity and Quality Management
2. Hydrogeomorphic Influences on Aquatic Ecosystems
3. Soil, Vegetation, Atmosphere Interactions
4. Social and Economic Dynamics

The fundamental hydrologic science hypotheses and questions listed here serve as the foundation for study of hydrologic processes related to water resources, water quality, biogeochemistry, riparian ecology, ecosystem state, streamflow and groundwater modeling, forecasting, resource management, and flood control. These questions are intended to illustrate the ability of a Great Salt Lake Hydrologic Observatory to address the five priority science topics and three cross cutting themes described by CUAHSI. . Although these questions are uniquely suited to the Great Salt Lake Basin, they concern hydrologic processes of broad national and societal significance.

Linking Hydrologic and Biogeochemical Cycles



How does climate variability affect soil microclimate (temperature and moisture regime) and soil organic carbon dynamics (SOC distribution, quality, decomposition, leaching) in vegetation types?

How does the sparse distribution of vegetation in much of the western U.S. and the variability of canopy structure and type (e.g. forests, sage, willows, etc.) influence the distribution of precipitation, evaporation/sublimation, and transpiration?

How will changing land use from predominantly agricultural to increasingly urban impact nutrient sources, loads, and cycling processes in the rivers of the Great Salt Lake Basin?

How might coupled biogeochemical cycles of C, N and P change with a transition from agricultural to urban land uses?

Hydrologic Extremes

Source: USGS

What is the outlook of episodic flooding events and inundation due to rises in the lake level?

What are possible realizations and frequencies of drought, and the effects on water resources?

How do these events alter feedbacks between the surface hydrology and atmospheric processes?

Hydrologic Influence on Ecosystem Functions

How are aquatic species (invertebrates and fisheries) and resources (i.e. habitat conditions) related ultimately to climate, topography, and geology?

How will these systems respond to change, both in climate and land use?

Sustainability of Water Resources

What are possible realizations and frequencies of drought, and the effects on water resources?

What is the outlook in terms of drought with respect to water resources, economic impact of lost lake industries, and reduced air quality due to dust generation?

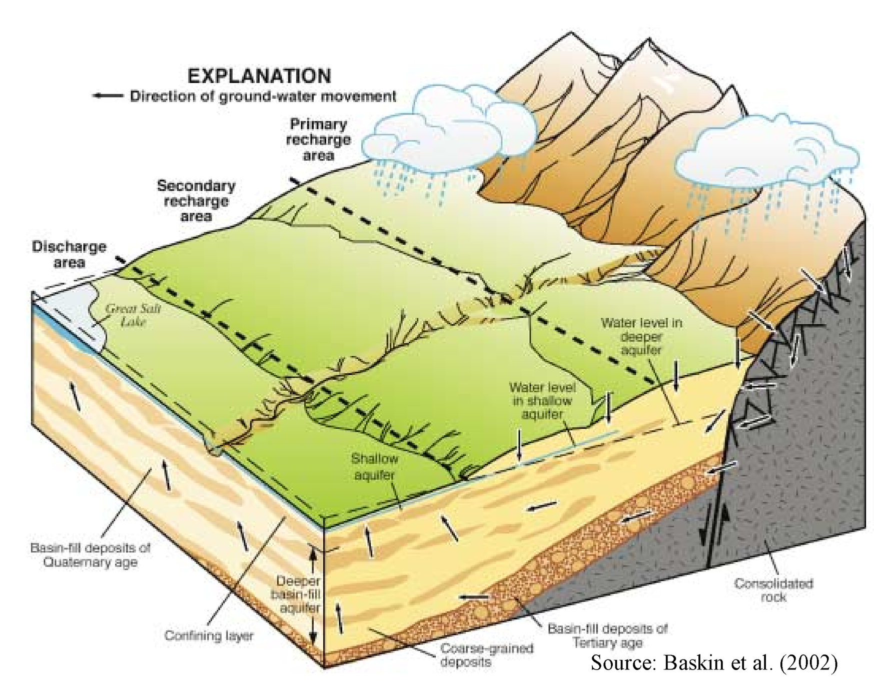
How is the sustainability of ground water resources related to the interaction between geology, precipitation and recharge?

What are the pathways by which recharge to groundwater occurs, and what is the role of faults and bedrock structure in hydrologic systems?

