Prediction of Nonlinear Climate Variations Impacts on Eutrophication and Ecosystem Processes and Evaluation of Adaptation Measures in Urban and Urbanizing Watersheds

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Abstract

a. Funding Opportunity: National Priorities: Systems-Based Strategies to Improve the Nation's Ability to Plan And Respond to Water Scarcity and Drought Due to Climate Change; EPA-G2014-ORD-L1

b. Project Title: Prediction of Nonlinear Climate Variations Impacts on Eutrophication and Ecosystem Processes and Evaluation of Adaptation Measures in Urban and Urbanizing Watersheds

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d. Institutions: University of Utah, Salt Lake City, Utah

e. Project Period and Location: January 2015 - December 2017. The work will be conducted in Salt Lake City, Utah at the University of Utaht; project area is north central Utah.

f. Total Project Cost: $1,000,000 + 25% cost share

g. Project Summary: The overall project goal is to develop an improved system-wide quality and quantity model of the Jordan River watershed that can be used by stakeholders to improve sustainable planning efforts related to water supply and demand forecasting, TMDL planning and implementation, policy decisions related to urban growth and water projects, and public education and outreach. Researchers from Engineering, Planning, and Sociology will utilize a unique combination of widely available process models for hydrodynamics, stormwater, hydrology, reservoir management, and land use planning, to explore holistic watershed approaches that look to participatory solutions to establish and improve resiliency and vulnerability metrics for urban water resources management. The dynamic models of surface water flows and water quality will be used under historic, projected, and climate-impacted projected scenarios to help establish which adaptive solutions fit within the societal context of stakeholders. The impacts of climate change on extreme events and future ecological responses will be studied using field and laboratory analyses with results transferred to our process models to improve prediction capabilities. By evaluating stakeholder based futuristic scenarios, the work expects to demonstrate the necessary collaborative actions to protect ecosystems and secure water for future generations in the face of climate change and population expansion. The project also intends to improve educational training to encourage the next generation workforce to look holistically at the challenges and opportunities with regard to sustainable communities.

h. Supplemental Keywords: nutrients, sediment oxygen demand, integrated assessment, conservation, reuse, socio-economic, public policy.

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Research Plan

1.0 Introduction and Objectives

The sustainability and integrities of water resources and ecosystems are threatened by dwindling supplies, growing demand, and anthropogenic disturbances leading to lower or altered streamflows, higher water temperatures, and increased pollutant loadings coupled with mobilization of freshwater phosphorous and nitrogen which contribute to oxygen-starved water, nuisance and toxic algae blooms, and reduced biodiversity (Carpenter et al. 1998; Vega et al. 1998; Billen and Garnier 2007; Diaz and Rosenburg 2008; Whitehead et al. 2009). Challenges are particularly acute in rapidly growing urban areas where demands for additional water and stressors to the ecosystem are increasing. It is widely recognized in the scientific community that stormwater runoff from impervious urban and suburban development can contribute significant amounts of pollutants into streams and rivers (U.S. EPA 2005; Karamouz et al. 2011). Selection and design of best management practices (BMPs) are done on a case by case basis without appropriate system-wide analysis of BMP selection (Young et al. 2011). Numerous studies from around the world have linked human development to deteriorating stream conditions and the need for integrated approaches to stormwater management (Paul and Meyer 2001; Rauch et al. 2005; Martin et al. 2006). Although solution frameworks have also been proposed in the literature with varying complexities, few have actually been successfully implemented due to a wide variety of factors (Luo et al. 2003; Rauch et al. 2005; Pahl-Wostl 2007).

The Jordan River basin in north-central Utah exemplifies urban stream environments throughout the western United States. Already subject to EPA approved TMDL issues related to dissolved oxygen, temperature, TDS, and *E. Coli* (Jensen and Rees 2005; Cirrus Ecological Solutions 2013), the combined impacts of climate change and population growth could result in a severe system-wide collapse of the ecosystem unless a holistic plan of action based on sound science and economic realities is developed and implemented. According to the 2012 projections by the Utah Governor’s Office of Management & Budget, population in the Utah Lake/Jordan River watershed will increase 72% by 2050 resulting in an additional 1,100,000 people. Consequently, the Utah Water Resources Department predicts a consumptive use shortfall of 800,000 acre-feet per year. Although this projection does not encompass climate impacts, it has generated enough concern that the Governor recently proposed development of a 50-year Utah water strategy. Initial comments expressed the common sentiment that localized solutions where communities are in competition for scarce resources will be destined to fail. A comprehensive framework is necessary to ensure sustainable growth that protects the environment and outdoor lifestyles.

The overall ***project goal is to develop an improved system-wide quality and quantity model of the Jordan River watershed that can be used by stakeholders to improve planning related to water supply and demand forecasting, TMDL planning and implementation, policy decisions related to urban growth and water projects, and public education and outreach***. The process builds on an approach adopted by the City of Los Angeles (2012) through integration of water supply, water conservation, water recycling, runoff management, and wastewater facilities planning using a regional watershed approach with climate change projections based on the

IPCC's Fifth Assessment Report (AR5) and public outreach. Such a framework would be applicable to urban and urbanizing communities throughout the United States.

To achieve this ambitious goal, these specific objectives will be addressed:

1) Develop a dynamic water quantity/quality model of Jordan River watershed using SWMM, DHSVM, EFDC, and WASP
2) Link the process-based model of the Jordan River watershed to a system dynamics model of the integrated urban water system for the Salt Lake City metropolitan area
3) Integrate each of the four AR5 climate projections into prediction of 2050 water quantity and quality baseline scenarios
4) Conduct field and laboratory analysis to parameterize kinetic coefficients and determine non-linear responses under climate scenarios
5) Examine land use planning implications including scale-related phenomenon related to headwater versus downstream economic, social, and ecosystem constraints
6) Hold participatory stakeholder workshops to develop future scenarios related to conservation, reuse, land use changes due to population, BMP/LID implementation, wildfire disturbances, and water management
7) Use models to examine impacts of scenarios and levels of investments needed to achieve a sustainable environment for economic and ecosystem protection
8) Create a framework for maximizing value of BMP placement through off-site investment to achieve water quantity and quality goals
9) Incorporate findings into classroom instruction that help prepare the future workforce in thinking holistically to solve tomorrow's challenges.

The expected outcomes of this project include:

a. A dynamic tool capable of accurately predicting the appropriate numeric nutrient criteria for the Jordan River and Utah Lake necessary to prevent eutrophication under existing and future climate conditions.
b. An integrated process-systems model capable of coupling detailed watershed-water quality dynamics (the process model) with planning, policy, people, and interconnected systems such as water supply and water demand (the systems model).
c. At least three peer-reviewed journal papers in engineering, ecology, planning, and sociology related venues.
d. Two public workshops to Jordan River stakeholders and other public outreach activities such as community seminars and K-12 education.
e. Revised curriculum contents integrating interdisciplinary research approaches and findings into case studies designed to expand the envelope of creative thinking.

We will continue to work closely with stakeholders across a broad spectrum (see Support letters) to develop a comprehensive management tool that can evaluate water management strategies for the entire Jordan River watershed. We have already established great working relationships with many stakeholder groups involved in the Jordan River watershed and they are eager to work with us to develop a shared vision of the future. Implementation of this comprehensive approach will guarantee scientifically defensible solutions that incorporate social and ecosystem needs and lead to a sustainable future.

