

**Utah Center for Water Resources Research
Annual Technical Report
FY 2013**

Introduction

The Utah Center for Water Resources Research (UCWRR) is located at Utah State University (USU), the Land Grant University in Utah, as part of the Utah Water Research Laboratory (UWRL). It is one of 54 state water institutes that were authorized by the Water Resources Research Act of 1964. Its mission is related to stewardship of water quantity and quality through collaboration with government and the private sector.

The UCWRR facilitates water research, outreach, design, and testing elements within a university environment that supports student education and citizen training. The UCWRR actively assists the Utah Department of Environmental Quality (UDEQ), the Utah Department of Natural Resources (UDNR), the State Engineers Office, all 12 local health departments, and several large water management agencies and purveyors in the state with specific water resources problems. In FY 13, the UWRL expended a total of almost \$9 million in water research support. USGS Section 104 funds administered through the UCWRR accounted for approximately three percent of this total. These funds were used for research addressing water and wastewater management problems, outreach, information dissemination, strategic planning, water resources, and environmental quality issues in the State of Utah. Five research projects were funded in FY12 with USGS 104 funds. These projects are respectively entitled, (1) "Drought Index Information System Development for NIDIS," (2) "Estimating Crop Water Use with Remote Sensing: Development of Guidelines and Specifications," (3) "UAV Monitoring and Assessment Applications in Municipal Water and Environmental Management Problems," (4) "Quantification of Water Quality Improvements Through the 900 S Oxbow Restoration and Stormwater BMP Renovation Project," and (5) Capturing Aerial Imagery on the San Rafael River, Utah, Using an Unmanned Aerial Vehicle (UAV) to Monitor and Assist in Evaluating Restoration Efforts." These projects dealt with the following water management issues: (1) Developing a capability to evaluate and implement drought indices on a spatial basis for inclusion in a National Integrated Drought Information System (NIDIS) pilot study creating a drought early warning system for the Upper Colorado River Basin; (2) Developing a framework for estimating crop water use using remote sensing through a standardized approach, thus providing guidelines and specifications for applying certain evapotranspiration (ET) models and producing ET products that are acceptable to the USGS WaterSmart program and the scientific and user community; (3) Investigating the value of using AggieAir, a low-cost, high-resolution multispectral remote sensing platform, as a tool to provide accurate and quality spatial data for municipal applications to help manage water and environmental issues in wetland and riparian areas, landfills, and parks and recreation areas; (4) Determining the impact of dissolved oxygen depletion from coarse particulate organic material in the Jordan River and determining the impact of dissolved organic material loading on the oxygen demand and subsequent oxygen depletion within the lower Jordan River (5) Using an inexpensive unmanned aerial vehicle (UAV) to provide high resolution, up to date aerial imagery in support of restoration schemes ongoing in the San Rafael River in South Central Utah and determining the accuracy and limitation of this platform for providing digital elevation and terrain models in place of more conventional, and more expensive, approaches. These projects all involved collaboration of local, state, and federal water resources agency personnel.

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USGS Section 104 funds were used to establish a data server to support the publication of drought index information for the NIDIS Upper Colorado River Basin (UCRB) pilot drought early warning system which aims to enhance access to drought related data and enable custom drought index calculation. A HydroServer using the CUAHSI HydroServer software stack on virtual servers hosted at the Utah Water Research Laboratory (UWRL) data center has been developed to publish drought index values as well as input data used in drought index calculations, with web services for the data sources necessary for drought index calculation. Procedures to aggregate the input data to the time and space scales chosen for drought index calculation have also been developed, and automated data and metadata harvesters that periodically scan and harvest new data from the input databases have been created to ensure that the data available on the drought server are kept up to date.

Irrigated agriculture is the largest consumptive water user in the western United States. Estimates of crop water use can be improved through more accurate evapotranspiration (ET) estimates. A research project supported with Section 104 funds this year is developing a framework for estimating crop water use using remote sensing through a standardized approach that will provide guidelines and specifications to be followed in order to apply certain models and produce ET products that are acceptable to the USGS WaterSmart program and the scientific and user community. This research includes reviewing and testing candidate remote sensing – based ET models to establish model performance and determining the uncertainty associated with the application of these models. A set of study sites will be selected from within the 17 western United States representing different climatic regions, and a variety of spatial and point datasets will be utilized. This work will benefit many hydrological modeling and water resources management applications.

Remote sensing and aerial imagery provide many benefits for water and environmental management problems. Several of these benefit include having more accurate, distributed, and complete spatial data than is possible with ground surveys alone. However, many water providers and environmental managers are not able to take advantage of these benefits due to the high cost and limited flexibility of conventional remote sensing technologies. A USGS-funded project is addressing these issues specifically for municipal applications in water and environmental management problems using a series of remote sensing platforms developed at Utah State University collectively called AggieAir™. AggieAir is a small, autonomous unmanned aircraft that carry multispectral onboard cameras that capture aerial imagery during flight at a lower price and a greater spatial and temporal resolution than most manned aircraft and satellite sources. The platform's multispectral cameras are able to capture visual (red, green blue), near-infrared (NIR), and a thermal infrared imagery. For this project, we collaborated with the city of Logan, UT and used AggieAir to gather aerial imagery over various types of municipal areas including a wetland, a riparian area, the city landfill and the city golf course. The imagery was processed in various ways to generate data that Logan City can use to help manage these areas.

Restoration and renovation projects initiated by the Salt Lake City Parks and Public Lands and Public Works departments in connection with the Red Butte Creek oil release that occurred in June 2010 are currently underway. A USGS-funded project was working to determine the effectiveness of these projects in removing pollutants and improving the water quality of discharges into Utah's Jordan River. Due to delays in the implementation of these projects the research focus shifted to improving the understanding of the dissolved oxygen depletion in the Jordan River. Sampling in stormwater channels that discharge into the Jordan River indicated that large amounts of coarse particulate organic material (CPOM) are being captured and stored in the water column at these outlets, which then decomposes and generates significant pulses of dissolved organic carbon that enters the Jordan River during rain events. Laboratory studies were carried out to determine the impact of this CPOM and the dissolved organic material loading on the oxygen demand and subsequent oxygen depletion within the lower Jordan River. Results include engineering options for

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management of the CPOM-derived oxygen demand.

Another USGS funded project is using AggieAir high-resolution multi-spectral imagery (RGB, NIR, and thermal imagery) of the lower San Rafael River to provide valuable information to the San Rafael Restoration Committee and the Utah Division of Wildlife Resources in support of ongoing river restoration projects. The imagery will provide spatial information regarding thermal refugia and detailed channel information for restoration projects in this region including efforts to restore the river to a more ecologically acceptable state, provide more comprehensive complex native fish habitat, encourage change in channel morphology through Tamarisk removal, and remove man-made barriers to enhance and encourage fish movement/passage throughout the entire drainage. Temperature probes will be installed to assist in calibrating the thermal imagery. This project has been delayed due to severe low flow conditions in the San Rafael River (less than 2 cubic feet per second for several months in the summer 2013). River levels are expected to return to semi-normal levels in 2014, and the project will be completed at that time.

These projects involved collaborative partnerships throughout the state with various local, state, and federal agencies.

Grant--Drought Index Information System for NIDIS

Basic Information

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Final Report

USGS Grant No. G10AP00039 Drought Index Information System for NIDIS

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Introduction

The National Integrated Drought Information System (NIDIS) pilot is focused on the creation of a drought early warning system for the Upper Colorado River Basin. This document is the final report for a project performed at Utah State University whose objective was creation of a capability for evaluation and implementation of drought indices on a spatial basis using the capability of and technology from the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS).

The goals of this project were to enhance access to drought related data and enable custom drought index calculation. This was driven by the difficulty that water managers face in assembling all of the datasets needed to calculate drought index values. The required data come from several different sources, are delivered in differing formats, and have differing spatial and temporal resolutions. Assembling the datasets for calculating drought index values required learning the data systems of each data source, downloading the data and converting them into consistent formats, and then transforming the data into consistent space and time scales for drought index calculation. This project aimed at making this process easier by automating as much of this process as possible and making the automatically generated data products available to a wide audience of users.

Our approach was to first establish a foundation of primary hydrologic information related to drought in the Upper Colorado River Basin (UCRB) pilot area (i.e., the input data required for calculating drought index values) and publish them on the Internet using the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI) Hydrologic Information System (HIS). By publishing the data using the CUAHSI HIS, we were able to ensure that each of the datasets was available via standardized web service interfaces and could be retrieved in standardized formats – alleviating much of the heterogeneity that makes integration of these data for drought index calculation so difficult.

We then developed methods for automatically aggregating the primary data used to calculate drought index values to time and space scales most relevant for drought index calculation. We also published the aggregated data using the CUAHSI HIS so that local customized drought index evaluation using the aggregated data was enabled, saving users time and effort. Finally, we extended the CUAHSI HIS map-based visualization tools to present visualizations of the published data through web map interfaces. By publishing the datasets using the CUAHSI HIS, they are now available for consistent access via several mechanisms, including the CUAHSI HIS HydroDesktop software that users can install on their own computers to download, visualize, and analyze the datasets created by this project.

In the following sections, we begin with a brief description of the CUAHSI HIS and then describe in more detail the specific activities that were undertaken as part of this project.

We describe the technical approaches that were used, and the products that were developed. We also highlight specific challenges that were encountered.

The CUAHSI HIS

The CUAHSI HIS (<http://his.cuahsi.org>) is an Internet based system that supports the sharing of hydrologic data. It consists of databases connected using the Internet through web services as well as software for data discovery, access, and publication. The HIS is founded upon the Observations Data Model (ODM) (Horsburgh et al., 2008), which is an information model for observations at stationary points that supports data publication through web services and provides community defined semantics needed to allow sharing information from diverse data sources. CUAHSI HIS software provides the capability for users to establish their own server and publish their data using web services that transmit data using Water Markup Language (WaterML). These web services support access to hydrologic data stored in ODM.

The CUAHSI HIS provides a flexible system for the sharing of data, and was chosen as a platform for supporting the publishing of calculated drought index values as well as for publishing the input data used to calculate them in easily accessible, standardized formats. The value of sharing both calculated index values and the input data used to calculate them is the flexibility that it affords users for developing their own custom measures of drought, for their own specific purposes. Two CUAHSI HIS components interacted in filling NIDIS drought index needs. Some extensions to the “off the shelf” capability of these components were required to fulfill NIDIS needs.

HydroServer

A CUAHSI HydroServer is a server platform that integrates and publishes hydrologic data related to a specific project, experimental watershed or purpose (Horsburgh et al., 2010). HydroServer is built on the Microsoft Windows Server operating system using commercial off-the-shelf software as well as custom software components developed by the HIS team. Commercial software includes Microsoft Windows Server with .Net Framework, Microsoft Internet Information Services, ESRI ArcGIS Server, and Microsoft SQL Server. Generally the latest version of each of this software is used. Software developed by the CUAHSI HIS Team includes: the Observations Data Model system comprising the ODM schema, tools and data loaders, WaterOneFlow Web Services, HydroServer capabilities database, the Time Series Analyst, and HydroServer web map application.

HydroDesktop

HydroDesktop is the desktop client developed to discover, download, and analyze data that have been published using the CUAHSI HIS system (i.e., data published on a HydroServer) (Ames et al., 2012). It provides the capability to retrieve information from a number of HIS Servers as well as to customize the display and analysis of this data through its plugin interface.

HydroServer Development for NIDIS

Utah State University established a CUAHSI HIS HydroServer to support publication of drought index information for the NIDIS Upper Colorado River Basin (UCRB) pilot drought early warning system. For this project, we built <http://drought.usu.edu> using the CUAHSI HydroServer software stack on virtual servers hosted at the Utah Water Research Laboratory (UWRL) data center. The drought HydroServer was developed as a platform to store and publish calculated drought index values as well as the input data used in drought index calculations. Figure 1 shows the overall architecture of the drought HydroServer that was developed and gives a high level view of all of the functional pieces that were developed for this project.

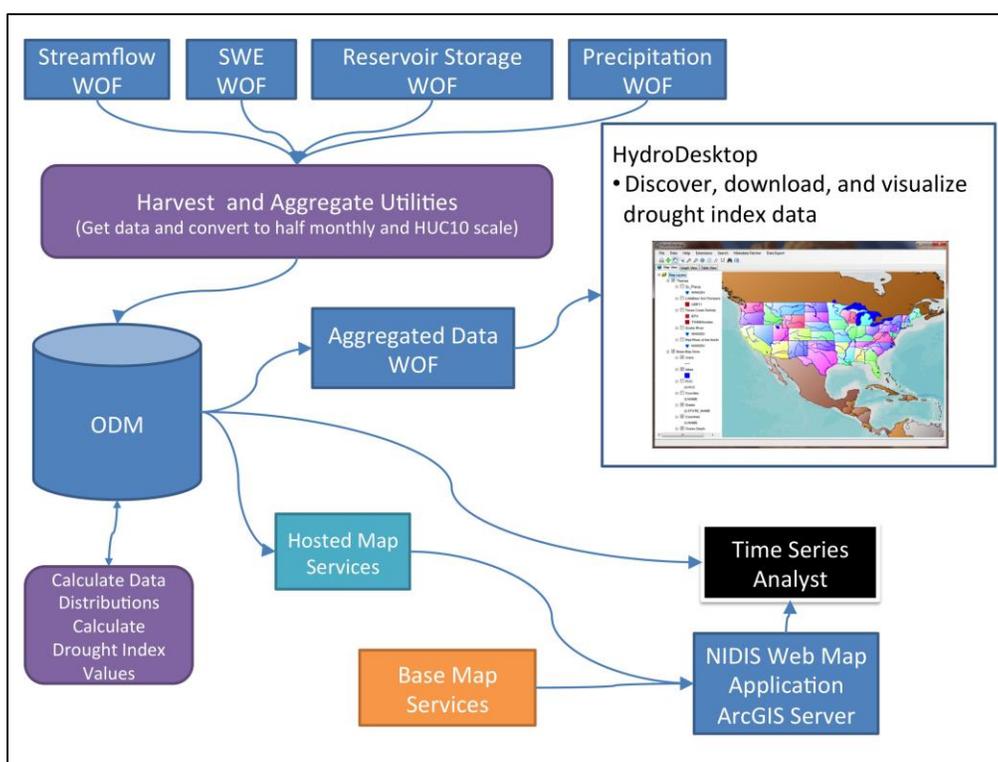


Figure 1. Overall architecture for the drought HydroServer.

On the drought HydroServer, we published WaterOneFlow (WOF) web services for the primary inputs to drought index calculation (streamflow, snow water equivalent, reservoir storage, and precipitation - blue boxes at the top of Figure 1). Higher-level products, consisting of spatial and temporal aggregations of the primary datasets, were created by the data harvest and aggregation utilities that we coded as part of this project (purple boxes in Figure 1) and were stored in an ODM database. We used the available tools on the drought HydroServer to enable visualization of the datasets within the published web services that we created (Time Series Analyst and NIDIS Map Application in Figure 1). We also developed web services for the aggregated datasets that enable users to discover,

access, and download all of the data from HydroDesktop. Each of these components is described in more detail in the sections that follow.

From a computer server perspective, the drought HydroServer was implemented as two Microsoft Windows Server 2008 R2 virtual machines. The first machine is an application server that is responsible for harvesting all of the primary datasets, writing them to a database, and then processing them into higher level data aggregations. These higher level aggregations are also written to a database. The second machine is a web server that hosts the databases for the primary and aggregated data as well as all of the web services and web applications that are part of the drought HydroServer. This virtual machine architecture is shown in Figure 2.

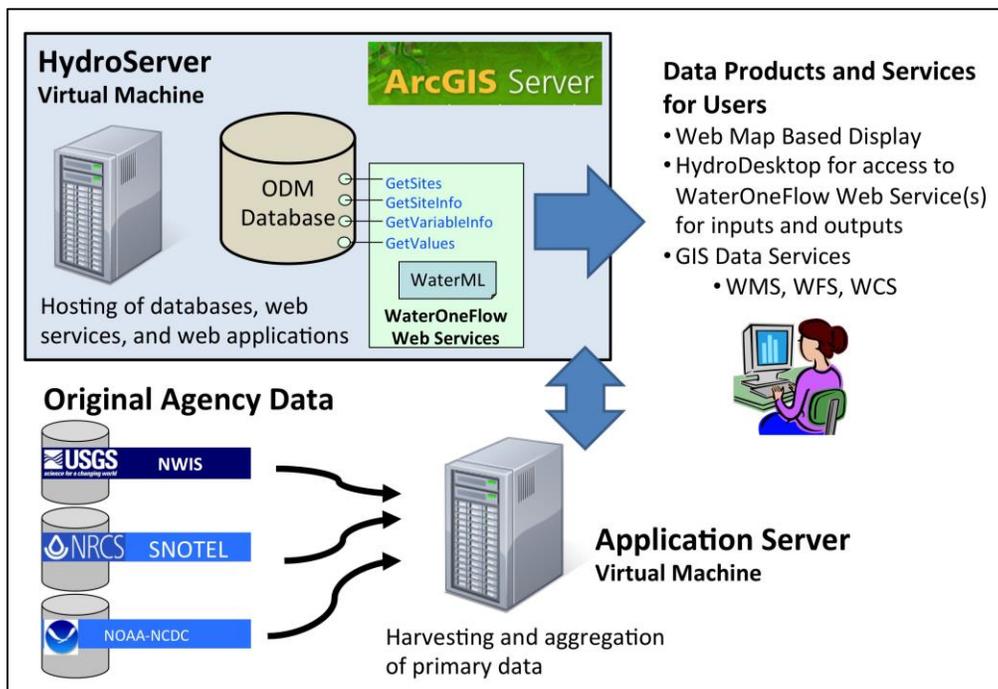


Figure 2. NIDIS drought HydroServer virtual machine architecture.

Organization of Observational Data for Producing Drought Index Calculation Inputs

Drought index calculations are generally not performed using raw observational data from monitoring points. Rather, space and time summaries of the data are used. In order to make the process for creating datasets at spatial and temporal scales most appropriate for drought index calculation more straightforward, we organized the preparation of data for use in drought index evaluation into the levels detailed in Table 1. The data levels in Table 1 range from Level 0, which are the original data as hosted by the agency, to Level 4, which are probabilities calculated on spatially and temporally aggregated data products. For this project, we chose the USGS 10-digit Hydrologic Units (HUCs) as the spatial scale and half monthly as the temporal scale for drought index calculation.

Table 1. Data levels for drought index input data.

Level	Description
0	Original agency data that are hosted on the agency’s website.
1	Level 1 data are time series obtained directly from the data source, but that may have undergone minor transformations such as unit conversions. Examples are daily streamflow values obtained from the USGS NWIS system or daily snow water equivalent data retrieved from the NRCS SNOTEL data system. For NIDIS, Level 1 data values were harvested from the original data source and stored locally on the NIDIS HydroServer for convenience in creating spatial and temporal aggregations of the data.
2	Level 2 data have gone through one degree of aggregation. Level 2A refers to data that have been aggregated in time from its initial time step (usually daily) to the time step chosen for drought analysis (half monthly). The method of aggregation depends on the quantity being aggregated. For example, precipitation is totaled, streamflow is averaged and converted to a volume (acre-ft) quantity, and reservoir storages at the end of the interval are recorded. Level 2B refers to data that have been aggregated in space (but not in time) from its initial data source (i.e., zonal aggregations). The ultimate goal is to have data aggregated in both space and time, but sometimes the time aggregation is done first (Level 2A) while other times the space aggregation is done first (Level 2B), depending on the data source.
3	Level 3 data have been aggregated in both space and time and are thus available at half monthly time step at the HUC 10 spatial scale for every HUC 10 in the UCRB.
4	Level 4 data are the statistical transformation of the level 3 data into a drought index, or drought index information, such as representing the quantity involved (e.g., reservoir storage within a HUC 10 watershed at the end of an interval) as a percentile of the historical reservoir storage.

Figure 3 shows the overall workflow for creation of the data at each of the levels described in Table 1. One of the goals for this project was to make each of the datasets (e.g., streamflow, precipitation, snow water equivalent, reservoir storage) available at each data level to make the process behind developing drought indices more transparent, and so that users could choose where to begin their drought index calculations.

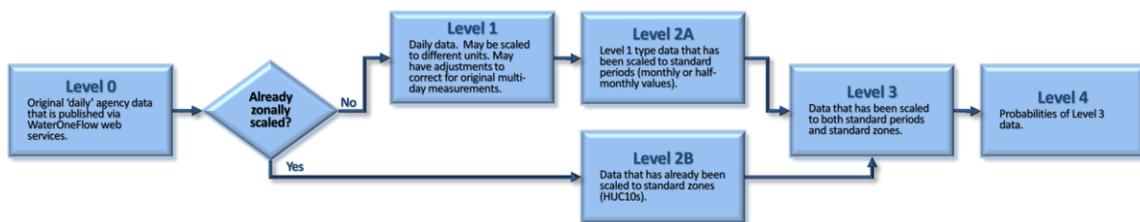


Figure 3. Workflow for creating data at each level relevant to drought index calculation.

Development of Web Services for Drought Related Data

Primary input data required for drought index calculation include streamflow, precipitation, reservoir storages, and snow water equivalent. Before this project began, only streamflow from the USGS National Water Information System (NWIS) was available as a standard WaterOneFlow web service. Over the course of this project, we established web services for other data sources necessary for drought index calculation. These efforts were necessary to ensure that the inputs to drought index calculations were available in a consistent format (i.e., WaterML)—which we knew would ease both discovery and access to the data water managers need.

Our development of WaterOneFlow web services for original agency data (Level 0 data as described above) took two different modes, depending on the data source. Figure 4 illustrates the two different modes. The pass through mode (Mode 1) on the left of Figure 4 was used for datasets where the agency had a website or data system that was easily accessible to computer code. The USGS NWIS, NRCS SNOTEL, and USBR reservoir data fit into this category. In this mode, we developed a metadata harvester that accessed the agency website to harvest metadata about the available data. These metadata were cached in a database on the NIDIS drought HydroServer, but the original agency data were not. For web services using Mode 1, the GetSites, GetSiteInfo, GetVariables, and GetVariableInfo web service calls retrieve metadata information from the catalog database on the drought HydroServer. The GetValues call, however, is “passed through” to the original data source’s website, where the data are retrieved automatically, transformed into WaterML, and then returned to the user.

The store and serve mode (Mode 2) on the right of Figure 4 was used for datasets that did not have an easily accessible website that could be called on the fly via code—or that had systems that were too slow to build a “pass through” GetValues web service call. Examples of these datasets include National Climatic Data Center (NCDC) precipitation data and snow water equivalent data from the Snow Data Assimilation System (SNODAS). In Mode 2, both the metadata and the data were harvested into a database on the drought HydroServer, and all of the WaterOneFlow web service calls, including GetValues, retrieve data from this “store and serve” database.

In the following sections, we describe each of the WaterOneFlow web services for Level 0 data that were used in this project. With the exception of the USGS NWIS streamflow web service that is hosted by CUAHSI at the San Diego Supercomputer Center, each of the web services below was developed for this project and is hosted on the drought HydroServer that we established for this project. We also describe in general the web services that provide access to data at the higher levels, but details of how these aggregated data were created are given in a subsequent section.

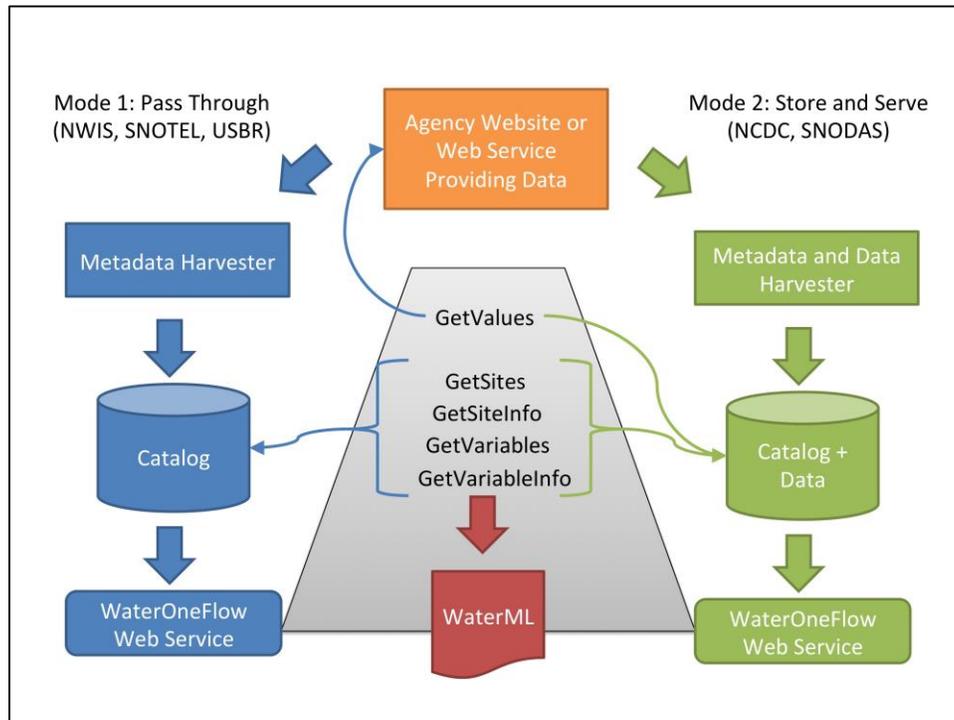


Figure 4. Modes for creation of WaterOneFlow web services for agency data.

WaterOneFlow Web Services for NRCS SNOTEL Snow Water Equivalent Data

The NRCS SNOTEL data service is a flow through web service that retrieves data directly from the NRCS SNOTEL website. The SNOTEL WaterOneFlow web service is available at:

<http://drought.usu.edu/SNOTEL/>

This is registered at HIS Central (<http://hiscentral.cuahsi.org/>) and is discoverable from HydroDesktop under data service title "NRCS SNOTEL Standard Variables."

Although the focus of this service for NIDIS was snow water equivalent data, this service provides access to data for all six standard variables available at all SNOTEL sites in the western United States. Metadata describing the sites and variables are stored on the drought HydroServer, but GetValues requests retrieve the latest data directly from the NRCS website. Current data are retrieved from NRCS data published in directories at the following web accessible location:

<http://www.wcc.nrcs.usda.gov/ftpref/data/snow/snotel/cards/>. Site information for the SNOTEL sites is retrieved from: <http://www.wcc.nrcs.usda.gov/nwcc/sitelist.jsp>.

Figure 5 shows the HydroDesktop display of the 453 SNOTEL sites for which data are available from this WaterOneFlow web service. Figure 6 shows the HydroDesktop display of the last 5 years of cumulative precipitation and Snow Water Equivalent available from one of these sites.

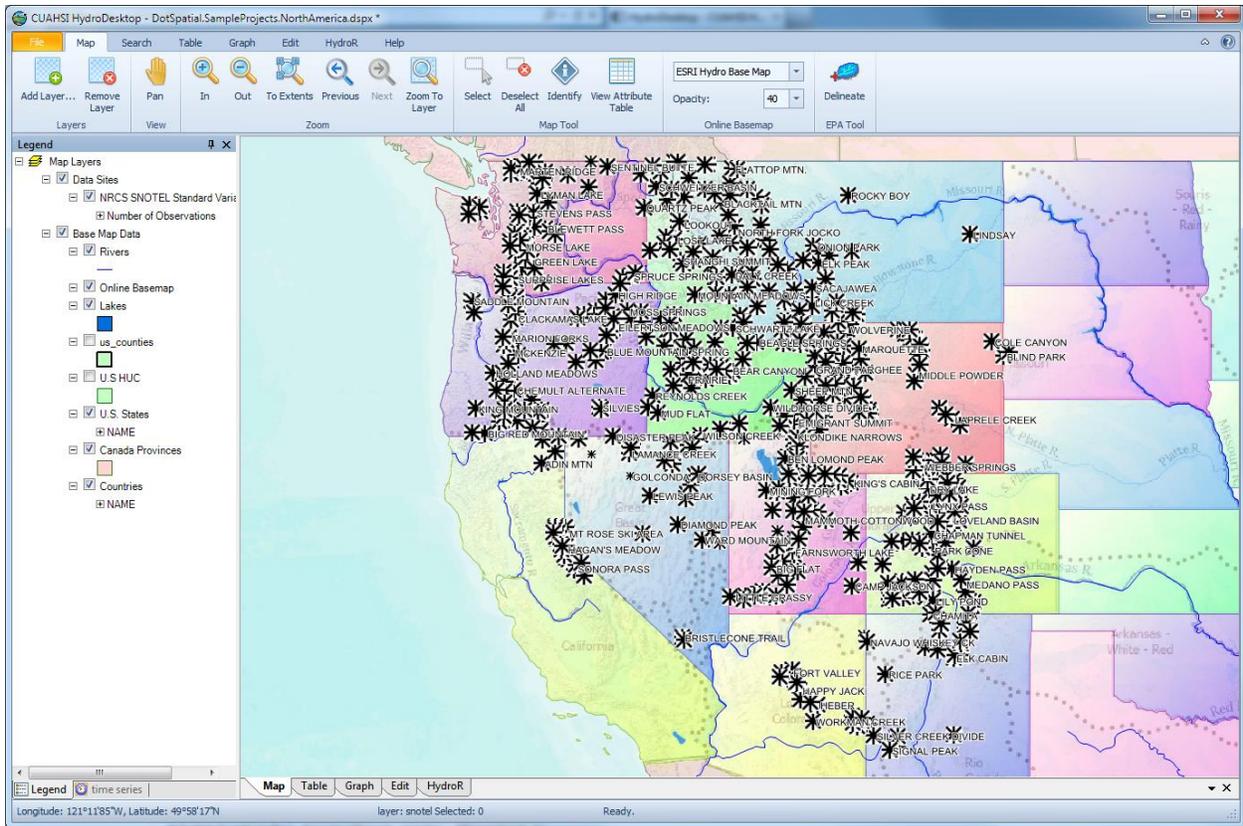


Figure 5. HydroDesktop display of 753 SNOTEL sites with data available using WaterOneFlow web services.