What are the groundwater budgets for the basins, and what are the contributions of bedrock-dominated groundwater flow to this budget?

How does the bedrock structure and composition of the mountainous regions affect the groundwater flow (alpine karst in carbonate rocks vs. deformed sedimentary rocks vs. igneous massifs)?

Where and how does bedrock flow cause underflow from one topographically defined watershed to another?



Source: Baskin et al. (2002)

Transport of Chemical and Biological Contaminants

What are the processes involved in movement of contaminants within the basin and into the Great Salt Lake?

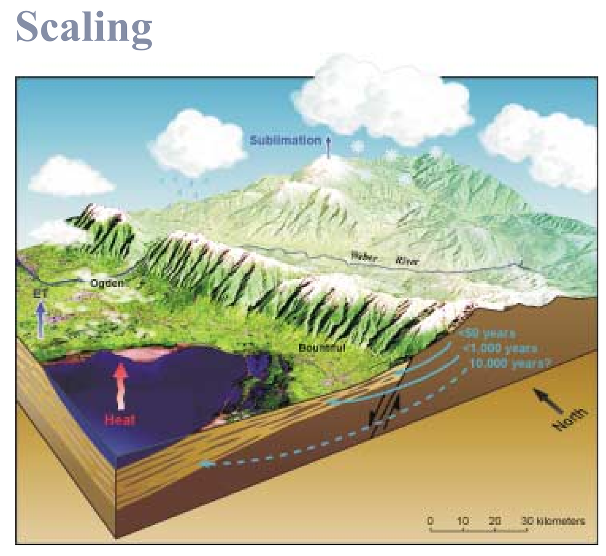
How are fluxes of contaminants within the Great Salt Lake Basin tied to land use, soil types, precipitation, and other watershed characteristics?

How can paleo-records in lake sediment cores aid in the understanding of sediment and pollutant fluxes within the basin?

What can tributary and lake water quality monitoring reveal about present fluxes and historic accumulation within the closed basin lakes?

How do biogeochemical processes affect the fate of dissolved and suspended constituents within the watershed, and what are the consequences of these processes on ecological systems?

Scaling



To what extent do the Great Salt Lake and surrounding salt playas impact precipitation in meteorologically down-gradient mountains relative to that arising from larger-scale atmospheric moisture fluxes into the Basin?

What roles do lake water evaporation and heating of overlying air masses play in down-gradient precipitation?

How do these roles change with lake volume?

What is the spatial distribution of groundwater residence times?

Does integration of this distribution lead to a meaningful recharge rate?

Can the spatial distribution and recharge rate of groundwater be linked to lake volume fluctuation?

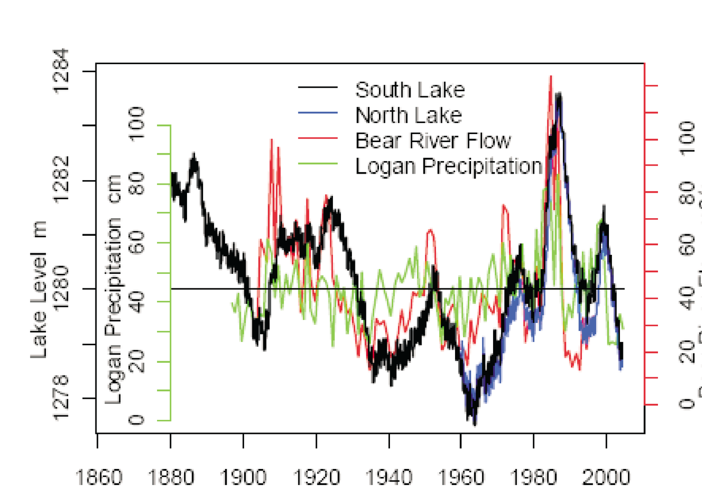
How much groundwater flux contributes to base flow in mid- and high-elevation streams?

Predictions and Limits to Predictions

How can we better predict natural and human induced changes in the hydrologic cycle so as to plan for and adapt to changes and uncertainties in water resources in a water-stressed semi-arid snowmelt driven system?

How can the historical record of Great Salt Lake volume, streamflow records, climate data, and other data sources be used to better understand the hydrologic processes in the Great Salt Lake Basin?

Can existing hydrologic models be modified or new models be developed that better describe the hydrologic processes of the mountain west, including the semi-arid lands of the Great Salt Lake Basin?