2.0 Background

2.1 Study Area

Utah's Jordan River is a 52-mile (95-km) long urban stream which flows through Salt Lake Valley and connects Utah Lake with the Great Salt Lake. The river is an important urban waterway running through Salt Lake City and 14 other municipalities before emptying into the Great Salt Lake. In fact, the river flows directly through 4 of Utah's 6 largest cities, making it an extremely important resource to the region. Figure 1 illustrates the urban and urbanizing areas that contribute runoff and contaminants to the river as well as the rural watershed that contributes to the drainage area through high mountain runoff and interbasin transfers from Strawberry Reservoir.

In the upper part of the basin, inflows to Utah Lake average approximately 612,000 acre-feet and are derived from the 3,846 square mile watershed. Elevations in the basin range from 11,754 feet to the lake elevation of 4,489 feet. Water quantity concerns include upstream blue-ribbon trout habitat, drinking water to more than 50% of Utah's population, agricultural supply, and habitat protection for the endangered June sucker (*Chasmistes liorus*) in the lower reaches (Bio-West 2008). Water quality concerns related to excess nutrients and toxic algal blooms also exist. Similar concerns exist for other upstream tributaries as a result of agricultural and natural processes. The recipient of these discharges, Utah Lake, also has an excess nutrient problem that threatens critical outdoor recreation activities such as fishing and boating and impacts the quality of water released into the Jordan.

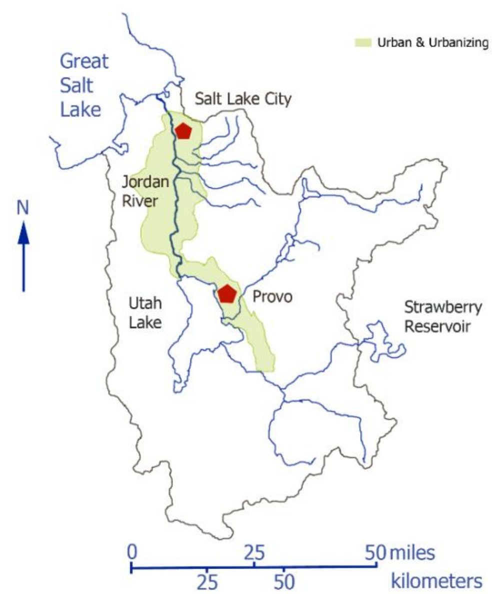


Figure 1. Jordan River Watershed

Downstream of Utah Lake, the Jordan River water budget consists of Utah Lake outflow, gaged and ungaged tributaries (from an additional 790 square miles), discharges from wastewater treatment facilities, urban stormwater outfalls, diffuse runoff, irrigation return flows, and groundwater. Cirrus Ecological Solutions (2009) estimates the relative contributions of flows (see Table 1) which leads to both water quantity and quality concerns in the lower watershed. For instance, the 1-million acre-feet of water stored in Utah Lake is at severe risk due to climate change. Of the total 612,000 acre-feet of inflow to the lake, only 51 percent is discharged into the Jordan. Because the lake is very shallow (average depth of 9-10 feet) and covers a large spatial area (surface area of 145 square miles), evaporation losses have been estimated to account for 42 percent of the annual outflow (PSOMAS/SWCA 2007). Groundwater seepage accounts for the remaining 7 percent. The impacts of climate change and growing populations pose additional threats to the tributary inflows along the Wasatch Front.

The Jordan River experiences many of the water quality concerns shared by urban streams throughout the western United States. The recent U.S. EPA-approved TMDL of the river identified issues include problems with total dissolved solids, temperature, *E Coli*, and dissolved oxygen (DO). While it is recognized that theses quantity and quality issues are related, holistic basin-wide solutions are missing. TMDL and associated water quality investigations have subdivided the watershed such that the Provo River is analyzed separately from Utah Lake, the Jordan River, or the even the other upstream tributaries. Droughts, changes in snow melt timing, and extreme events induced by climate change and the implications of land use changes due to population and economic growth are not explicitly factored into the solution schemes. In other words, some of the most important natural and human dimensions influencing these ecosystems are missing. Thus proposed solutions are likely to be inadequate with respect to the magnitudes of the problem and they often pit upstream users against downstream interests rather than address the challenges in an integrated fashion.

Table 1. Jordan River Water Budget

	Average Annual Volume (acre-feet)	% of Total
Utah Lake	416,000	52.0
Gaged Tributaries	125,500	15.7
Ungaged Tributaries	8,900	1.1
Urban Stormwater	17,700	2.2
WWTP (3 facilities)	91,700	11.5
Diffuse Runoff	1,900	0.2
Irrigation Return Flow	17,600	2.2
Groundwater	120,700	15.1
Total	800,000	100.0

2.2 Research Hypotheses

Research results from the objectives and outcomes described previously will be used to statistically evaluate several key null hypotheses. Our primary hypotheses are:

H_o 1: Climate change impacts to water quality and quantity in urban areas will require adaptation measures beyond traditional historic time series data-related design practices due to extreme wet and dry periods.

H_o 2: There remains sufficient resilience in the Jordan River system to accommodate a major urban area and maintain a clean and safe water supply through careful, cooperative, and innovative community planning, engineering, and design.

H_o 3: Regional stakeholder-driven solutions to water quality issues will prove more cost effective and more beneficial to the environment than individual projects.

H_o 4: Effective planning and adaptive management for extreme events will help alleviate the adverse economic and ecosystem impacts of wildfires, droughts, and floods.

H_o 5: Education and outreach can be used to develop innovative solutions that are embraced by stakeholders throughout the watershed and thus implemented on a broader basis.

Addressing these hypotheses will require us to determine how climate change impacts the quantity and quality of water resources in the Jordan River watershed, investigate how drought and flood related events exacerbate flow and quality, study how water management can be used to mitigate changes in snowmelt-driven hydrographs, train an innovative workforce, and assess how public outreach can improve adoption of results.

2.3 Related Research

While we have not had direct funding from this EPA program, our team members have had EPA and other grants related to improving water quantity and quality components in the valley. For example, Envision Tomorrow Plus, our scenario planning model, was developed under a HUD-DOT-EPA Sustainable Communities Initiative Implementation grant.

3.0 Research Approach and Activities

3.1 Overview

To meet U.S. EPA program goals, this project was specifically designed to investigate the direct and secondary interrelated impacts of climate change (including extreme events) on surface and groundwater water quality and availability in the Jordan River watershed for the protection of human and ecosystem health, and develop innovative, cost-effective management options that address these impacts. Integration of the individual objectives will result in a plan that specifically addresses all of the U.S. EPA-posed questions:

- Q1. How does drought (seasonal and prolonged), exacerbated by extreme weather and climate change, affect water quality and availability of surface water and groundwater?
- Q2. How do subsequent drought related events, such as changes in surface runoff and wildfire, lead to additional changes in water quality and availability?
- Q3. How can changes in water quality driven by other variations in the hydrological cycle related to drought, such as changes in the timing and intensity of spring snowmelt and runoff, affect water quality?
- Q4. What adaptive management strategies and innovative, cost-effective technologies provide communities and ecosystems with protection and resilience against direct and secondary drought related impacts exacerbated by climate change?
- Q5. How can the proposed management strategies and technologies be demonstrated in different communities to facilitate adoption of sustainable water management?

Additionally, our modeling framework will be used to demonstrate locally that comprehensive regional solutions will be more beneficial than solutions that pit upstream and downstream communities against each other or that divide the stakeholder groups along narrow boundaries of special interest. It will illustrate how innovative community planning facilitates environmentally sustainable change. We will also demonstrate the utility of the model for urbanizing areas throughout the country.

