Sample and Analysis Plan

Stream Water Quality and Quantity for GAMUT

Version 1.2
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Prepared by the iUTAH Water Quality Team

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Revision History

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Contents

Acronyms/Abbreviations

BYU	Brigham Young University
EPSCoR	Experimental Program to Stimulate Experimental Research
GAMUT	Gradients Along Mountain to Urban Transitions
iUTAH	Innovative Urban Transitions and Arid-region Hydro-sustainability
MDF	Modeling and Data Federation
NSF	National Science Foundation
NWIS	National Water Information System
TN	Total nitrogen (mg/L)
TP	Total phosphorus (mg/L)
USGS	United States Geological Survey
USU	Utah State University
UU	University of Utah

1. Introduction

This Sample and Analysis Plan was prepared by the Water Quality sub-group of iUTAH's Research Activity 1 (Ecohydrology). Team members included colleagues from multiple institutions and agencies:

- BYU – Zach Aanderud, Greg Carling, Joe Crawford, Dylan Dastrup, Timothy Goodsell, Erin Jones
- USGS – Matt Miller
- USU – Michelle Baker, Jeff Horsburgh, Amber Jones, Julie Kelso, Elizabeth Ogata, Tony Melcher, Nancy Mesner
- UU – Dave Bowling Jim Ehleringer, Dave Eiricksson, Steven Hall

The purpose of this document is to provide a description, justification, and a plan for collection of iUTAH – related environmental samples at established sites of the iUTAH Gradients Along Mountain to Urban Transitions (GAMUT) surface water observatory network. Of particular importance, this document describes our approaches and methodologies for establishing streamflow rating curves, baseline water chemistry, and proxies of continuous sensor data that are collected by GAMUT instrumentation.

1.1 Background

In August 2012, the National Science Foundation's EPSCoR program awarded a Track 1 Research Infrastructure Award to Utah State University on behalf of the state of Utah. The purpose of the award is to increase research capacity and enhance research competitiveness in STEM (science, technology, engineering, math) fields across the state. With this award, the State chose to enhance capacity related to water sustainability.

A long-term infrastructure component of the award was aimed at building a terrestrial and aquatic environmental observatory focused on gradients along mountain to urban transitions (GAMUT). Three distinct watersheds were selected as long-term observatories Logan River, Red Butte Creek, and Middle Provo River. The watersheds differ in current urban footprints, rates, and types of land use conversion to urban area, size, and elevation. Details of the GAMUT design and installation are provided online at iutahepscor.org.

The GAMUT network includes 14 stream monitoring stations, aimed at providing real-time data collection on stream flow and water quality, much like USGS NWIS monitoring stations found across the USA. There are two classes of stream GAMUT stations; basic and advanced (Table 1).

It is anticipated that the GAMUT network will be a long-term investment by the State of Utah, lasting beyond the length of the 5-year iUTAH project, and forming a foundation for further research and training activities. The GAMUT network also serves as a critical link between academic institutions and state agencies, and as a long-term environmental observatory bridging urban planning needs, environmental sustainability, and connectivity of wildland and urban landscapes.

Table 1. Sensors, sensor types, and sensor units for instruments deployed at fundamental and advanced GAMUT stations in the three watersheds affiliated with the iUTAH project.

Sensor	Sensor type	Units	
Stream stage	Pressure transducer	cm	All stations*
Temperature	Thermistor	°C	All stations
Electrical Conductivity	Electrode (nickel cell)	mS/cm	All stations
pH	Electrode	pH	All stations
Dissolved Oxygen	Optical (lifetime luminescence)	% sat; mg/L	All stations
Turbidity	Optical (laser diode)	NTU	All stations
Chlorophyll	Optical (fluorescence)	RFU	Advanced
Phycocyanin	Optical (fluorescence)	RFU	Advanced
fDOM	Optical (fluorescence)	QSE	Advanced
Nitrate	Optical (MBARI-ISUS)	mg/L	Advanced