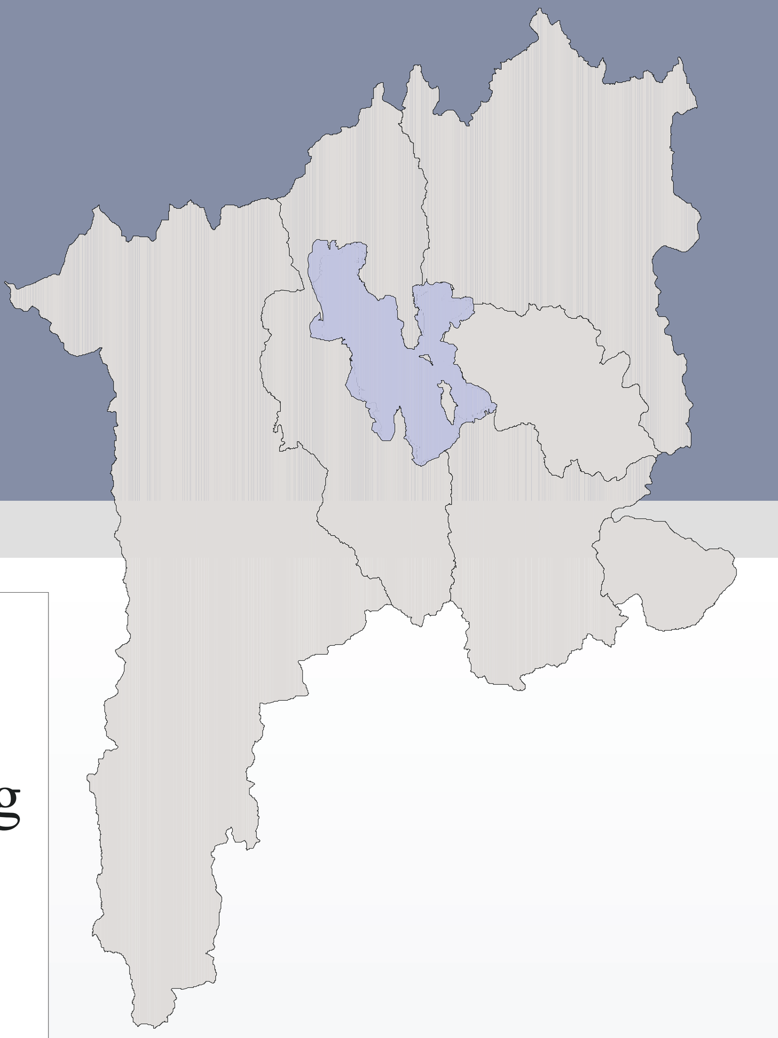
Forcing, Feedbacks, and Coupling

How does the aggregate water balance of a watershed reflect the integrated effect of nonlinear interactions among runoff, vegetation dynamics, mountain block groundwater dynamics, urbanization and water use dynamics?

What are the relative roles played by long and short-term climate variability and land use change due to population and economic growth in the region in driving the system dynamics?

Infrastructure

The basin has a rich hydrologic measurement infrastructure and long hydrologic record. Paleohydrologic observations in the closed basin lakes (Bear Lake and the Great Salt Lake) further extend this record.