3.2 Objectives 1 and 2: Process-based Modeling Framework

The current Jordan River Phase 1 TMDL is predicated on results from the QUAL2Kw model explained by Pelletier and Chapra (2008). While this one-dimensional model has been widely used for stream and river TMDL assessments (Barber et al. 2007; Tetra Tech 2009; Delaware DNREC 2012), there are a number of estimated input parameters that vary considerably from location to location. With respect to the Jordan River, Hobson (2013) recommended that additional work was needed to: 1) support sediment oxygen demand calculations, 2) characterize nutrient uptake pathways in benthic processes, and 3) improve methods for integrating ecological and mechanistic modeling approaches for nutrient criteria. Furthermore, the 1-D nature of the model makes it inadequate for wide shallow lakes. Another critical issue is the model reflects steady-state conditions with respect to flow. While this may be acceptable in some cases because low flows represent the critical periods, recent data from field investigations on the Jordan suggest that storm events cause significant variations in loadings and resulting streambed conditions that impact SOD and thus DO. In Objectives 1 and 2 we will develop the process models for Utah Lake and the Jordan River and then link them to create a system wide integrated view of water resources in the watershed.

A dynamic model of the system is proposed that links several well-established and proven models (DHSVM, EFDC Hydro, ET+, SWMM, GoldSim, and WASP) together in a unique combination that utilizes the strengths of each model (see Table 2). Attempts to integrate process models such as these to investigate watershed scale phenomenon are just beginning. Many Earth System Models are done at scales not suitable for local decision making (Luo et al. 2013). This underlying model will be a combination of EFDC V1.0 and WASP V7.3 applied to Utah Lake and the Jordan River. Boundary condition inputs from the rural portions of the watershed (those outside the urban areas shown in Figure 1) consisting of flow and temperature will be derived using DHSVM V3.1.2 (Sun et al. 2013) and local measurements. Stormwater outfall flows and concentrations from urban areas will be determined using SWMM. With historically available data we will model 2005-2014 to establish current baseline conditions. This will include ongoing data collection efforts currently being conducted by the Utah Division of Water Quality, the municipality of Salt Lake City, our own research projects, the USGS, and other local agencies subject to data QA/QC verification.

We will use our GoldSim model of the integrated urban water system of the study area to simulate all aspects of stormwater, water supply, wastewater, natural processes, and interconnected systems. The dynamic process-based model noted above and the systems model will be used in tandem to study the broader water system decision making and its implications for Jordan River water quality response. For example, changes in water demand and management will alter return flows to the Jordan River having potentially significant impacts.

Future scenarios will encompass a combination of climate (temperature and precipitation) and development/land use alternatives. The future climate drivers to DHSVM and SWMM will be downscaled 2050 AR5 simulation results (see objective 3) which will be used to predict hydrographs under four Representative Concentration Pathways. Three downscaling processes (Composite Delta, Bias Corrected and Spatially Downscaled, and Hybrid Delta) will be examined to ensure we can incorporate extreme events with reasonable degrees of accuracy (Lee and Hamlet 2011). Changes in evaporation losses from Utah Lake will be quantified and examined in context with lake and upstream reservoir operation under hydrograph modification. ET+ will be used to generate urban growth scenarios for the region. ET+ is a linked system of spreadsheets and ArcGIS that explores outcomes of urban growth scenarios through a series of modules that parameterize built and unbuilt aspects of an urban landscape. These results will be used in SWMM to generate pollutant loadings under BMP/LID strategies ranging from zero to capture of 0.75 inches of runoff.

We have done some preliminary work on these models already. SWMM has been used to model stormwater runoff contributions to the Jordan River from Salt Lake County (the majority of the urban land use directly entering into the Jordan River) for current and future land use conditions under historical and future climate change conditions based on the CMIP5 statistically downscaled and dynamically downscaled projections. This research has been coupled to similar studies we have performed in other places in the U.S. (e.g., New York City (Zahmatkesh et al. 2014)) as we develop a nationwide perspective of climate impacts on stormwater runoff. However, since the Jordan River Watershed is a highly regulated, urban waterway with numerous water exchanges and storage facilities we found it challenging to model these connections at such a large scale. Therefore, we chose to couple our SWMM to a system dynamics model (GoldSim) to effectively simulate the complexities of the system not captured in SWMM. For instance, we use the system dynamics management model to simulate dynamic changes to diversions, consumptive uses, return flows, wastewater flows and other inputs and outputs from the Jordan River that are influenced by climate. For this work we have been closely collaborating with Salt Lake City Public Utilities (see letter of support) as part of their Climate Impacts Modeling team. Much of this past, ongoing, and future work will be leveraged for this study.

Table 2. Summary of Models and Linkages

Model	Purpose
Distributed Hydrology Soil Vegetation Model (DHSVM)	DHSVM is a distributed hydrologic model that explicitly represents the effects of topography and vegetation on water fluxes through the landscape. It will generate hydrographs and stream temperatures for the mountainous watershed tributaries feeding Utah Lake and the Jordan River.
Storm Water Management Model (SWMM)	SWMM will be used to predict the impacts of climate change (including extreme events) on urban and urbanizing stormwater runoff quantity and quality. Land use changes and the adoption of low impact development controls will be examined to generate various passive to aggressive policies. These quantities will be used as loading functions to WASP.
Envision Tomorrow Plus (ET+)	ET+ provides outputs concerning the impacts of policies, development decisions, and current growth trajectories, and can be used by communities to develop shared visions of desirable and attainable futures. Scenario comparisons include a comprehensive range of indicators relating to land use, housing, demographics, economic growth, development feasibility, fiscal impacts, transportation, environmental factors, and quality of life. ET+ will generate development scenarios incorporated into SWMM along with BMPs/LID practices to predict future contaminant loadings.
Environment Fluid Dynamics Code (EFDC Hydro)	EFDC is a hydrodynamic model for simulating aquatic systems in one, two, and three dimensions. This model will be used to provide necessary hydrodynamic inputs to the advanced receiving water quality model (WASP) for Utah Lake and the Jordan River.
Water Quality Analysis Simulation Program (WASP)	WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. It will be used to simulate surface water quality as a result of climate, hydrology, land use, point & non-point loadings, and the impacts of potential policies.
Goldsim	Goldsim is a Monte-Carlo simulation software for dynamically modeling complex systems. It operates as an integrated model accepting inputs, incorporating outputs from models, executing a reservoir model, and operating other sub-models within the integrated water system model.

This project will lead to significant refinement and enhancement of the process models by allowing us to collect localize kinetic parameter data, incorporate Utah Lake impacts, add dynamic flow features for historic and future scenarios, improve boundary condition inputs and benthic exchange parameters. All of these will enable us to address the important Q1-Q5 set of questions posed in the RFP.

3.3 Objective 3: Integration of AR5 into 2050 quantity and quality baseline predictions

The IPCC's Fifth Assessment Report (AR5) considers four Representative Concentration Pathway (RCP) scenarios that reflect increases in radiative forcing [W m^{-2}] in year 2100 compared to 1750. Thus, RCP2.6, RCP4.5, RCP6.0 and RCP8.5 signify increases of 2.6 W m^{-2}, 4.5 W m^{-2}, 6.0 W m^{-2}, and 8.5 W m^{-2} related to prescribed CO_2 concentrations of 421 ppm, 538 ppm, 670 ppm, and 936 ppm, respectively. The Coupled Model Intercomparison Project Phase 5 (CMIP5) web site (http://cmip-pcmdi.llnl.gov/cmip5/availability.html) provides access to numerous GCM simulations through its Earth System Grid Federation. We will use the downscaled predictions for the 2050's to drive our integrated model and examine system changes as a result of growth only and growth with climate change to illustrate the changes in baseline predictions.