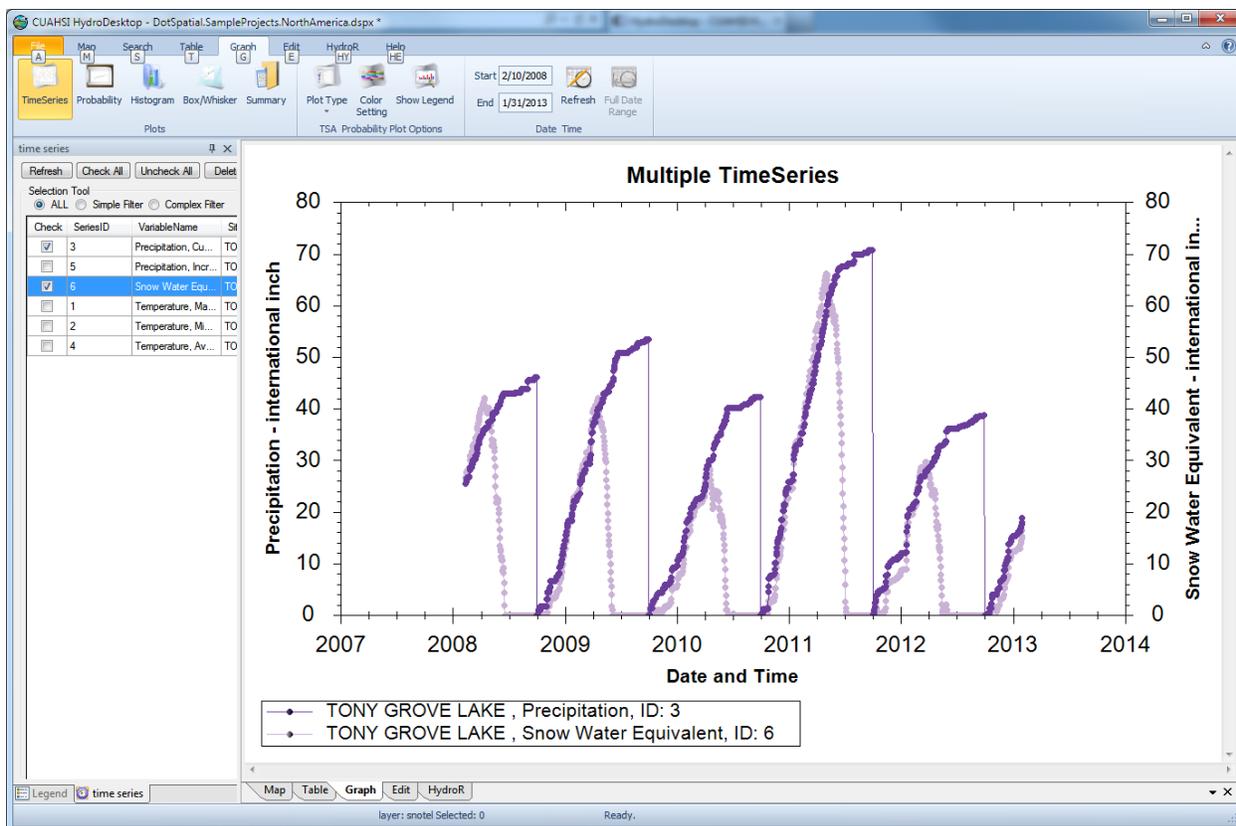


Figure 6. HydroDesktop display of Snow Water Equivalent and cumulative precipitation from Tony Grove Lake SNOTEL site for the last 5 years.

WaterOneFlow Web Services for NCDC Precipitation Data

The NCDC precipitation service is a hold and serve data service that provides access to NCDC precipitation data for sites within a 50-mile buffer around the Upper Colorado River Basin. The NCDC precipitation web service is available at:

http://drought.usu.edu/NCDC_Precip/

This is registered at HIS Central (<http://hiscentral.cuahsi.org/>) and is discoverable from HydroDesktop under data service title "NCDC Upper Colorado River Basin Precipitation."

NCDC data were retrieved from <ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/>. The responsiveness of this website is slow, which precluded establishing a flow through web service. The entire period of record was downloaded during the development of the system. We also developed a harvester that uses periodic retrievals from this website to update the data held in our database. This harvester is run twice a month prior to the aggregation of half monthly level 2 data.

Figure 7 shows the HydroDesktop display of the 2258 NCDC sites for which data are available from this WaterOneFlow web service. Figure 8 shows the HydroDesktop display

of the last 5 years of precipitation from one of these sites. A challenge in working with this data is variability in the lengths of record and availability of the data. Many days are encoded as no-data when it is more likely that these are days with no precipitation.

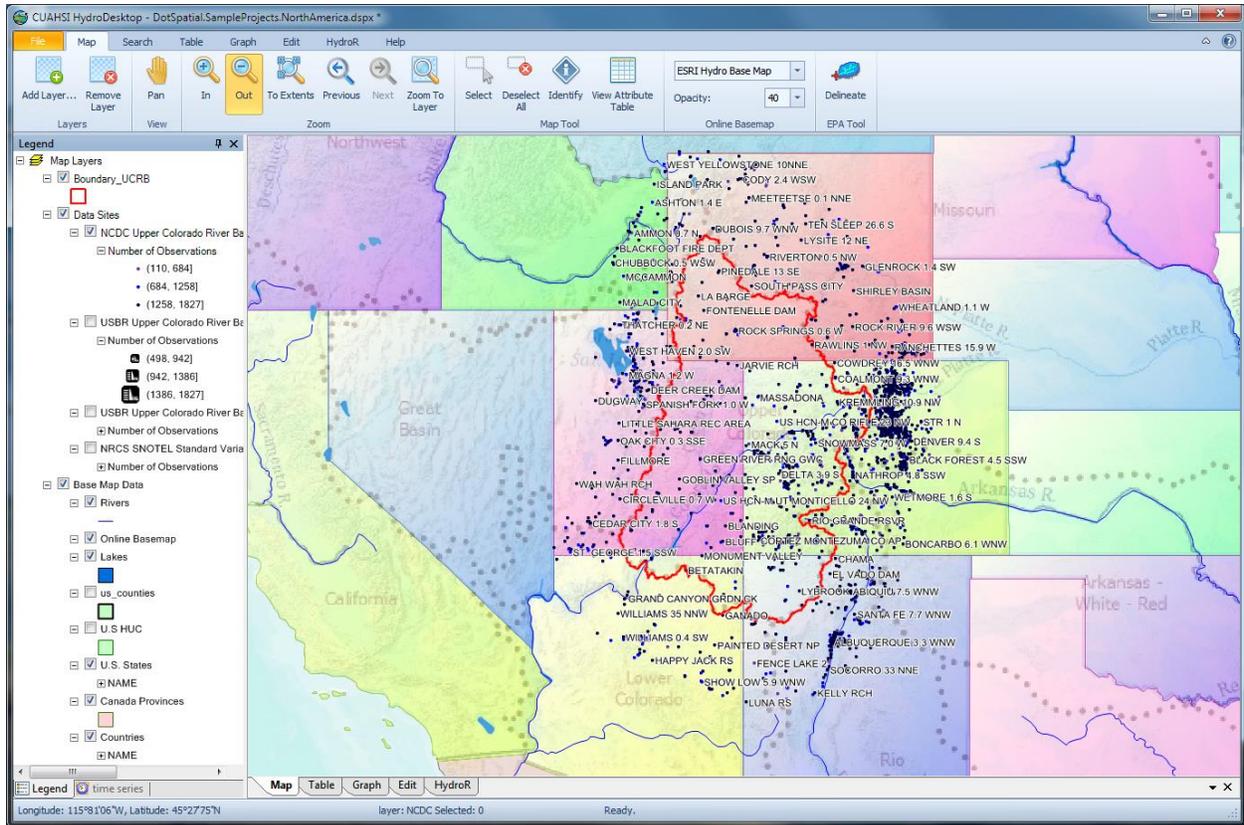


Figure 7. HydroDesktop display of 2258 NCDC sites with data available using WaterOneFlow web services within a 50-mile buffer of the Upper Colorado River Basin.

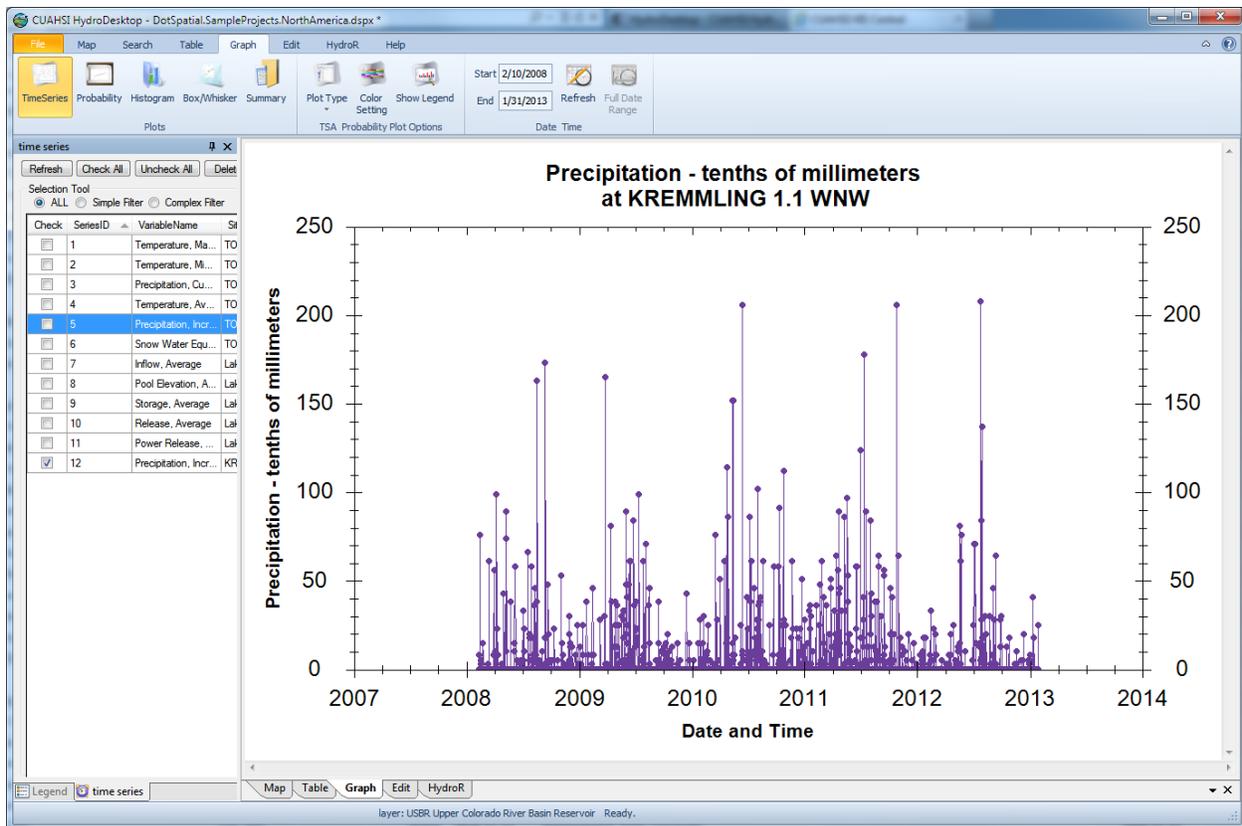


Figure 8. HydroDesktop display of Precipitation from Kremmling for the last 5 years.

WaterOneFlow Web Services for USBR Reservoir Data

The USBR reservoir data service is a flow through data service that provides access to inflow, outflow, elevation, and storage data from US Bureau of Reclamation Reservoirs in the UCRB. The USBR reservoir data service is available at:

<http://drought.usu.edu/USBRReservoirs/>

This is registered at HIS Central (<http://hiscentral.cuahsi.org/>) and is discoverable from HydroDesktop under data service title "USBR Upper Colorado River Basin Reservoir Data."

Metadata for this service, including a list of sites, available time periods for data, and available variables are stored on the drought HydroServer, but GetValues data requests are passed through and retrieve the latest data from the USBR website:

<http://www.usbr.gov/uc/crsp/GetSiteInfo>.

Figure 9 shows the HydroDesktop display of the 59 sites for which USBR Reservoir data are available from this WaterOneFlow web service. Figure 10 shows the HydroDesktop display of the last 5 years of inflow, storage and release from one of these sites.

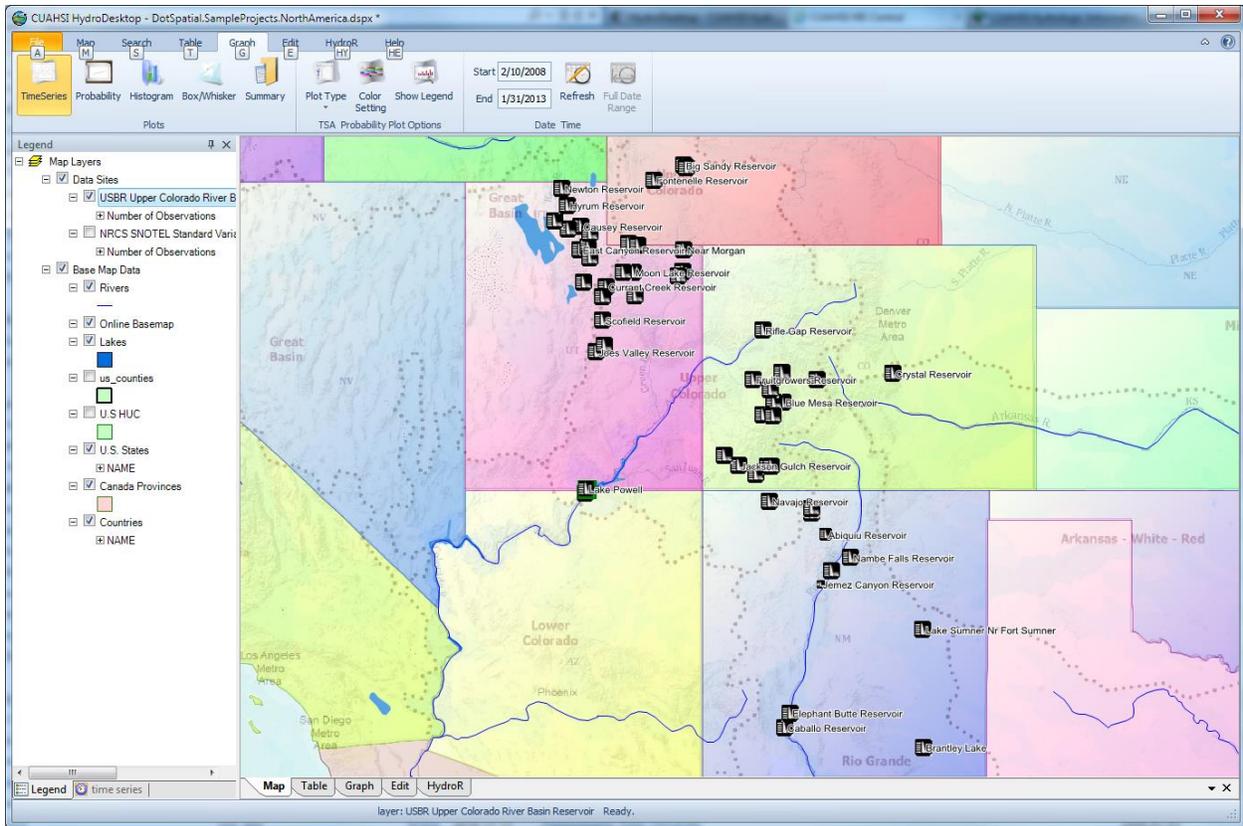


Figure 9. HydroDesktop display of USBR Reservoir sites with data available using WaterOneFlow web services in the Upper Colorado River Basin.

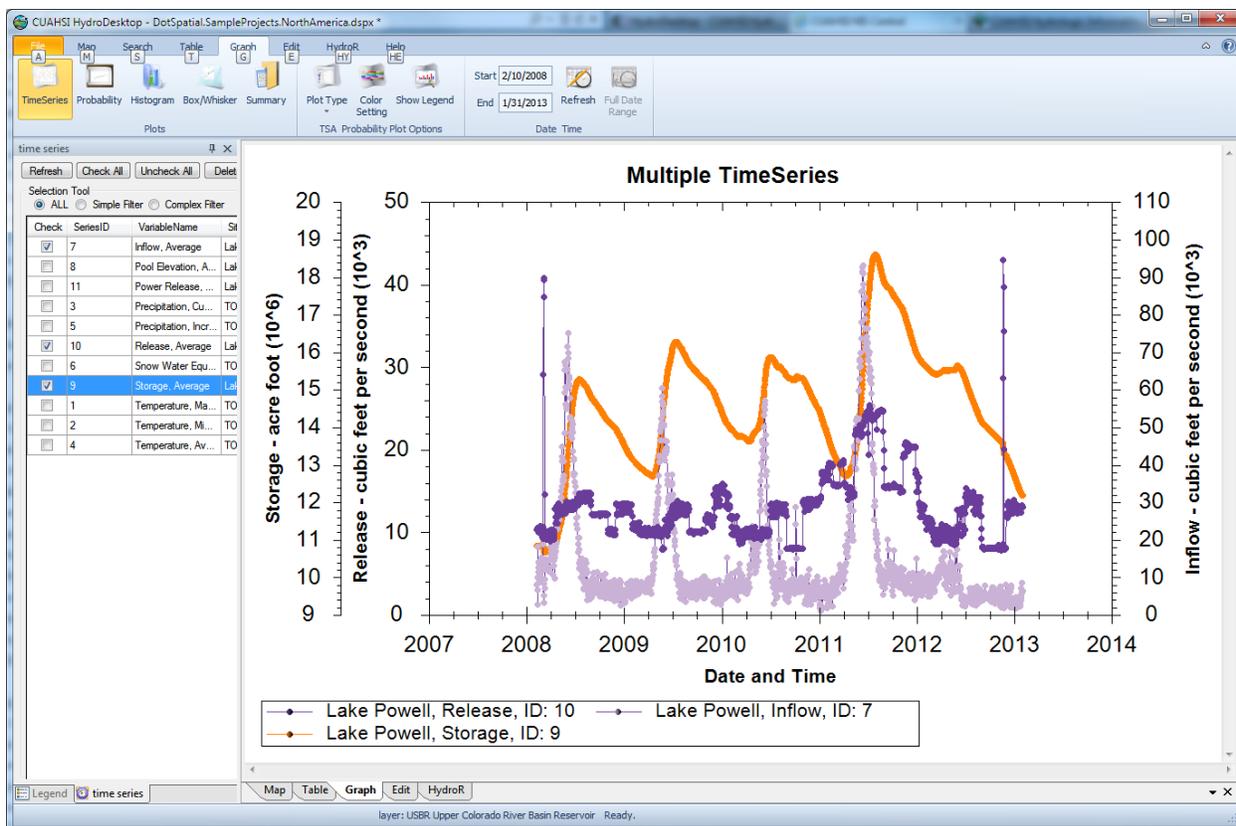


Figure 10. HydroDesktop display of data for the last 5 years from Lake Powell.

WaterOneFlow Web Services for SNODAS Snow Water Equivalent Data

Two web services have been established to publish data from the NOHRSC Snow Data Assimilation System (SNODAS). These web services provide data at different levels of spatial aggregation:

HUC10: http://drought.usu.edu/SNODAS_HUC10/

HUC8: http://drought.usu.edu/SNODAS_HUC8/

These are registered at HIS Central (<http://hiscentral.cuahsi.org/>) and are discoverable from HydroDesktop under data service titles "SNODAS HUC 8 Model Results," and "SNODAS HUC 10 Model Results."

Currently these web services provide access to model simulation results of snow water equivalent provided by NOHRSC. The files containing the SNODAS data products were very large and precluded on the fly access for a pass through GetValues call. Instead, we downloaded the historical model results and parsed them into ODM databases on the drought HydroServer. We then created procedures for periodically updating of this data as new SNODAS product results become available.

Figure 11 shows the HydroDesktop display of the HUC8 and HUC10 sites for which data are available from these SNODAS WaterOneFlow web services. Note that the "site" associated with each HUC is at its centroid. Figure 12 shows the HydroDesktop display of the last 5 years of snow water equivalent and snow depth from one of these sites. Note that this Figure illustrates a challenge in handling missing data, in this case the snow water equivalent for 2010. These data represent averages of SNODAS gridded values over the pertinent HUC.

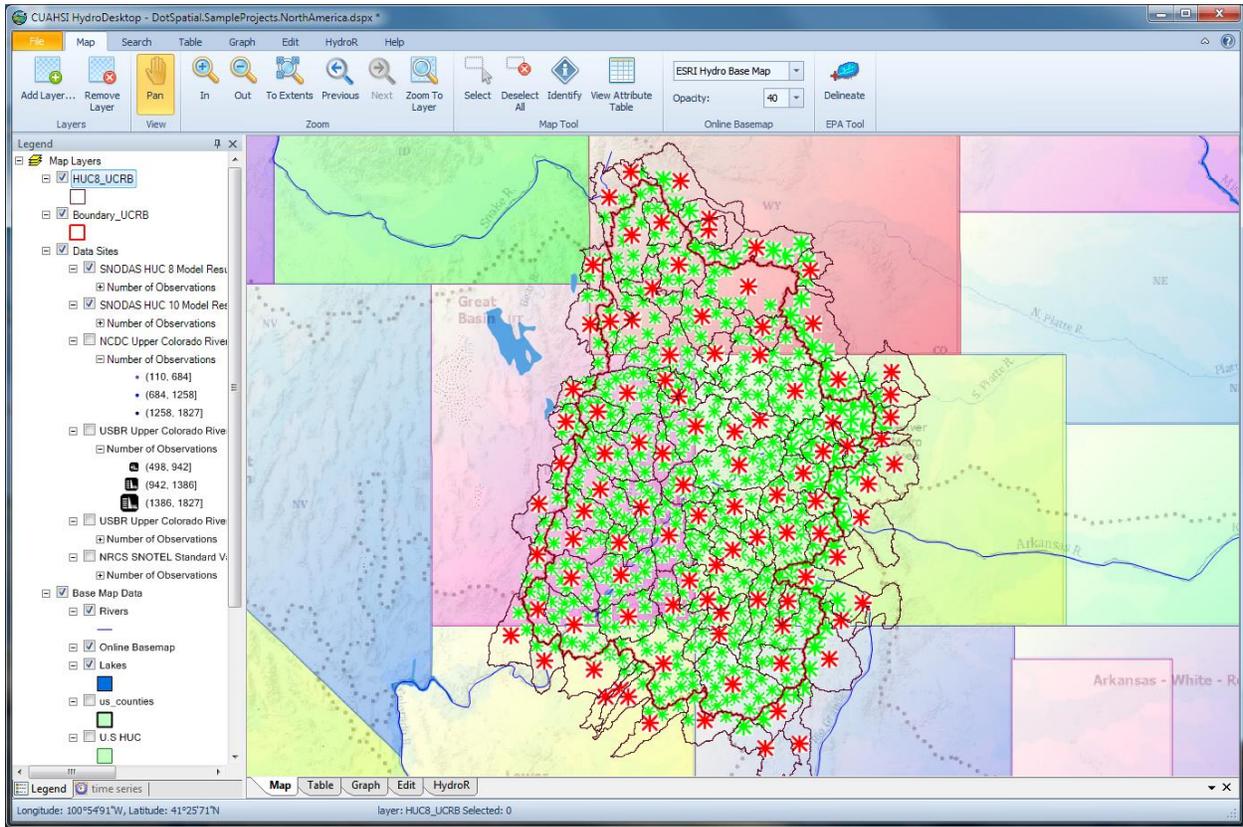


Figure 11. HydroDesktop display of SNODAS sites with data available using WaterOneFlow web services in the Upper Colorado River Basin.

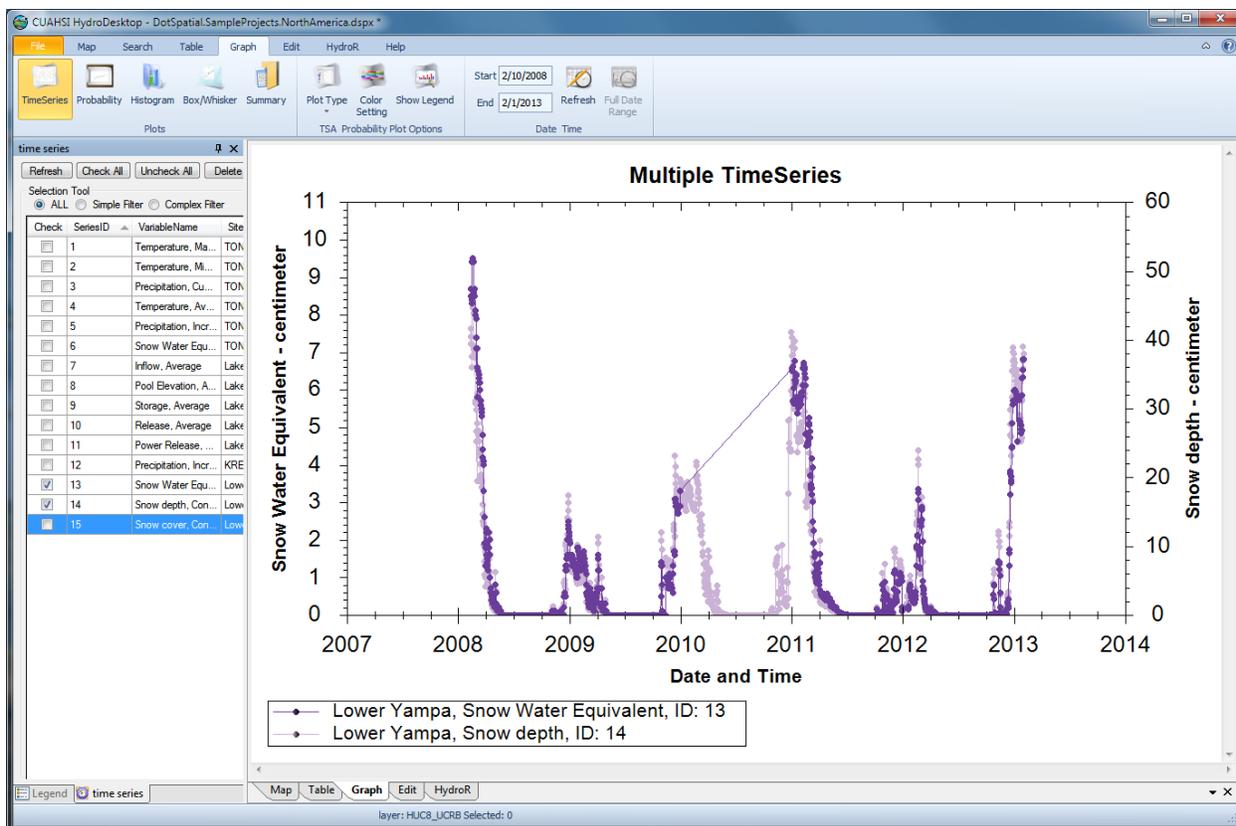


Figure 12. HydroDesktop display of SNODAS data for the last 5 years from the Lower Yampa HUC 8.

WaterOneFlow Web Services for USGS Streamflow Data

The primary streamflow data source for the drought HydroServer is the USGS NWIS daily streamflow service established by CUAHSI in partnership with the USGS. This service provides access to daily streamflow data for any USGS gage site in the US and is available at:

<http://river.sdsc.edu/WaterOneFlow/NWIS/DailyValues.aspx>

These data are discoverable from HydroDesktop under data service title "NWIS Daily Values."

WaterOneFlow Web Services for Higher Level Data Products

In order to produce higher level data products from the primary, Level 0 data sources listed above, we developed harvesting and aggregation algorithms that ingest the Level 0 data, aggregate them in both time and space, and then store the results in an ODM database on the drought HydroServer. We then use standard CUAHSI HIS WaterOneFlow web services to serve these higher level datasets in WaterML format. The WaterOneFlow web service that provides access to the time and space aggregated data is available at:

<http://drought.usu.edu/NIDISTimeSeries/>

These data are discoverable from HydroDesktop under data service title "NIDIS Upper Colorado River Basin Drought Index Data."

In the following section, we describe in more detail the code and algorithms used to harvest and aggregate the data from Level 0 to Level 4 data products.

Development of Data Harvesting and Aggregation Applications

Much of the work on this project was associated with developing data and metadata harvesting code in support of developing Level 0 and 1 WaterOneFlow web services, as well as with developing code for temporally and spatially aggregating data to automate the advancement of datasets used as inputs to drought index calculations from Level 0 to Level 4. The automated data and metadata harvesters we developed periodically scan and harvest new data from each of the input data sources, ensuring that the data available on the drought HydroServer is kept up to date. The data aggregation code then performs the aggregations to produce the higher level data products (i.e., progressing the data from Level 0 to Level 4). In the following sections, we describe the process that was used and the code that was developed to harvest and aggregate data for each of the primary input datasets for drought index calculations.

The Data Summary Application

We developed a data summary application that harvests data from each of the Level 0 web services, writes the latest harvested data to Level 1 ODM databases on the drought HydroServer, and then coordinates the calling of additional code that was written to spatially and temporally aggregate each of the input variables to Levels 2, 3, and 4. The data summary application was written in C# using the Microsoft Visual Studio development environment and is scheduled for regular execution on the drought HydroServer application server (Figure 2).

The data summary application was written to be entirely automated. It takes as input a single database table that lists the sites for which data are to be harvested and aggregated. Each record in the table represents a time series of data for a site in the UCRB and consists of a single site/variable combination (e.g., a time series of streamflow data at a particular USGS gage). Each record in the input table also includes a time aggregation method that is appropriate for the type of data being aggregated. For example, time aggregated snow water equivalent is represented by end of interval values (the value at the end of the time interval is chosen to represent the period).

In order to enable spatial aggregation of the data, we had to translate observations made at individual monitoring points to zonal aggregate values, where the zones are the HUC10 watersheds. To facilitate this, we used geographic information systems (GIS) to preprocess

the HUC10 watersheds and monitoring site locations to generate weights for each monitoring site that could be then be used to scale values from individual monitoring sites in calculating a zonal aggregate for a HUC10 unit. The weights represent the degree to which each monitoring site contributes to the spatially aggregated value calculated for an individual HUC10. In the sections below, we describe how the weights were calculated for each variable; however, the process for applying the weights was the same for each variable. We implemented the processing of the weights to calculate data aggregated to the HUC10 spatial scale as a stored procedure in Microsoft SQL Server.

The following is the general process that the data summary application follows each time it is executed. For each time series listed in the input table to be summarized, the data summary application does the following:

1. Read the record from the input data table to get the site, variable, and aggregation method information.
2. Check the Level 1 ODM database for the current time series to get the timestamp of the latest data value.
3. Query the Level 0 WaterOneFlow web service to retrieve the most recent data values for the current time series.
4. Compare the data retrieved from the Level 0 WaterOneFlow web service to the Level 1 ODM database and add any new records to the Level 1 ODM database.
5. Call the SQL Server stored procedure to time aggregate the current half monthly period using the appropriate time aggregation method and write the result to the appropriate Level 2 ODM database.
6. Loop through each of the HUC10 units in the UCRB and do the following:
 - a. Get the weights associated with monitoring sites that are associated with the current HUC10.
 - b. Call the SQL Server stored procedure to create a spatially aggregated value for the current HUC10 and variable for the current half monthly period and write the result to the appropriate Level 3 ODM database.
 - c. Call the SQL Server stored procedure to calculate the component drought index value (Level 4 data) for the current HUC10, variable, and current half monthly period and write the result to the appropriate Level 4 ODM database.