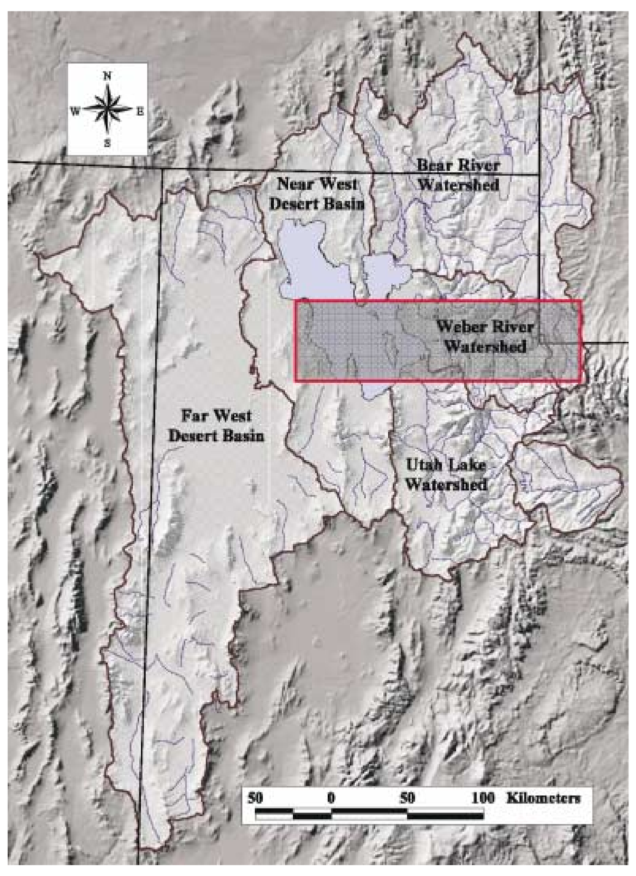


Proposed Core Data Infrastructure

It is proposed that the overall Great Salt Lake Basin be represented by selected focus areas in the contributing watersheds complemented by discrete measurements across the entire basin.

Input and involvement from the hydrologic community is sought to achieve a balance in the design that ensures a full partnership between universities, government, and the private sector at local, state, and national levels.

Mountain to Basin Transect



The essential hydrologic processes occurring in the Great Salt Lake Basins occur within the topographic, climatic, biological, and land use gradients between the mountain catchments and basin bottoms. We propose a highly instrumented 30-km mountain-to-basin transect (red rectangle) to investigate hydrologic processes extending from the mountain ridge top to the Great Salt Lake.

The following are characteristics of the proposed transect:

- Range in elevation from about 1200 m to 3200 m
- Range in precipitation from about 15 cm/yr to 150 cm/yr
- Range in evapotranspiration regimes from semi-arid to alpine
- Range in groundwater residence times from 10 to 10,000 years
- Range in biome type from semi-arid shrubland to alpine forest
- Range in land use from pristine to urban

This transect location has access and instrument and communication advantages with respect to sampling, including direct line-of-sight to the Promontory Point WSR-88D radar and existing meteorological equipment and communication infrastructure at the Francis Peak FAA radar installation located at the ridge crest.

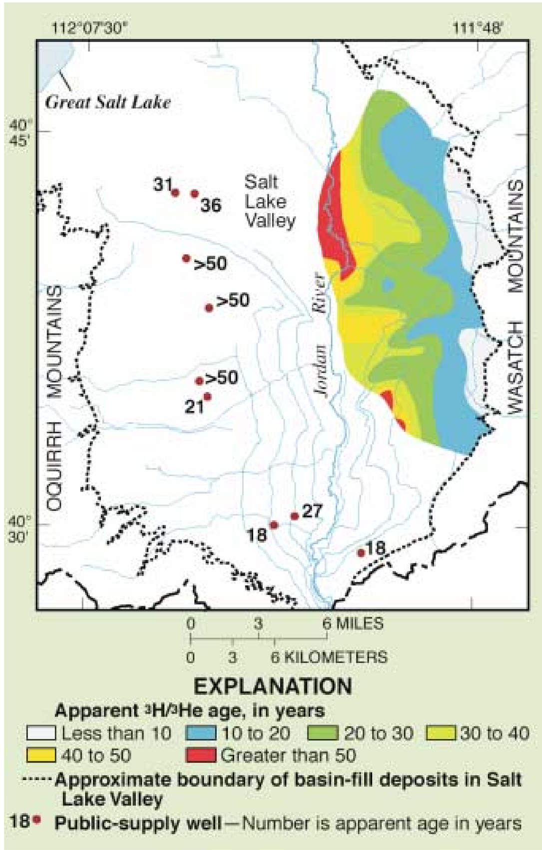
Less dense atmospheric measurements meteorologically upwind of the Great Salt Lake (West Desert Basin) will be made to allow observation of changes in air mass characteristics across the lake and mountain front.

Dense atmospheric, snowpack, and surface hydrologic and subsurface hydrologic monitoring will be conducted between the Great Salt Lake and the portion of the Weber Basin directly east of the Wasatch ridge crest.