3.4 Objective 4: Field and laboratory measurements of kinetic coefficients

The WASP model will be used to predict surface and benthic water quality in Utah Lake and the Jordan River. The kinetic equations in the model currently account for temperature effects on various biochemical processes through empirical temperature coefficients. There is considerable uncertainty associated with the range of literature values such that site-specific measurements are needed to model existing conditions. However, empirical coefficients, even those associated with *in-situ* measurements and adjusted during historic model calibration and validation, are unlikely to scale appropriately with climate change. While studies have been conducted to predict future stream and lake temperature response to global warming (Mohseni et al. 2002; Morrill et al. 2005; van Vliet et al. 2013), the complex non-linear biogeochemical responses to changes in water column temperatures have not been adequately investigated (Canadell 2000; Pielke et al. 2003; Burkett et al. 2005). Predictions of nutrient cycling including algal responses based on these empirical equations need further investigation to reduce uncertainty and provide assurances for management strategies. This important challenge for earth systems models will be addressed in this study. Sediment oxygen demand (SOD) is a big contributor to the DO sinks in the Jordan River and Utah Lake. To predict SOD over temperature variations, empirical equations are used. Likewise, other kinetic coefficients such as those associated with Monod Kinetics in the modeling efforts are temperature dependent. The equations used to predict the temperature dependent variations of different water quality parameters mostly use quadratic function. However, this may not be true always. For example, our own in situ SOD measurements in Jordan River indicated that most of the winter SOD values for many sites could not be predicted using the empirical Van Hoff temperature equation. The measured winter SOD values were significantly higher than those predicted using the temperature coefficients in Van Hoff equation.

Initially, to establish parameters for the historic calibration/validation of the WASP model, we will employ a combination of *in-situ* field measurements and laboratory scale techniques to determine the appropriate empirical values to use for sediment oxygen demand, ammonia oxidation to nitrite and then to nitrate (nitrification), nitrate oxidation to the nitrogen gas (denitrification), primary production, re-aeration, deoxygenation, organic matter oxidation, methanogenesis and methane oxidation. We have sampled 10 locations in Utah Lake (shown in Figure 2) suggested by the Utah Division of Water Quality (UDWQ) for SOD, nutrient fluxes from sediments, phosphorus speciation in sediments, sediment characteristics. Historic data obtained by UDWQ is also available for nutrients and organic carbon. Despite these available resources, it is difficult to predict temperature dependency of common water quality parameters because the available data is not complete in its entirety. Likewise, we have been monitoring the Jordan River for the last 5 years for sediment oxygen demand, nutrient concentrations and fluxes, sediment organic and carbon contents. Seasonal data is also collected by the UDWQ but together with our data, this data does not help establish dependency on small temperature changes.

In this objective we will conduct *in-situ* measurements for selected oxygen and oxygen demand-related parameters at 10 locations in Utah Lake (shown in Figure 2) and an additional 6 locations in Jordan River. The *in-situ* experiments will measure: 1) sediment oxygen demand across seasons to incorporate wide temperature differences using our in-house build SOD chambers, 2) primary productivity using across small temperature difference using in situ transparent chambers in Jordan River, and 3) suspended bottle experiments in the Utah Lake. These *in-situ* chambers have been used by us in previous investigations. Details of the procedures are provided elsewhere (Hogsett and Goel 2013). To determine SOD variations and primary productivity, we will conduct experiments in the lab, in which case sediment core samples for SOD and water samples for primary productivity will be used. In this way, we will be able to able to establish variations in SOD and primary productivity over very small temperature changes.

Additionally, to predict future nonlinear biogeochemical process responses to climatic conditions, water column and benthic sediment core samples will be collected and transported to incubation chambers in our laboratory. We will then conduct laboratory experiments scale tests to determine chlorophyll a in water samples, nitrification, denitrification, BOD oxidation rates under controlled temperature conditions. The information will be used to determine how the empirical coefficients in WASP can be scaled for future predictions or whether a new process-based equation should be programmed into the model framework to improve predictions.

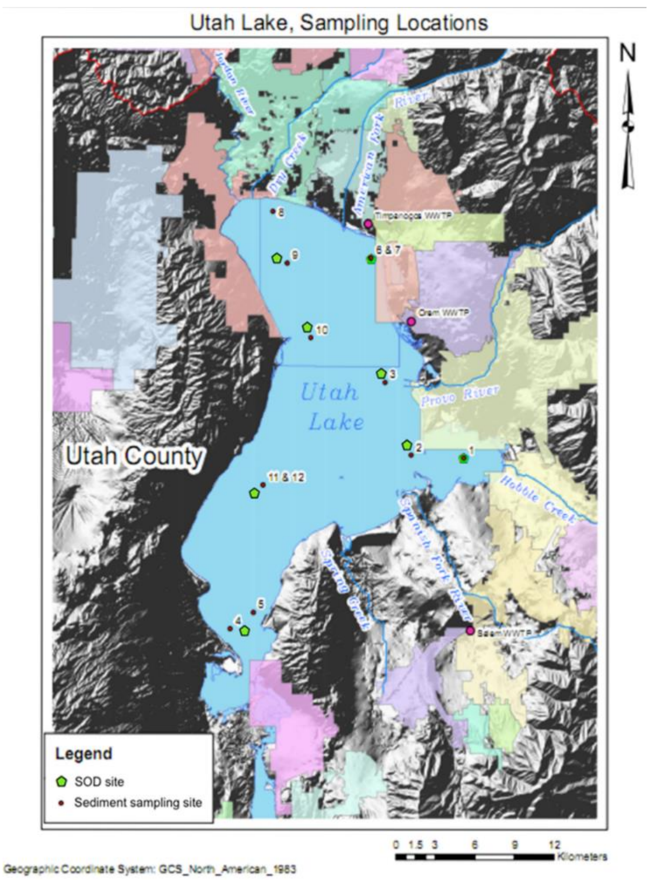


Figure 2. Sampling locations in Utah Lake

3.5 Objective 5: Examination of land use planning decisions

The metropolitan region within which the

Jordan River watershed lies is one with an impressive history of cooperative regional planning (Scheer 2012). Beginning in the late 1990s, a series of major outreach and planning initiatives resulted in the adoption of a regional vision for how to handle future growth, known as the Wasatch Choice for 2040. In 2011, the region was the recipient of a HUD-DOT-EPA Sustainable Communities Implementation grant to develop a series of tools to implement the vision. Through a partnership between the University of Utah and several public and private entities, one of the tools developed under this grant was an open-access scenario planning software package called Envision Tomorrow Plus (ET+). ET+ is now being used along the Wasatch Front at scales from the parcel to the region, and locally calibrated datasets for use with ET+ are available.