In the sections that follow, we describe the specific algorithms that were used to create the weights that were used in the spatial aggregation of streamflow and precipitation data to the HUC10 level.

Harvesting and Aggregating Streamflow Data

The NWIS Daily Values web service that provides access to daily average streamflow values from USGS streamflow gages was used here to provide level 0 streamflow data as input to the streamflow aggregation. The data summary application first reads the list of gages in the UCRB to be aggregated and then loops through each one, calls the Level 0 web service, downloads the data, and writes it to a Level 1 database on the drought HydroServer. The

data summary application then calls code that was written to spatially and temporally aggregate the data to monthly and half-monthly intervals at each USGS gage location (level 2A). Level 3 streamflow data for each HUC 10 is obtained as a weighted average of level 2A data at stream gages as well as storage changes for reservoirs that may be impacting streamflow. We used terrain analysis methods (Tarboton, 2013) to delineate the subwatershed draining directly to each stream gage. A gage subwatershed is defined as the area that drains directly to a stream gage without first draining through another stream gage. For each stream gage we also identified reservoirs that impacted flow at the gages. Natural unit runoff is computed for each gage subwatershed as the gain in streamflow in that watershed minus any changes in storage in that subwatershed (Figure 13). In this Figure, Q_1 and Q_2 represent measured discharges and S_1 a measured reservoir storage. A_A and A_B are the areas of subwatersheds A and B and R_A and R_B the gage subwatershed unit runoff for subwatersheds A and B.

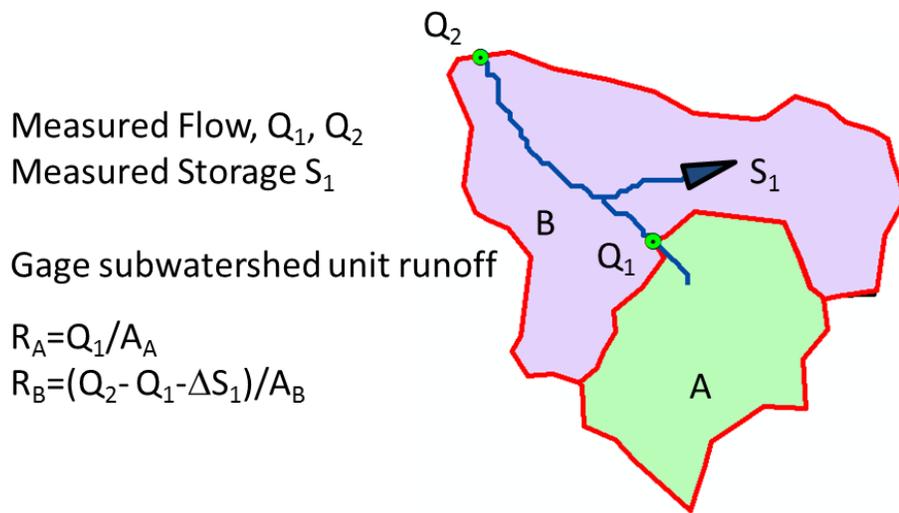


Figure 13. Natural unit runoff computed from measured flow and storage changes.

HUC 10 areas do not generally perfectly overlap with gaged subwatersheds. The unit runoff for each HUC 10 was evaluated as an area weighted average of overlapping gage subwatersheds (Figure 14).

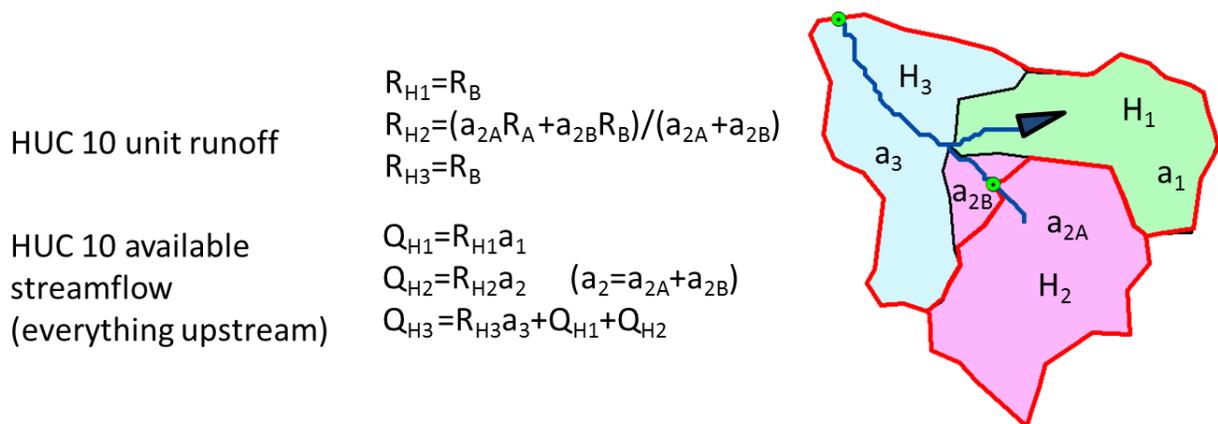


Figure 14. HUC 10 unit runoff and streamflow calculation.

In this Figure, the HUC 10 areas are outlined in black and shaded the same color, while gage subwatersheds are indicated using the red outline. The available streamflow in each HUC 10 is the sum of streamflow originating in the HUC area and inflowing HUC areas. By using the formulae above, each quantity is expressed as a weighted sum of measured quantities, the weights being derived from areas and the connectivity.

The code that performs the spatial and temporal aggregation was written as a Microsoft SQL Server stored procedure operating on a table of weights that was derived using GIS analysis.

Harvesting and Aggregating Precipitation Data

The NCDC Precipitation data service that provides access to daily precipitation from gages in the NCDC system within a 50 mile buffer around the Upper Colorado River Basin provides level 0 precipitation data as input to the precipitation aggregation. We filtered these gages to those with at least 10 years of reasonably complete record and currently recording data (as of October 2010). The data summary application first aggregates daily precipitation values to monthly and half monthly intervals at each site. If more than 10% of data were missing, a no data value was recorded, and sites with fewer than 10 years with 90% complete data were excluded from the set used for spatial aggregation. They do, however, remain in the system. HUC 10 subwatershed aggregate precipitation is then derived as a weighted average of point values for each aggregation interval. The weights associated with each gage for each HUC 10 subwatershed were calculated using linear interpolation within a triangulated irregular network constructed from Delauney triangles that use each gage as a vertex. To account for orographic effects, this linear interpolation was on precipitation normalized by the 30-year mean annual precipitation from PRISM (Daly et al., 2008).

Inputs to this procedure are the gage locations, denoted \underline{x}_i , (here \underline{x} represents a vector location (x,y)), the PRISM annual precipitation surface, $A(\underline{x})$ representing the annual precipitation at each location within the domain, and precipitation at each gage location for a time period, denoted P_i . The desired output is P_b , the average precipitation over a subwatershed for a time period. An intermediate quantity is $P(\underline{x})$, the precipitation at each point in space for a time step.

We first define the normalized single time step precipitation at each gage location as

$$N_i = P_i / A(\underline{x}_i)$$

A set of Delauney triangles are then constructed over the domain using the gage locations as nodes. Delauney triangles are the geometric complement of Voroni polygons, which are known in Hydrology as Thiessen polygons. A linear normalized precipitation surface, $N(\underline{x})$, can be defined for each triangle based upon the normalized gage values at each node. This is represented in terms of basis functions $\phi_i(\underline{x})$ (e.g. Celia and Gray, 1992) for each node that range linearly from 1 at the node to 0 at the opposite edge of the triangle

$$N(\underline{x}) = \sum_{\text{gages } i} \phi_i(\underline{x})N_i$$

The actual precipitation surface for the time step is then obtained by scaling the normalized precipitation surface by the annual surface

$$P(\underline{x}) = N(\underline{x}) \times A(\underline{x})$$

Expanding in terms of the definitions of $N(\underline{x})$ and N_i we obtain

$$P(\underline{x}) = \sum_{\text{gages } i} \phi_i(\underline{x})A(\underline{x})N_i = \sum_{\text{gages } i} \left\{ \phi_i(\underline{x}) \frac{A(\underline{x})}{A(\underline{x}_i)} \right\} P_i = \sum_{\text{gages } i} w_i(\underline{x})P_i$$

where the weight $w_i(\underline{x})$ gives the contribution from the gage at location i to precipitation at location \underline{x} .

$$w_i(\underline{x}) = \phi_i(\underline{x}) \frac{A(\underline{x})}{A(\underline{x}_i)}$$

Note that this weight has built in to it an adjustment for the annual precipitation surface, such that if gage location \underline{x}_i has lower annual precipitation than location \underline{x} (due to perhaps being at lower elevation in an orographic precipitation field) the weight $w_i(\underline{x})$ accounts for this. The full precipitation surface $P(\underline{x})$ is not actually required at each time step. What is required is the sub-watershed average precipitation

$$P_b = \int_{\text{sub-basin}} P(\underline{x})d\underline{x} = \sum_{\text{gages } i} \left(\int_{\text{sub-basin}} w_i(\underline{x})d\underline{x} \right) P_i = \sum_{\text{gages } i} w b_i P_i$$

In this equation the integral is over the particular sub-basin. The weight

$$w b_i = \int w_i(\underline{x})d\underline{x} = \int \phi_i(\underline{x}) \frac{A(\underline{x})}{A(\underline{x}_i)} d\underline{x}$$

represents the contribution from the gage at location i to the sub-basin average precipitation. Note that this weight does not depend on the amount of precipitation P_i in any time step. Therefore, these weights are calculated in advance and stored as a weights table in the system. Numerically, the weight equation is evaluated by summing over each grid cell of the DEM grid used to delineate gage subwatersheds and determine elevation. This method relies on the same input and philosophy as the common Thiessen polygon method for estimating basin-average precipitation but, by using linear interpolation on Delauney triangles, provides a smoother interpolation and also accommodates adjustments for an annual precipitation surface (Figure 15).

Example Precipitation Weights

HUC10	Precip Station	Weight
140200401	5037299999	0.2811
140200401	5174399999	0.3575
140200401	5630699999	0.3614
140200402	5037299999	0.4382
140200402	5174399999	0.3565
140200402	5548499999	0.0026
140200402	5630699999	0.2026
140200403	5037299999	0.1142
140200403	5366299999	0.0820
140200403	5160999999	0.0002
140200403	5174399999	0.0000
140200403	5195999999	0.3545
140200403	5630699999	0.4489
140200404	5037299999	0.1531
140200404	5366299999	0.0133
140200404	5160999999	0.0000
140200404	5174399999	0.1086
140200404	5195999999	0.0515
140200404	5630699999	0.6735
140200405	5037299999	0.0082
140200405	5366299999	0.0078
140200405	5160999999	0.0292
140200405	5174399999	0.1032
140200405	5195999999	0.0011
140200405	5219699999	0.0990
140200405	5572299999	0.0447
140200405	5630699999	0.7068

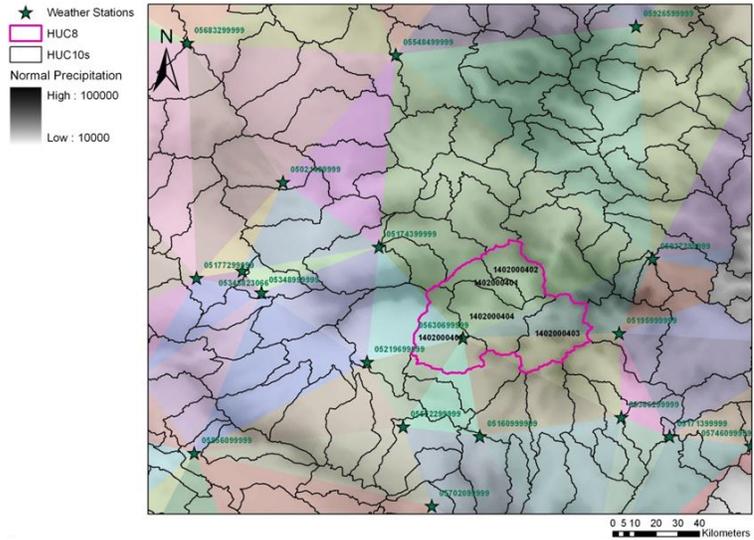


Figure 15. Illustration of precipitation stations and weights used in HUC10 aggregate precipitation calculations.

Web Based Presentation of Drought Related Data

In addition to the above observational data web services, we implemented the HydroServer suite of web applications for visual presentation of the drought related data published on the drought HydroServer. These applications include the HydroServer Website, the HydroServer Map Application, and the Time Series Analyst. As an additional part of this project, we developed a set of web map services that display calculated component drought index values for each of the major drought index inputs (streamflow, precipitation, reservoir storage, and snow water equivalent). We describe each of these applications and services in the following sections.

HydroServer Website

The HydroServer website (Figure 16) is a standard part of the CUAHSI HIS HydroServer software stack. It is a web application that presents metadata about all of the data services published on a HydroServer. The drought HydroServer website is available at <http://drought.usu.edu>. On the drought HydroServer website, users can view information about each of the observational data services and geospatial data services published on the HydroServer.

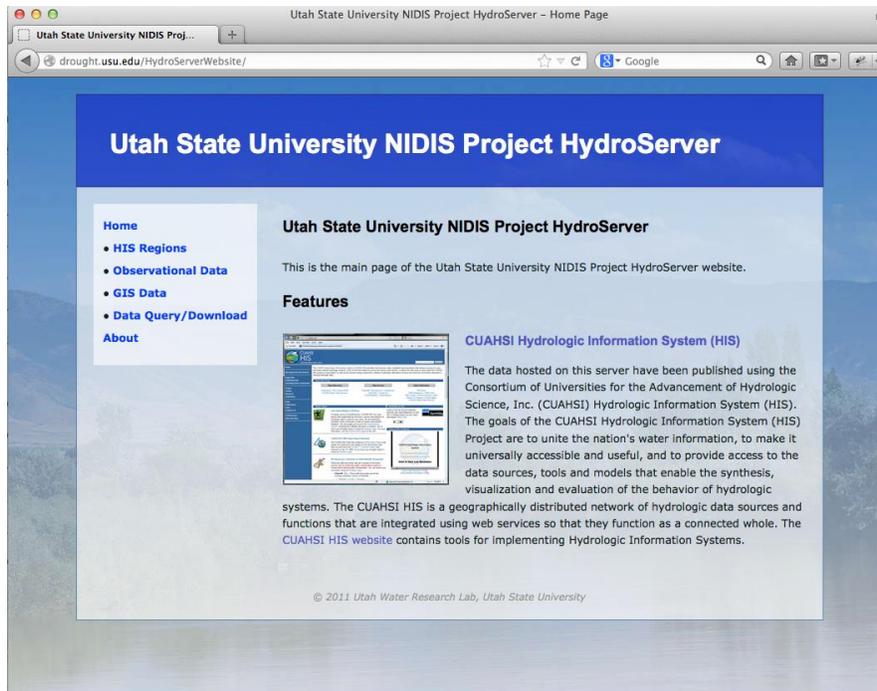


Figure 16. Drought HydroServer website where users can learn about observational and geospatial data services published on the drought HydroServer.

HydroServer Map Application

The HydroServer map application (Figure 17) provides a web-based mapping display of published geospatial datasets for a particular study area or region (in this case the UCRB study area). It is available at <http://drought.usu.edu/nidismap/>. The HydroServer map application also provides the capability of adding layers that display the locations of monitoring sites at which observational data have been collected. When users click on one of these sites using the hyperlink tool, the HydroServer map application launches the Time Series Analyst (described below) with data for the selected site. Using the HydroServer map application, users can orient themselves geographically, see the location of monitoring sites (e.g., streamflow gages, SNOTEL sites, reservoirs, etc.) in relation to the locations of other sites and spatial features, and then click on individual sites to access the data using the Time Series Analyst.

As base map layers for the HydroServer map application, we published the following geospatial datasets as Open Geospatial Consortium Web Map Services (WMS) on the drought HydroServer:

- UCRB Study Area – This layer shows the boundary for the UCRB pilot project area.
- NIDIS Monitoring Sites – These layers show the location of monitoring sites from the major data sources that were used in this project (USGS NWIS gages, SNOTEL Sites, NCDC precipitation gages, USBR reservoirs, etc.)

- USGS HUCS – These layers show the boundaries of the USGS 8 and 10 digit HUCs in the UCRB.
- UCRB Major Rivers – This layer shows the major water courses within the UCRB.
- ESRI Street Base Map – This is a base map layer published by ESRI. It is used to provide context for all of the other layers and contains terrain, roads, cities, and other information helpful for spatial context.

These datasets underlie the HydroServer map application), which provides map based display of drought information over the UCRB pilot (Figure 17).

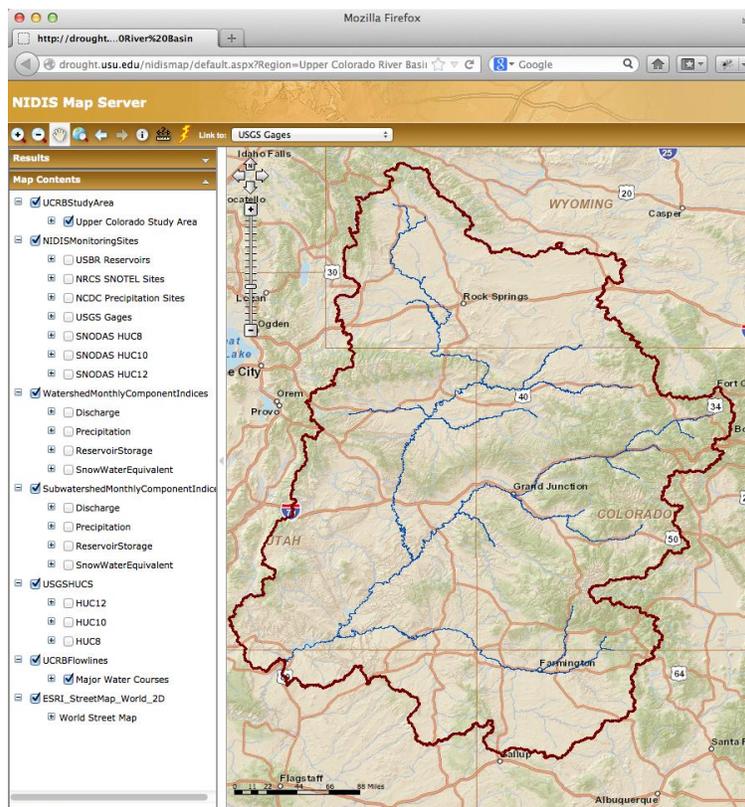


Figure 17. Drought HydroServer map application.

Time Series Analyst

The Time Series Analyst (Figure 18) provides users with quick and easy visualizations of the observational data published on the drought HydroServer and is available at <http://drought.usu.edu/tsa/>. It provides a variety of plot types and summary statistics for a selected time series and also allows users to restrict the time range, view metadata for each dataset, and export the data in simple CSV formats. Users can select an observational data layer in the “Link to:” drop down menu on the toolbar of the drought HydroServer Map application and can then use the hyperlink tool to click on individual sites within the selected layer to launch the Time Series Analyst with data for the selected site.

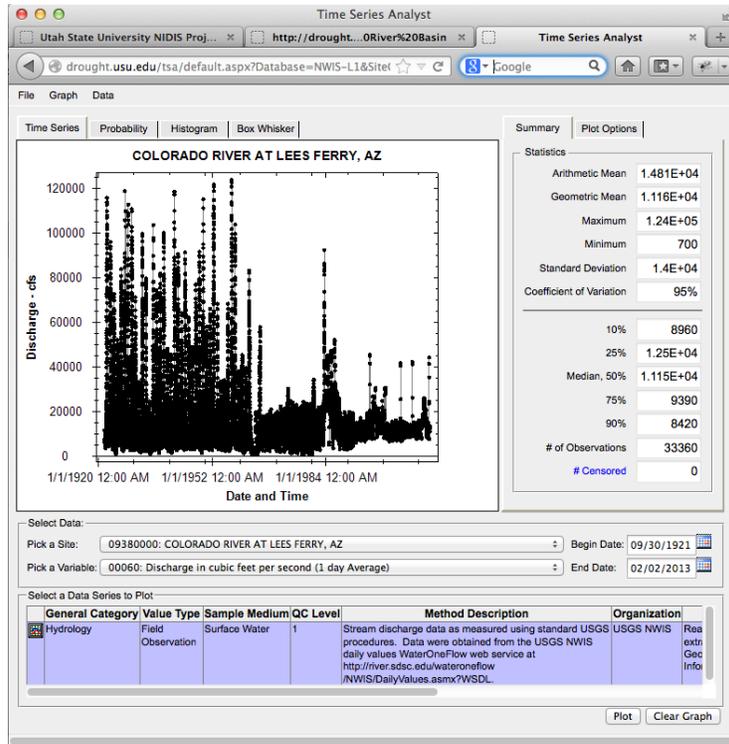


Figure 18. Drought HydroServer Time Series Analyst.

Web Map Services for Calculated Drought Index Values

To demonstrate the capability of automatically calculating and displaying drought index values, we developed a set of web map services that display component drought index values for each of the major drought index variables (streamflow, precipitation, reservoir storage, and snow water equivalent). These web map services display a color-coded map of the HUC10 units within the UCRB, where the colors represent the percentile within which the value of the variable for the current period falls. These maps provide a quick visualization of where current values for each of the major variables are in relationship to all other historic values.

We developed these component indices for both HUC10 watersheds (i.e., the HUC10 and all of its upstream contributing area) and HUC10 subwatersheds (i.e., only the local area of the HUC10) using the methods described above. The web map services for component indices are automatically updated each time new Level 4 data are added to the databases by the data harvesters and aggregators. Figure 19 shows an example of the HUC10 watershed component drought index values for snow water equivalent for the first half monthly period in January 2013. For this project, new component index values are automatically added to the database approximately every two weeks (half monthly).

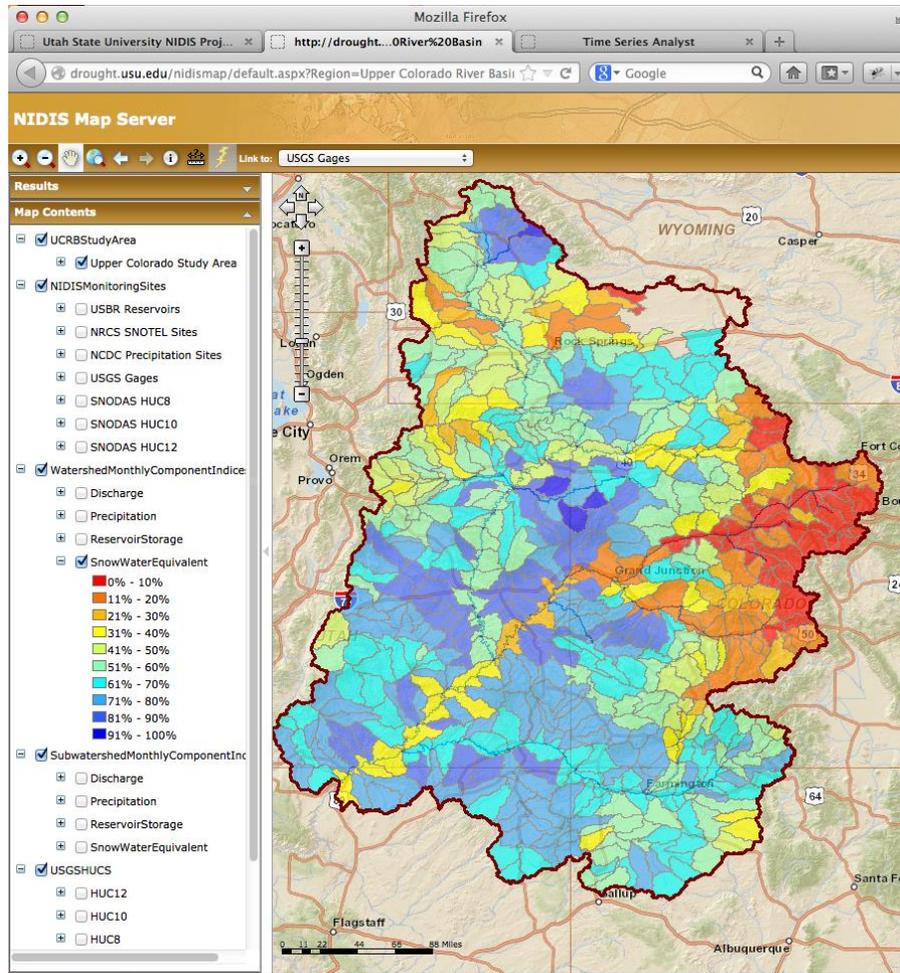


Figure 19. Screen shot showing calculated component drought index values as of the first half monthly period in January 2013 for HUC10 watersheds in the UCRB as displayed in the drought HydroServer map application.

Conclusion

This project has developed a system for publishing integrated information on drought conditions in the Upper Colorado River Basin NIDIS pilot area. It relies on technology developed as part of the CUAHSI Hydrologic Information System and publishes data in the WaterML format using WaterOneFlow web services developed by CUAHSI. This system represents a useful resource for drought related data in the Upper Colorado River Basin.

A number of new data products and services were developed as part of this project.

New web services that enhance the accessibility of existing data:

- WaterOneFlow web service for SNOTEL data
- WaterOneFlow web service for NCDC precipitation data in the Upper Colorado River Basin
- WaterOneFlow web service for USBR reservoir data in the Upper Colorado River Basin
- WaterOneFlow web service for SNODAS Snow water equivalent data aggregated for HUC 8 and HUC 10 watersheds in the Upper Colorado River Basin

New Data Products for drought assessment published on the drought.usu.edu web services:

- HUC 10 level aggregate unit natural runoff at monthly and bi-monthly intervals derived from USGS gaged streamflow and adjusted for changes in reservoir storage
- HUC 10 level total watershed discharge at monthly and bi-monthly intervals derived from USGS gaged streamflow and adjusted for changes in reservoir storage
- HUC 10 level aggregate precipitation at monthly and bi-monthly intervals derived from NCDC stations
- HUC 10 level aggregate snow water equivalent at monthly and bi-monthly intervals derived from SNODAS

The percentiles of these quantities serve as drought indices by quantifying present conditions relative to historic values. The following percentile drought indices are published on the drought.usu.edu server.

- HUC 10 level unit natural runoff percentiles at monthly and bi-monthly intervals
- HUC 10 level total watershed discharge percentiles at monthly and bi-monthly intervals
- HUC 10 level aggregate precipitation percentiles at monthly and bi-monthly intervals
- HUC 10 level aggregate snow water equivalent percentiles at monthly and bi-monthly intervals

This system resides on Windows 2008 Server virtual machines within the Utah Water Research Lab (UWRL) data center. Establishment and operation of this system for the duration of this project was paid for by project funds. Ongoing operation of this system is currently unfunded and the system is being operated on a best effort basis with UWRL funds. This is not sustainable over the long term. Staff time to address issues that arise, such as security and maintenance updates to operating systems and software, is limited and there is a danger of this capability being lost if the UWRL is unable to continue its operation. The entire system is available for transfer to NIDIS or another facility to operate on a more sustainable basis. However, no such facility has been identified, and the project discussions did not resolve questions as to the eventual disposition of this system due to it being based on the Microsoft Windows Software stack used by the CUAHSI HIS, while NIDIS data centers that could potentially house this used Linux software stacks.

Project Participants

This project was led by Dr. David G. Tarboton and Dr. Jeffery S. Horsburgh. Graduate students provided research support and developed methods for harvesting and aggregating data to appropriate scales for drought index calculation. The following graduate students were supported by this project:

Jeanny Miles (Graduate Student)
Avirup Sen Gupta (Graduate Student)
Andrew Barney (Graduate Student)

In addition to graduate students, this project supported professional computer programmers that assisted the graduate students in coding the methods and algorithms for harvesting and aggregating data. The following programmers were supported by this project:

Stephanie Reeder (Programmer)
Kim Schreuders (Programmer)

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Award--Estimating Crop Water Use with Remote Sensing: Development of Guidelines and Specifications

Basic Information

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End Date:	9/18/2014
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Congressional District:	
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Focus Category:	Water Use, Agriculture, Methods
Descriptors:	satellite remote sensing, crop water use
Principal Investigators:	Christopher M.U. Neale

Publications

1. Lewis, Clayton; Hatim M. E. Geli, and Christopher M. U. Neale, 2014, Comparison of the NLDAS Weather Forcing Model to Agrometeorological Measurements in the western United States, Journal of Hydrology, Vol. 510, pp. 385-392. DOI: 10.1016/j.jhydrol.2013.12.040.
2. Hobbins, M; H. M. E. Geli; C. S. Lewis; G. Senay; and J. Verdin, 2013, NOAA introduces its first-generation reference evapotranspiration product, poster presented at 2013 Fall Meeting, AGU, San Francisco, California, 9-13 Dec.

Estimating Crop Water Use with Remote Sensing: Development of Guidelines and Specifications

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1. Introduction

Irrigated agriculture is the largest consumptive water user in the western United States. Improved estimates of crop water use through evapotranspiration (ET) estimates are important because of the diminishing water resources and competition for water in the 17 western states. Several programs have been established by states and federal government agencies to help monitor water resource in the western US including programs such as WaterSmart by the US Bureau of Reclamation. The key element in estimating crop water use is ET estimates. Also, knowledge of ET is useful for many applications including hydrological modeling and water resources management.

As indicated by the USGS, the aim of this work is to solve the water balance at the 12 digit HUC watersheds scale and eventually the 8 digit HUC level.

2. Statement of Work

Estimating crop water requirements that are acceptable by the community of users and water agencies in the western states, as well as by the USGS WaterSmart, for reporting purposes is a challenging problem. A wide range of ET models are available in the literature, providing different approaches and estimates. The application of some of these models, in particular the remote sensing-based models, can be considered subjective because some of them rely on modeler perception, experience, and understanding on the selection of inputs.

The main research objective is to develop a framework for estimating crop water use using remote sensing through a standardized approach. This framework will provide guidelines and specifications that would need to be followed by different states in order to apply certain models and produce ET products that are acceptable to the USGS WaterSmart program and the scientific and user community. The main objective includes the following activities:

1. Review currently available ET estimation models
2. Select candidate models and conduct an intercomparison analysis
3. Perform sensitivity analysis of remote sensing-based ET models to input error from using gridded forcing weather data
4. Review cropland data base and report on its accuracy, availability, and ease of use.
5. Review and investigate the use of thermal and multispectral band imagery from multiple sensors

A conceptual diagram of the statement of work with the suggested activities of the remote sensing of ET framework shown in Figure 1.