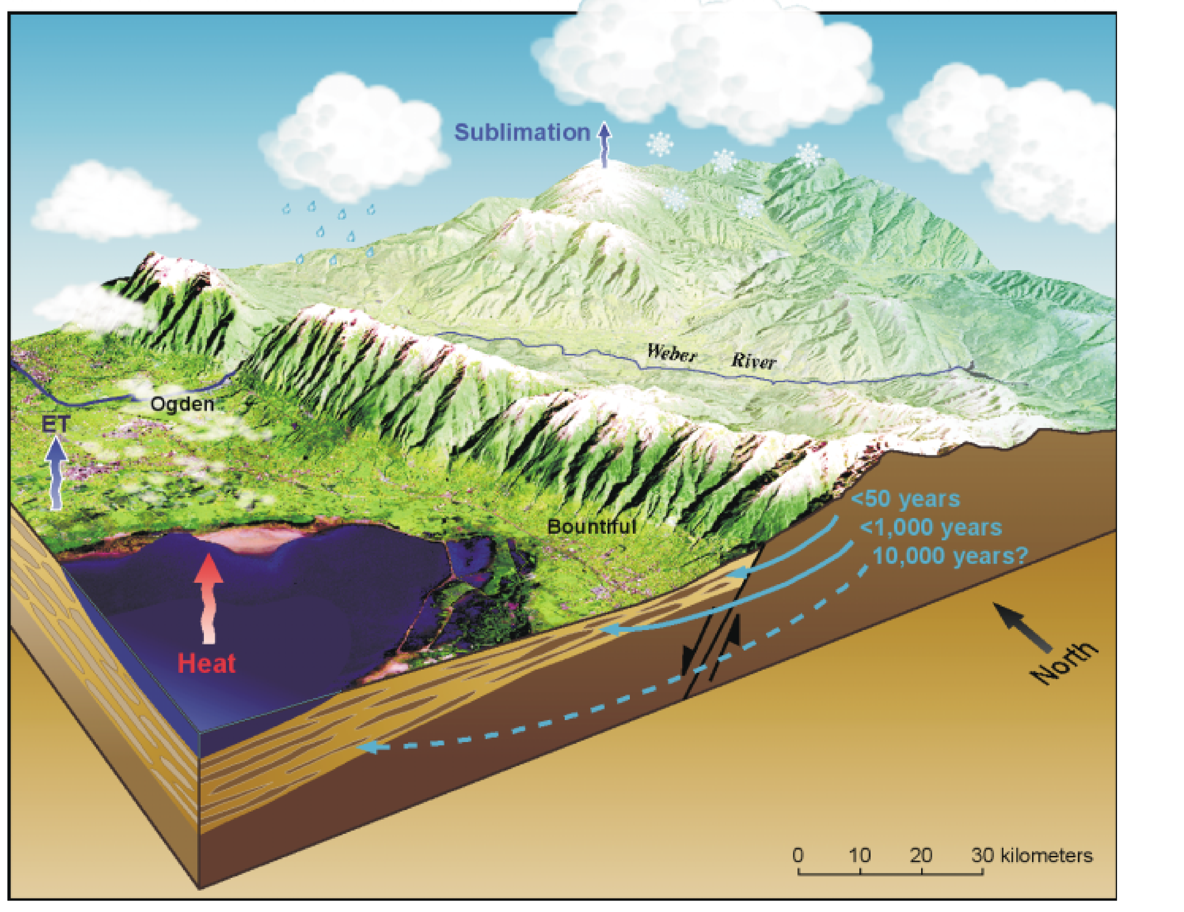
Less dense atmospheric, snowpack, and hydrologic infrastructure will be deployed within the eastern most portion of the Great Salt Lake Basin to the high Uinta Mountains.

The transect provides a compactness that presents not only logistical advantages, but also advantages in terms of increased interaction among researchers from different disciplines. The transect lies within 50 km of cities and universities that can provide necessary infrastructure support.

- Atmospheric fluxes will be quantified using an array of moisture and wind profilers that will be assimilated into mesoscale meteorological models.
- Remote sensing measurements will be used to observe energy balances, snow and evaporation, soil moisture and vegetation.
- Precipitation will be measured using radar, as well as shielded precipitation gages and snow pillows (SNOTEL).
- Meteorological flux stations (temperature, wind, humidity, eddy covariance) will monitor land to atmosphere exchange.
- In-situ soil moisture will be sampled using TDR and dielectric probes.
- Deep (greater than 300 m) multilevel sampling wells will be used to measure ground water levels, fluxes, and for sampling of age dating and environmental tracers. The deep wells will provide an unprecedented evaluation of flow and transport processes (including the interaction between groundwater and the thermal field) through a combined fractured rock and granular aquifer system.
- Stream gauging stations will include measurements of discharge, as well as water quality and tracers of interest.