ET+ has a flexible structure that allows incorporation of new datasets and models to explore specific questions associated with changes in urban population and land use. It is designed for participatory planning activities involving stakeholder groups. The basic inputs to ET+ are associated with individual prototype buildings, including size, footprint, use, cost to build, land costs, and other site uses such as parking and landscaping. Multiple prototype buildings are then mixed together with other elements of the urban environment, such as streets, public spaces, infrastructure, etc. to create development types which are then transferred base maps in ArcGIS creating a scenario. ET+ can also pick up existing conditions data from the base map or other sources and include this in the scenario calculations. The GIS module sums all the parameters associated with buildings and development types over the scenario area and reports summary indicators for each scenario created. Outputs currently calculated by ET+ include population, jobs, developed area, impervious area, infrastructure requirements, water and energy use, travel behavior, open space/parks area, land use mix, green infrastructure, and many more.

As previously stated, 2012 projections predict population in the Utah Lake/Jordan River watershed will increase 72% by 2050 resulting in an additional 1,100,000 people. A strong precedent and opportunity exists for using ET+ to explore future land use planning scenarios in association with the Jordan River and existing stakeholder partnerships making this a natural step forward in watershed planning based on science and rooted in the local community. We will use the 2050 growth projections and ET+ to identify likely development scenarios and GIS overlays that will be used in conjunction with SWMM to generate future pollutant loading estimates with varying levels of BMP/LID solutions at scales ranging from site to regional facility investments. Pollutant loads will be based on comparisons to measured data, development density, and typical BMP/LID removal rates for each pollutant.

3.6 Objective 6: Development of Future Scenarios

We will conduct a series of 3 workshops throughout the Jordan River valley to present and discuss scenario alternatives to stakeholder groups ranging from private citizens to regulatory agency personnel. We will use these forums to get feedback to the population growth scenarios modeled with ET+ as well as examine additional future scenarios including, but not necessarily limited to, the following:

* <u>Fire disturbance in upstream rural landscape</u>: Forest fires can lead to changes in runoff and water quality as infiltration rates often are reduced by 50% or more (Robichaud 2000) and the lower infiltration capacity can lead to increases in overland flow rates and pollutant loads (Flannigan et al. 2009). Impacts of wildfires on water quality and quantity can be quite significant (Moody and Martin 2001; Owens et al. 2005; Moody and Martin 2009; Robichaud et al. 2010; Boll et al. 2011) and there is irrefutable evidence that climate change is causing an

increase in wildfire activity throughout the world (Gillett et al. 2004). Westerling et al. (2006) found that the observed increase in large forest wildfires in the western United States since the mid-1980s is associated with unusually warm springs resulting in early spring snowmelt and longer summer dry seasons. Furthermore, the Intergovernmental Panel on Climate Change (IPCC 2007) found the trend in wildfires across North America is likely to intensify under current climate projections. A comprehensive investigation by Littell et al. (2009) found a strong linkage between climate and wildfire area burned in the western United States during 1916–2003 and concluded that future wildfire area burned will likely depend on ecosystem-specific seasonal variation in climate.

We will address these issues by incorporating ten land use scenarios related to wildfire severity (heat intensity and area burned) into the DHSVM model. We will look at policy decisions related to the level of firefighting activity under these various scenarios.

* Extreme Events: Climate change is steadily increasing the occurrences of extreme events at both the high and low ends of the spectrum. For example, there is an increasing trend in peak annual discharges measured by the USGS for the Spanish Fork River near Provo (inflow to Utah Lake). While predicting extreme events in climate projections is still difficult, we will address risk of prolonged droughts and flooding using the IPCC reports as a guideline that state the 1-in-20 year maximum daily precipitation amount is *likely* to be a 1-in-5 to 1-in-15 year event and similar statements concerning temperature extremes. We will examine the sensitivity of model results and incorporate these types of decisions regarding future flow and pollutant outputs.

* Stormwater BMP/LID implementation: Utah regulations on BMP/LID pertain to new development and redevelopment activities. While these strategies help prevent water quantity and quality problems from deteriorating, they do little to address existing problems. Moreover, there is evidence that regional water quality design storms may be inadequate because: 1) future events are likely to be more frequent and severe than historically-based design storms, and 2) pollutant cycling of SOD/DO components may be flushed into the system during events exceeding the design storm thus contributing to problems after the stormwater has dissipated. Salt Lake City Public Utilities has an aggressive stormwater policy requiring BMPs meet 100-year, 24 hour storm event runoff requirements, limiting maximum allowable discharge to 0.2 cfs/acre, but even this may not be sufficient to reach water quality goals. Furthermore, many surrounding communities have adopted less restrictive standards in line with the City of Draper which uses a 10-year (0.93 inches), 3-hr modified Farmer-Fletcher distribution (Hansen et al. 2012). We will demonstrate the consequences of these policies on a regional basis by modeling the implication of capture volumes, outflow rates, and design events as well as BMP location and type.

Additionally, although rainwater harvesting has been legal in Utah since May 2010, many homeowners and business owners have not utilized this or other water conservation strategies. We will use our modeling effort to demonstrate to stakeholders the implication of aggressively pursuing rain barrels, on-site rain gardens, and other associated strategies. This effort will be enhanced by working with Salt Lake County to improve their BMP guidance by incorporating additional successful implementations in the area.

* Water management strategies to reduce evaporation losses, reduce water supply and stormwater management system vulnerabilities, and improve water quality: As mentioned

before, Utah Lake loses 42% of inflow to evaporation and this is likely to increase under climate change unless management practices are varied. We will create evaporation estimates for the climate change scenarios and run the EFDC/WASP model to show how these losses impact water quantity and quality. We will then investigate potential centralized (e.g., reservoirs, aquifer storage and recovery) and decentralized (e.g., rainwater harvesting, water reuse) management schemes using the integrated systems model. Alternative management schemes (e.g., aquifer storage and recovery, new treatment facilities, management of high mountain reservoirs, new diversions, and demand management) will be addressed. Details of these operational scenarios will be worked out with various stakeholder groups during the project. Implementing these into the model will provide stakeholders with information regarding the consequences of adaptive management plans.

* <u>Water policy impacts</u>: The ET+ framework is perfectly suited to explore policy implications on water demand and will be used to determine altered water demand patterns in response to changes in land use/development codes. The SWMM modeling component will be able to analyze changes to stormwater policy reflecting potential new U.S. EPA volume control rules as well as exploring potential TMDL response measures at the local government level. From a broader systems perspective, the implications of changes to water law affecting reuse, exchanges, and conservation will be examined.

* <u>Incorporation of climate change and water quality interactions</u>: A significant contribution of this research will be the development through our laboratory work of new understanding of the nonlinear behavior of climate induced responses of algae and water quality kinetic parameters. Moreover, the integration of these new relationships into process models of water quality and further connection to the broader systems model will enable for the first time evaluation of climate impacts on water quality response using empirically-based water quality dynamics.

3.7 Objective 7: Evaluation of alternative and complementary scenarios

Through workshops, as well as public outreach and education, we will present scenarios to stakeholders to increase awareness of watershed issues. At the same time, we will gather information regarding attitudes, opinions, and values of citizens, as these issues influence changes in household practices, support for public planning, and willingness to participate in programs. We will use this knowledge to reflect on how to present alternative scenarios and how to engage different segments of the populations, given diverse interests.

As noted above, an array of water policies have been adopted by communities in the Jordan River watershed. We will present to the public the existing environmental, economic, and social consequences of these policies. Additionally, we will share the expected outcomes of these policies given the impacts associated with climate change, existing development, and growth dynamics for the region. Our assessment addresses the various social and ecological risks and costs, and likely constraints associated with changes in the watershed. It also notes the potential dangers of pitting one group against another, such as those who live downstream versus those who live upstream.

