

**Utah Center for Water Resources Research  
Annual Technical Report  
FY 2017**

# 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 2017, the UWRL expended a total of more than \$9 million in water research support. USGS Section 104 funds administered through the UCWRR accounted for approximately one percent of this total. These funds were used for research addressing water management problems, outreach, information dissemination, strategic planning, water resources, and environmental quality issues in the State of Utah. Two research projects were funded in FY 2017 with USGS 104 funds, and two FY 2016 projects were delayed and extended into FY 2017. These projects are respectively entitled, (1) "Mapping Didymosphenia in the Logan River Drainage," (2) "Use of sUAS for Mapping Wetland Flow Paths and Consumptive Use in the San Rafael River, Utah," (3) "Water Strategy Advisory Team: An Assessment of the Envision Utah Process to Improve Water Management," and (4) "Researching Optimal Methods for Educating Hydrologist and Future Water Managers Using the USGS National Water Census Data Portal."

These projects dealt with the following water management issues: (1) Understanding the water chemistry and flow factors that affect bloom forming behavior of *Didymosphenia geminata* in the Logan River drainage and using that information to determine the risks for specific stream reaches relative to ecosystem and ecological impacts. (2) Using sUAS technology to monitor the impact on wetland flow and consumptive water use due to invasive Tamarisk along the San Rafael River in Utah to assist state water managers in their eradication and stream restoration efforts; (3) Evaluating the effectiveness of the Water Strategy Advisory Team created by Utah's governor to assist with a 50-year water plan for Utah and assessing its value as a template for use in other states and jurisdictions; and (4) Developing educational materials to integrate National Water Census Data Portal data into national hydrologic science education.

## Research Program Introduction

*Didymosphenia geminata* “Didymo” is a stalk forming benthic diatom species that has the potential to bloom, covering large areas of a streambed. Diatom community composition is generally a bell-weather of ambient water quality and environmental conditions. Didymo is extremely nutrient pollution sensitive, occurring in a bloom-state only in specific ambient phosphorus conditions. In recent decades increases in aggressive bloom-forming behavior of Didymo have occurred in streams across the globe, and particularly in the western US, reducing recreational and aesthetic value and causing infrastructure problems such as the fouling of water intakes. This species is also anticipated to thrive in many Utah rivers with similar climatic conditions. The specific conditions that lead to widespread and persistent blooms remain unclear, but this USGS-funded research project has begun to address this significant knowledge gap by mapping the distribution of diatom species in the Logan River drainage, focusing on below dam and spring reaches, and will evaluate the environmental controls on the presence or absence of Didymo in the Logan River drainage and create risk maps for specific stream-reaches given appropriate chemistry and flow conditions.

Tamarisk is one of the main invasive vegetation species in and along Utah’s rivers and wetlands. Dense thickets of this non-native invasive woody shrub develop extensive root systems that substantially increase resistance of sediment to erosion, increasing channel narrowing and depth-to-width ratio. Eradication efforts along the San Rafael River in Utah have been quite successful; however, Tamarisk has proven to be resilient, redeveloping between eradication activities (usually 2 to 3 years). Utah water managers and decision makers are concerned with riverbank or wetland morphological (flow path) changes to historical conditions and the amount of consumptive water use due to Tamarisk invasions as they relate to river restoration efforts. This USGS-funded project is using current unmanned aerial technologies to monitor the invasive vegetation and to evaluate its water use and impacts on wetland flow paths.

Like other semi-arid states, Utah is facing unprecedented water challenges. Utah’s governor created a Water Strategy Advisory Team (WSAT) to assist the state in developing a strategy to develop a “50-year water plan for Utah.” The team brought together a group of 38 water managers, elected officials, special interest groups, water attorneys, and academics to collaboratively develop a set of goals and priorities for future water policy, and the group produced a series of process documents and final survey results in August of 2015. This USGS-supported project is employing a qualitative methods application known as “policy assessment” to analyze and assess the WSAT experience and process, determine its effectiveness in achieving stated objectives related to water policy planning in Utah, and recommend ways to improve achievement of policy objectives for similar processes in the future.