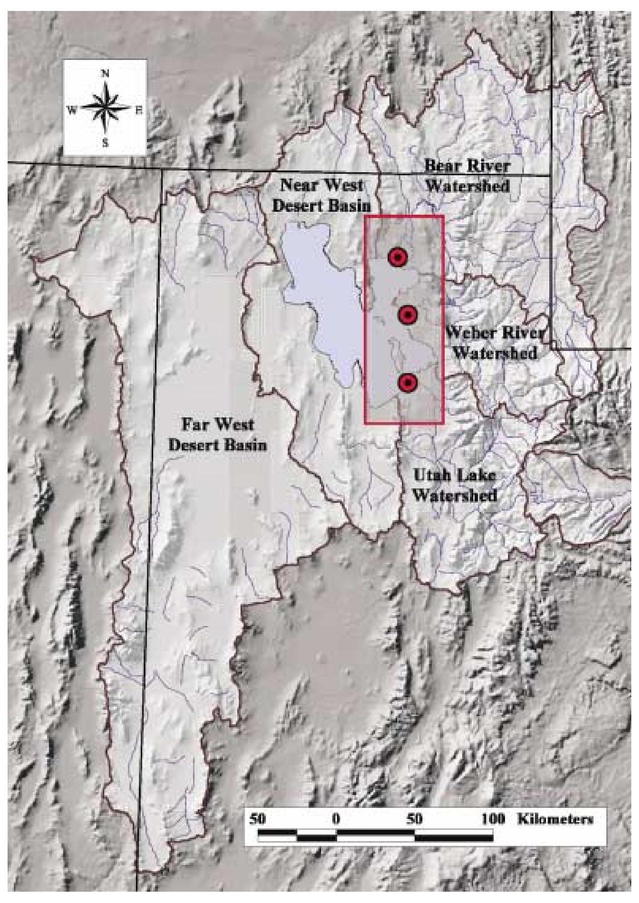


The mountain to basin transect will build upon recently obtained groundwater age data in the Salt Lake basin east of the Wasatch Mountains depicted in the figure above (Thiros and Manning, 2004). The change in age as a function of distance (age gradient) provides a direct measure of groundwater velocities and recharge rates (Manning, 2002).



This figure illustrates in a simple manner the conceptualization of several key hydrologic processes in the Great Salt Lake Basin that will serve as a basis for delineating the basin into stores for the quantification of storages, flow paths and fluxes. Stores include the atmosphere, snow pack, streams, lakes and reservoirs, soil moisture, and groundwater. Core data will focus on observing these quantities at multiple nested scales. The figure highlights the short distances over which large ranges in elevation, climate, vegetation, and land use occur. The compact nature of these mountain basin systems allows the development of densely instrumented areas to observe strong contrasts and process gradients.

Lake Sediment Coring, Tributary and Lake Sampling Program



Lake sediment cores provide a record of long term climate and hydrologic processes, as well as long term water quality trends; since they avoid the issues associated with short record lengths, inconsistent analytical methods, and below-detection aqueous concentrations.

Closed basin lakes are integrators and recorders of signals that might otherwise be difficult to discern based on discreet measurements made in individual tributary watersheds.

We propose to formalize a collaborative program involving core characterization activities, hydrologic monitoring activities, and biogeochemical investigations in order to relate climate, sediment accumulation, ecological indicator, and contaminant records to corresponding processes in the contributing watersheds.

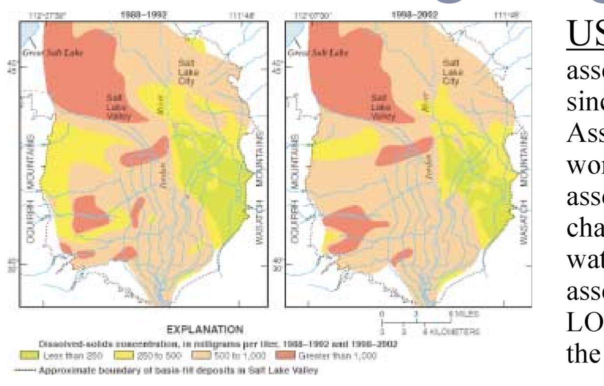
Proposed infrastructure includes a program to core distal deltas of the three main tributaries and to monitor sediment and water quality parameters in contributing tributaries as well as the Great Salt Lake.