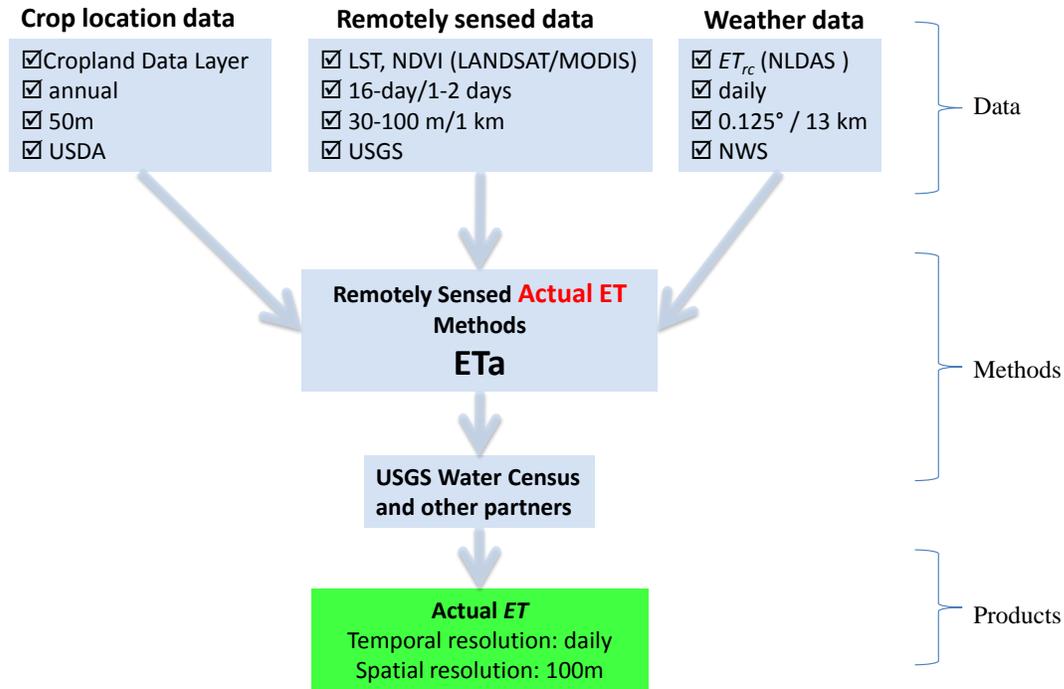


Figure 1: A conceptual diagram of the suggested remote sensing of ET framework.

3. Methodology

Several remote sensing models were selected to conduct the analysis. The selection of these models was based on the required input data and the desired spatial and temporal resolution of the actual ET maps. To provide informative theoretical background about the process of modeling ET using remote sensing a report reviewing some of the models was prepared. This review report consists of two parts with the first one provides information about available models and details on their application. This first part of the report is in its final editing stage. The second part will discuss sensitivity analysis of the models input on the estimated actual ET. The models are tested over irrigated cropland sites selected based on the availability, quality, and suitability of ground-based verification data. These candidate models will also be tested over natural vegetated areas to enable evaluating their performance over a wide range of surface types. This will allow the establishment of model performance over a wide range of agricultural crops and eventually different surface types outside of the irrigated areas. With the availability of different sources of gridded weather forcing data that can be used over data scarce regions the analysis will report on associated uncertainty.

3.1. Candidate Models

A review of currently available remote sensing of ET models was conducted in order to select candidate ones for further intercomparison analysis. These models provide a broad range of the current practices in this arena and are presently accepted by the scientific community and the users. The selection was based on different criteria but with a particular attention on those models focused on cropland types of surfaces. The following were identified:

- Thermal remote sensing based models, which include all those that use the radiometric surface temperature obtained from different sensors as an input for estimating the surface energy balance components. Several models are being considered:
 - The Two Source Energy Balance (TSEB) Model by Norman et al. (1995) with its recent improvements and modification included in Dis-ALEXI (Norman et al., 2003)
 - METRIC by Allen et al., (2007)
 - SEBS model (Su et al., 2002)
 - SSEB simplified surface energy balance developed by a group from the USGS (Senay et al., 2008)
 - ReSET (Garcia, and Elhaddad, 2007)
- Hybrid ET Approach
 - TSEB has been coupled with the reflectance-based crop coefficient method with a recently developed hybrid approach that couples the surface energy balance approach with water balance model. (Neale et al., 2012).
- Crop coefficient-based approach
 - ET framework developed by Melton et al. - (NASA)
- Priestly-Taylor approach
 - Evapotranspiration Priestly-Taylor Jet Propulsion Lab (PT-JPL) by Fisher et al. (2012).

Review report part 1 which currently in it is final editing stage will be completed by the end of June 2014. This part of the report will cover the following:

- Types of models based on methodology and application.
- Detailed review of each candidate models' algorithm
- Comments on the required input data of each

Part 2 of the report which is under preparation will identify possible sources of uncertainties and errors for each.

3.2. The study sites

Three study sites were selected to test the candidate models that represent different climate regions and surfaces. These sites are from within the 17 western United States and are representative of the different irrigated and rainfed agricultural areas as well as natural vegetated surfaces. The sites include (Figure 2):

- The Palo Verde Irrigation District (PVID), California. The data for this site were collected by the remote sensing services lab at USU and the Alliance of Universities – Central State University through a project funded by the USBR. The data spans about 3.5 years from 2006 to 2009. It includes flux measurements, irrigation canal and drainage flows, and airborne and satellite images. The main crops are alfalfa and cotton crops. Data are also available for Salt Cedar forests in the riparian zone of the Colorado River.

- Walnut Gulch Experimental watershed, AZ. The area is naturally vegetated covered mostly with desert shrubs and grassland. Flux and satellite remotely sensed imagery will be used to conduct the analysis.
- Agricultural area in Mead, Nebraska. The area contains irrigated and rainfed soybean and corn fields.

3.3. Model Intercomparison Scheme

3.3.1. Test Sites and Modeling Scheme

An agreement with modelers is reached to apply each of the selected models over the selected testing sites. Three sites were selected (Figure 2) that represent different surface types and climatic regions. These sites include:

- The Palo Verde irrigation district (PVID), California (Site 1)
- The Walnut Gulch watershed, Arizona (Site 2)
- Mead, Nebraska (Site 3)

The data for Site 1 and 2 were sent for analysis while the data for Site 3 is under preparation and will be sent by end May 2014.

The received modeling results for Site 1 and 2 were about 90% and 20%, respectively. The results for these two sites are expected by the end of June 2014.

3.3.2. Models Evaluation

Utah State University will implement the model validation stage using ground based measurements expected results by end of June 2014.

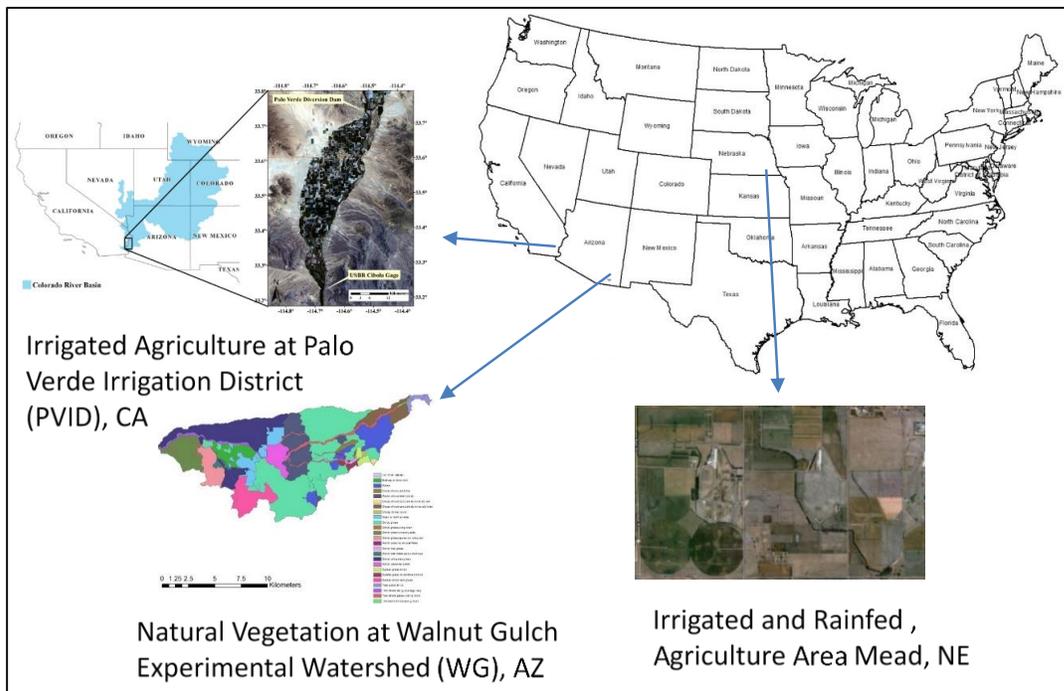


Figure 2: the selected testing sites for the model intercomparison task.

3.4. Remote Sensing, Weather and Spatial Datasets

Spatial and point datasets that are being used in remote sensing of ET were identified and it includes

- Thermal and multispectral imagery from Landsat TM, MODIS, and GOES
- Cropland Data Layer, produced annually by USDA, and its vector Common Land Units database of parcel boundaries
- Hourly weather data from weather station networks from the different states
- Spatial reference ET and other gridded weather forcing data including, for example, air temperature, wind speed, vapor pressure, and solar radiation

The USGS is currently testing a new algorithm that will eventually provide atmospherically corrected thermal and multispectral Landsat satellite imagery. We are using this product in testing the ET models as a way of standardizing the calibration of imagery. This will ensure the quality of the data, guarantee a single source of data, and remove the uncertainties that could arise from using atmospheric correction from individual users that might apply different models and/or methods.

3.5. Comparison of Gridded and Ground Based Weather Forcing Data

The use of ground based weather data might not be appropriate in some situations when applying remote sensing of ET models at regional scales over large areas. The near real time gridded weather forcing data called NLDAS phase 2 can be a potential source of spatially distributed weather data to be used in these models. However these data are at a relatively coarse resolution of 14 km, which is not ideal for agricultural studies at field scales or irrigated areas surrounded by desert or semi-arid vegetation. The data need to be compared against ground based measurements to identify errors and biases. Several hundred ground based weather stations were identified over agricultural areas within the 17 western states (Figure 3) filtered using the NASS Cropland data set. The main variables that were include air temperature, solar radiation, vapor pressure and wind speed.

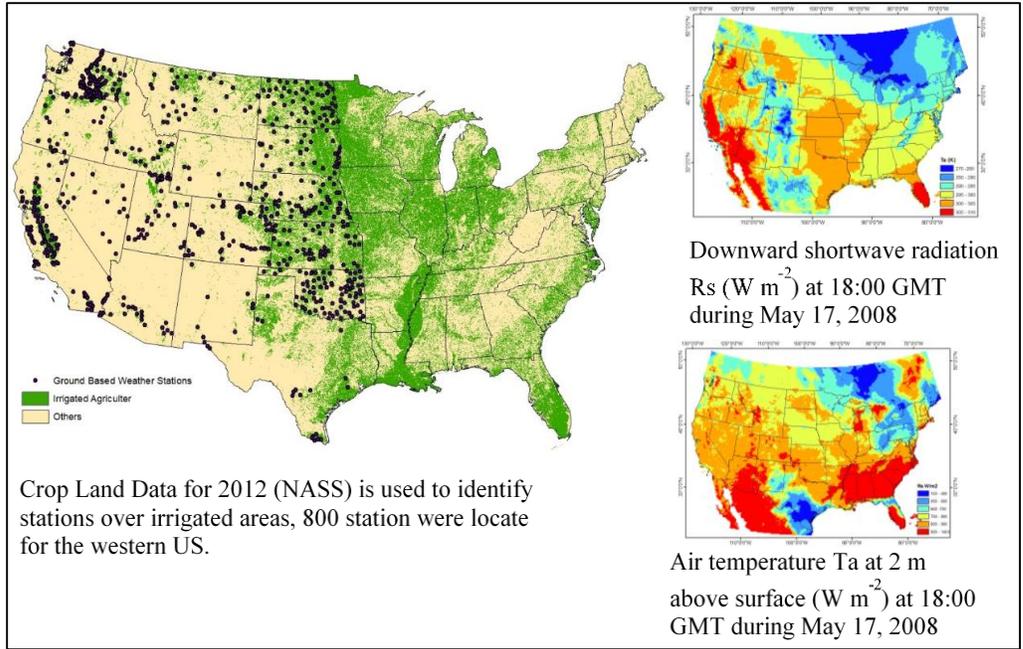


Figure 3: Location of the selected ground stations with over agricultural areas based on the crop land data.

4. Principal findings and significance

4.1. Comparison of gridded weather data

The results of the comparison of NLDAS gridded weather forcing with ground based data are shown in Figure 4 (Clay et al., 2014). The results indicated that there can be large discrepancies between NLDAS forcing and surface values over irrigated areas. This suggest that the use of these data without adjustment or bias correction could lead to large errors when applying remote sensing of ET models at large spatial scales. A peer review manuscript was published (Clay et al. 2014) provided detailed results about the comparison (Figure 5) and also discussed the use of the NLDAS in estimating reference ET (Figure 6).

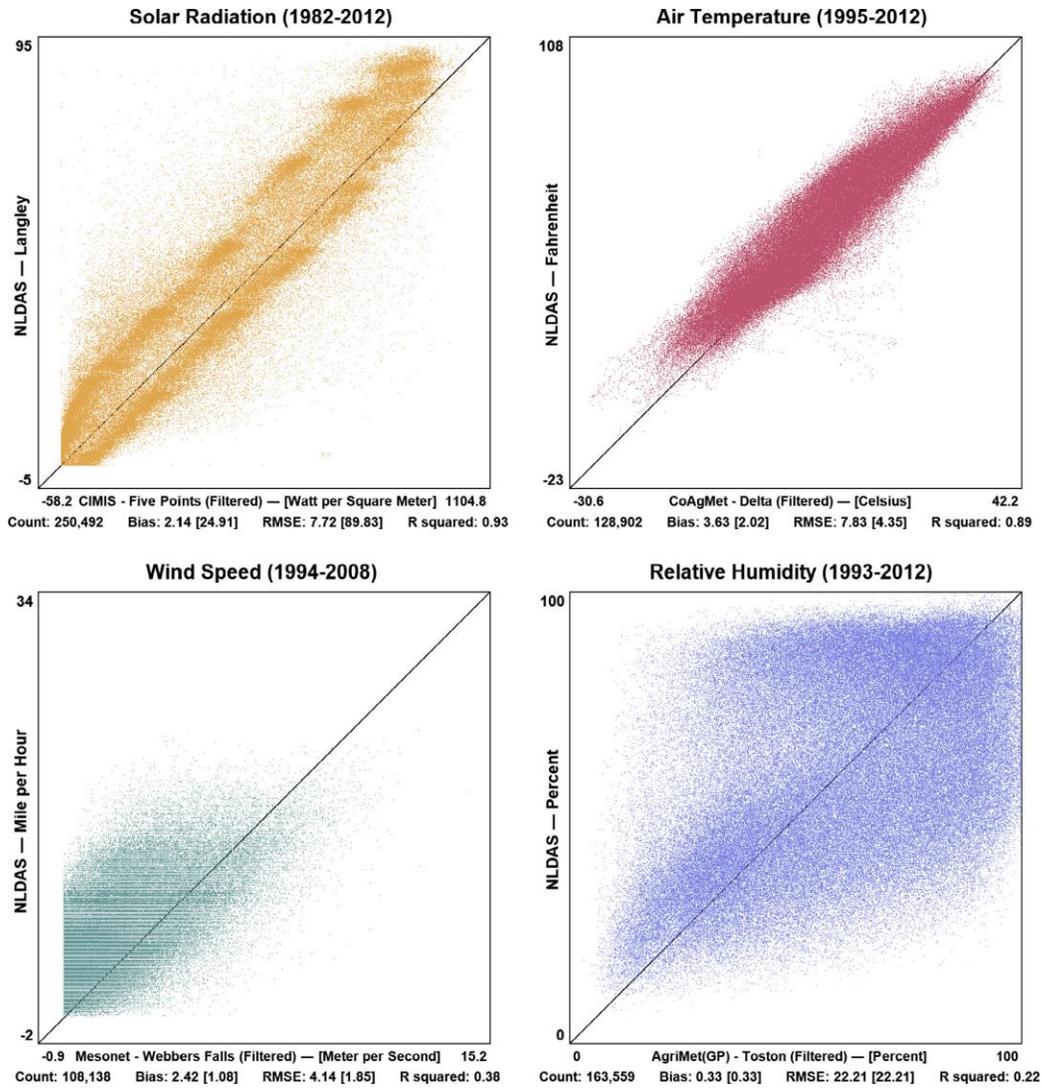


Figure 4: Scatterplot of Ta, Rs, and U comparisons between NLDAS and ground weather forcing before and after suggested bias correction NE Lincoln station (12W 55N) 1994-2012 .

RMSE

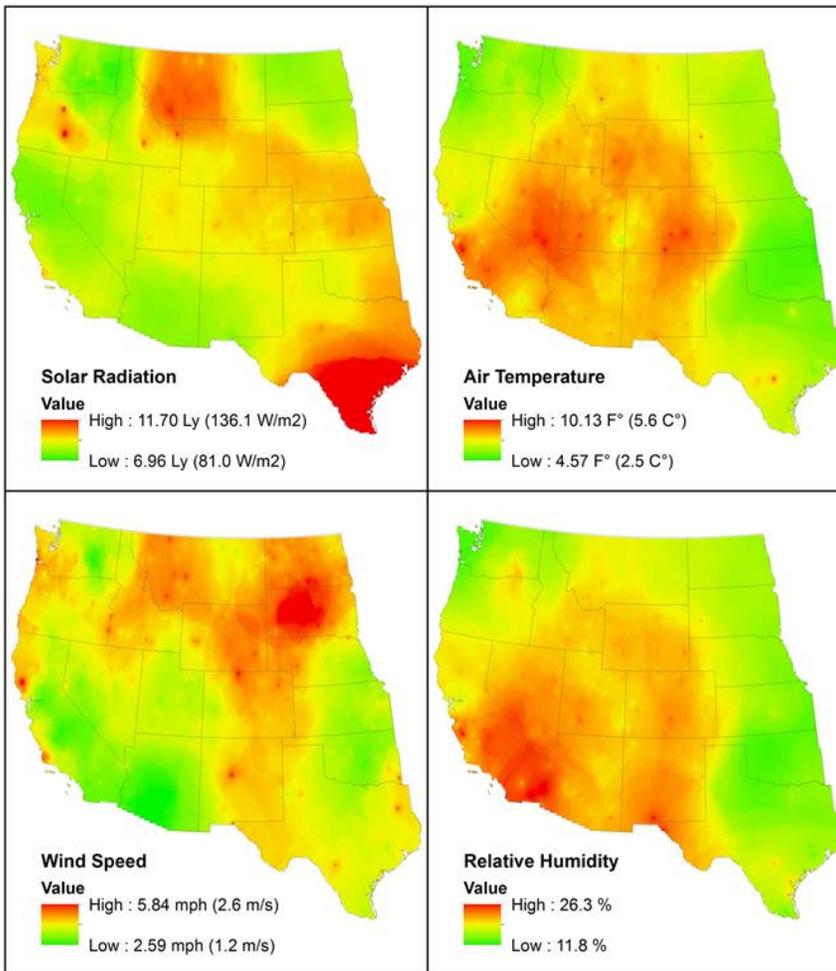


Figure 5: The root mean square error for the comparison between ground and NLDAS based weather forcing data including air temperature, wind speed, relative humidity, and solar radiation (Clay et al. 2014).

Reference ET (Daily)

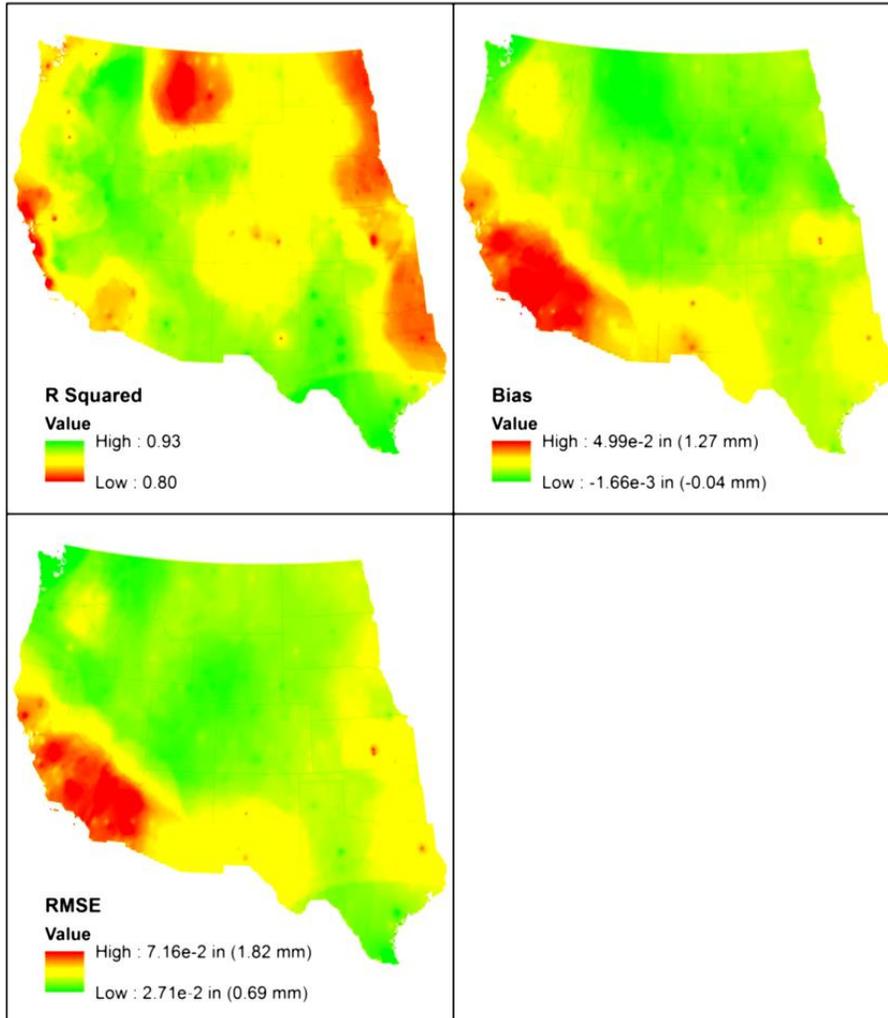


Figure 6: The comparison between reference ET estimates based on the ASCE Standardized equation using ground and NLDAS based weather forcing data (Clay et al. 2014).

4.2. The Effect of Using Gridded Weather Forcing Data on Actual ET

A preliminary analysis was conducted to study of the effect of using NLDAS weather forcing and ground based data in estimating actual ET. The two source energy balance model (TSEB) was utilized to provide such estimate and the analysis was carried out over PVID, CA. These results (Figures 7- 8) indicated that:

- Estimates of daily actual ET during satellite overpass based on both NLDAS and ground –based weather forcing data showed reasonable agreement when compared with Bowen ratio flux towers measurements. However the use of NLDAS data resulted in overestimation of actual ET of about 18% compared to 8% with ground based weather forcing data.

- Based on analysis over selected single alfalfa field estimates of seasonal actual ET with the use of NLDAS resulted in overestimation of about 12% compared to 4% with ground based weather forcing data.

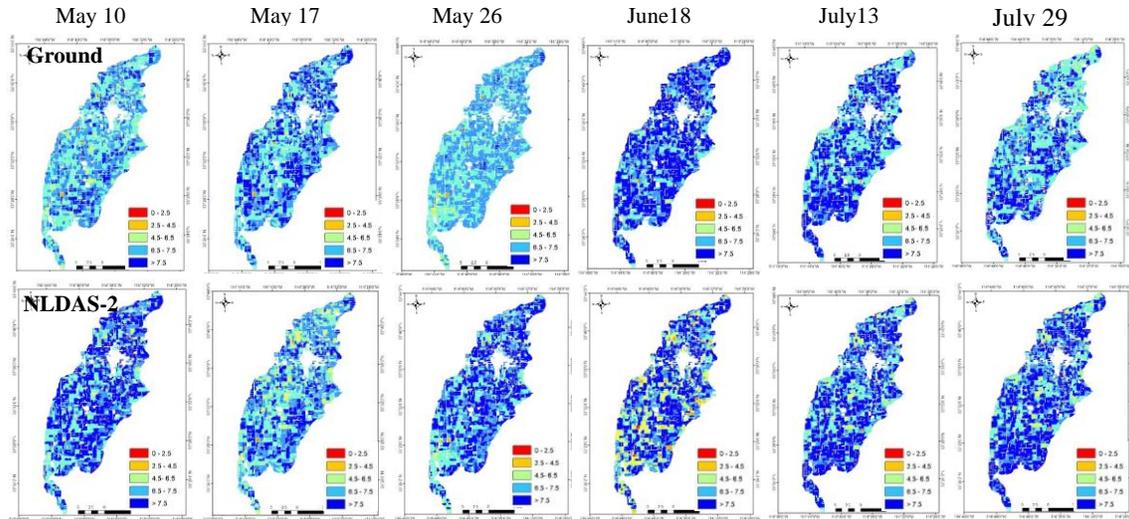
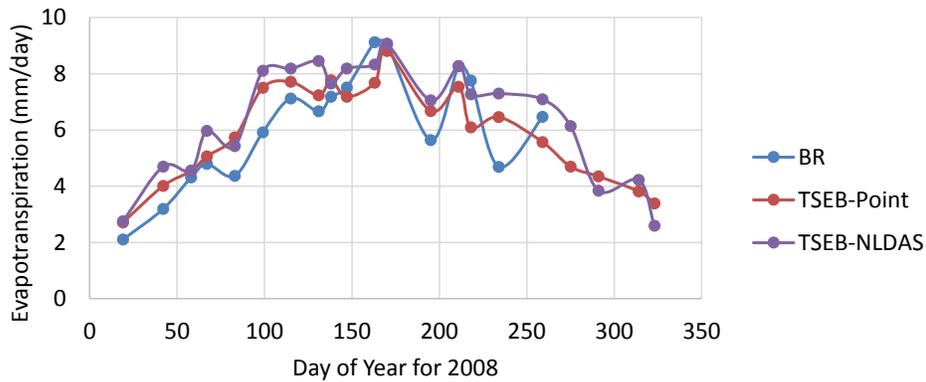


Figure 7: Estimates of actual ET using TSEB based on NLDAS and ground-based weather forcing data. This results is based on data collected over the PVID, CA during summer of 2008.

Actual Evapotranspiration from Bowen Ratio, TSEB-Point, and TSEB-NLDAS during Lansat 5 Overpass



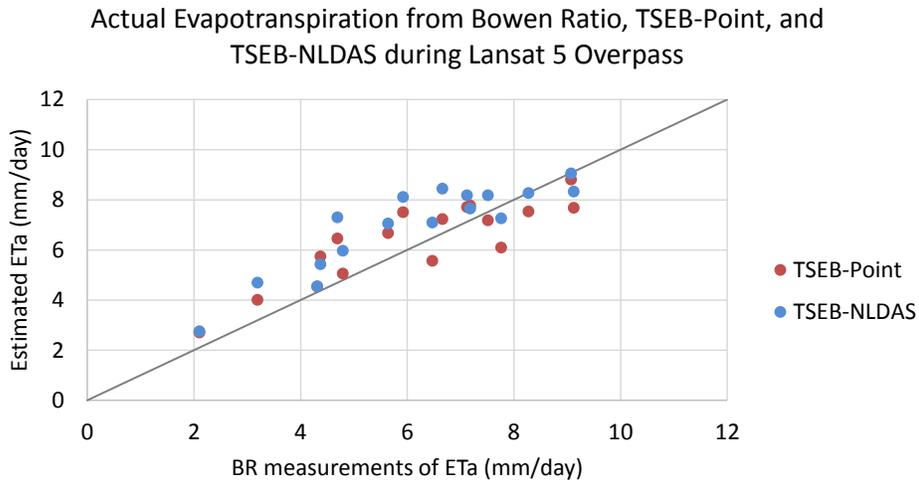


Figure 8: Comparison of actual ET estimates based on NLDAS and ground-based during the satellite overpass dates.

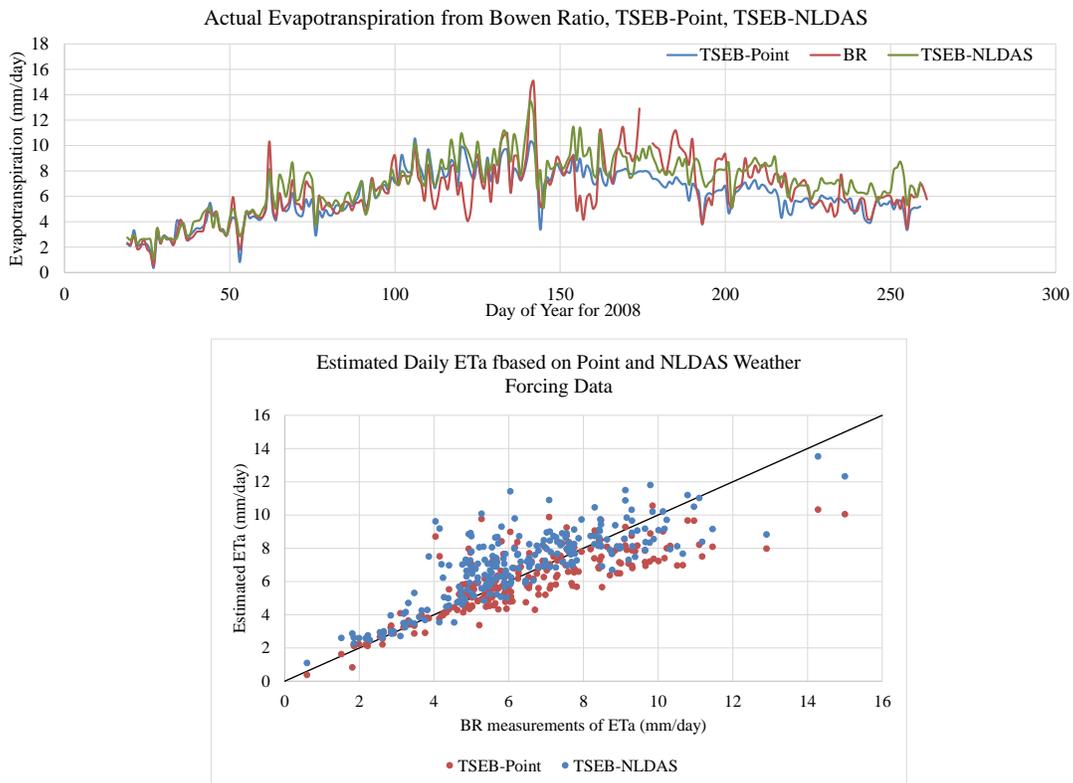


Figure 9: Seasonal actual ET estimates based on NLDAS and ground-based weather forcing data.