We will present alternative scenarios, noting the importance of effective planning and adaptive management for climate changes, including extreme events, and social needs. These alternative scenarios present how coordinated regional planning, using innovative solutions, engineering, and design, can help maintain clean and sufficient water supply for urban areas, while enhancing the overall resiliency of social institutions. In presenting this material, we can evaluate the social, economic, and environmental costs associated with alternative scenarios, revealing the connections between these realms. Quality of life, health and environmental risks, and prosperity can all be evaluated using the models employed in this project. The scenarios can be presented in a manner that resonates with the attitudes and values of the public, while recognizing the diverse connections and uses of the land, such as agriculture and recreation.

Public outreach and education will also be used to demonstrate how water and energy saving practices, such rain barrels and gardens, can be used improve watershed conditions. Through ongoing engagement with public, we can assess what type of education and training is most effective in facilitating changes in behavior. Outreach is intended to invest the public in the project and planning of more sustainable practices.

3.8 Objective 8: BMP/LID prioritization model framework for supply and protection

This objective address an important sustainability issue that conflicts with historical approaches used by public utilities to guide development and re-development. Traditionally, improvements to stormwater or other systems associated with development/re-development take place at the location of the activity. The required improvements are subject to policy and ordinance controls. However, we submit that the most sustainable (i.e., cost effective, environmental beneficial, and socially empowering) solution is to direct improvements to locations with the greater overall benefits. This is an area of research need and one that hopefully will lead to changes in the current paradigm of governing the development/re-development process. We propose to apply our process, planning, and systems modeling frameworks to explore the validity of our hypothesis that improvement allocation strategies can be more sustainable if they are global instead of tied to a site development. As part of this analysis, we will build on our work developing new water supply vulnerability metrics (Goharian et al. 2014) and extend to provide new resiliency and vulnerability metrics for stormwater systems and integrated water systems and combine with cost, environmental, and social metrics that can effectively represent the trade-offs in site improvements versus watershed improvements.

3.9 Objective 9: Development of classroom materials

Members of the project team have been involved in educational outreach and development of new classroom material. Prioritized by the University of Utah President, new curriculums based on water sustainability and climate change are the thrust of several departments on campus. This includes five new cluster hires in a “Water, Climate, and Society” theme of which the Departments of Civil & Environmental and Sociology are well integrated. The research proposed modeling, land use planning, and social choice experimental plans and findings will be integrated into both new and existing graduate and undergraduate courses in the form of case studies design to demonstrate the utility of holistic adaptive community planning. This will help create a new generation of problem solvers trained to think beyond traditional boundaries.

4.0 Innovation

This project aims at developing a new paradigm in adaptive management by using innovative theoretical concepts and methodologies across boundaries of social, economic and engineering. Specifically, an integrated solution will be found by developing:

a. a dynamic tool for TMDL evaluation and implementation under climate change

b. a non-linear kinetic coefficients related to dissolved oxygen, SOD, and nutrient transformations
c. a novel framework for identifying off-site BMP implementation scenarios that benefit system sustainability and resiliency metrics
d. a comprehensive regional assessment and planning of watershed.

5.0 Sustainability

The U.S. EPA *Sustainability Primer* identifies the intersection of Environmental, Economic and Social pillars as the so-called triple bottom line with respect to the long-term sustainability of our actions. This research project is the embodiment of these ideals in that it looks to incorporate growth and economic development in a manner that encompasses our societal values and protects and enhances the ecosystem. We address the environmental pillar by looking to protect ecosystem services, improve water quality by reducing or eliminating stressors, and promote water conservation strategies. Economically, we are looking to minimize lifecycle costs by implementing a systems-based approach that enhances coordinated economic planning that will maximize investment potentials. Creating livable communities serves as the foundation for vibrant economic relations and economic opportunities. Our planning efforts consider the prospects of future growth and incorporate this essential issue into the modeling input. ET+ is designed specifically to explore multiple aspects of sustainability in every scenario it produces. ET+ has as its core a return-on-investment model. Thus every scenario produced in ET+ includes a calculation of economic feasibility from the standpoint of both developers and public jurisdictions. Socially, we are looking to increase stakeholder participation, public awareness of environmental conditions, and the resiliency of social systems to deal with the impacts of climate variations. Public outreach and education serves to empower citizens to make changes that can reduce risks and conflicts. The comprehensive regional planning proposed attempts to coordinate changes that will meet social needs in the long run, allowing communities to thrive. The integration of these efforts will insure that this project thoroughly addresses the issue of sustainability.

6.0 Expected Results, Benefits, Outputs, and Outcomes

This project will provide integrated solutions to environmental problems and improve the public's ability to protect the environment and human health. Working with agencies throughout the watershed (see letters of support), we will incorporate the following key elements:

- *Water Quality Kinetics*. The project will produce new understanding of water quality kinetics and reactions under temperature scenarios representative of climate change that will help inform not only this study and others but also set laboratory protocols and model integration guidelines for others to follow.
- *Process Modeling Framework.* The integration of existing models (SWMM, DHSVM, EFDC, WASP) will be demonstrated for the study of climate modified stormwater runoff and receiving water response. The software (e.g., data bridges, databases) produced will be available for others to use and the methodology demonstrated will provide a framework for others to follow with existing models in their area.
- *Planning Scenario Informed Analysis.* Using ET+ we will demonstrate the use of planning and policy decision making to guide scenario development for use in process and system modeling of climate impacts.

- *Coupled Process-Systems Modeling*. Coupling the process models with a systems model provides the power to analyze the interconnections and feedbacks of system level changes on explicit receiving water response. Many challenges exist and this research will address them and provide guidance in this important research area moving forward.
- *New Resiliency and Vulnerability Metrics*. Resiliency and vulnerability metrics are quite common for water supply and distribution systems. This project will develop for the first time analogous metrics for stormwater, wastewater, and integrated urban water systems inclusive of receiving water quality.

The result will be a comprehensive scientifically defensible set of results that clearly indicate the impact of management decisions concerning land development, stormwater regulations, BMP/LID implementation, and conservation efforts on water quality and quantity in the basin.

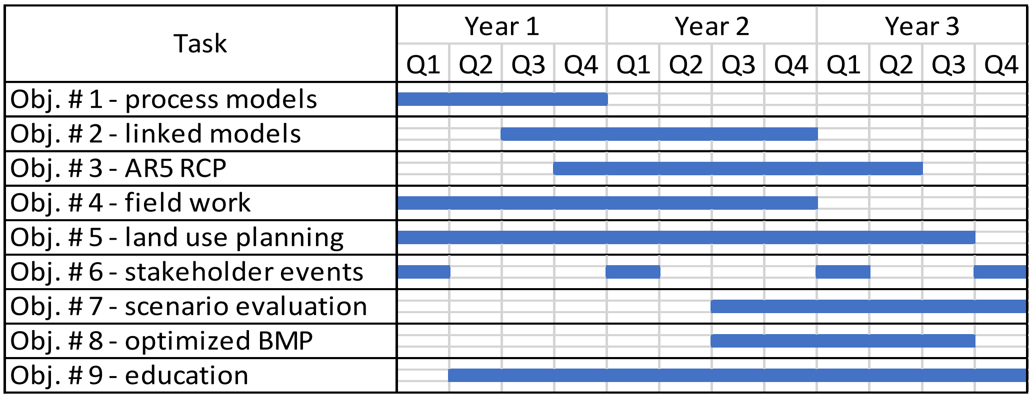
7.0 Project Management

Our interdisciplinary team consists of five senior investigators from Civil & Environmental Engineering (3), City and Metropolitan Planning (1), and Sociology (1) who will all contribute significantly to the success of this project. While it is essential that the objectives be completed in a truly integrated fashion, each of the faculty members is assigned primary and secondary responsibilities (see Table 3). Overall project management will be undertaken by Dr. Michael Barber who has over 25 years of professional experience related to water resources. Through the use of regular monthly team meetings with faculty and graduate students, the tasks identified in the proposal will be performed. Each senior team member will be asked to provide quarterly updates with respect to % completion, achievements, and primary challenges with respect to completing tasks on schedule. Discussion on how any delays may permeate the schedule of other tasks and how to reduce impacts will be held. Plans for addressing any issues will also be presented and discussed. This information will be transferred to a revised GAANT chart to allow quarterly tracking and insure that new tasks derived from stakeholder interactions are properly addressed.