Comparisons between prehistoric and historic records in the cores with historic and present day monitoring will provide a basis for evaluation of biogeochemical processes controlling the fate of dissolved and suspended constituents within the watershed, and the consequences of these processes to ecological systems.

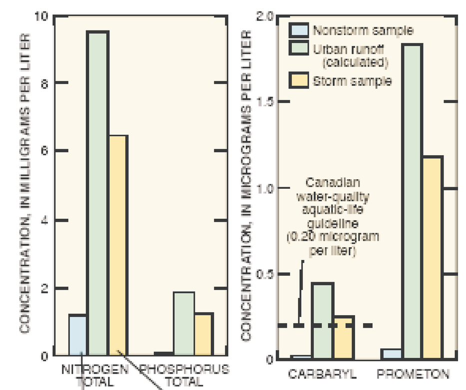
This proposed infrastructure will allow us to answer:

- To what extent do lake sediment records of sediment transport and contaminant transport indicate differences in processes occurring within respective contributing watersheds over prehistoric versus historic predevelopment versus modern times? Can climatic and anthropogenic influences be clearly distinguished? Are differences apparent in the lake sediment record for watersheds of differing development histories?
- Can the observed differences in lake sediment records be linked to known biogeochemical processes occurring in those watersheds? Are there critical locations at which these processes take place?
- For known contaminant loadings to the contributing tributaries, are there contaminants for which there is no representation in the lake sediments despite expectations based on known processes? What are the processes that eliminate these contaminants from the system prior to deposition in the lake? Where in the hydrologic system are the eliminating processes located?

Past and Ongoing Studies in the Great Salt Lake Basin

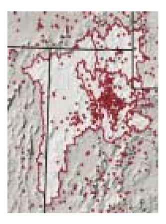


<u>USGS NAWQA</u> - Recognizing the need for long-term, nationwide assessments of water resources, the U.S. Congress has appropriated funds since 1991 for the USGS to conduct the National Water-Quality Assessment (NAWQA) Program. Scientists in the NAWQA Program work with partners in government, research, and public interest groups to assess the spatial extent of water quality conditions, how water quality changes with time, and how human activities and natural factors affect water quality. The Great Salt Lake Basins is one of 51 water-quality assessments initiated since 1991.
LOCATION: Bear River, Weber River, and Utah Lake Watersheds and the Great Salt Lake



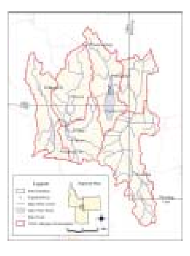
<u>Western Lakes Catchment Systems</u> - The USGS Bear Lake Project started in 1998 with the goal of creating records of past climate change for the Bear Lake region, including changes in precipitation (rain and snow) patterns during the last 10,000 years. As part of the project, the USGS is determining how the size of Bear Lake has varied in the past to assess the possibility of future flooding and drought. In addition, the USGS is studying the extent of human influences on sediment deposition, chemistry, and life in the lake. Sediments in Bear Lake provide a detailed, but indirect, record of climate covering the last million years. Records such as this are critical to the understanding of current and future climate changes because they provide perspective on the trends and magnitude of climate change observed today.
LOCATION: Bear Lake and the Great Salt Lake

Nutrients and pesticides are transported to Little Cottonwood Creek in urban runoff, substantially increasing the concentration of these contaminants during storms.



<u>MesoWest Atmospheric Monitoring</u> - The MesoWest project networks surface atmospheric data from weather observing stations across the United States with particular emphasis placed on the intermountain region of the western United States. The data from the newtwork are placed in a common database to provide timely access to real-time weather observations. Over 150 surface observing stations are available within the Great Salt Lake Basin with an additional 150 stations within 100 km of the basin.
LOCATION: Great Salt Lake Basin wide