4.3. List of Papers and Presentations

Introduction of the suggest project framework and dissemination of preliminary results was achieved through presentation in professional conferences and workshops. A list of presentations is provided below:

- Geli, H. M. E., & Neale, C. M. U., 2013, The use of a Hybrid Evapotranspiration Model with Multiple Source Remote Sensing Data, ASA meeting, Tampa, Florida
- Geli, H. M. E., Lewis, C. S., and Neale, C. M. U., 2014, Seasonal evapotranspiration using a two-source energy balance model and gridded weather forcing and reference evapotranspiration data, presented at 2014 ASABE International symposium, ASABE, Raleigh, North Carolina, 7-11 April
- Geli, H. M. E., Neale, C. M. U., Hobbins, M. S., Verdin, J., and Senay, G., 2013, Actual Evapotranspiration using a two source energy balance model and gridded reference ET_0 , presented at 2013 Fall Meeting, AGU, San Francisco, California, 9-13 December
- Geli, H. M. E., Neale, C. M. U., Verdin, J., & Senay, G., 2013, Estimation of Crop Water Use with Remote Sensing: Development of Guidelines and Specification, presented at the USCID conference, Phoenix, AZ.
- Hobbins, M, Geli, H. M. E., Lewis, C. S., Senay, G., and Verdin, J., 2013, NOAA introduces its first-generation reference evapotranspiration product, presented at 2013 Fall Meeting, AGU, San Francisco, California, 9-13 Dec
- Lewis, C. S., Geli, H. M. E., Neale, C. M. U., Verdin, J., and Senay, G., 2013, Comparison of the NLDAS Weather Forcing Model with Ground-Based Measurements over Agricultural Areas Throughout the Western United States, presented at the Spring Runoff Conf., Utah State University, Logan, Utah, USA 9-10 April 2013
- Lewis, S. C., Geli, H. M. E., Neale, C. M. U., 2013, Comparison of the NLDAS Weather Forcing Model to Agrometeorological Measurements in the Western United States, Journal of Hydrology.

4.4. Summary of progress

The project is presently in its third year and a summary of the project progress is shown in Table 1.

Table 1: Summary of the project progress

Items					0	20%	40%	60%	80%	100%
1	Identification and review of currently available remote sensing of ET models									
			Identification and selection of models for testing							
2	Defining a common Framework		Summary Review (report) of Existing Practice							
			a	Models Review Report						
			b	Input Data						
				1	Cropland Data					
				2	Weather Data					
				3	Standardized Imagery					
			c	Modeling Process						
			d	Evaluation of ET						
3	Final Framework									
4	Community review									

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UAV Monitoring and Assessment Applications in Municipal Water and Environmental Management Problems

Basic Information

Title:	UAV Monitoring and Assessment Applications in Municipal Water and Environmental Management Problems
Project Number:	2012UT167B
Start Date:	3/1/2012
End Date:	3/28/2013
Funding Source:	104B
Congressional District:	UT1
Research Category:	Engineering
Focus Category:	Conservation, Floods, Hydrology
Descriptors:	None
Principal Investigators:	David Rosenberg, Austin Jensen

Publications

There are no publications.

UAV Monitoring and Assessment Applications in Municipal Water and Environmental Management Problems

Rosenberg, David, Austin Jensen, & Shannon Syrstad

Problem Description

For water and environmental management applications, remote sensing can be useful by giving managers accurate and quality spatial data on what they are trying to manage. Sriharan et al. (2008) used aerial imagery to map invasive plant species in a wetland to help managers remove them effectively. In a riparian area, Everitt and Deloach (1990) used aerial imagery to map Chinese Tamarisk. Even though research has shown that remote sensing can be a very useful tool, many do not use it due to high cost, long processing time and inflexibility (Pinter et al., 2003). Free GIS state services or applications like Google Earth can be used for aerial imagery instead of purchasing the data. However, the imagery from these sources is often out-of-date, has poor resolution, and rarely includes all spectral information to allow for the use of modern classification software or other advanced analytic techniques. To deal with some of these problems and provide remote sensing data to a wider range of managers and stake-holders, a new series of remote sensing platforms, collectively called AggieAir™, has been developed at Utah State University (see Figure 1). AggieAir platforms are small, autonomous aircraft (commonly known as “unmanned aerial vehicles”, or UAVs) with multiple on-board cameras to capture aerial imagery during flight. AggieAir is capable of capturing visual (red, green, and blue), near-infrared (NIR), and thermal imagery. For this project, we will investigate the value of the use of AggieAir to cities, such as Logan, UT, to help them manage environmental issues by capturing aerial imagery over areas of interest. The types of areas in which Logan City are interested include wetland and riparian areas, landfills, and parks and recreation areas such as a golf course.

In order to reduce the human footprint on the environment and protect people and property from natural disasters such as floods, cities should carefully manage their environmental resources. Resources include constructed and natural wetlands. Logan City operates 240 acres of constructed polishing wetlands for wastewater treatment and 35 acres of land used for leachate treatment, stormwater runoff, and wetland mitigation. The City has a Utah Pollutant Discharge Elimination System (UPDES) permit, which allows treated wastewater to be discharged into the backwaters of a local reservoir located on a major tributary to the Bear River. The permit requires the city to maintain pollutant levels in discharged wastewater below a threshold standard. The polishing wetlands help remove the regulated contaminants. To ensure that the wetlands are effective at removing the contaminants, the vegetation must be managed to promote native species and remove invasive plant species. Aerial photography can help city managers identify plant species, growth patterns, and dead spots in treatment wetlands where re-planting and maintenance is needed. The use of small UAVs to accomplish these tasks has not been previously explored.

Cities are also concerned with managing riparian areas. Each spring, employees from the Logan City Street department walk the banks of the Logan River to look for debris in and near the river.

On average, Logan city uses 14 employees over 5 days to identify locations of collected flotsam and deadfall trees. Once these debris piles are located, the city removes the debris to allow the spring runoff water in the river to flow freely without debris collecting on bridges and irrigation head gates or otherwise creating flood hazards. The average cost for these activities includes \$10,000 in labor and \$10,000 for equipment and fuel. Quick and efficient identification of debris piles could significantly reduce the cost by reducing the manpower and equipment needed for this project. Aerial photography could reduce removal costs if it could be accomplished at a sufficient geographic and temporal resolution at a competitive cost.

Many cities must also manage landfills to properly dispose of waste collected by the city. Logan City operates 90 acres of landfill. To prevent the contents in the landfill from affecting the surrounding environment, frequent inspections of the landfill surface are critical to monitor signs of seeps, leaks, or erosion. It is also necessary to monitor stormwater management systems to properly control stormwater run-off and run-on. If stormwater comes in contact with landfill refuse it becomes leachate and must be treated properly. It would be of great benefit to landfill operations to have aerial photography to monitor unwanted changes in the landfill surface to minimize leachate. It would also be of benefit to record changes in elevation as materials are compacted into the landfill.

Parks and recreation are an important part of a city that must also be managed. Logan City maintains the Logan River golf course within in its jurisdiction to enhance and provide a high quality of life for local citizens. Each year groundskeepers for the Logan City golf course spend many hours driving and walking the course to identify areas of the course which develop dry or dead vegetation due to lack of consistent watering or inadequate application of fertilizers. Aerial remotely sensed imagery can help groundskeepers to quickly identify areas of the golf course that need additional water or fertilizers, improve grass maintenance, and save money on manpower and equipment to walk the golf course.

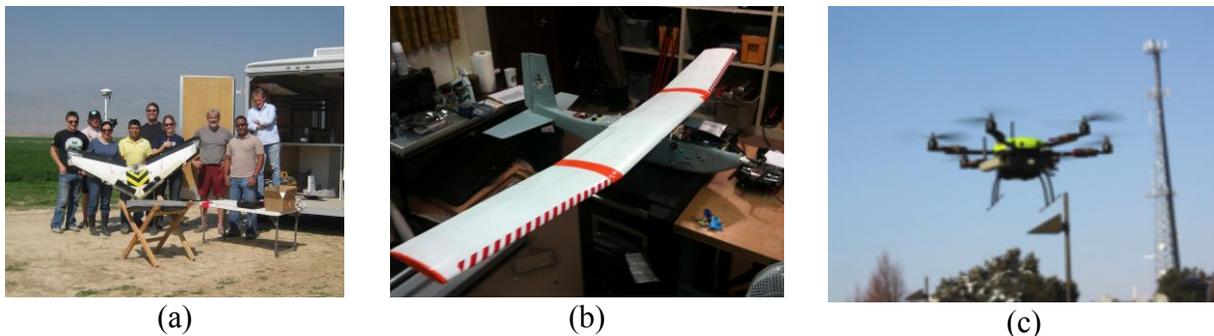


Figure 1: Current AggieAir UAV Platforms; (a) the older flying wing; (b) Minion and Titan class aircraft (Minion shown in the photograph); (c) AggieAir vertical-takeoff-and-landing platform

AggieAir vehicles are specifically designed as low-cost, scientific-grade remote sensing platforms. Using on-board navigation sensors, each aircraft is able to navigate according to a preprogrammed flight plan without a human operator. Since AggieAir aircraft were designed to be used in remote areas for field work applications, only an open field is required for takeoff and landing, not a runway or road. To launch the fixed-wing aircraft (Figure 1.a and Figure 1.b), a

bungee is staked into the ground, attached to the aircraft, pulled back and released. For the landing, the aircraft simply lands on its belly. AggieAir platforms weigh from 3 to 25 pounds, depending on the class, and have wingspans from 72 to 144 inches. Again, depending on class of aircraft, they can fly for 30 to 90 minutes, and all are battery powered.

AggieAir acquires multispectral imagery. Currently, visual (red, green and blue), near- infrared (NIR), and thermal infrared imagery is available. After each flight, hundreds of individual images are retrieved from the cameras and processed. For processing, each image is tagged with the position and orientation data of the UAV when the image was exposed. This data can be used to automatically georeference each image immediately after the flight. To stitch all of the images together into a mosaic, third-party software called EnsoMOSAIC is used. EnsoMOSAIC stitches all the images together and creates an orthorectified mosaic. EnsoMOSAIC can also be used to generate digital elevation models (DEMs).

AggieAir has been used in many different types of water-related and environmental projects by researchers at USU. Some of these projects include wetland and riparian applications (Jensen et. al, 2011; Zaman, McKee, and Jensen, 2011). Here, we demonstrate applications and benefits for municipal areas in wetland wastewater treatment, landfill operation, removing debris from riparian corridor, and irrigating a golf course.

Scope of Work

Four tasks using AggieAir were identified for data collection and analysis that are of value to Logan City:

1. Acquire multi-spectral imagery for nine square miles of a wetland area within Logan City in the visual, NIR, and thermal bands of the spectrum. Classify the imagery for different types of wetland vegetation. This data will be used by Logan City to help manage mitigation wetland areas and to find out which areas are suitable for fill.
2. Fly the Logan River from the mouth of Logan Canyon to the city boundaries to capture aerial imagery of the river in the visual and NIR bands. Use collected imagery to assist city workers to identify where to find debris in the river so that it can be removed before spring runoff.
3. Fly the Logan River City Golf Course. Capture aerial imagery in the visual, NIR, and thermal bands and map turfgrass water stress. Share the results with groundskeepers to help them water the grass more efficiently. Repeat two times over the summer.
4. Make a detailed, high-resolution flight over the Logan City Landfill. Capture visual, NIR and thermal imagery and use to generate a digital terrain map (DTM), and to investigate the possibility of using aerial imagery to detect seeps, leaks and erosion. Repeat two times over the summer.

After the imagery was captured from AggieAir, it was stitched together into orthorectified mosaics. If further image processing is needed, the mosaics were converted to reflectance mosaics.

All of the data acquired by AggieAir are stored on a server at the Utah Water Research Laboratory (UWRL). Access to this data and its metadata has been given to Logan City and other interested parties through Secure File Transfer Protocol (SFTP). The mosaics can also be served via Google Earth.

Wetland Results

Figures 2 and 3 show the orthorectified mosaics of the Logan City wetlands in the visual and NIR spectrum (25cm resolution). The mosaics include the wetlands managed by Logan City in the north, the Logan City sewage lagoons in the center, and the landfill in the south east of the mosaic.

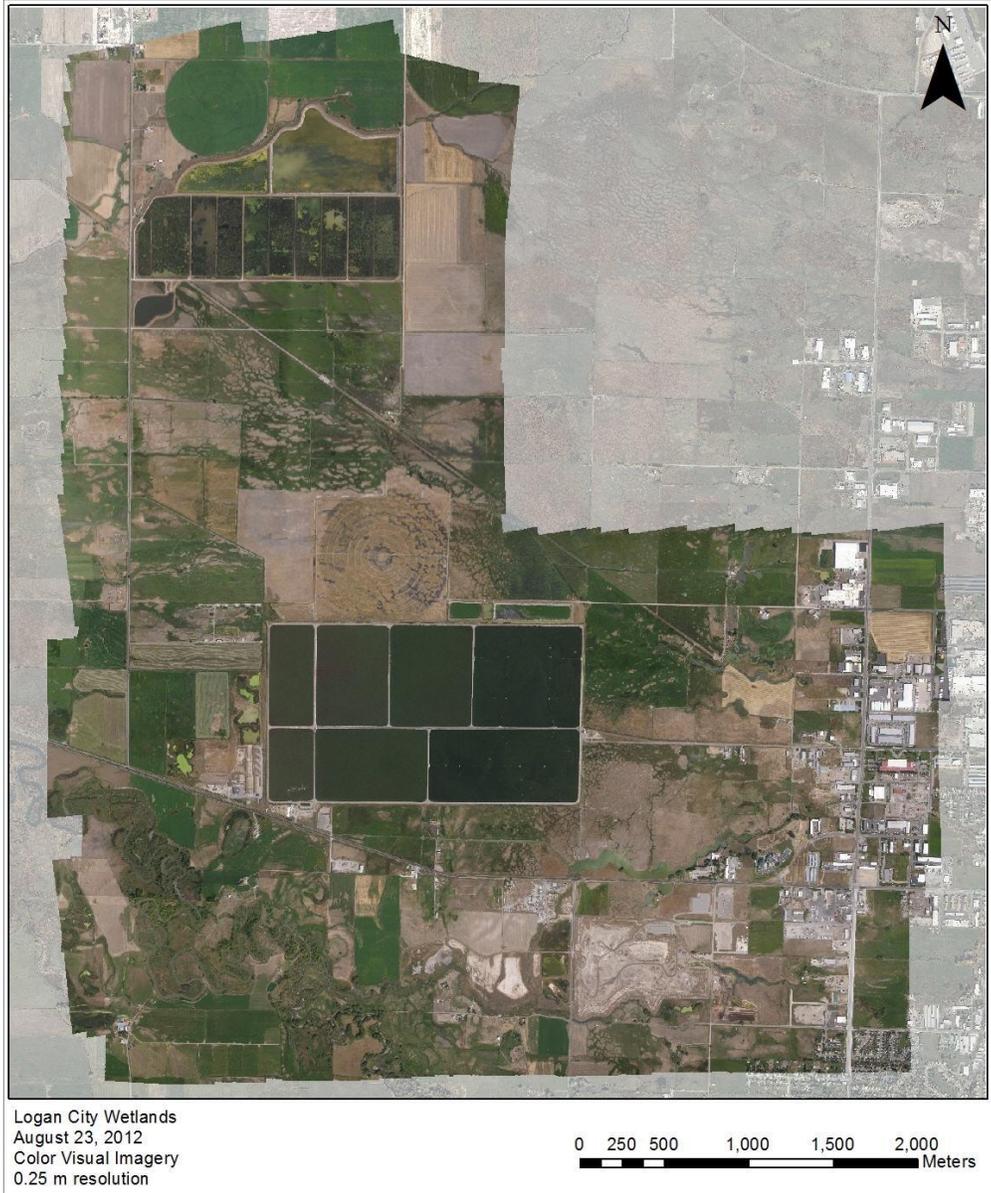


Figure 2: Logan City Wetlands - Visual Mosaic



Figure 3: Logan City Wetlands - NIR Mosaic

In addition to collecting imagery in the visual and NIR spectra, thermal imagery was also collected over the wetland area. Figure 4 shows the portion of the mosaic over the Logan Lagoons. Notice the circular temperature patterns in the water from the aeration system.

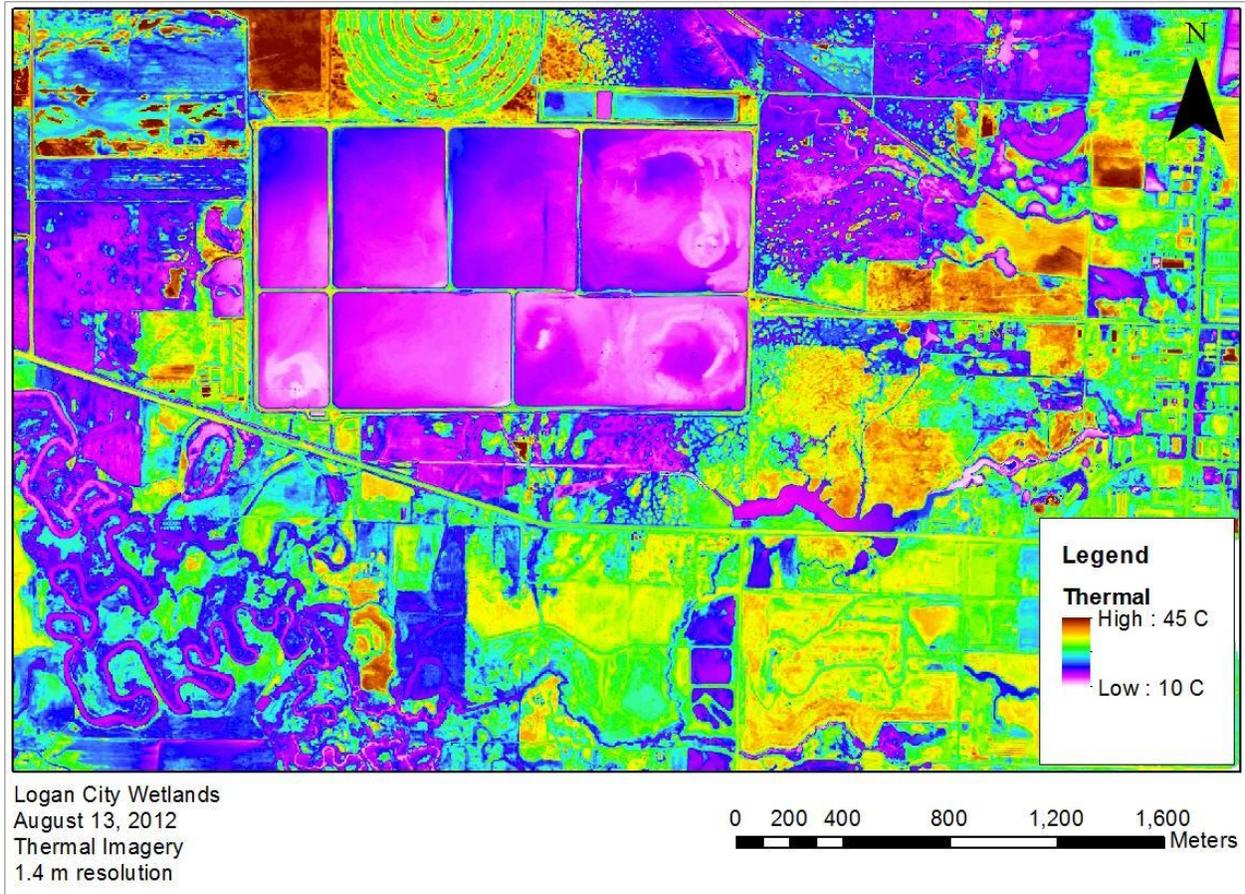


Figure 4: Thermal Mosaic over sewage treatment lagoons.

Wetland Classification

Ground Truth Sampling

Logan City field crews collected ground truth sample points of known wetland species with a Global Positioning Service (GPS) on July 25, 26 and 29, 2012. There were 32 hardstem bulrush samples, 48 cattail samples, 4 cement, 1 structure and 1 water sample. The horizontal precision of the GPS points ranged from 0.5 to 1.5 meters with an average of 0.636 meters. The plant species that were identified and mapped were cattail and hardstem bulrush. See Figure 5 for a map of the ground truth data of the GPS collection efforts.

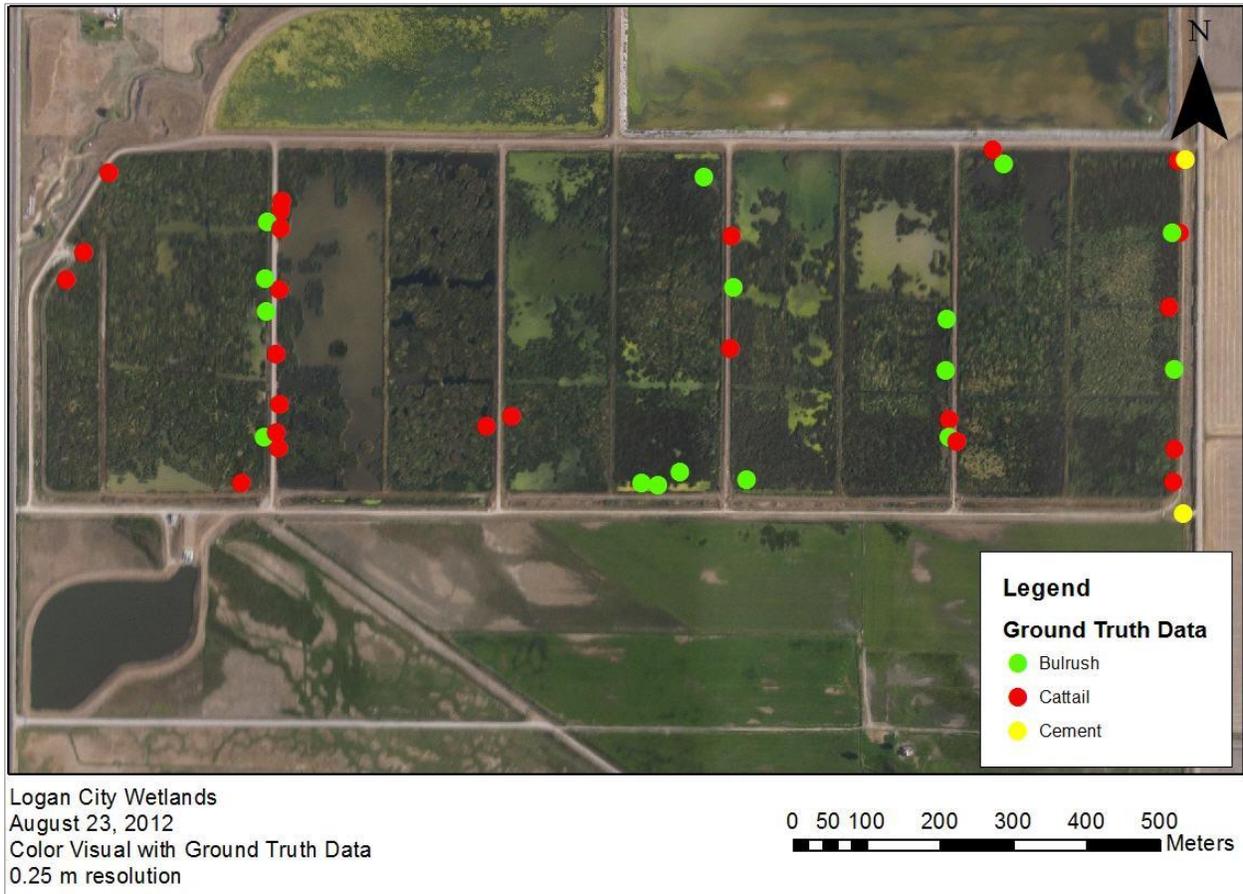


Figure 5. AggieAir imagery showing ground truthing locations of Logan City collected data.

Reflectance Mosaics

Once visual-color and near-infrared mosaics were generated from EnsoMosaic, the digital numbers of the 8-bit images were converted to reflectance values which is “the ratio of the radiant flux reflected by a surface to that reflected into the same reflected-beam geometry by an ideal, perfectly diffused standard surface irradiated under the same conditions” (Nicodemus et al. 1977), or the fraction of electromagnetic radiation which was reflected by the surface being analyzed. The current steps for converting orthorectified mosaics to reflectance values are: (1) generate RGB and NIR orthorectified mosaics from post flight imagery, (2) calculate the corrected brightness value for each spectral band of the reflectance panel photos, (3) calculate the reflectance factors for each spectral band for the reflectance panel, (4) calculate the reflectance images for individual bands using the orthorectified mosaics, and (5) perform layer stack on bands to create a final reflectance mosaic. Spectralon white reflectance panels were used in the field before and after flights using the same cameras on board the flight to capture white panel images. These images are used in step 2 above.

Reflectance Images and Layer Stacking

For the Logan City Wetland work, a fifth layer was added to create a 5-band reflectance image. This was the normalized differential vegetation index (NDVI), which is the most widely accepted

vegetation index for agricultural and vegetation studies (Schmaltz 2005). It uses the red and NIR bands. NDVI is robust and requires no atmospheric correction. It also reduces the impact of sunlight intensity variations, which is ideal for post mosaic classification. NDVI values range from -1 to 1. Calculation of the NDVI is shown in the following equation:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

Supervised Classification

Using ERDAS Imagine, supervised classification was performed using the ground truth points and polygons of wetland plant species provided by Logan City on the five-band reflectance image. The plant data was divided into training and testing sets. The training set was used to create spectral signatures unique for each plant species, while the testing set was used for accuracy assessment. Although the bulrush and cattail species were spectrally similar (see Figure 6), and by ERDAS standards could have been merged, the individual cattail and bulrush signatures were merged but species were left separate.

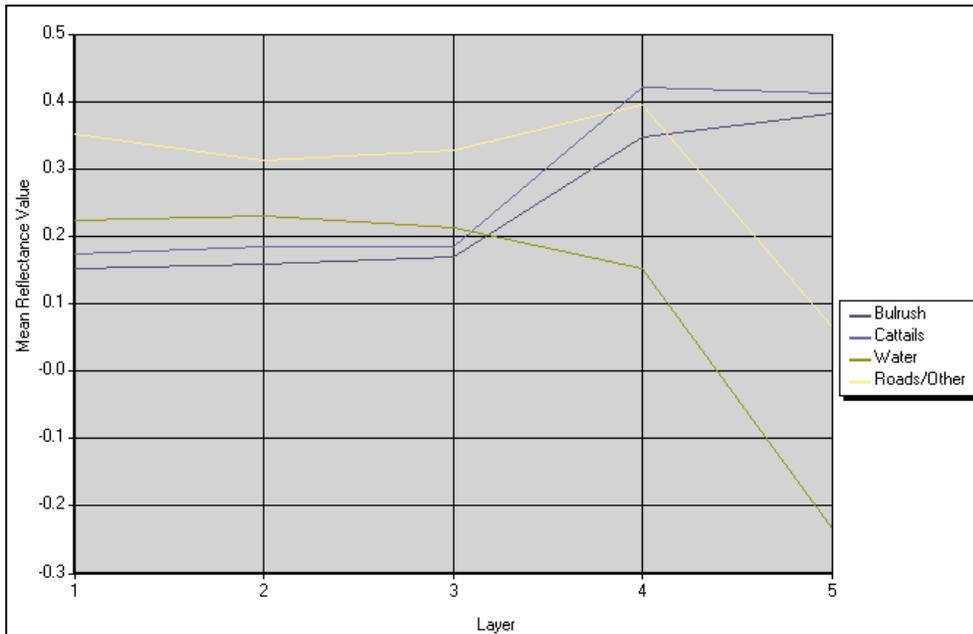


Figure 6. Mean reflectance values for Logan City Wetlands spectral signatures

Additional signatures were added to represent all water and all “ground (gravel roads, ditches, cement). After the spectral signatures were defined, the classified image was generated using the five-band reflectance mosaic with a Parallelepiped/Mahalanobis Distance classifier.

Table 1 of signature separability

Signature Name	1.	2.	3.	4.
1. hardstem bulrush	0	1227.44	1999.00	2000.00
2. cattail (broad/narrow)	1227.44	0	2000.00	2000.00
3. water	1999.00	2000.00	0	2000.00
4. road/other surfaces	2000.00	2000.00	2000.00	0

Table 1 shows the separability matrix of the four classes using Transformed Divergence. If classes are nothing alike spectrally, they have a separability of 2000 (the highest). Typically classes with a separability of 1700 or lower are merged. However, the Logan City Wetlands study, the bulrush and cattail were left separately despite the 1227.44 separability in order to maintain two species signatures.

Classification Accuracy Assessment

“Accuracy assessment” is a general term for comparing the classification data to spatial data that are assumed to be true. The purpose of this comparison is to determine the accuracy of the classification process (ERDAS Field Guide 2010). The testing data set was used to determine what the pixel was defined as and how it should be classified. The results produce a *producer’s accuracy* and a *user’s accuracy*. The producer’s accuracy is the total number of correct points in a class divided by the number of points of that class as derived from the ground truthing data and represents the probability that a pixel in a given class will have been classified correctly on the image. The user’s accuracy is the total number of correct points in a class divided by the total number of points of that class as derived from the classification data and represents the probability that a pixel classified as a particular class on the image is actually that class. The Kappa statistic indicates how well the classification results agree with the ground truth data. It conveys the “proportionate reduction in error generated by a classification process compared with the error of a completely random classification” (ERDAS Field Guide 2010). Table 2 shows the results of supervised classification.