Table 3. Roles and Responsibilities

Investigator	Primary Responsibilities	Secondary Responsibilities
Barber, M.	Project Management Water Quantity and Quality Modeling	BMP/LID Practices Field Work
Burian, S.	Integrated Urban Water Modeling Stormwater Management and LID Practices Climate Impacts	Field Work Public Outreach and Education
Goel, R.	Field and Laboratory Studies of Water Chemistry for SOD/DO	Education Agency Coordination
Hinners, S.	Land Use Planning with ET+ Scenario Development	Public Outreach and Education
Clark, B.	Societal Values Public Outreach and Education	Scenario Development

The post-doc and graduate students will also be asked to provide written progress reports to the management team on a quarterly basis and participate in monthly team meetings. The proposed schedule is shown below for each major objective. An expanded detailed GAANT chart will be used to track progress during the grant period.



We have excellent computational and laboratory facilities. In addition to departmental computers, major modeling efforts will be conducted at the University's Center for High Performance Computing using a multi-cluster workstation automatically backed up to a secure location. The water quality laboratory in Civil & Environmental Engineering is capable of conducting all relevant analyses in this proposal once the QAPP has been submitted and approved.

Utilizing these approaches, procedures, and controls will ensure that awarded grant funds will be expended in a timely and efficient manner while successfully completing the project objectives within the grant period.

Quality Assurance Statement

This section summarizes the quality assurance and quality control practices that will be used during our project to assure that the results obtained satisfy the project objectives in accordance with the guidelines specified in the RFP. It follows the format recommended by the U.S. EPA (2007) report and covers the three main areas of our proposed project; 1) model development, 2) 3rd party data usability; and 3) QA/QC procedures adopted for our data collection efforts.

Model Development

We will adopt the procedures developed in the U.S. EPA (2002) guidance document for QA plans linked to computer modeling projects including model development and application as well as the use of environmental data acquired from other sources. Environmental data is broadly defined as any measurement or information that describe environmental processes, location, or conditions; ecological or health effects and consequences; or the performance of environmental technology.

While our overall modeling approach uses established methodologies for critical components, the unique scaling and model linkages proposed requires examination of important model assumptions and limitations to ensure the final product is scientifically sound, robust, and defensible. Thus, our emphasis in the design and QA management in the modeling portion of the project is focused on model simulations and input/output data management. Successful completion of the project objectives will entail three specific QA efforts. First, we must document all modeling runs, model input and output files, and pre and post-processing codes. Second, we must document the acquisition of meteorological and water quality monitoring data used for model evaluation. Third, we must document the actual model evaluation for contemporary simulations in terms of the evaluation steps and results. Specific aspects of the project design and associated QA management for each of these three areas are presented in following sections. Although this document is aimed at regulatory modeling, there are useful suggestions for documentation of any modeling study. To the extent that it is appropriate, we will incorporate these guidelines into our QA efforts.

Modeling Design and Methods

Our overall approach will involve multiple SWMM/ET+/DHSVM/EFDC/WASP simulations for contemporary periods (2004-2014) and for future periods (2045–2055). Each of these models has undergone rigorous scrutiny within the scientific and regulatory communities. A broad integrated urban water resources modeling framework would include atmospheric, hydrological, geological, environmental, economic, and sociological components. These components have complex interactions with human-natural water systems. The GoldSim Monte-Carlo simulation software which is used before by Burian can be used to provide dynamic simulation of the inter-related parts of the modeling framework. Integrated water system components in this study are divided to two different categories. The first category includes the components which affect the water system directly such as the natural system hydrology, water supply, water quality, stormwater, and climate. The second category has indirect impact on the water system such as demand and management actions.

The framework integrates various models included in the two categories to support the broadest set of possible climate, water quality and decision analyses. Following this strategy, the framework can be designed to help to plan and manage the water infrastructure system and related sources to maximize the economic benefits and social welfare, leading towards sustainable solutions. GoldSim served as the integrator with interfaces to the external codes of various software for specific calculations. External software was connected to GoldSim by embedding equations or by calling code through dynamic-link library (DLL) interfaces. DLL interfaces were needed to connect GoldSim with external models which were too sophisticated to be implemented with equations within GoldSim. For example, the Snowmelt Runoff Model (SRM) was included within GoldSim, but the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) was connected using a DLL created in C++ to model the stormwater runoff. GoldSim also has the capacity to execute dynamic probabilistic simulations that can be used for this application. System dynamics (SD) modeling is another way to do modeling within GoldSim when there is interrelationship and causal loop between different elements in our system. This concept can give us this ability to represent future climate projections, data from the Coupled Model Intercomparison Project (CMIP) to project water quality and quantity of the Jordan River watershed that with use of water supply and demand forecasting, TMDL planning and implementation, policy decisions related to urban growth and water projects.

We will establish documentation methods for tracking model version and options used for each specific simulation. This will also include creation of appropriate metadata and consistent file naming conventions for model inputs and outputs. Similarly, we will obtain this type of documentation for the global model runs used as input for our work. Log files for each model simulation will be kept together with model outputs to provide additional references to options and switches used in respective simulations.

The ability of the codes to correctly represent model theory will be assessed. In addition, specific tests are planned to ensure operations are verified. Continuity checks, mass conservation checks, and testing of numerical stability and convergence properties will be conducted. Plans for testing need to be worked into the various phases of the project. Model simulations will be planned to reproduce the statistical distribution properties of the field and laboratory data. Evaluation will be done by comparing cumulative frequency distribution plots of data to frequency distributions plots from comparable model predictions. This quantitative evaluation will be integrated with qualitative assessment.

As the individual modules evolve through different scales and levels of uncertainty with development (e.g., screening models, a medium-resolution segment scheme, and a high level resolution phase), assessments will be planned to determine if they are acceptable to pass on to the next phase. Ultimately, the whole framework needs to be assessed, and these individual assessment results will provide background for planning such an assessment.

The final project papers will include detailed sections on model framework, documentation, calibration, evaluation, output uncertainty, and a summary of the model application in sufficient detail that other modelers can critique and utilize the approaches and model. This peer-review process helps insures the validity of the underlying principles of the modeling effort.

Existing Data Validation and Usability

We will use published runoff data from the U.S. Geological Survey (USGS) supplemented by field measurements of velocity and flow made by the research team members. USGS flow data is widely used and accepted throughout the country. For our measurements, we will use calibrated instruments and follow published USGS guidelines.

We will use existing data collected by State agencies, Salt Lake City municipality, and other stakeholder groups in the watershed to calibrate our modeling efforts. Much of the information has been collected in support of ongoing TMDL studies and thus has been collected under approved QAPP plans. We will obtain copies of these documents to enable us to understand the procedures used to collect data.