In its role as the primary U.S. government agency for water data collection and dissemination, the United States Geological Survey (USGS) recently created and deployed a National Water Census Data Portal (NWC-DP) that provides access to streamflow, evapotranspiration, precipitation, aquatic biology and other data at the national level. This project recognizes the value of these data sets for hydrologic science education and aims to bridge the gap between pencil and paper-based hydrology curriculum and this USGS NWC-DP resource. Specifically, this USGS Supplemental project has developed an R package, called National Water Census Education (NWCEd), and five associated laboratory exercises that integrate R and web services based access to the NWC-DP datasets. Using custom functions built into the NWCEd, students are able to access unprecedented amounts of hydrologic data from the NWC-DP, which can be applied to current hydrology curriculum and analyzed using the new R software.

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

# Water Strategy Advisory Team: An Assessment of the Envision Utah Process to Improve Water Management

## Basic Information

<b>Title:</b>	Water Strategy Advisory Team: An Assessment of the Envision Utah Process to Improve Water Management
<b>Project Number:</b>	2016UT201B
<b>Start Date:</b>	3/1/2016
<b>End Date:</b>	2/28/2018
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	UT2
<b>Research Category:</b>	Water Quality
<b>Focus Categories:</b>	Water Use, Irrigation, Management and Planning
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Daniel McCool, Marian HubbardRice

## Publications

There are no publications.

# “Water Strategy Advisory Team: An Assessment of the Envision Utah Process to Improve Water Management (104B)”

*Professor Daniel McCool and Marian Rice  
2016UT201B*

*February 19, 2018*

## Problem and Research Objectives:

Utah is facing unprecedented water challenges. The state is expected to double its population by the year 2050. Climate change is expected to reduce supply. A growing recreation economy is demanding its share of water. Energy production is using dramatically more water than in the past. In October, 2013, the governor of Utah created a “Water Strategy Advisory Team” (WSAT) to assist the state in developing a strategy to “develop a 50-year water plan for Utah.” Specifically, the WSAT was charged with these tasks:

- Solicit and evaluate potential water management strategies;
- Frame various water management options and the implications of those options for public feedback; and
- Based on broad input, develop a set of recommended strategies and ideas to be considered as part of the 50-year plan (Herbert, 2013).

The WSAT was part of a broader effort administered and facilitated by Envision Utah, a nonprofit public-private partnership, called “Your Utah, Your Future” to plan for the future needs of the state. Envision Utah created advisory teams for eleven major issues; water proved to be the most contentious (Envision Utah, 2015).

The WSAT approach to water planning was novel, innovative, and sent a clear message to the public that Utah needs to plan carefully to meet its future water needs. The team brought together a very diverse group of 38 water managers, elected officials, special interest groups, water attorneys, and academics. The goal was to collaboratively develop a set of goals and priorities for future water policy. At the initial meeting, the governor’s representative established four principles to be addressed:

1. Conservation
  2. Maintenance of current infrastructure
  3. Planning for population growth
  4. The need for innovation
- (Envision Utah, 2013)

The WSAT met approximately ten times, and produced a series of process documents such as: “Baseline Assumptions,” “Policy Questions, Issues, and Methods,” “M&I Water Scenarios,” and “Key Policy Questions.” A public survey was conducted in 2014 that presented five pre-set water scenarios (Envision Utah, 2015). The final results of the survey were released in August, 2015.

## Conceptual Framework

The research assesses the extent to which the Water Strategy Advisory Team (WSAT) met its objectives, and assesses its value as a template that could be used by other states and jurisdictions. The WSAT process is examined within the framework of Integrated Water Resources Management (IWRM), which places great value on collaborative decision-making and a holistic approach to water planning (Conradin, 2010; U. S. Army Corps of Engineers, 2014). Shabman and Scodari note that “the concept of IWRM is being advocated as a better way to approach the challenges of 21<sup>st</sup> Century water management (Shabman & Scodari, 2012).” IWRM focuses on the coordinated and systemic development, management, protection, and preservation of water and associated natural and human resources in order to maximize human welfare, preserve the ecosystem that maintains all life, and do so in a manner that is fair and just to all natural and human communities (Lenton & Muller, 2012; United Nations Environment Programme, 2012).

## Methodology:

This study employs a methodology known in the social sciences as “qualitative methods,” with a specific application known as “policy assessment.” The Qualitative method is widely employed in the social sciences, humanities, and other fields such as public health (Denzin and Lincoln 2000, 2011; Consortium on Qualitative Methods 2015). It is especially useful in Political Science when analyzing complex, on-going policy problems (Lamont and White 2009; Bennett, Barth, and Rutherford 2003). Basic policy assessment consists of four qualitative research steps:

1. Identify the objectives of the policy.
2. Assess the extent to which those objectives have been achieved.
3. Explain why the objectives have/have not been achieved.
4. Recommend ways to improve the achievement of policy objectives (Patton, Sawicki, and Clark 2012).