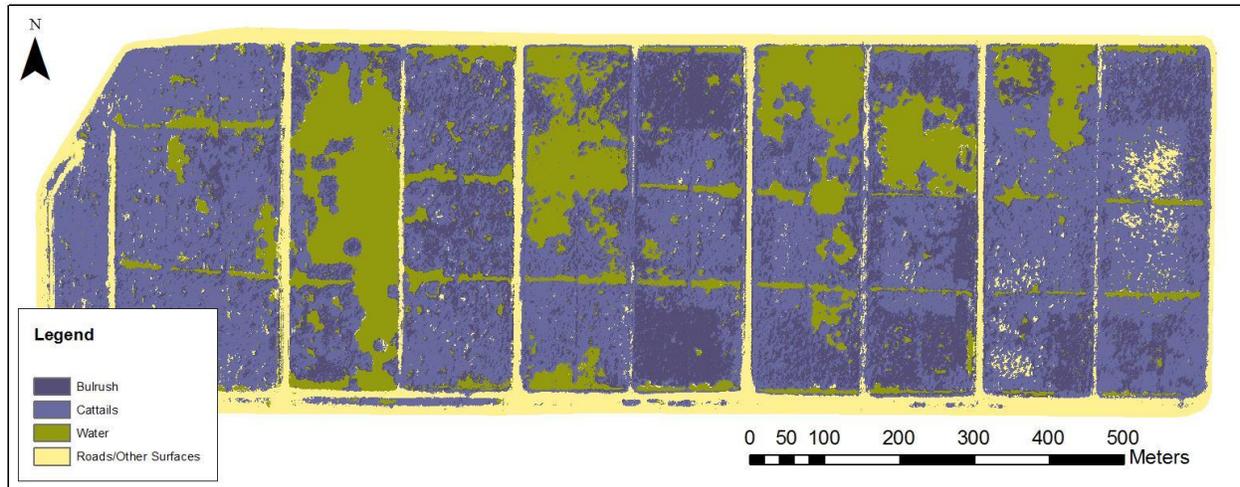


Figure 7 Map of classified Logan City Wetlands

Table 2 of accuracy assessment results

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistic
hardstem bulrush	9	11	5	55.56%	45.45%	0.0455
cattail	11	6	3	22.27%	50.00%	-0.0500
roads/other surfaces	1	4	1	100.00%	25.00%	0.2125
Totals	21	21	9			

Overall accuracy = 42.86%
 Overall Kappa Statistic = 0.0735

Overall, the accuracy assessment results are quite low. This is a result of the poor ground truthing data that was collected. Only two unique types of wetland species were identified. Ideally hand drawn polygons could have been used to delineate areas rather than a non-field based employee seeding AOI (area of interest) polygons using GPS points. The 0.6+ m on average GPS horizontal error may have contributed if the GPS point was sampled fairly close to a different species. To improve the accuracy, GPS locations should have been captured somewhat in the middle of a species patch. Since this is usually difficult in wetland environments, hand drawn polygons on a base map would assisted in the signature file generation.

The areas of interest (AOIs) that were created from the GPS points were generated using the seeding/growing tool in ERDAS which searched for spectrally similar pixels based on a set of parameters. The seeding tool was quite sensitive to the slightest classification parameter modifications. The parameter setting was very biased and different technicians may have differencing AOIs as the parameters were determined successful by visual interpretation. Error may have been introduced in the AOI process while using highly sensitive seeding parameters and 0.6+ meter accuracy GPS points.

Logan River Results

In order to achieve objective number two, imagery over the Logan River needed to be captured before spring runoff, before the trees grew their leaves, and after the snow melted. This gave us a very small window of opportunity (a few weeks). Unfortunately, due to some aircraft technical issues, rainy and windy weather, and the high risk scenario of flying over an urban area, we were unable to fly during this window and therefore were not able to collect the data needed by Logan City employees. In the future, we recommend flying in rural areas. Figures 8 and 9 show the visual and NIR mosaics that we have captured of the Logan River in the past.

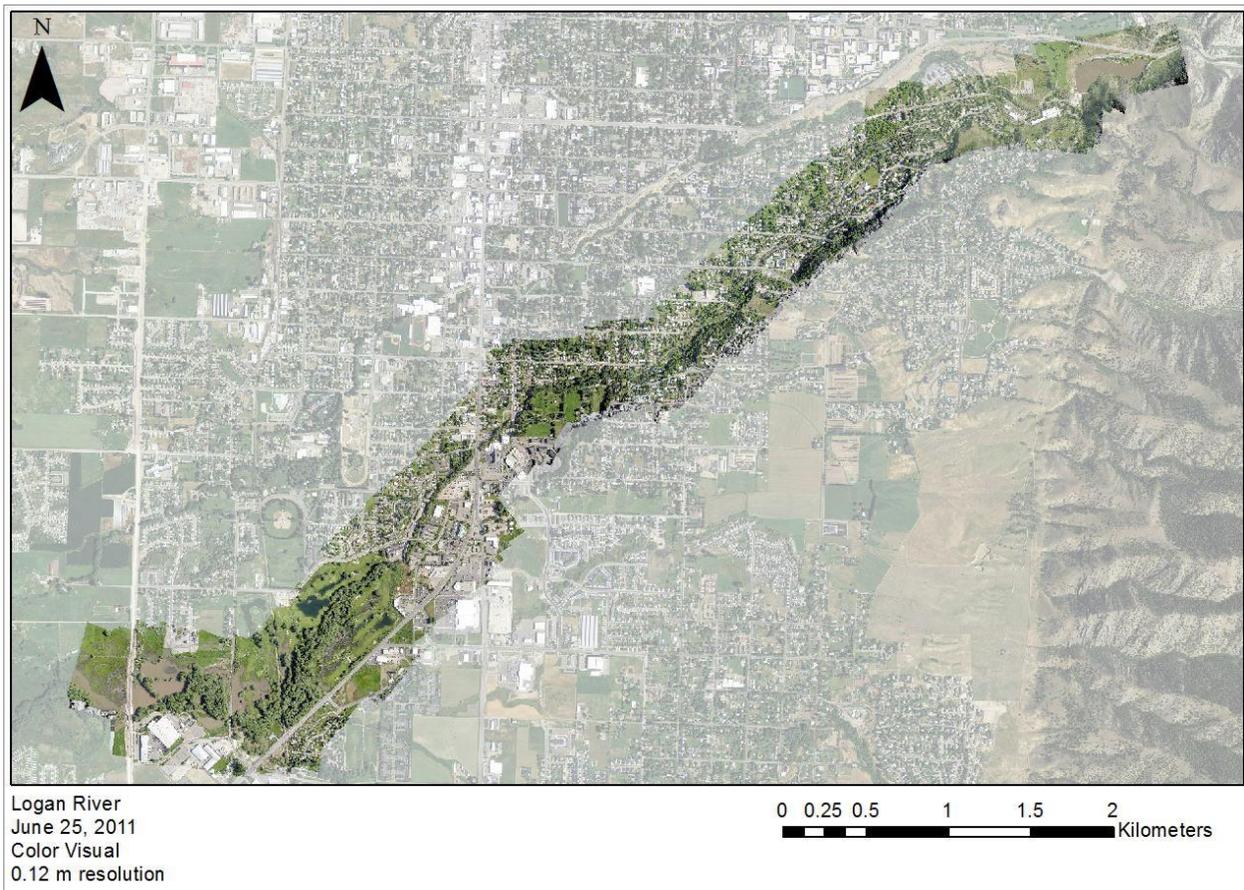


Figure 8. Logan River visual color imagery flown by AggieAir

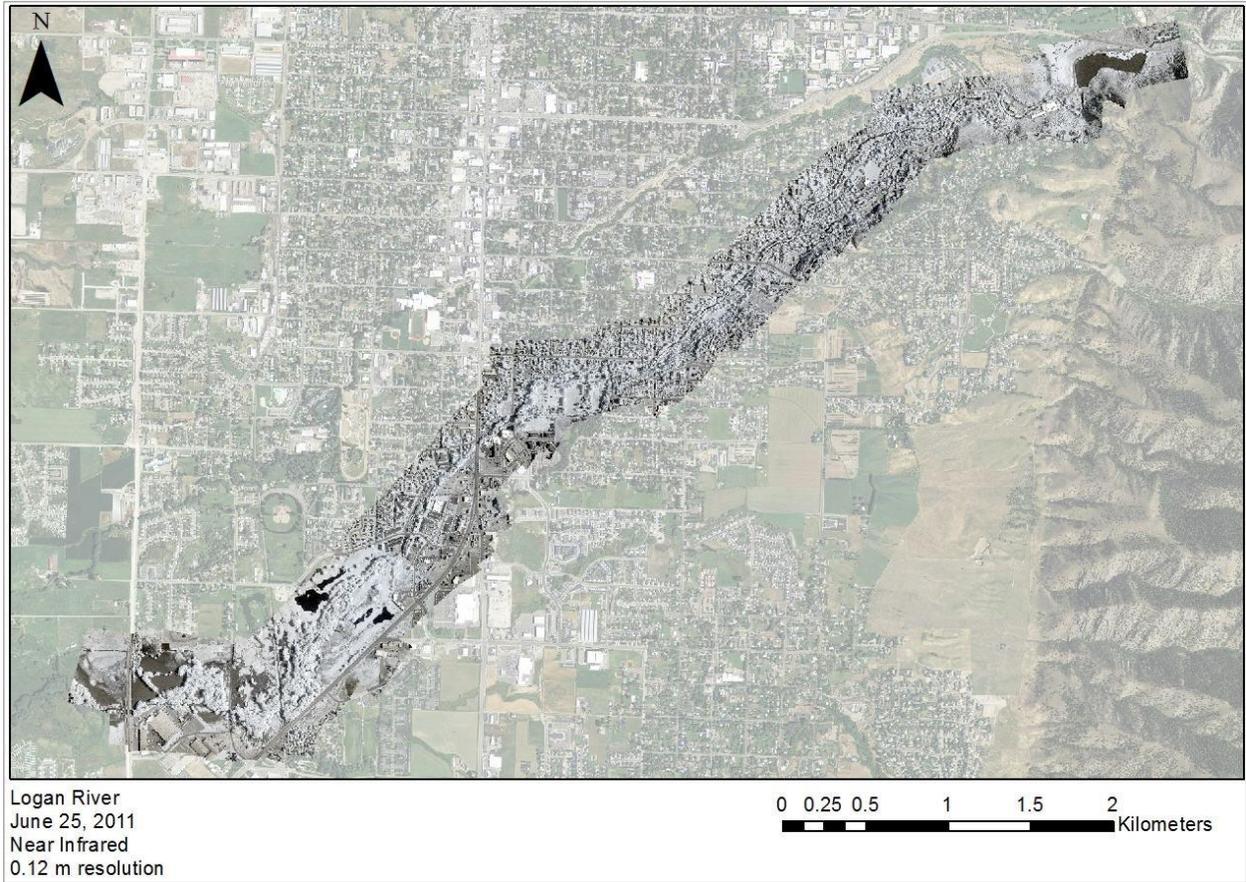


Figure 9. Logan River visual near infrared imagery flown by AggieAir

Logan City Golf Course Results

Figures 10, 11, and 12 show AggieAir remote-sensed visual, NIR, and heat images acquired for the Logan City Golf Course. The NIR mosaic in Figure 11 shows the value in having NIR imagery because of how easily the water is defined from the land. The NIR mosaic also shows the putting greens as the brightest white areas. The thermal results (Figure 12) show yellow and orange hot spots in turfgrass grass and indicate areas where golf course managers should water before the turf shows visible signs of stress. This map could help golf course managers use water more efficiently.



Figure 10. Logan Golf Course visual imagery flown by AggieAir.



Figure 11. Logan Golf Course NIR imagery flown by AggieAir

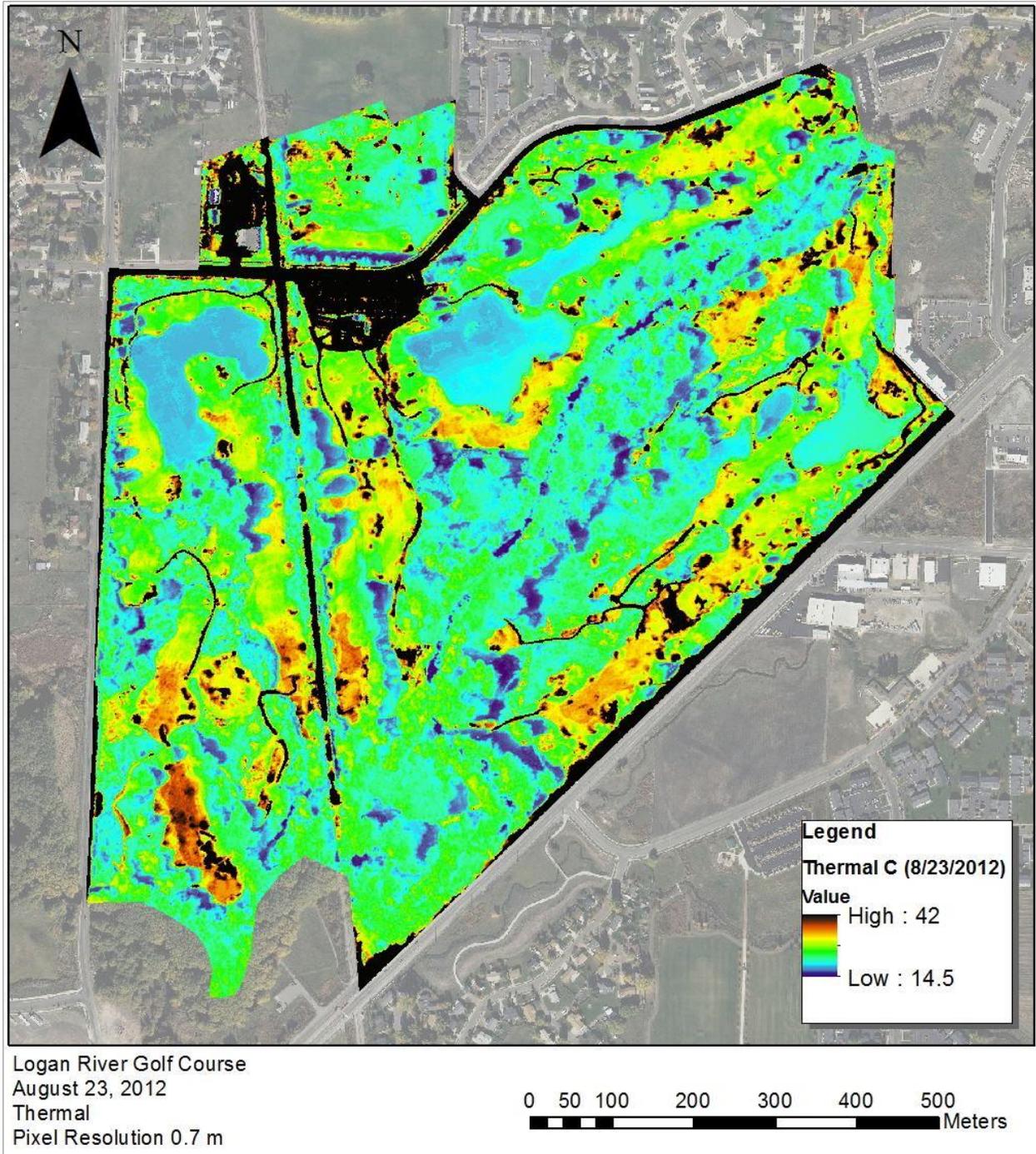


Figure 12. Logan Golf Course thermal imagery flown by AggieAir

Logan City Landfill Results



Figure 13. Three-dimensional aerial view of Logan City landfill.

Figure 13 shows a three-dimensional area view of the Logan City landfill. The mosaic and digital elevation model used to generate this image were created using AggieAir Imagery and Agisoft PhotoScan Professional (AgiSoft LLC, 2014). Based on this elevation model, the volume and surface area of the Logan City landfill were calculated. The volume measurement is 3,218,100 m³ and the surface area of the landfill is 906,537 m² in August 2012. These sorts of measurements can easily be achieved with AggieAir using AgiSoft at a high frequency to check landfill growth over time. Figure 14 shows an image of the digital elevation model and illustrate the fine level of details that can be picked up by the software.

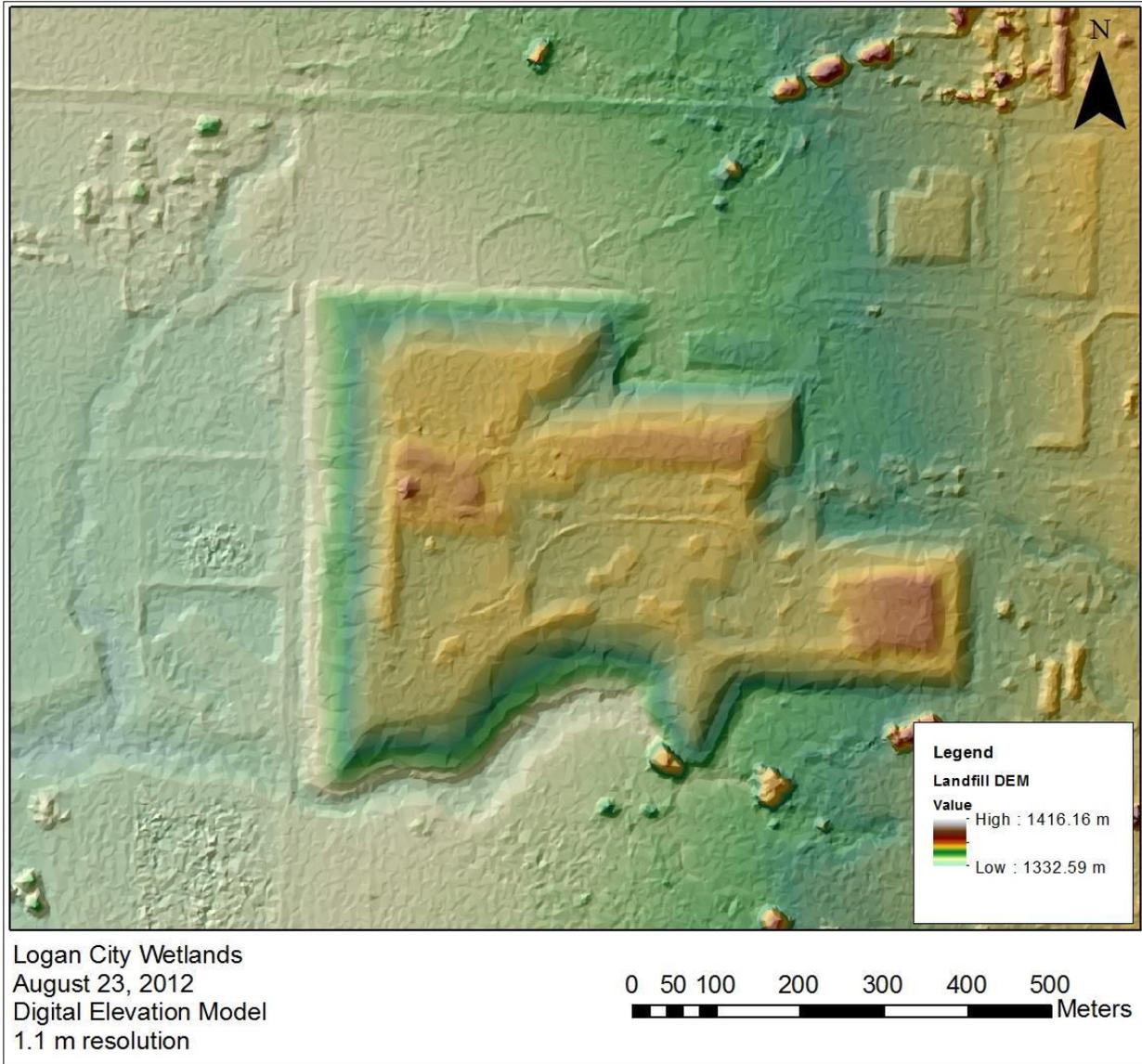


Figure 14. Digital Elevation Model of Logan City Wetland using AggieAir imagery and Agisoft PhotoScan Professional with ArcGIS generated hillshade overlaid on DEM.

Figure 15 shows the NIR mosaic over the landfill and Figure 16 shows the thermal mosaic. With these two mosaics, seeps and leaks could easily be detected either by the absorption of the NIR light and a dark spot on the NIR mosaic or by a cool spot displayed by the thermal mosaic. One interesting detail shown by the thermal mosaic is the warmer areas on the south facing slopes of the landfill.



Figure 15. Near Infrared imagery of Logan City Landfill flown with AggieAir.

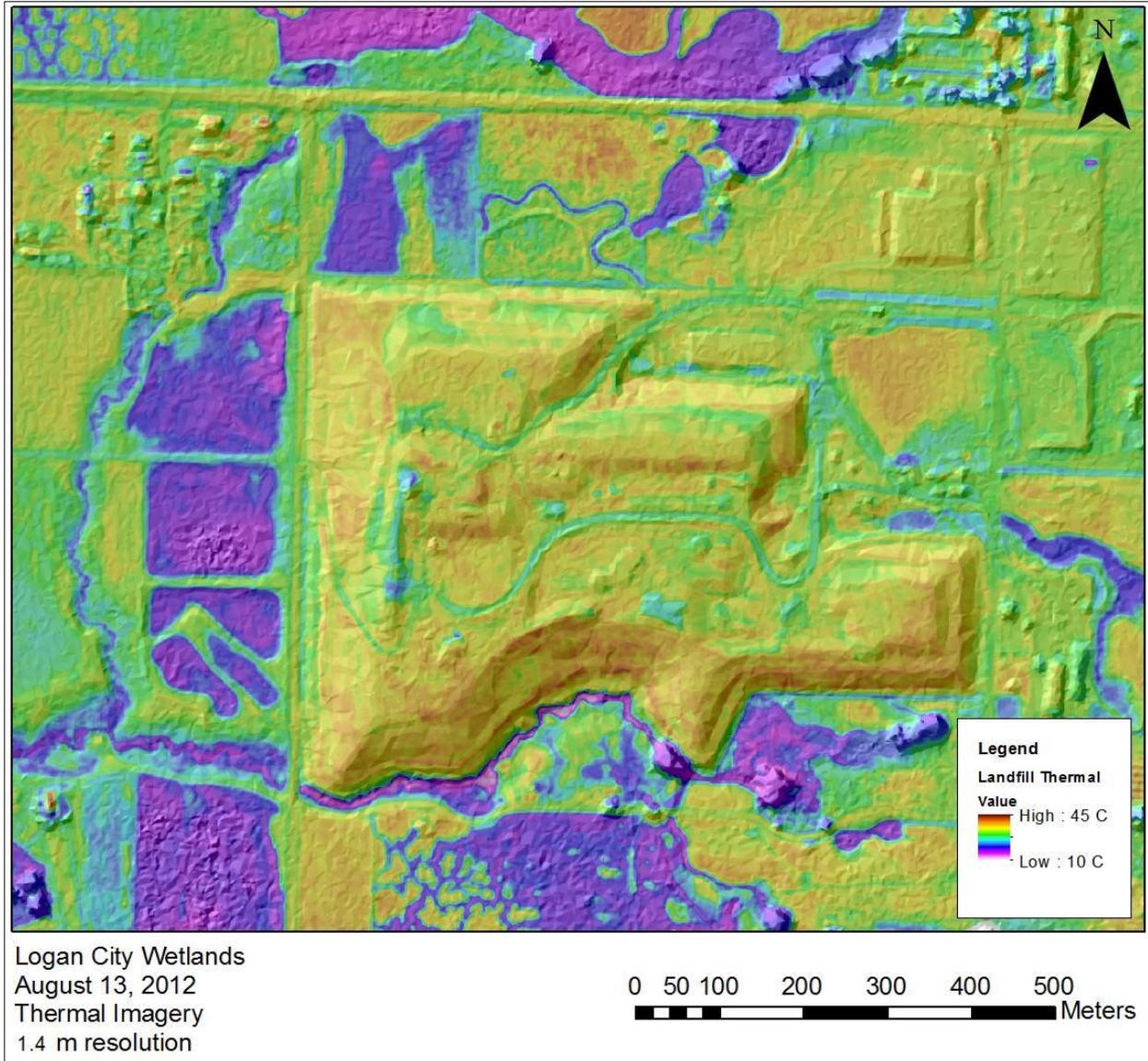


Figure 16. Temperature (Celsius) of Logan City Wetland using AggieAir imagery and Agisoft PhotoScan Professional with ArcGIS generated hillshade overlaid on DEM.

Conclusions

This project investigated the use of AggieAir toward municipal water and environmental management problems. For wetland mitigation applications, multi-spectral imagery for nine square miles of a wetland area was mapped and classified for different types of wetland vegetation. Aerial imagery of the Logan River was captured and could be used to assist city workers to identify where to find debris in the river so that it can be removed before spring runoff. Imagery was also captured over the Logan River City Golf Course. The thermal imagery was successful at showing areas of the course which were abnormally hot and could be related to water stress. A map like this could help groundskeepers water the grass more efficiently. Finally,

a detailed, high-resolution digital terrain map (DTM) of the Logan City Landfill was created. Along with the thermal image, city officials could use this data to look for seeps, leaks, erosion, and check Landfill volume. Future work includes showing this data to city officials to verify its usability and cost-effectiveness.

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Quantification of Water Quality Improvements Through the 900 S Oxbow Restoration and Stormwater BMP Renovation Project

Basic Information

Title:	Quantification of Water Quality Improvements Through the 900 S Oxbow Restoration and Stormwater BMP Renovation Project
Project Number:	2013UT189B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	UT2
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Treatment, Wetlands
Descriptors:	None
Principal Investigators:	R. Ryan Dupont

Publications

There are no publications.

Quantification of Water Quality Improvements through the 900 S Oxbow Restoration and Stormwater BMP Renovation Project

R. Ryan Dupont
(2013UT189B)

Problem Description

The 900 South Oxbow Restoration and the 900 South Stormwater Channel Renovation projects (Figure 1) are being carried out by the Salt Lake City Parks and Public Lands and Public Works Departments in connection to the Red Butte Creek oil release that occurred in June 2010, and in response to the Jordan River Total Maximum Daily Load study being conducted by the Utah Department of Environmental Quality’s Division of Water Quality (DWQ). The research presented in this report was conducted to determine the effectiveness of these two projects in removing pollutants and improving water quality of discharges into the Jordan River.



Figure 1. Location of 900 South Oxbow Restoration project and 900 South Filtration Wetland Stormwater BMP project. (Salt Lake City Department of Public Utilities, 2012)

900 South Stormwater Channel

The 900 South Stormwater Channel is one of two discharge points for water from Red Butte Creek and was therefore included in mitigation efforts associated with the 2010 Chevron oil release settlement. The purpose of the renovation is to improve the quality of discharges to the Jordan River from its tributaries and a portion of Salt Lake City stormwater runoff through improvements to riparian vegetation within the channel, and through increasing hydraulic retention time and improving wetland treatment within the channel. Prior to channel renovation, waters in the channel were visually polluted and the banks were overgrown with non-wetland type vegetation. Figure 2 illustrates the condition of the channel prior to the start of the renovation project.



Figure 2. Overgrowth of stormwater channel banks and straightness of channel prior to start of channel renovation project.

900 South Oxbow

The 900 South Oxbow Restoration project was initiated to improve dissolved oxygen levels in the Jordan River. Low dissolved oxygen is the cause of water quality impairment in the Lower Jordan River, and this project is underway to use a natural oxbow in the river to create a wetland treatment area for the removal of oxygen depleting organics and reaeration of river water in this oxygen impaired section of the Jordan River.

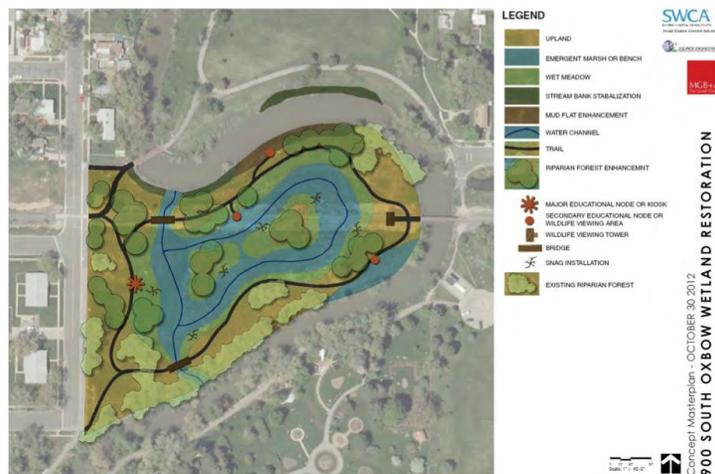


Figure 3. Conceptual master plan of the 900 South Oxbow Restoration project showing wetland feature inlet and outlet locations. (Salt Lake City Parks and Public Lands Division, 2012)

Research Objectives

In the proposal initially submitted for this research the following objectives were listed:

1. To determine the baseline loadings of various pollutants associated with the 900 South Oxbow and existing stormwater canal and assess the relative contribution of these pollutant sources to water quality impacts to the Jordan River.
2. To determine the reduction in pollutant loadings associated with the restoration of the 900 South Oxbow site and renovation of the 9th South stormwater BMP area over the study period.
3. To evaluate the long-term pollutant reduction potential of these areas by quantifying pollutant distribution throughout this sites between site soils and vegetation, and potential pollutant removal possible through above ground biomass harvesting.

Because of delays in the implementation of both the stormwater channel renovation and the 900 South Oxbow restoration projects (Figures 4 and 5) due to funding delays by Salt Lake City, measurement of the performance of the completed wetland systems (Objective 2) and pollutant uptake by wetland vegetation (Objective 3) was not possible during the performance period of this project. Baseline loading data from the 9th South stormwater collection system discharge and treatment channel were possible (Objective 1), as was the change in pollutant concentration across the treatment channel prior to renovation (Objective 2), and these preliminary loading and performance results, along with revised objectives and research findings are discussed below.



Figure 4. Treatment channel at end of research looking upstream (east).



Figure 5. Treatment channel observation platform at end of research.

Due to the delays in construction schedules for the 900 South oxbow and stormwater channel renovations, the research focus shifted to improving the understanding of the dissolved oxygen depletion in the Jordan River. Sampling at the 9th South stormwater channel, as well as sampling at another, more conventional piped discharge location at 13th South in Salt Lake City, indicated that there are large amounts of coarse particulate organic material (CPOM) being captured and stored in the water column at these outlets, and that these solids decompose and generate significant pulses of dissolved organic carbon that enter the Jordan River during rain events. Based on these observations, sampling and laboratory studies were carried out to determine the impact of this CPOM and the generation of dissolved organic material loading on the oxygen demand and subsequent oxygen depletion within the lower Jordan River.

Methodology

Sampling

Water and solids samples used for this study were collected from five sites in the Jordan River watershed (Figure 6). Sites 1 and 2 were at two outfall locations for the Salt Lake City storm drain system into the Jordan River. Sites 3 and 4 were at Liberty Lake and Parley's Canyon Creek, respectively. Solids samples were collected from throughout Site 5 based on revised objectives discussed below.