<u>Bear River Laboratory Watershed</u> - A collaborative team at Utah State University, the Utah Water Research Laboratory, Utah Division of Water Quality, the Bear River Commission, and others participated in nominating the Bear River as a Targeted Watershed for EPA's Targeted Watersheds Grants Program. This study, which will be funded for three years starting Fall of 2004, will implement studies in the Bear River basin to develop and demonstrate: 1) an integrated Watershed Information System to facilitate data collection, data analysis, information transfer, and public outreach; 2) a water quality trading program to allow point and nonpoint pollutant sources to trade water quality credits; and 3) dynamic water quality modeling to support water quality trading and analysis of potential water quality management scenarios.
LOCATION: Bear River Watershed



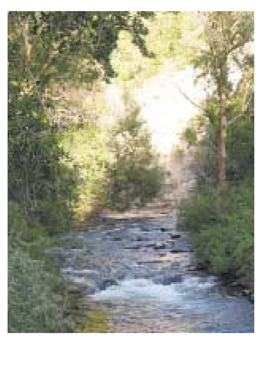
<u>Red Butte Canyon Ecohydrologic Studies</u> - The Red Butte Canyon Research Natural Area is located immediately east of the University of Utah campus. It is a 20.8 square mile (5,140 acre) protected watershed in nearly pristine condition, with land cover ranging from grassland to aspen-fir forest. The watershed, which is the only protected and near pristine canyon in the Wasatch Range of Utah, has been set aside primarily for research and education, and has a long and rich research history. It is managed by the U.S. Forest Service.
LOCATION: Utah Lake Watershed, just east of Salt Lake City

<u>Deseret Ranch Paired Basin Vegetation Manipulation Studies</u> - It is hypothesized that vegetation restoration will influence the residence time distribution of water within a catchment because connectivity among stores of water (soil water, groundwater, etc) will be significantly influenced. This hypothesis is being investigated at a field site located in the Northern Wasatch Mountains of Utah. Two headwater basins to the Ogden River have been instrumented with stream gauges and other instrumentation in an attempt to develop residence time distributions for these catchments prior to and after manipulation to determine how the hydrology of the catchment is altered. Both catchments are roughly 1,000 acres in size, and both are located on Deseret Land and Livestock property.
LOCATION: Upper Weber River Watershed

<u>Southwest Jordan Valley Groundwater Cleanup Study</u> - The project is designed to clean up ground water contaminated from historic mining activities in the Oquirrh Mountains in southwest Salt Lake County. Over the next 40 years, extraction and treatment of groundwater from the contaminated zones will remove contaminants and provide municipal-quality drinking water to the public in the Affected Area. By removing contaminated water from the underlying aquifer, the project will also improve groundwater quality and prevent further migration of the contamination in the valley.
LOCATION: South Jordan

<u>Reynolds Creek Experimental Watershed</u> - The Reynolds Creek Experimental Watershed is located within a few hours drive from Salt Lake City. This highly instrumented watershed, which is external to the Great Salt Lake Basin, but represents similar topography, climate, and hydrologic characteristics, has a 45 year history of monitoring can be used for hydrologic process studies in a physiographic setting similar to that of the Great Salt Lake Basin.
LOCATION: Southwestern Idaho

<u>Utah Division of Water Quality Monitoring</u> - Utah assesses the quality of its surface water resources to protect it for drinking, fishing, boating irrigation, stock watering, and supporting aquatic wildlife. Ground water is assessed to protect it for drinking, agricultural, and industrial use. Data are compared against State water quality standards to determine beneficial use support. Water quality data are used to identify impaired water bodies and establish water quality goals for implementing projects to restore or protect water quality. Water quality data are also collected to do load analyses for discharge permits and to assure that permit requirements under the Utah Pollution Discharge Elimination System (UPDES) program are being met, to evaluate the effectiveness of nonpoint source pollution remediation projects, and to do Total Maximum Daily Load analyses for selected water bodies or watersheds. Idaho, Wyoming, and Nevada have similar programs.
LOCATION: Great Salt Lake Basin wide



<u>Pacificorp Hydrologic Operations</u> - PacifiCorp operates 9 of the 15 streamflow gages in the Bear River Basin and uses these gages to support operation of 4 hydroelectric facilities, irrigation deliveries, and documentation for minimum-flow and ramping requirements. PacifiCorp also maintains a NWS cooperative weather station at the north end of Bear Lake, which also records pan evaporation. The Pacificorp Hydrologic Operations team is interested in the integration of hydrologic and watershed information systems for the real time optimization of system operations.
LOCATION: Bear River Watershed

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