This research performed all four of those steps for the WSAT process.

The proposed study, relying on IWRM as a framework for analysis, attempts to answer the following questions:

1. Was the WSAT collaborative, fair and open?

2. Did the WSAT take a systemic, holistic approach to water resources management?
3. Did the WSAT focus on the interdependency of water resources and other natural resources?
4. Did the WSAT balance social, economic, and environmental goods and services?
5. Did the WSAT recommend a bottom-up, stakeholder-driven process rather than a top-down approach to resolving water conflicts?
6. Did the WSAT recommend a comprehensive, multi-dimensional approach to problem-solving?
7. Did the WSAT balance short-term gains with long-term impacts?
8. Did the WSAT consider inclusivity and equality for all stakeholders and segments of society in the development and administration of water policy?
9. Did the WSAT process, as facilitated by Envision Utah, improve water planning and help prepare Utah for future water demands?
10. What is your overall assessment of the WSAT and the final report issued by Envision Utah?

We obtained answers to these questions by accessing multiple sources. First, we developed a questionnaire that was sent to all 38 members of the WSAT, asking each team member to evaluate the WSAT experience by answering the ten questions posed above. Second, we sent the same questionnaire to a selection of water stakeholders who were not on the WSAT; this includes water managers, interest groups, elected officials, academics, water attorneys and the interested public in order to assess their opinions of the WSAT effort. We then performed a series of quantitative and qualitative comparisons between the two, including comments provided by both groups. We evaluated all of the written material that was produced by the process, including the final report. Finally, used secondary sources such as articles, published research, and government reports/analyses that were used by the WSAT during its deliberations or were referenced or utilized by WSAT members. Future research includes conducting in-person interviews with the three co-chairs of the WSAT, and the employees of Envision Utah who facilitated the process.

## Principal Findings and Significance:

When the application was submitted for the USGS grant, it was assumed the Water Strategy Advisory Team (the "WSAT") had completed its work without issuing a final report. No meetings had been held for many months, there was no follow-up, and the word we heard was that the whole process had been so contentious that it had been abandoned. Thus, the fall semester of 2016 appeared to be the perfect time to do a post-mortem assessment of the process. However, the three co-chairs of the WSAT produced a draft final report September 2016. Due to the long period of no communication, the draft report came as a surprise to the members listed above. The submission of the draft report sparked controversy for the members as well as the public. Due to this, the governor and his environmental advisor realized more work was needed to produce a balanced report that could gain the acceptance of most of the WSAT members.

In January 2017 the co-chairs established sub-committees to draft various portions of a revised final report. This included an ambitious schedule; however, the members stated they need more time than the schedule allowed. During this time, a preliminary paper was completed (Appendix A), which was subsequently presented at the Twelfth International Conference on Interdisciplinary Social Sciences in Hiroshima Japan on July 28, 2017 (Appendix B).

The final Governor's State Water Strategy was completed in July 2017 (Envision Utah, 2017) and presented to Governor Herbert on July 19, 2017. After the completion of the final strategy, work on the research started. A questionnaire was developed that evaluates the WSAT experience (Appendix C). This questionnaire was sent to all 38 members of the WSAT on November 21, 2017 as well as subsequent follow-up reminder e-mails asking the WSAT members to complete the questionnaire. The questionnaire was then sent to various water stakeholders who were not on the WSAT. The Non-WSAT group included water managers, interest groups, elected officials, academics, water attorneys, and interested public in order to assess their opinions of the WSAT effort.

Summaries of the results of the two questionnaires are included in Appendix D and Appendix E. Analysis demonstrates there is a difference and some disagreement between the WSAT members and Non-WSAT stakeholders. In addition, there is some disagreement between members of the WSAT. Results find respondents in both the WSAT and Non-WSAT groups do not represent the population as a whole. Both samples are primarily well-paid and well-educated males. Overall the WSAT group was more pleased with the process than the Non-WSAT, which indicates problems the WSAT group had with inclusion. Since the completion of the Governors State Water Strategy, there has been proposed legislation such as H.B. 244 (2018) to allow water providers to reduce water rates for culinary customers that meet certain water efficiency or conservation requirements. This is a result of the Governor's State Water Strategy Recommendation 8.2, which states: Structure water-related revenues to balance social, economic, and environmental values (Envision Utah, 2017). Therefore, this research project has initiated additional research into collaborative water management.