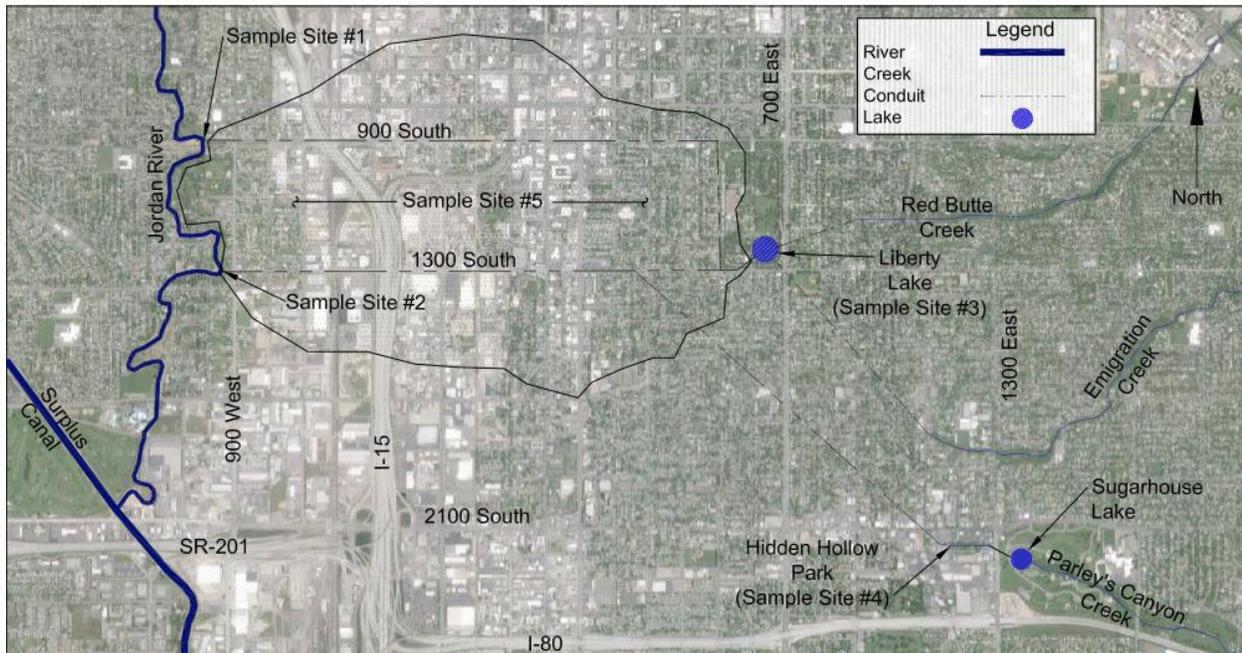


Figure 6. Sampling locations for water and solids samples collected and analyzed in this study.

These locations were selected to bracket the portion of the watershed that is believed to contribute the highest level of stormwater pollutants to the lower Jordan River near the 9th South

Oxbow area. Samples from Sites 1 to 4 were analyzed for total suspended solids (TSS), volatile suspended solids (VSS), total dissolved nitrogen (TDN), and DOC.

Water samples were collected as grab samples using 1 L plastic bottles attached to a pole with the sample being retrieved from approximately 1 foot below the water surface when possible. The water was distributed into containers as described in Table 1. As each of the sample containers was filled, a label was attached to the container indicating location, date, time, sampler name, preservation method, and bottle type. Sample containers were kept in a cooler while they were transported, and a completed chain of custody form accompanied the samples. Samples were analyzed at the Utah Water Research Laboratory Water Quality Lab in Logan, Utah. Once at the testing laboratory, a laboratory log number and log-in date were added to the sample label, and the samples were placed in cold storage at 4°C until they were analyzed. The holding time for each of the samples is also indicated in Table 1. The frequency of sampling events was dependent upon precipitation in the contributing watershed. Samples were taken during dry days as well as rainy days to quantify base loads versus storm-generated pollutant loading to the Jordan River (Objective 1).

Table 1 - Summary of Water Sampling Containers, Preservatives, and Corresponding Holding

Analyte	Container Type	Volume	Preservation	# of Replicates	Holding Time (days)
COD	Plastic Bottle	100 mL	Store at 4°C	1	28
DOC	Amber Glass Vial	40 mL	Phosphoric Acid - H ₃ PO ₄	3	28
TSS/VSS	Plastic Bottle	100 mL	Store at 4°C	1	2
TDN	Plastic Bottle	100 mL	Sulfuric Acid - H ₂ SO ₄	1	28
BOD	Glass Jar	250 mL	Store at 4°C	1	2

Organic solids (CPOM) samples for the DOC/TDN leaching and BOD tests were collected from within Site 5 so that a more complete view of the decomposition process, and its impact on stormwater and stream water quality could be obtained, than if samples were collected from the storm drain or river. Organic solids samples were collected in 1-gallon plastic bags and stored at 4°C until testing was conducted. Approximately 5 to 10 grams each of leaves, wood, seeds and grass were collected from plants, trees, and yards within Site 5. Samples were collected at the beginning of the Fall of 2013. Figure 7 illustrates the experiments and measurements that were conducted on the samples to document the impact of CPOM leaching on the generation of DOC and oxygen demand over time.

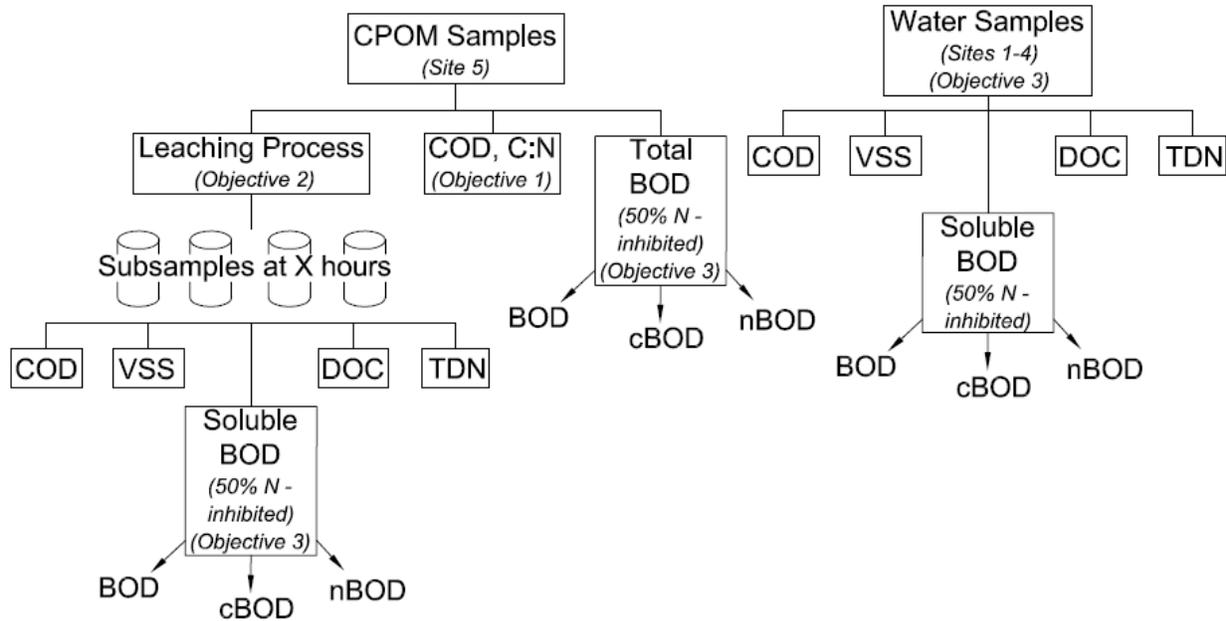


Figure 7. Diagram of experimental analysis of samples for determining baseline loading and potential CPOM leaching impacts on water quality in the lower Jordan River.

DOC/TDN Leaching and Analysis (Revised Objective)

Known masses (1-3 g) of solids from the fresh unmodified plant and wood samples were added to 750-mL of deionized water in 1 L bottles. The bottles were kept at 20°C on a mixing platform for 48 hours. At time periods of 1, 3, 6, 10, and 24 hours, a 125 mL subsample was retrieved from each bottle. The subsample was filtered through a 1 mm filter to capture any suspended CPOM particles. The captured material was rinsed from the filter back into the 1 L bottle with approximately 125 mL deionized water. The volume of water in the 1 L bottle was returned to 750 mL after each subsample was retrieved. A 25 mL volume was separated out from each subsample and stored at 4°C for BOD testing. The remaining volume of the subsamples were vacuum filtered using Whatman GF/C 1.3 µm glass microfiber filters to remove suspended particles. A standard TSS test was run using the subsample filters to track mass-loss during the course of the experiment. A standard VSS test was conducted using the filters from the TSS test. In three amber glass vials approximately 20 mL of the subsample filtrate were placed for DOC analysis, and were preserved with phosphoric acid and stored at 4°C until analyzed. In a 50 mL plastic snap cap, approximately 20 mL of the subsample filtrate was sampled for TDN analysis, and was preserved with sulfuric acid and stored at 4°C until analyzed. DOC analysis was completed using a Teledyne Tekmar Apollo 9000 Combustion TOC Analyzer. Analysis of TDN was done using a Seal Analytical AQ2 Automated Discrete Analyzer (Serial # 090749). The TDN samples were digested prior to analysis in order to measure TDN.

Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) analyses were conducted in general accordance with the procedures found in Standard Methods for Examination of Water and Wastewater: 5210 Biological Oxygen Demand (BOD) #1 (APHA, 1999), and in The Amplified Long-Term BOD Test published by the Georgia Environmental Protection Division (GEPD, 1989). The Standard Method BOD test (BOD₅) provides specific laboratory procedures for determining the 5-day BOD for a sample. The GEPD method (BODLT) provides laboratory procedures and test specifications for analyzing samples for longer periods.

A sample from each CPOM classification and the 25 mL subsamples from the DOC/TN leaching test was placed in 300-mL bottles, and diluted sufficiently to maintain at least 3.0 mg/L of DO in any test bottle; and reaerations should not exceed one in every 10 days (on the average). Dilution preparation followed the procedures found in Section 2.1.2 of BODLT (GEPD, 1989). Bottles were placed in an incubator at 20°C in the dark, and DO measurements are taken for each sample classification and DOC subsample and recorded every day until the change in DO was less than 0.1 mg/L/day or at 40 days, whichever occurred first. In the event that the DO levels in the sample drop below 3.0 mg/L during the test, reaeration was performed in accordance with Section 2.5.5 of BODLT (GEPD, 1989). By convention, the 20-day BOD is considered the ultimate BOD (BOD_u).

Principal Findings and Significance

Baseline Loadings from Discharges to the Jordan River (Original Objective 1)

Dry weather DOC and VSS concentrations and estimated loading rates for samples collected from throughout the study area as summarized in Figures 8 and 9, respectively.

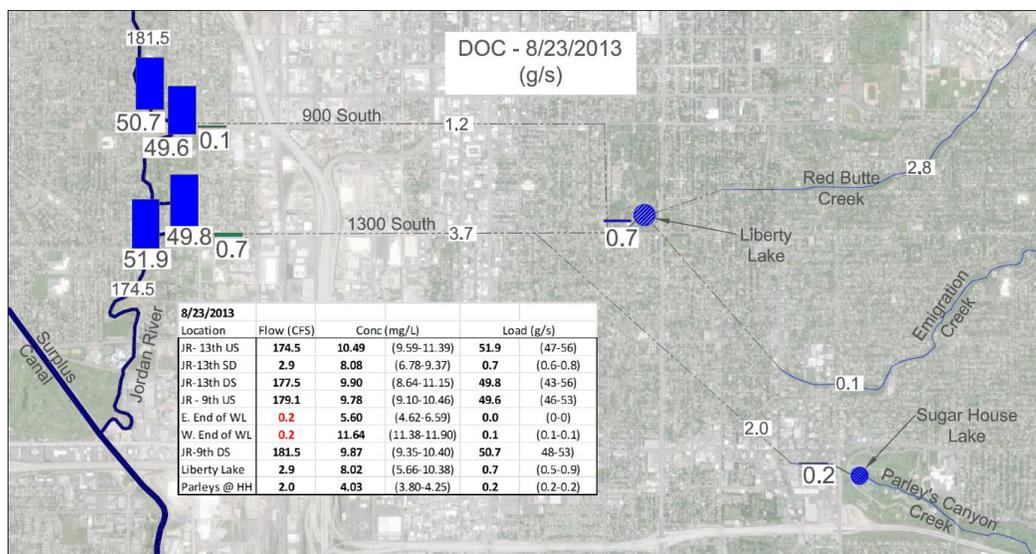


Figure 8. Dry weather DOC concentrations and estimated loading rates at locations from throughout the Jordan River study area, 8/23/2013.

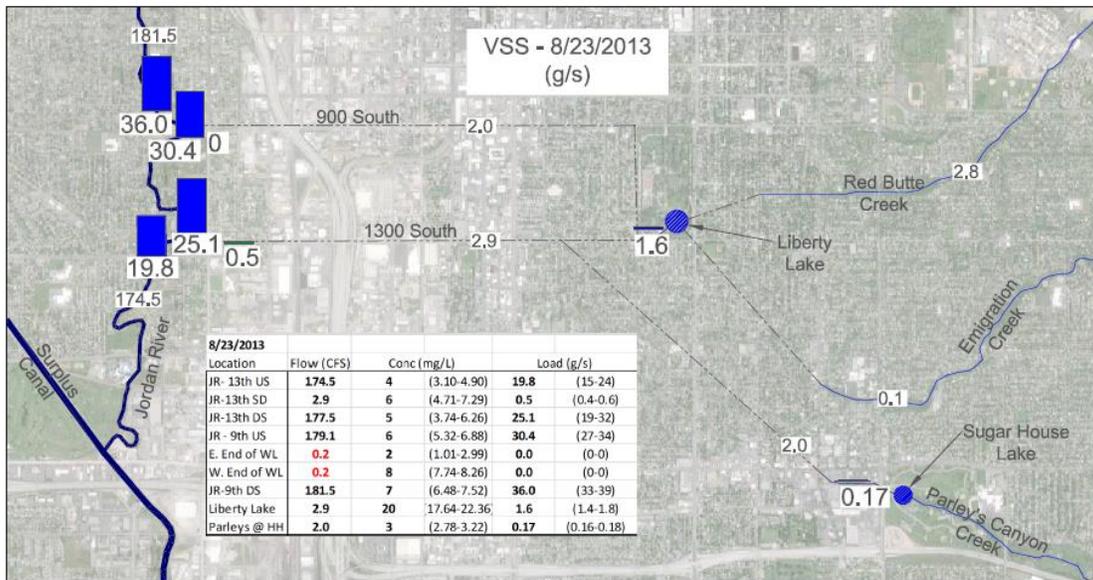


Figure 9. Dry weather VSS concentrations and estimated loading rates at locations from throughout the Jordan River study area, 8/23/2013.

As indicated from these figures, stormwater discharge contributions of DOC and VSS to the lower Jordan River during dry weather conditions are small (2%) compared to Jordan River loading upstream of these stormwater discharge locations. During rainfall events, however, stormwater discharge represents significant loadings of both DOC and VSS to the Jordan River (>40%) as indicated in Figures 10 and 11.

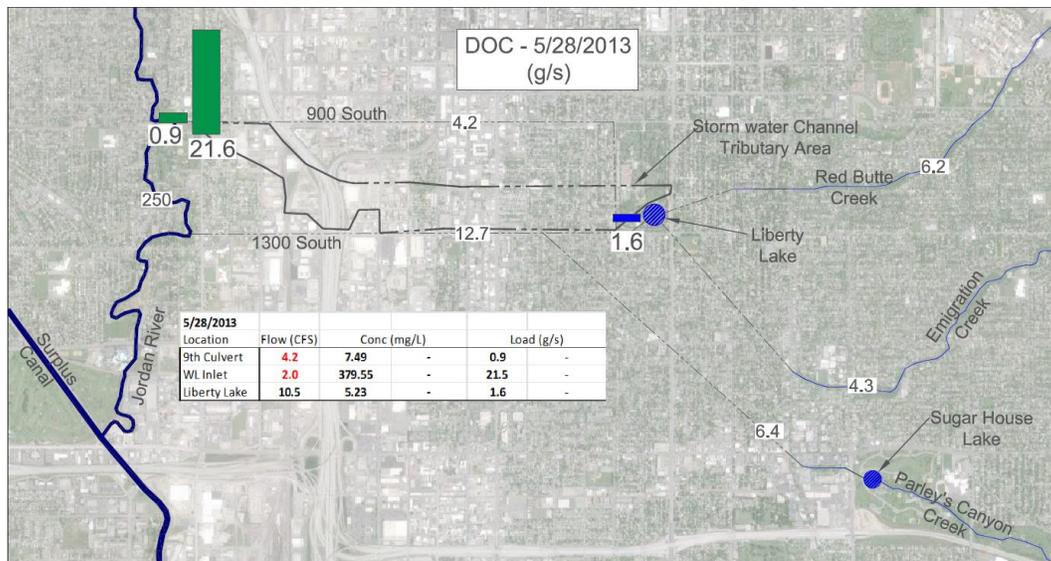


Figure 10. Wet weather DOC concentrations and estimated loading rates at locations from throughout the Jordan River study area, 5/28/2013.

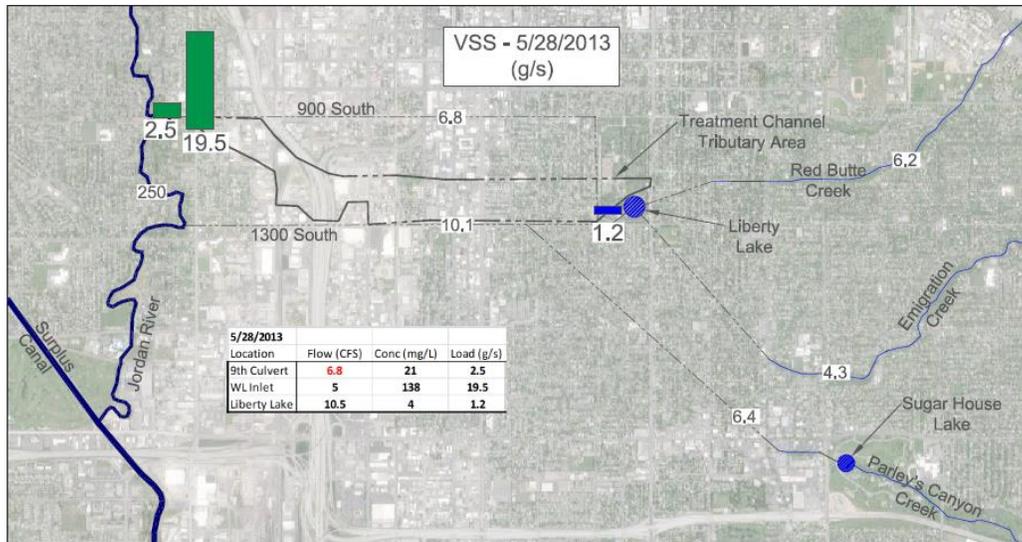


Figure 11. Wet weather VSS concentrations and estimated loading rates at locations from throughout the Jordan River study area, 5/28/2013.

Pre-construction rain event samplings at the upstream and downstream ends of the stormwater channel produced the following results for removal efficiency within the channel.

These results suggest stormwater from the drainage area between Liberty Lake and the Jordan River is a significant contributor to pollutant loading to the Jordan, and that management of pollutant discharge within the drainage area is essential to protect the Jordan River from episodic loadings of high carbon, oxygen depleting materials in the stormwater runoff.

Reduction in Pollutant Loadings through the 9th South Stormwater Channel (Original Objective 2)

Sampling of water was conducted at the upstream and downstream ends of the 9th South stormwater channel as well as upstream and downstream of its outlet into the Jordan River during dry periods and rain events. These samples were analyzed for total and volatile suspended solids, available metals, nutrients (N and P), and dissolved organic carbon. A summary of the results of these analyses are shown in Table 2 and indicate that the channel is contributing both DOC and VSS to the Jordan River during rain events. This is likely caused by resuspension of particles and release of dissolved organics during higher flows through the channel prior to its renovation as a functioning wetland treatment channel. Also, the large variation in VSS removal is due to significant variation in the VSS concentrations during the storm due to significant scouring of the unimproved stormwater channel during the first flush period of the runoff event. The release of copper from the stormwater channel may be attributed to the high amount of metal debris and trash that had accumulated in the channel between storm events. A removal efficiency of 8% and 13% of zinc and lead, respectively, and a 16% removal of Total N indicates that there was some marginal amount of metal and nutrient uptake into either sediments or plant material within the channel prior to its renovation.

Table 2. Pollutant removal within the 9th South stormwater channel during a rain events (5/20/13 and 9/13/13) prior to renovation.

Analyte	Average Percent Removal
DOC	-11%
Total Nitrogen	16%
VSS†	-897% ± 1605%
Copper	-21%
Zinc	8%
Lead	13%

† Three replicates available for VSS analysis. All other results represent a mean of duplicate samples.

Coarse Particulate Organic Material Study (Revised Objective)

Because of elevated levels of DOC observed in discharge from the 9th South stormwater channel during runoff events (Figure 10), the leaching of dissolved organic material and subsequent oxygen demand from CPOM carried with stormwater runoff became a primary objective of this study. The results of the laboratory leaching tests indicate a significant loading of BOD generated from coarse particulate organic matter in this stormwater within a time frame relevant to the transport of this material within the storm sewer system from the drainage area to the Jordan River in the range of 1 to 3 hours (Figure 12). The same pattern is seen with the generation of VSS, DOC, COD, and TDN (Figures 13, 14, 15 and 16). The units used in these figures, mg/g solids/hour, represent the mass flux of pollutant per unit mass of solid, calculated from the result of the analysis in mg/L, divided by the starting mass of solids placed in the leaching reactor at time 0, divided by the number of hours the water was in the leaching reactor when the sample was collected for analysis.

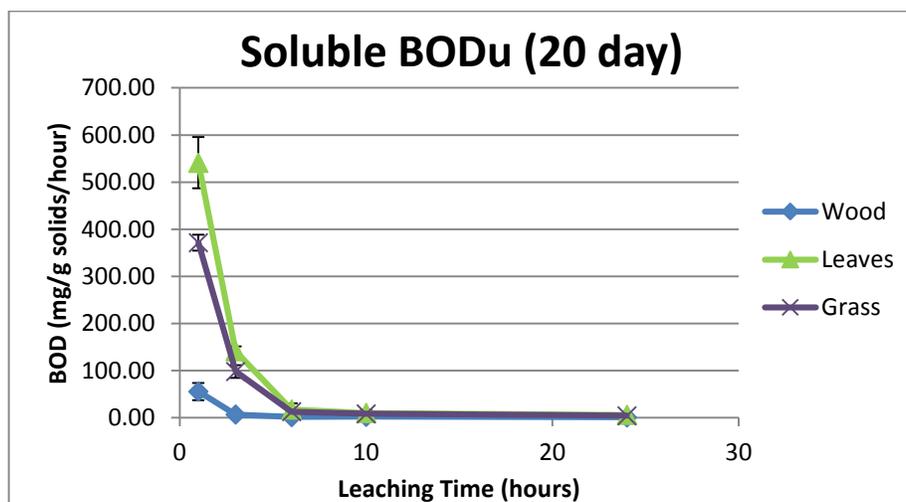


Figure 12. Ultimate soluble BOD generation during the laboratory leaching tests.

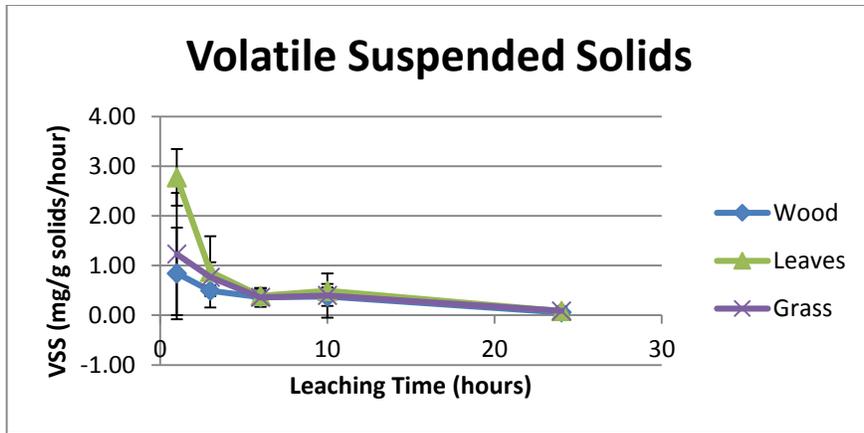


Figure 13. VSS generation during the laboratory leaching tests.

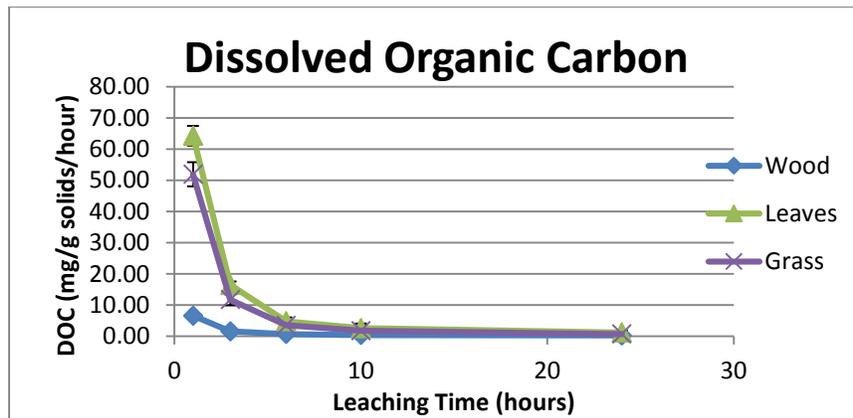


Figure 14. DOC generation during the laboratory leaching tests.

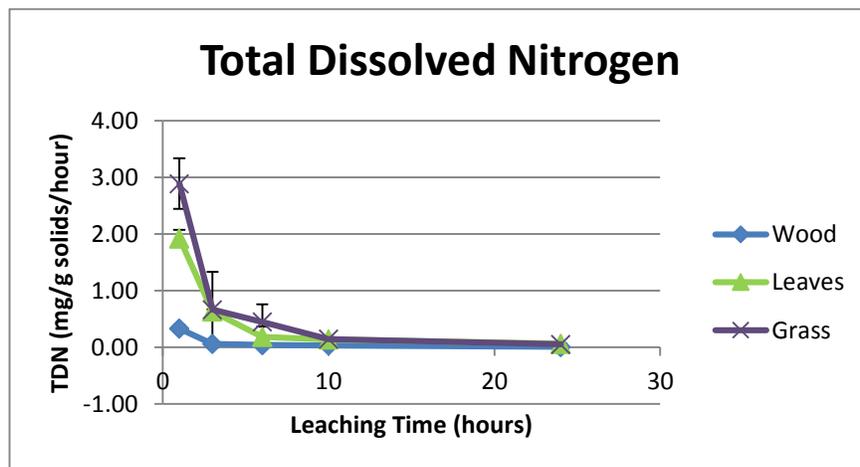


Figure 15. Total dissolved nitrogen generation during the laboratory leaching tests.

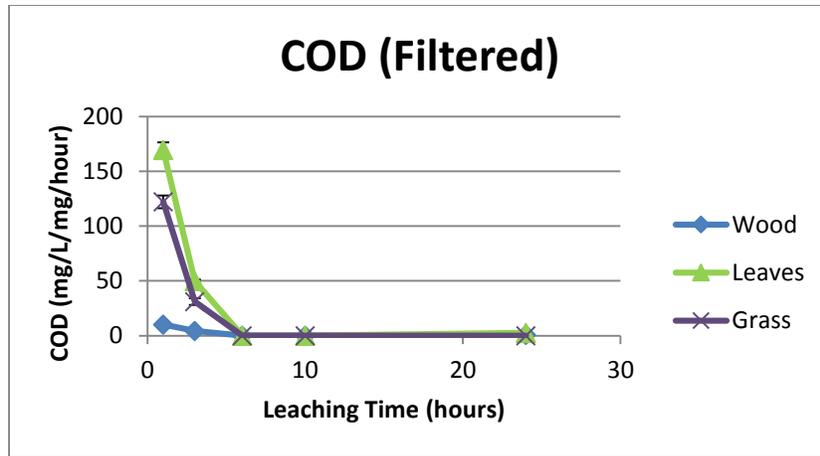


Figure 16. COD generated generation during the laboratory leaching tests.

Regression analysis of the relationship of BOD to DOC and BOD to COD resulted in R^2 values above 0.99 (Figures 17 and 18), suggesting a relatively constant relationship between these various measures of organic content over time regardless of the starting organic material. In addition, it appears that COD and/or DOC are good indicators of the biodegradability and subsequent oxygen requirement of organics leached from the materials in the stormwater drainage study area used in this research as measured in the long-term BOD test

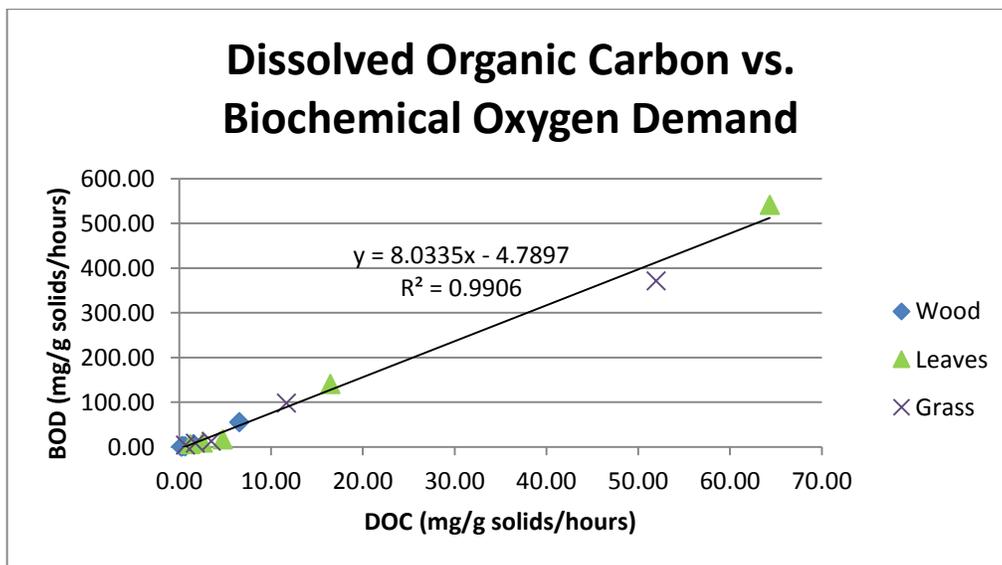


Figure 17. Relationship of DOC to BOD mass flux rates for the organic solids collected from the study area.