Additional field and laboratory water quality data will be collected as part of this project. We will use the same QA/QC techniques currently being used in an EPA-funded Wetland Development grant to complete this task. All of the SOPs and the QA/QC plan are contained in a QAPP document approved by EPA. This document will be modified as necessary to meet any new field components related to velocity and diffusion measurements in Utah Lake and the Jordan River. The post-doc assigned to this project will be the designated QA/QC reviewer.

New information will use the following data management procedures.

Data Management

Measured field data on temperature and flow depth at non-USGS stations will be sampled and stored on-site with battery powered data loggers (Campbell Scientific, Inc., Logan, UT). Data stored on the data loggers will be retrieved every two weeks to four months by manual download, depending on storage requirements and site conditions. Retrieved raw data will be backed up electronically on departmental computers and external hard drives. Copies will be provided to UU researchers on portable media. Field and laboratory data will be screened by inspecting graphical representations of the raw data within two weeks of retrieval or measurement and then both raw and screened data are backed up electronically.

Computer simulation information will be stored at the UU High Performance Computing Center. This storage is backed up on a weekly basis. Outputs from key production runs will be also stored on external backup hard drives.

Additional Data Collection Efforts

ANSI/ASQC E4-1994 represents a national consensus standard for environmental sampling authorized by the American National Standards Institute (ANSI) and developed by the American Society for Quality (ASQ). This information is incorporated in many subsequent U.S. EPA guidance documents in support of EPA Order 5360.1 CHG 2 (U.S. EPA 2000).

The summary provided in this 3-page QA Statement does not completely address all the details of the QA/QC plan. Team members have expertise in developing Quality Assurance Project Plans (QAPPs) for a number of TMDL and related environmental sampling projects. Therefore, additional documentation could be easily provided if this project is selected for funding.

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Budget and Justification

Justification of Expenses

The following describes the basis for calculating costs identified in the SF-424A form.

1. Personnel: Dr. Michael Barber will serve as Project Manager and lead on water modeling of Utah Lake and the Jordan River. Dr. Steve Burian will lead stormwater modeling effort while Dr. Ramesh Goel will lead the environmental sampling efforts. Dr. Sarah Hinners will be responsible for urban planning efforts and Dr. Brett Le Clark will lead social behaviors and public outreach tasks. The PI (Barber) has 1 month of salary (8.33%) of his time while the other four senior faculty members (Burian, Goel, Hinners, and Le Clark) will each devote 5.0% of their time to the project (see Table A3). All rates are at normal academic salary levels. In addition, a post-doc (1/3 of their time) will be responsible for developing QAPP procedures, sample analysis, and QA/QC at a full-time rate of $4,000 per month. There will be 3 PhD students (years 1, 2 and 3), 1 MS student (years 1 & 2), and hourly undergraduate students ($12.50/hr). The graduate students are assumed to devote 50% of their time to the project. The total salary and wages budget is $465,946.

Table A3. Personnel

Position/Title	Annual Salary	% Time Allocated to Project	Year 1 Cost ($)	Total Project Cost ($)
Project Manager/Water Modeling	188,892.	8.33	$15,741.	49,137.
Storm Water Modeling	121,644.	5.00	6,082.	18,986.
Environmental Sampling	144,000.	5.00	7,200.	22,476.
Urban Planning	86,667.	5.00	4,333.	13,527.
Social Behavior	108,239.	5.00	5,412.	16,894.
Environmental Lab Post-Doc	48,000.	33.33	15,998.	49,941.
PhD Graduate Student 1	46,944.	50.00	23,472.	72,294.
PhD Graduate Student 2	46,944.	50.00	23,472.	72,294.
PhD Graduate Student 3	46,944.	50.00	23,472.	72,294.
MS Graduate Student	42,144.	50.00	21,072.	42,987.
Undergraduate Students	26,000.	43.27	11,250.	35,118.
Total Personnel				465,946.

2. Fringe Benefits: Total charges of $125,431 include health, retirement, tuition, and other applicable expenses billed at established university rates. Dr. Barber's fringe rates are 25.3% while other faculty rates are at 37%. The fringe rate on the Post-Doc salary is 52% while the graduate student rate is 14%. The fringe rate on undergraduate students is 8%.

3. Travel: Table A4 summarizes the travel expenses associated with this project. They include travel funds for the annual NCER program progress reviews and a final workshop to report on results as directed by this RFP. It is anticipated that two people will attend the annual meeting and the final workshop. In addition, there is $1,344 requested for sample collection activities and

another $2,323 for conference travel for project-related presentations at annual AGU conference in San Francisco. All rates are at established Federal rates for the area of travel.

Table A4. Travel Summary				
Purpose of Travel	Location	Item	Computation	Cost
EPA STAR Review	DC	Airfare	2 trips x 2 people x $1,150	$4,600.
		Lodging	2 trips x 2 people x 2 nights x $224	1,792.
		Per Diem	2 trips x 2 people x 2 days x $83	664.
EPA STAR Workshop	DC	Airfare	1 trip x 2 people x $1,150	$2,300.
		Lodging	1 trip x 2 people x 2 nights x $224	896.
		Per Diem	1 trip x 2 people x 2 days x $83	332.
Presentations	CA	Airfare	2 trips x 1 person x $380	760.
		Lodging	2 trips x 1 person x 3 nights x $189	1,137.
		Per Diem	2 trips x 1 person x 3 days x $71	426.
Field Work	Utah	Mileage	24 trips x 100 miles x $0.56/mile	$1,344.
Total Travel				$15,808.

4. Equipment: A workstation core will be purchased through the University of Utah's Center for High Performance Computing (CHPC). Each node consists of an Intel Xeon E5-2670 processor at a cost of $6,045 including cables and switch costs.

5. Supplies: Our request for supplies includes water quality analyses, laboratory sampling chambers, field probes, field instrumentation, conference registration, and computer services. We will perform monthly field sampling and laboratory experiments to determine climate change impacts on kinetics during the first two years of the project. Expenses related to sample collection, water quality standards, laboratory supplies, chamber construction, and other disposable supplies are estimated to be $39,671. An additional $15,000 is requested for field probes (DO, temperature, pH, conductivity) and field-deployable temperature/pressure sensors. Conference registration of $1,200 is requested for conferences in years 2 and 3 of the project. Cluster storage space and remote weekly backups at the CHPC are included in the budget. Year 1 expenses will be primarily $1,100 for storage space and backup disks. The Year 2 request of $3,000 is for additional storage space to store the vast amount of simulation data generated by the models.

6. Contractual: We estimate $3,000 ($1,500/yr for 2 years) will be spent on monthly boat rental for sampling in Utah Lake. This is cost effective compared to boat ownership.

7. Other: A total of $2,500 for publication charges and printing expenses for workshops and other outreach activities.

8. Indirect Costs: A total of $321,298 in F&A charges are assigned to this project. This is at the federally negotiated rate of 49% on all charges except tuition and equipment.

University Cost Share: The University will contribute $250,000 to this project including $49,946 in matching Post-doc support (33% time), $25,972 in post-doc benefits, $76,697 is supplies including computers, workshop support, software, and additional water quantity/quality sampling, $18,135 in workstation cluster equipment (3 nodes to make 4 node cluster), $3,000 in

CHPC storage charges in year 3, and $76,251 in F&A charges. This is in addition to the water quality data being collected and provided by local agencies in support of TMDL process.

Resumes

Current and Pending Support

Support Letters