* 3 stations in Middle Provo, and 1 station in Red Butte obtain stage measurements from USGS gauges

1.2 Objectives

Sensors at GAMUT stations generally make continuous measurements of *indicators* of water quantity and quality (Table 1), rather than direct measurements of stream discharge and water chemistry. Thus, discrete environmental samples must be collected in order to interpret sensor output. At the same time, such baseline data should provide iUTAH investigators and partners with important information to guide research questions and study designs, and calibration data for models of water quality and water balance. Data collection outlined in this plan will be used to:

A. Establish and verify rating curves in order to transform continuous measures of stream depth to volumetric flow (discharge)

B. Provide baseline measurements of standard water quality parameters

C. Enable development of proxies between discrete water quality data and continuous data from real-time sensors at GAMUT aquatic stations

1.3 Site Descriptions

Aquatic stations are installed in three watersheds:

1. Provo River at Soapstone, Below Jordanelle Reservoir, at Lower Midway and at Charleston (http://data.iutahepscor.org/mdf/provo-river)
2. Red Butte Creek at Knowlton Fork, Above Red Butte Reservoir, at Red Butte Gate, at Cottom's Grove, and at Foothill Drive (http://data.iutahepscor.org/mdf/red-butte-creek)
3. Logan River at Franklin Basin, at Tony Grove, at the USU Water Lab, At Main Street, and at Mendon Road (http://data.iutahepscor.org/mdf/logan-river)

1.4 Project Organization

Michelle Baker (USU) is the iUTAH Project Director. Co-Principal Investigator Jim Ehleringer (UU) leads major facilities for iUTAH, under which the GAMUT facility falls. There are three watershed leads and associated technicians:

- Logan River (USU) = Scott Jones, Chris Cox, Jobie Carlisle
- Red Butte (UU) = Dave Bowling, Dave Eiriksson
- Middle Provo (BYU) = Zach Aanderud, Joe Crawford

Technicians oversee the day-to-day operations of the GAMUT stations, with assistance from graduate students and other student employees as needed. GAMUT technicians also conduct QA/QC of incoming data streams and work closely with the iUTAH Data and Modeling Federation (Jeff Horsburgh (USU) and Amber Jones (USU)).

2. Data Quality Objectives

Data quality requirements and design rationale presented here are informed by the US EPA's seven-step data quality objective (DQO) process (EPA 2006). This process defines the type, quantity, and quality of data required so that the data collected support the goals of the study in such a way that is consistent with professional and nationally accepted standards.

2.1 Problem Statement

Problem

Most GAMUT stations did not have established rating curves (relationship between stage (cm) and volumetric flow rate (m^3/s)) at the time that stations were installed. Water quality sensors can record parameters such as electrical conductivity and turbidity, but we have little sense of how these indicators of water quality relate to actual water quality metrics such as total dissolved solids (in the case of conductivity) or total suspended solids or total phosphorus (in the case of turbidity). Advanced water quality sensors that bracket urban sections in each watershed are also fairly novel. For example the fluorometric sensors for chlorophyll and fDOM are calibrated to a standard fluorophore (rhodamine in the case of chlorophyll and quinine sulfate in the case of fDOM). Thus while these sensors measure fluorescence properties of the water, the output must to be calibrated to discrete water samples to translate sensor output to extracted chlorophyll and in the case of fDOM sensors, DOC concentration and absorbance at 254 nm (Downing et al. 2012). Finally, the nitrate sensors are calibrated to nitrate standards and do read nitrate concentration, but fDOM in the water may cause an interference, thus environmental samples will be required to better interpret sensor output.

This problem will be addressed by coordinated sampling of stream flow (rating curve) and water chemistry at each GAMUT station in all seasons in order to capture a variety of hydrochemical conditions.