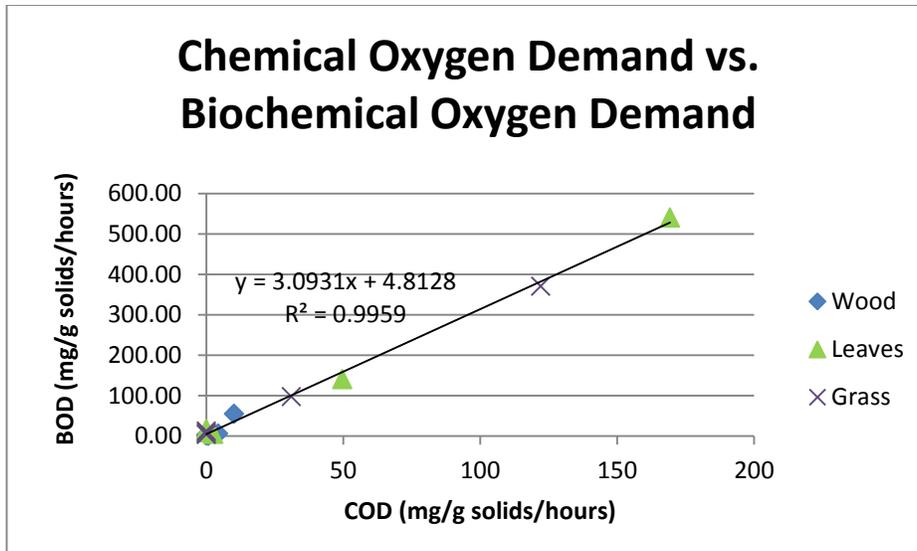


Figure 18. Relationship plot of COD to BOD mass flux rates for the organic solids collected from the study area.

The time course of the BOD/DOC and the BOD/COD ratios was also evaluated as a function of the starting materials, and as shown in Figures 19 and 20, these ratios did change over time and in slightly different patterns depending on the starting material. Both ratios were consistently found to be at a minimum value at 6 hours for all materials tested, (Figures 19 and 20). The most biologically active material leaches from the solids within 1 hour of contact with water, but the organic compounds leaching between 3 and 6 hours are less biodegradable than materials leaching both before and after this period. However, the biodegradability of the leached organics continues to increase overtime after the minimum point with more contact with the leaching solution.

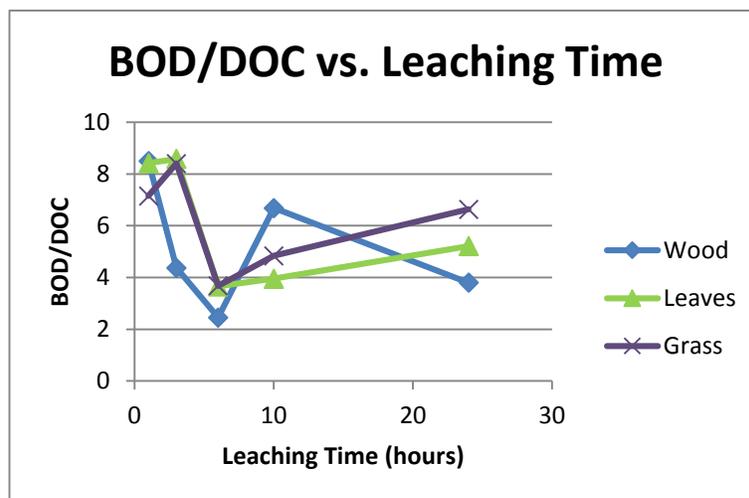


Figure 19. Time course of the BOD/DOC ratio as a function of starting material evaluated in the study.

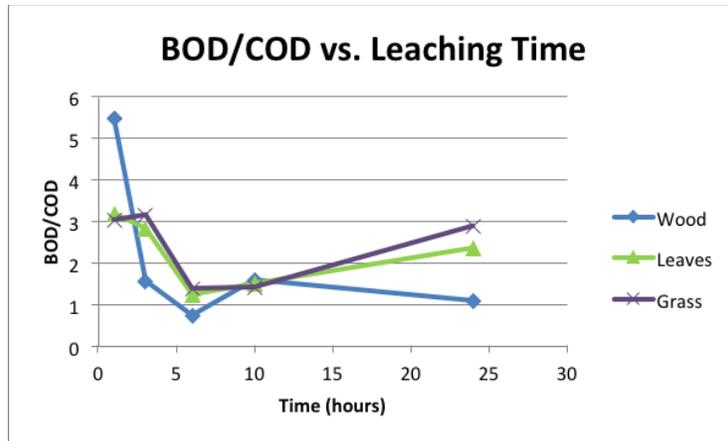


Figure 20. Time course of the BOD/COD ratio as a function of starting material evaluated in the study.

Significance

These results support the conclusion that the CPOM-derived dissolved organic material has a potentially significant impact on the dissolved oxygen levels in the Jordan River. The time period within which the highest levels of BOD/unit solids are generated is 1 to 3 hours after entering the stormwater collection system and coming into contact with storm runoff, approximately the flow time from Liberty Lake to the discharge points on the Jordan River. Once the CPOM (leaves, grass, wood) enters the storm drain system, it is captured within debris retention basins and may be retained there for weeks to months, depending on the maintenance schedule. These results indicate that the production of biologically active organic material from collected stormwater is rapid and complete within a 6 to 10 hour period, and if the CPOM and its associated leachate-derived, biodegradable dissolved organic material is not prevented from entering the stormwater collection system in the first place, stormwater will continue to be a significant episodic source of BOD load and rapid oxygen depletion in the lower Jordan River. Engineering options for management of this CPOM-derived oxygen demand include: 1) lot scale landscape management techniques to reduce the generation of CPOM; 2) more aggressive citywide street sweeping and green waste collection programs to reduce CPOM load to the storm sewers, or 3) increased decentralization of stormwater management and implementation of green infrastructure designed to increase stormwater treatment within the drainage area and decrease the volume of stormwater runoff centrally collected and transported to the Jordan River.

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Environmental Protection Division. 1989. *The Amplified Long-Term BOD Test, Protocol/Procedure and Test Specifications*. Georgia Department of Natural Resources, Atlanta, Georgia. 38 pp.

Capturing Aerial Imagery on the San Rafael River, Utah, Using an Unmanned Aerial Vehicle (UAV) to Monitor and Assist in Evaluating Restoration Efforts

Basic Information

Title:	Capturing Aerial Imagery on the San Rafael River, Utah, Using an Unmanned Aerial Vehicle (UAV) to Monitor and Assist in Evaluating Restoration Efforts
Project Number:	2013UT190B
Start Date:	3/1/2013
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	UT3
Research Category:	Biological Sciences
Focus Category:	Geomorphological Processes, Acid Deposition, Management and Planning
Descriptors:	
Principal Investigators:	Bethany T. Neilson, Ian Mark Gowing

Publications

There are no publications.

“Capturing Aerial Imagery on the San Rafael River, Utah, Using an Unmanned Aerial Vehicle (UAV) to Monitor and Assist in Evaluating Restoration Efforts”

*Bethany Neilson and Ian Gowing
(2013UT190B)*

Problem and Research Objectives:

The San Rafael River is recognized as being in a severely degraded state and is on the 303D list of degraded waters in the state of Utah. Current river restoration projects are aimed at restoring the river to a more ecologically acceptable state, providing more comprehensive complex habitat to the native fish, encouraging change in channel morphology through removal of Tamarisk, planting more native riparian species along the river corridor, and removing man-made barriers to enhance and encourage fish movement/passage throughout the entire drainage. For this project, an Unmanned Aerial Vehicle (UAV) will be used to provide high resolution, up to date aerial imagery to assist in evaluating restoration schemes that are on-going on the San Rafael River, South Central Utah.

Methodology:

The AggieAir Flying Circus, a service center at the Utah Water Research Water Laboratory will provide high resolution multispectral aerial imagery using a UAV. This work was contracted in 2011 by the Utah Division of Wildlife Resources and includes flying the lower 50 miles of the San Rafael River and providing RGB, NIR, and thermal imagery after a high river flow event. Using these data, the San Rafael Restoration Committee expect to use the resulting high resolution imagery to obtain spatial information regarding thermal refugia and detailed channel information integral for baseline information needed within the San Rafael restoration effort. Temperature sensors will also be positioned within the entire study reach to help calibrate the thermal imagery.

Principal Findings and Significance:

Due to the severe low flow nature of the San Rafael River (< 2 cubic feet per second for several months during the summer 2013), all UAV flights by the AggieAir Flying Circus were postponed until 2014, when it is anticipated the river levels will return to a semi-normal state. In May 2014, the temperature sensors will be installed along the entire 55 river miles of the San Rafael River to assist with calibration of the thermal imagery, which we plan to capture in July/August 2014.

It is expected that the data and analyses provided by the AggieAir Flying Circus will significantly improve the information content of the entire data collection effort for the San

Rafael restoration process and will help to answer significant research questions on the effects of tamarisk control on river morphology. The thermal imagery captured by Aggie Air will support efforts to address the thermal regime within the San Rafael River.

The project will also yield significant research results on the accuracy and limitations of the use of inexpensive UAV platforms to provide data such as digital elevation and terrain models in place of more conventional—and much more expensive—approaches, such as LiDAR.



The San Rafael River, summer 2013 during a period of extreme low flow.

Partners/Collaborators:

State: Dan Keller – Utah Division of Wildlife

State: Paul Birdsey – Utah Division of Wildlife

Federal: Justin Jimenez – Bureau of Land Management

Information Transfer Program Introduction

The individual research projects documented in the Research Project section of this report have information and outreach components integrated within them. These include research findings published in the technical literature and findings and water management models and tools provided on the web pages of the Utah Center for Water Resources Research (UCWRR) and individual water agencies. Beyond this, Information Transfer and Outreach activities through the UCWRR, the Utah Water Research Laboratory (UWRL), and Utah State University (USU) have had an impact on the technical and economic development of the State of Utah. As part of the UCWRR outreach activities supported by USGS 104 funds, there continues to be a vigorous dialogue and experimentation with regard to the efficiency and effectiveness of outreach activities of the UCWRR. Faculty are engaged in regular meetings with State of Utah water resources agencies, including the Department of Environmental Quality (DEQ), the Department of Natural Resources (DNR), the State Engineer's Office, and numerous municipal water supply and irrigation companies to provide assistance in source water protection, on-site training, non-point source pollution management, technology transfer, development of source water protection plans (SWPPs), and efficient management of large water systems within the context of water-related issues in Utah. UCWRR staff, through the facilities at the UWRL, provides short courses both on- and off-site within the State of Utah, regionally, and internationally. Generally offered from one to five days in duration, short courses are tailored to meet the needs of the requestor. The following is a partial list of information transfer and outreach activities, short courses, and field trainings that involve UCWRR staff.

Information Transfer in Support of the Utah Center for Water Resources Research (UCWRR)

Basic Information

Title:	Information Transfer in Support of the Utah Center for Water Resources Research (UCWRR)
Project Number:	2013UT191B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	UT1
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	None
Principal Investigators:	R. Ivonne Harris, Carri Lyn Richards

Publications

1. UCWRR, 2013, The Water bLog, Utah Center for Water Resources Research Newsletter, Vol. 4(1), <http://uwrl.usu.edu/partnerships/ucwrr/newsletter/index.html>
2. UCWRR, 2013, The Water bLog, Utah Center for Water Resources Research Newsletter, Vol. 4(2), <http://uwrl.usu.edu/partnerships/ucwrr/newsletter/index.html>

Information Transfer in Support of the Utah Center for Water Resources Research (UCWRR)

R. Ivonne Harris

Problem

The Water Resources Research Act of 1964 established the Utah Center for Water Resources Research (UCWRR). The Center is housed at Utah State University in Logan, Utah. The general purposes of the UCWRR are to foster interdepartmental research and educational programs in water resources; administer the State Water Research Institute Program funded through the U.S. Geological Survey at Utah State University for the State of Utah; and provide university-wide coordination of water resources research.

Objectives

The center plays a vital role in the dissemination of information. Utah is home to approximately 50,000 miles of rivers and streams and 7,800 lakes. This water is an essential resource for the economic, social, and cultural well-being of the State of Utah. As one of 54 water research centers, the UCWRR works to "*make sure that tomorrow has enough clean water.*"

A major component of the information transfer and outreach requirements of the UCWRR is the development of appropriate vehicles for dissemination of information produced by research projects conducted at the Center. This project provides on-going updates of the UCWRR web page, with information transfer specifically identified as the key objective. This project is in the process of disseminating semi-annual newsletters for the Utah Center that feature research projects and their findings, water-related activities in the state, and on-going work by researchers affiliated with the Center.

Methods

Web Pages

A vital objective in the dissemination of information for the UCWRR was the development of an up-to-date web page. The UCWRR web pages have been developed to make information available, thus creating a tool wherein interested parties can find solutions to water problems. The design of the web pages is developed with Adobe "Dreamweaver" software and CSS. Pictures are taken from the various on-going projects and added to the web pages. The address for the UCWRR is <http://uwrl.usu.edu/partnerships/ucwrr/>. Figures 1 and 2 are pictures of two of the pages. The web pages are works-in-progress and the pages are periodically updated.

1. The "Homepage" explains the center's purpose.
2. The "About Us" gives an overview of the center and its affiliations.

3. The “People” page gives an overview of the governing body of the center as well as key contact staff.
4. The “Research and Publications” page guides you to the various projects and reports. This page is updated periodically.
5. “The Water bLog” page provides access to current and past issues of the Center’s newsletter (described in the next section).
6. The “Contact” page has the center’s address and mode of contact.

UtahState University USU home A-Z Index calendars myUSU contact people/web search

- Home
- About Us
- People
- Research & Publications
- Newsletter
- Contact Us

UCWRR

Utah Center for Water Resources Research

"Linking watershed science to the people of Utah"

Welcome to the Utah Center for Water Resources Research (UCWRR). Utah is home to approximately 50,000 miles of rivers and streams and 7,800 lakes. This water is an essential resource for the economic, social, and cultural well-being of the State of Utah. As one of 54 water research centers, the UCWRR works to "make sure that tomorrow has enough clean water".

The center promotes and coordinates the development of research and instructional programs that will further the training of water resource scientists and engineers

1600 Canyon Road, Logan, UT 84321 -- (435) 797-3155
January 30, 2014

Figure 1. Home page for the UCWRR.



UCWRR

Utah Center for Water Resources Research



- Home
- About Us
- People
- Research & Publications
- Newsletter
- Contact Us

Research and Publications

- 2013 UCWRR Summary
- 2011 UCWRR Summary
- 2010 UCWRR Summary
- 2009 UCWRR Summary
- 2008 UCWRR Summary

Research Reports

- Drinking Water and Wastewater Treatment
- Environmental Quality Management and Remediation
- Surface and Groundwater Quality and Quantity
- Water Conveyance, Distribution, and Control
- Water Education and Technology Transfer
- Water Resources Planning and Management

Other Research

- Water Quality Management
- Air Quality Analysis
- International Water Development and Outreach
- Hill Air Force Base
- Hydraulics Testing
- Physical Modeling of Dams
- Bioremediation
- Water Quality Monitoring
- Wastewater Treatment
- Great Salt Lake Basin
- Water Resources Planning and Management
- Outreach/Education
- Institute for Natural Systems Engineering
- Air Quality Analysis
- Virgin River Basin-Wide Habitat Assessment
- Environmental Management Research Group
- Hydraulics Laboratory Research
- Surface Water Hydrology
- Hazardous and Toxic Waste Remediation
- Public Lands Planning and Management
- Utah On-Site Wastewater Treatment Training Program
- Water Quality Engineering
- Water Resources Planning and Management



The center promotes and coordinates the development of research and instructional programs that will further the training of water resource scientists and engineers



Figure 2. Research and Publications page for the UCWRR.

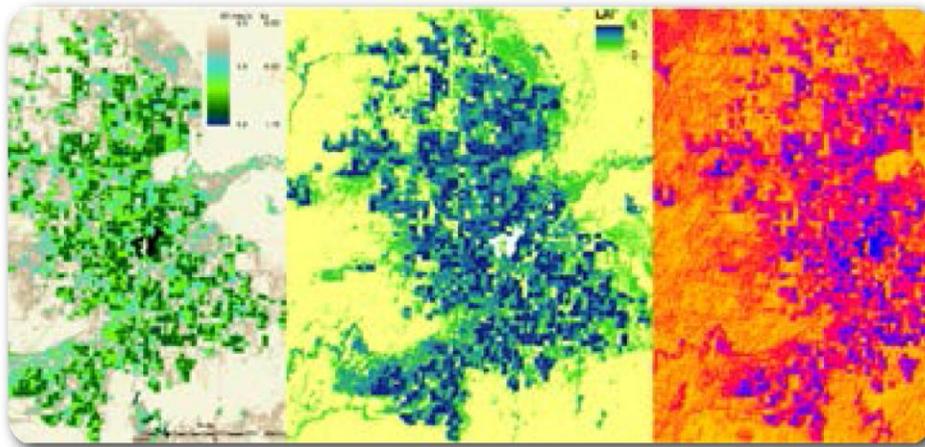
Newsletter

A semi-annual newsletter *The Water bLog* continues to be published. *The Water bLog* is disseminated electronically at the UCWRR web site at

<http://uwrl.usu.edu/partnerships/ucwrr/newsletter/index.html>

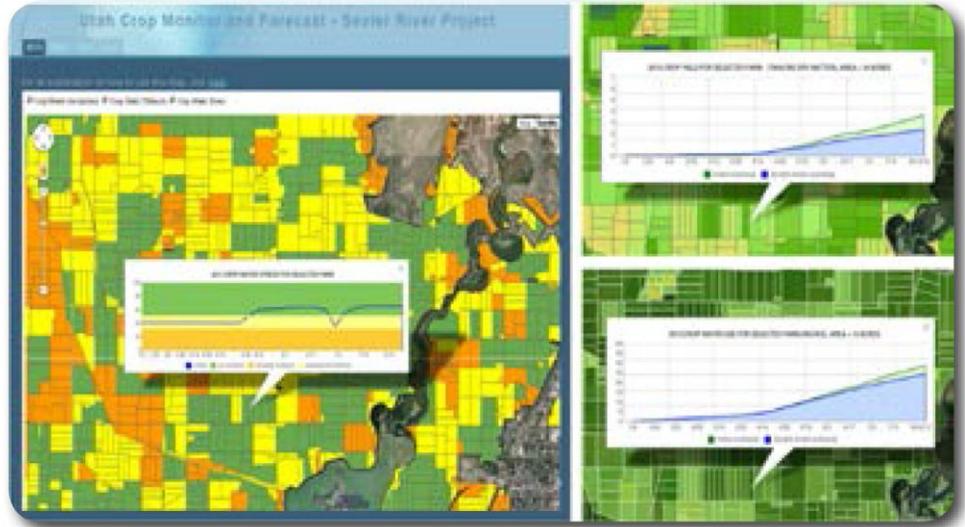
and through e-mail. The newsletter is e-mailed to approximately 350 readers. The main purpose of the newsletter is to highlight research projects and their findings. These will be of great interest and value to the State of Utah, as well as nationally and internationally.

A recent copy of the newsletter was sent out December 2013 and a new one will go out in May 2014. One of the research projects featured in the December 2013 newsletter was “Irrigation Management Looks into the Future.” Farmers and managers need access to timely information about current water needs and crop conditions—or better yet, the ability to see into the future—to accurately predict irrigation timing and needs and manage irrigation water delivery more precisely, while improving crop productivity. Dr. Alfonso Torres-Rua and other UCWRR researchers have developed a new decision support system platform, called the Crop-Water Monitoring and Information System (CWMIS). The CWMIS integrates state-of-the-art monitoring and forecasting algorithms (based on readily available Landsat Satellite Mission data) to provide irrigated and non-irrigated agriculture with current and short-term (8 and 16 days in advance) forecasting information about crop water use and crop growing conditions at the pixel level (15 m) and aggregated to farm and irrigation system levels.



CWMIS uses pixel-based estimations of evapotranspiration (mm/d) (left), Leaf Area Index (center), and surface temperature (right) to provide individual-farm-level actionable information.

CWMIS layer maps of the Lower Sevier River Basin displaying (1) current and past crop water stress (left), (2) accumulated dry crop biomass in TM/acre (upper right) and, (3) accumulated crop water use in inches (lower right) .



Another research project featured in the November 2012 Newsletter was “Addressing Adverse Water Quality Episodes in Park City, Utah” where Park City, Utah has experienced some troubling water quality episodes in the past several years. UCWRR researchers are looking into the causes of these events and seeking ways to maintain a consistent high-quality drinking water supply.

Park City, Utah, is famous for its ski resorts and for hosting the Sundance Film Festival. It was named “The Best Town in America” by *Outside* magazine in 2013. However, Park City is also becoming infamous for its drinking water quality. In 2007 and 2010, Park City experienced water quality episodes that featured discolored water with high levels of arsenic, thallium, manganese, iron, and mercury in the water distribution system.

The city has an incredibly complex water system that features a variety of water sources (including groundwater, surface water, and water passing through old mine tunnels), several treatment plants, unique water demand patterns, and a complicated water distribution system with more than 50 pressure zones. This project will help Park City manage its complex water system to provide high quality water to citizens and visitors.



An array of water samples collected during an ice-pigging cleaning trial.



Foam swabs before and after passing through pipes.

In the past year our UCWRR faculty members and researchers have traveled around the globe conducting and presenting their research and enhancing and sharing their extensive water resources expertise.



Dr. William Doucette lectures at a week-long PhD summer course in Lyngby, Denmark

Dr. William J. Doucette, a UCWRR faculty member well known for his research into the uptake of chemicals into plants, was recently invited to lecture at the Technical University of Denmark, Department of Environmental\Engineering, for a week-long PhD summer course, “Modeling of Plant Uptake and Application to Environmental Science and Engineering,” organized by Dr. Stefan Trapp. Students from Denmark, Israel, Germany, Ireland, the UK, Norway, Sweden, France, China, Turkey, the Czech Republic, Switzerland and the US were in attendance.

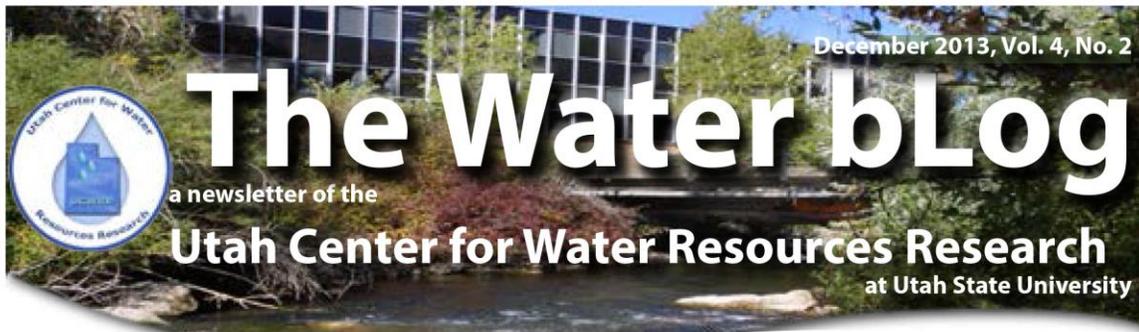
Figure 3 shows the first page of *The Water blog’s* December 2013 issue. For an electronic copy of current or past newsletters, please go to:

<http://uwrl.usu.edu/partnerships/ucwrr/newsletter/>.

Dr. William Doucette lectures at a week-long PhD summer course in Lyngby, Denmark

Data Base

Another concern the UCWRR has is making available electronic copies of research projects and reports. These are being converted to PDF format and have been added to a database to make them available on-line. This is a work in progress and some of the publications can be found in our website at <http://uwrl.usu.edu/publications>.



Welcome!

The Water bLog is the semi-annual newsletter of the Utah Center for Water Resources Research (UCWRR), housed at the Utah Water Research Laboratory. The center supports the development of applied research related to water resources problems in Utah and promotes instructional programs that will further the training of water resource scientists and engineers. Each issue of **The Water bLog** reports on a small selection of the current or recently completed research projects conducted at the center. More information is available online at:

<http://uwrl.usu.edu/partnerships/ucwrr>

Message from the Director



Mac McKee, Director

Water is a critical resource for many aspects of our society—from agriculture to industry, and from communities to countries. Access to a reliable and safe water supply is essential to our wellbeing. Here at the Utah Center for Water Resources Research, we are developing new ways to monitor water use and forecast future water demands in order to provide better information for efficient water management. Many of these solutions can be applied to other locations throughout the state and beyond.

This edition of the **Water bLog** highlights two current projects that exemplify the broad range of research ongoing at the UCWRR. The first project is giving farmers and water managers timely information about soil and crop conditions, up to 16 days in the future, allowing more efficient use of irrigation water, while maintaining crop productivity. The second project is assessing the causes of water quality challenges in Park City, Utah, and developing methods to preserve a high quality drinking water supply for its citizens. These projects represent only a small portion of the active research ongoing at the UCWRR that is finding practical solutions to natural resources challenges throughout the state. ■

INSIDE:

Research Highlight:

- ▶ Irrigation Management Looks into the Future
- ▶ Addressing Adverse Water Quality Episodes in Park City, Utah

In the News

- ◆ Student scholarship Awards
- ◆ Faculty NSF Award

Far Afield

UtahStateUniversity



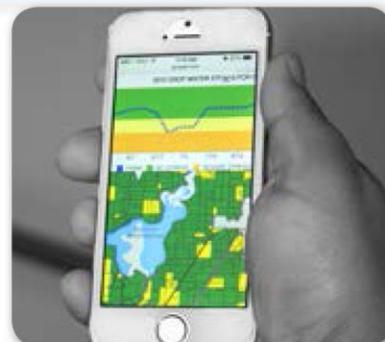
RESEARCH HIGHLIGHT

Irrigation Management Looks into the Future

Researchers at the UCWRR have developed a new Crop-Water Monitoring and Information System (CWMIS) that can give farmers and water managers a glimpse to current and into the future—up to 16 days into the future, to be precise.

The past century has seen many innovations in agriculture that have improved water policy, management, distribution, and monitoring, but irrigation water delivery and on-farm management are often still based on factors such as water rights allocation, tradition, and past irrigation experience—factors not necessarily related to actual crop water use.

Farmers and managers need access to timely information about current water needs and crop conditions—or better yet, the ability to see into the future—



The CWMIS is available on the internet

The Water bLog December 2013, Vol. 4, No. 2

Figure 3. The Water bLog, the Newsletter for the UCWRR

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	3	0	0	0	3
Masters	1	0	0	0	1
Ph.D.	0	0	0	1	1
Post-Doc.	0	0	0	0	0
Total	4	0	0	1	5

Notable Awards and Achievements

Relative to project 2011UT164S, a report to Congress that address the progress toward establishing the national assessment and water resources availability and use was prepared and submitted by the USGS. This report acknowledges the collaboration and partnership between the USGS and Utah State University with respect to the project described above. The citation for the report is provided: Alley, W.M., E.J. Evenson, N.L. Barber, B.W. Bruce, K.F. Dennehy, M.C. Freeman, W.O. Freeman, J.M. Fischer, W.B. Hughes, J.G. Kennen, J.E. Kiang, K.O. Maloney, MaryLynn Musgrove, Barbara Ralston, Steven Tessler, and J.P. Verdin, 2013, Progress toward establishing a national assessment of water availability and use: U.S. Geological Survey Circular 1384, 34 p., available at <http://pubs.usgs.gov/circ/1384>.

Graduate Student Noah Schmadel, a graduate student in Civil & Environmental Engineering, received AGU's Outstanding Student Paper Award for his research presentation titled, "The role of spatially variable stream hydraulics in reach scale, one-dimensional solute predictions," at the 2013 AGU Fall Meeting in San Francisco, California (December 9-13, 2013). Only the top 3-5% of student presenters in each focus area are presented with this award.

Publications from Prior Years

1. 2012UT168B ("Performance of Stormwater Bioretention Systems in Utah's Climate and Hydrologic Conditions") - Dissertations - Heiberger, John R., 2013, Infiltration and Potential Groundwater Recharge Performance of Stormwater Bioretention Designed for Semiarid Climates, MS Thesis, Department of Civil and Environmental Engineering, College of Engineering, University of Utah, Salt Lake City, UT, 98.
2. 2012UT168B ("Performance of Stormwater Bioretention Systems in Utah's Climate and Hydrologic Conditions") - Other Publications - Heiberger J. and C. Pomeroy, 2013, Infiltration and Potential Groundwater Recharge Performance of Stormwater Bioretention Designed for Semiarid Climates, in Conference Proceedings of the World Environmental and Water Resources Congress, Cincinnati, Ohio, 19-23 May 2013.
3. 2011UT154B ("Reducing the Dangers of Low Head Dams in Utah") - Articles in Refereed Scientific Journals - Olsen, R., M. Johnson, and S. Barfuss, 2013, Risk of Entrapment at Low-Head Dams, *Journal of Hydraulic Engineering*, 139(6), 675–678.
4. 2008UT105B ("Low-Level Outlet Works Air Vent Sizing Requirements for Small to Medium Size Dams") - Articles in Refereed Scientific Journals - Wright, N. and B. Tullis, 2014, Prototype and Laboratory Low-Level Outlet Air Demand Comparison for Small-to-Medium-Sized Embankment Dams, *Journal of Irrigation and Drainage Engineering*, 140(6), 04014013.
5. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Other Publications - Andriyas, S. and M. McKee, 2013, Recursive partitioning techniques for modeling irrigation behavior, *Environmental Modelling & Software*, 47:207-217, ISSN 1364-8152, <http://dx.doi.org/10.1016/j.envsoft.2013.05.011>
6. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Articles in Refereed Scientific Journals - Bachour, R., W. Walker, A. Torres-Rua, and M. McKee, 2013, Assessment of Reference Evapotranspiration by the Hargreaves Method in the Bekaa Valley, Lebanon, *Journal of Irrigation and Drainage Engineering*, 139(11), 933–938
7. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Other Publications - Andriyas, Sanyogita and Mac McKee, 2013, Recursive partitioning techniques for modeling irrigation behavior, *Environmental Modelling and Software*, 47:207-217, <http://www.sciencedirect.com/science/article/pii/S1364815213001321>.
8. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Articles in Refereed Scientific Journals - Ticlavilca, Andres M., Mac McKee, and Wynn R. Walker, 2013, Real-time forecasting of short-term irrigation canal demands using a robust multivariate Bayesian learning model, *Irrigation Science*, 31:151-167, DOI 10.1007/s00271-011-0300-6
9. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Dissertations - Bachour, Roula, 2013, Modeling and forecasting evapotranspiration for better management of irrigation command areas, Ph.D. Dissertation, Civil and Environmental Engineering, College of Engineering, Utah State University, Logan, UT, 99, <http://digitalcommons.usu.edu/etd/2077>.
10. 2006UT69B ("Irrigation Demand Forecasting for Management of Large Water Systems") - Other Publications - Ticlavilca, A.M., A.F. Torres, and M. McKee, 2013, Spatial Root Zone Soil Moisture Estimation and Forecasting Using the METRIC Evapotranspiration Product and Multivariate Relevance Vector Machines, Poster presentation at American Geophysical Union Conference, San Francisco, CA, USA, December 9-13, 2013.