Project Team

Implementation of this Plan will require a collaborative effort across iUTAH institutions. The team consists of members from the following:

- Utah State University – Design standard operating procedures (SOPs) for collection and analysis of stream water samples
- Brigham Young University – Design SOPs collection and analysis of stream water E. coli and Total Coliform samples from streams
- GAMUT technicians – Maintain GAMUT aquatic sensors following SOPs; Perform quality control (QC) checks of sensor data; Coordinate with RFA1 graduate students and other research personnel to plan and implement sample collection following established SOPs
- RFA1 Graduate student at USU – Act as liaison between field and lab (water chemistry); Maintain water chemistry lab data base and coordinate with iUTAH Data and Modeling Federation; Perform QC checks of lab data per established SOP.

Available Resources

Personnel. The iUTAH award provides for personnel and resources at BYU, USU, and UU to collect environmental samples at approximately biweekly intervals (20-25 samples per site), roughly about as often as GAMUT sensors will require field checking and maintenance. Biweekly sampling is not necessarily the best sampling interval for establishing chemical proxies. Sampling at advanced aquatic stations will also include samples collected every 1-3 days during snowmelt, as well 10+ samples during opportune storms.

Analyses. Costs for chemical analyses of routine water samples (anions, cations, filtered and unfiltered nutrients, DOC, chlorophyll, TSS and VSS) are included in the USU award under the facility 1 budget category.

Relevant Deadlines

It is important that data collection for rating curve development begin soon after GAMUT stations are installed so that stream depth can be converted to volumetric flow. This data product is critical for iUTAH researchers interested in understanding and modeling water balance. Water chemistry sampling should occur at the same time as stream flow is measured for the rating curve. All GAMUT stations should be installed and recording data by June 30, 2014, and regular sampling as outlined in this plan will be expected to be in place at that time.

2.2 Research Goals

Objective

The objective of this plan is to collect environmental data that will accomplish the following:

1. Establish a rating curve (relationship between stream stage and discharge) at each GAMUT station.
2. Allow interpretation of GAMUT sensor output using chemical proxies collected as discrete environmental data.
3. Allow calibration of water quality and quantity models being developed and tested under the iUTAH research umbrella

4. Provide background information describing chemical and microbiological water quality at different times of the year at each GAMUT station that can serve as context for and support a variety of research projects as they are launched under the iUTAH umbrella.

Key Questions

The overarching goal of Research Focus Area 1 of the iUTAH project is to strengthen Utah's capacity to monitor and understand the ecohydrologic system of the Wasatch Range Megapolitan Area (WRMA). This will be accomplished by improving watershed-scale measurement capacities, and using this instrumentation to conduct research aimed at better understanding ecohydrologic processes that influence Utah's water resources. Guiding research questions related to water quality include (Crowl et al. 2013):

- What is the spatial and temporal variability of biogeochemical transformations that affect water quality?
- What is the relationship between snowpack chemistry and runoff chemistry?
- What are major nitrogen (and other chemical) sources and loading rates to WRMA streams and how do they vary along mountain-to-urban gradients? How do these vary seasonally, with storm/runoff events, and with varying antecedent conditions?
- What are *Escherichia coli* sources across the WRMA and how do they relate to water quality indices and overall microbial community structure in streams?

Underlying these questions is a need to understand the ambient water quality in the study watersheds. Toward that end, the iUTAH GAMUT network was designed in part to provide real-time data on stream flow and indicators of water quality. GAMUT design was completed in late 2012, and site instrumentation began in spring 2013. While some stations are at or near USGS monitoring stations, for the most part there are few accessible environmental data with which we can put the current monitoring data in context. The purpose of this document is to describe sampling and analysis plans for surface waters of the GAMUT. A separate, snow chemistry team will develop a similar sample and analysis plan.

Possible Outcomes

1. The desired outcome is that sufficient data are collected to create reliable rating curves and to develop chemical proxies of water quality at each GAMUT station. The Water Quality team will evaluate data collected and make recommendations as to whether or not, and to what extent further sample collection should continue.

2. Potential risks to achieve desired outcome include a lack of resources (especially travel and personnel) available on a given day to complete necessary sampling. Suggested remediation measures include quarterly planning meetings at a minimum to ensure resource availability, and a shared calendar with specific personnel identified for data collection.

3. Sensor failure is another risk. The Water Quality team recommends that iUTAH invest in at least one spare sensor so that duplicate measurements can be made as part of the field quality control process (see Data QA/QC plan) and that could be used to replace failed sensors.

2.3 Variables/Characteristics to be measured

Each regular, bi-weekly site visit will collect the following (see separate SOP for field collection; see section 4 below for laboratory analyses to be conducted):

1. Water surface elevation (cm) on the stage plate installed at each GAMUT site
2. Filtered water chemistry; grab sample from thalweg (mid channel)
3. Unfiltered water chemistry; grab sample from thalweg
4. TSS and VSS filter; grab sample from thalweg
5. Chlorophyll filter; grab sample from thalweg
6. Unfiltered bacteria sample for Total Coliform/*E. coli* analysis

In addition to regular, bi-weekly site visits, technicians will plan and execute stream discharge measurements at strategic locations and times aimed at capturing a wide range of discharges at each site. These discharge sampling events may be coordinated with regular, bi-weekly sampling events, but may have to be more or less frequent depending on streamflow conditions at the sites. Each discharge measurement visit will collect the following (see separate SOP):

1. Surveyed water surface elevations within the established cross section at each site at the beginning and end of the discharge measurement
2. Water surface elevation on the stage plate installed at each GAMUT site at the beginning and end of the discharge measurement
3. Discharge (m^3/s) at the site

Special baseline studies are described in detail below (section 3.3). One special case of special study is synoptic sampling wherein unfiltered water is collected from ~20 locations in each GAMUT watershed and analyzed for *E. coli*, water isotopes, and total N and P.

2.4 Study Boundaries

Temporal

Streamflow and water chemistry will be measured as described in this plan through at least year 5 of the iUTAH project. Data will be made available to all iUTAH investigators through the Data and Modeling Federation website. The Water Quality team will prepare a short report of the data annually to provide information to and receive feedback from the iUTAH research community.

Practical Constraints on Data Collection

1. Property access is being negotiated and confirmed
2. Availability of staff, vehicular, and sampling equipment may limit some activities
3. Weather, and winter access may limit ability to collect samples, some sites may not have year-round flow
4. iUTAH research personnel are not to sample alone
5. Sample numbers. Between 20-25 measurements at each GAMUT station across the entire range of flow are recommended per year, especially including snowmelt and storms. Spackman Jones et al. (2011) used considerably more samples (148-175) to develop water

quality surrogates for sensor outputs using TP and TSS in the Little Bear River; however, existing iUTAH resources may not allow that level of replication. To optimize resource availability with data collection needs, it is recommended that a minimum of 20 samples/GAMUT/year be collected at all stations, and that data from 2-3 storms (15-30 samples each) be collected at each enhanced GAMUT station during the next 3-4 years.

6. Types of analyses. Resources limit the types of analyses in the USU budget to facile and inexpensive measures of water quality. Samples can be archived for additional investigator-driven analyses using other resources. Requests for additional sample collections can be considered on a case by case basis, and will require approval of iUTAH research personnel and their supervisor(s). The Water Quality Team recommends a separate plan be developed for sample archival.

2.5 Decision Rules

Each year, the Water Quality Team will analyze available data and will make recommendations as to revisions to the Sample and Analysis Plan. If sufficient information has been collected to generate reliable rating curves and chemical surrogates of sensor outputs, then the recommendation will be to stop making detailed measurements.

Tolerance limits for laboratory water quality analyses are defined in the SOPs for each analyte (http://canoeecology.weebly.com/uploads/2/1/0/0/21002098/abl_analytical_lab_manual.pdf). The QA/QC plan in these SOPs includes spikes, sample duplicates, blanks, and certified reference materials – results above or below a 20% threshold will be considered invalid, and will require reanalysis of the sample(s). All samples will be run blind.

It is assumed that these data quality objectives, sampling, analyses, and QA/QC methods will be reviewed and revised as needed on an ongoing basis b y the iUTAH Water Quality Team.

3. Sampling Plan

This sampling plan attempts to address fundamental data requirements for the GAMUT network. It is not meant to describe the many investigator-driven research activities that may require similar data collection and laboratory analyses. Note that GAMUT sensor calibration and QA/QC objectives are described in a separate GAMUT QA/QC plan. We outline three broad categories of work to be completed in support of the GAMUT network:

1. Environmental sample collection: These activities will provide necessary input to analyses aimed at establishing rating curves and water chemistry surrogates of sensor outputs. Environmental samples also will provide important context and background information for research related to surface water quantity and quality across the iUTAH project.

2. Developing water quality proxies to sensor outputs: These are ways of analyzing the data from environmental samples to better interpret GAMUT sensor data.

3. Baseline studies: These include special sample collections aimed at providing baseline data, context or to stimulate research questions.

3.1 Environmental Sample Collection

Baseline environmental sampling is required to optimize GAMUT station output. While this may be considered "monitoring," there are important scientific outcomes possible as described in section 3.2. Furthermore the effort will provide important data to be incorporated into planned RFA1 graduate student and postdoctoral research projects.

1. Measuring stream flow
2. Water quality sampling
3. Sampling particulate constituents

3.2 Developing water quality proxies to sensor outputs

Analyzing and interpreting real-time sensor data is a research challenge in hydrologic science. iUTAH has the opportunity to lead this challenge in analyzing data from the GAMUT network. We envision several research outcomes from this effort including improvements to establishing surrogates of water quality from sensor output (Spackman Jones et al. 2011), assessing nutrient constraints on ecosystem metabolism (Cohen et al. 2013), and developing loading estimates and yields that are important in guiding water quality policy. Note that Utah has insufficient data to contribute to national estimates of nutrient loads and yields in surface water http://www2.epa.gov/nutrient-policy-data/estimated-total-nitrogen-and-total-phosphorus-loads-and-yields-generated-within.

3.3 Baseline Studies

Synoptic Sampling

As the GAMUT was being designed and installed, the iUTAH leadership made the decision to allocate GAMUT sampling and analysis resources to synoptic baseline sample collection at ~ 20 locations in each of the 3 study watersheds. Sampling began in June 2013 and will continue every 4-6 weeks for at least 12 months. Parameters to be measured include:

- Tsotopic composition of water (UU conducts analyses on all watersheds, Jim Ehleringer POC)
- *E. coli*/total coliform counts (BYU conducts analyses on all watersheds, Erin Jones POC)
- Total N and P concentrations (USU conducts analyses on all watersheds, Julie Kelso POC)

Initially, personnel from across the 3 watersheds collaborated to sample at all locations. Over time as part of this plan, resident personnel will conduct these sampling efforts in order to more efficiently use travel resources.

Additional Baseline Sampling

iUTAH postdoctoral researcher Steven Hall (UU) is conducting biogeochemical studies and analysis of nitrate sources within the GAMUT watersheds. In that vein additional filtered samples will be collected as part of routine baseline samples for analysis of isotopic composition of $^{15}NO_3$ at the UU SIRFER lab (resources for analysis of these samples will be provided by UU subaward).

In fall 2013 the USU-ABL lab installed a new instrument to measure fluorometeric properties of DOM in stream water. These measurements allow one to characterize the DOM as being of microbial or terrestrial origin. iUTAH graduate student Julie Kelso's (USU) dissertation focuses on dynamics of anthropogenic organic matter in streams, and additional filtered and acidified samples will be collected as part of routine baseline samples for this purpose (resources for analysis of these samples will be provided by USU).

Given that both Hall and Kelso are actively engaged in field sampling associated with the GAMUT, these additional sample collections will not be overly burdensome additions to routine sampling over the next 1-2 years.

Sample Archiving

It is not possible to foresee all of the interesting potential uses for water samples after the major analyses have been completed. A decision was made by the iUTAH leadership to archive synoptic and baseline water samples whenever possible. USU purchased two upright freezers for that purpose. These are located in the College of Agriculture and Applied Science's Biotechnology Center where iUTAH has lab space. The iUTAH Water Quality team recommends that iUTAH Leadership Team develop a set of decision rules describing the number and types of samples that can be archived, who decides when a sample can be removed from archive, and who decides when a sample can be used or consumed.

4. Laboratory Analyses

Detailed SOPs and QA/QC information will be available by contacting the laboratory responsible for conducting the specific analysis (http://canoeecology.weebly.com/uploads/2/1/0/0/21002098/abl_analytical_lab_manual.pdf). Where analysis of the same constituent is to be conducted by more than one lab, a round-robin analysis of certified reference material and sample splits will be conducted to ensure inter-lab comparability. The USGS conducts a semi-annual interlab comparison study using a standard reference material that could be useful in this regard (http://www.cuahsi.org/hmf-srs.aspx).

Filtered samples will be analyzed for the following constituents:

1. Major anions and cations (ion chromatography)
2. NO3-N + NO2-N (colorimetric)
3. NH4-N (colorimetric)
4. SRP (colorimetric)
5. NP-DOC (catalytic oxidation) and total dissolved N
6. Absorbance at 254 nm

Solids collected on filters should be analyzed for the following constituents:

1. TSS
2. VSS
3. Chlorophyll

Unfiltered samples should be analyzed for Total N and Total P (persulfate oxidation followed by colorimetry) and Total Coliforms

5. Data Management

All of the data resulting from sampling under this plan will be published via the iUTAH Modeling & Data Federation (MDF). Amber Spackman-Jones is the POC between the analytical lab(s) and the MDF. Once entered into the MDF, the data will be available to all iUTAH researchers and partners. The time between sample collection and the availability of analytical results online will depend on the workload of each analytical laboratory; however, all results will be posted within timelines specified within the iUTAH Data Management Policy (iutahepscor.org).

5.1 Sample Identifiers

Each physical sample (bottle or container) to be collected will be assigned by the Baker Lab at USU a globally unique identifier before the sample is collected in the field. These identifiers will be affixed to the sampling containers and will accompany the samples in the field, in the laboratory, and eventually in the physical sample archive.

5.2 Sample Data Workflow

The following figure shows the sample data workflow for the samples collected as part of this effort. As described above, unique identifiers will be assigned by the technicians or the laboratories before the samples are collected in the field. The technicians then collect samples in the field and submit them to the respective laboratories for analysis. Metadata describing each of the samples will be entered by the technicians using online forms provided by the iUTAH MDF. Each laboratory has a single point of contact that will enter the data corresponding with each sample analysis into online forms provided by the iUTAH MDF. The data will then be reviewed by the iUTAH MDF data manager and entered into the operational databases for each of the GAMUT watersheds for publication online.

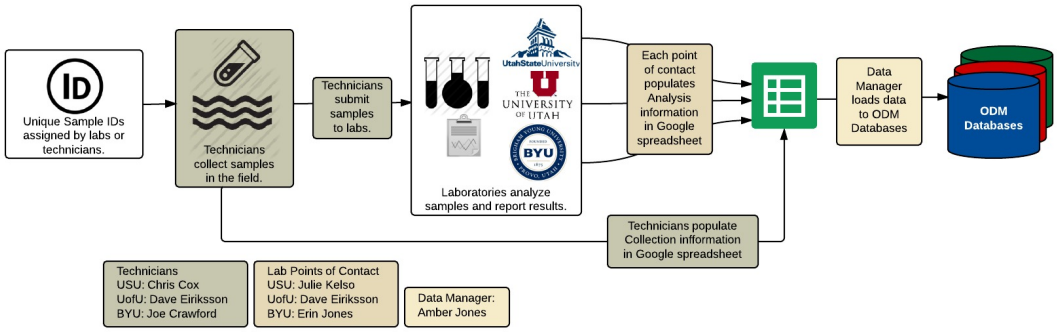

Figure 1. iUTAH water quality sample data workflow.

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