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## Appendix A

Water Strategy Advisory Team: An Assessment of the Envision Utah Process to Improve  
Water Management

**Integrated Water Resource Management:  
A Typology of Collaborative Processes,  
Applied to the Utah Governor's Water Strategy Advisory Team**

**By**

**Marian Hubbard-Rice and Daniel McCool**

**Presented at the  
International Conference on Interdisciplinary Social Science**

**Hiroshima, Japan**

**July 26-28, 2017**

**Version: 05 (June 30)**

*Abstract*

Nearly all contemporary models of conflict resolution rely on some form of collaboration. Collaboration entails a formal procedure that includes a variety of stakeholders in a deliberative process designed to reach a decision point. This is certainly true for the predominant decision-making model in water resources, Integrated Water Resource Management (IWRM). Like other models of conflict resolution and decision-making, IWRM places great emphasis on including stakeholders as policy choices are considered and adopted. However, IWRM, again like other models that stress collaboration, has failed to fully specify the parameters and characteristics of collaboration; all collaborative processes are not equal. In this paper, we develop a typology of collaborative processes in an effort to solve this problem. We then apply our typology to an analysis of an innovative collaborative process established by the governor of Utah, called the Water Strategy Advisory Team (WSAT).

*Keywords:* Integrated Water Resources Management (IWRM), state water planning, collaborative planning, urbanization, conservation, Municipal and Industrial (M&I) use, irrigation, ecosystem services, capacity building

## I. Introduction

The State of Utah is facing unprecedented water challenges. The state is expected to double its population by the year 2050 and climate change is expected to reduce as well as alter timing of water resources. Furthermore, a growing recreation economy is demanding its share of water. Energy production is using dramatically more water than in the past. Due to these drivers, in October, 2013, the governor of Utah created a “Water Strategy Advisory Team” (WSAT) to assist the state in developing a strategy to “develop a 50-year water plan for Utah.” Specifically, the Team was charged with the following tasks:

- Solicit and evaluate potential water management strategies;
- Frame various water management options and the implications of those options for public feedback; and
- Based on broad input, develop a set of recommended strategies and ideas to be considered as part of the 50-year plan (Herbert, 2013).

The WSAT was part of a broader effort administered and facilitated by Envision Utah, a nonprofit public-private partnership, called “Your Utah, Your Future” to plan for the future needs of the state. Envision Utah created advisory teams for eleven major issues; water proved to be the most contentious (Envision Utah, 2016c).

The WSAT approach to water planning was novel, innovative, and sent a clear message to the public that Utah needs to plan carefully to meet its future water needs. The team brought together a very diverse group of 38 water managers, elected officials, special interest groups, water attorneys, and academics. The goal was to collaboratively develop a set of goals and priorities for future water policy (Envision Utah, 2013).

This research assesses the extent to which the WSAT met its objectives, and assess its value as a template that could be used by other states and jurisdictions. The WSAT

process will be examined within the framework of Integrated Water Resources Management (IWRM), which places great value on collaborative decision-making and a holistic approach to water planning (U. S. Army Corps of Engineers, 2014).

IWRM is defined as “a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Global Water Partnership, 2008).” IWRM focuses on the coordinated and systemic development, management, protection, and preservation of water and associated natural and human resources in order to maximize human welfare, preserve the ecosystem that maintains all life, and do so in a manner that is fair and just to all natural and human communities (Lenton & Muller, 2012; United Nations Environment Programme, 2012). Parts of the concept of with Integrated Water Resources Management (IWRM) concept have been around for several decades, however it was in 1992 when Agenda 21 and the World Summit on Sustainable Development that the concept was made the object of extensive discussions as to what it means in practice (United Nations, 2014). Shabman and Scodari note that “the concept of IWRM is being advocated as a better way to approach the challenges of 21<sup>st</sup> Century water management (Shabman & Scodari, 2012).” Inherent in these ambitious goals is the assumption that the most just, fair, and equitable solutions will only be found via an inclusive process that involves a multiplicity of stakeholders. The multiple stakeholder approach asserts that influence and the right to be heard is based on each stakeholder’s unique perspective and expertise (Hemmati, 2002, p. 7).

## II. A Typology of Collaborative Processes

Collaboration is at the center of IWRM; it is the preferred process of decision-making because it has the potential to reduce conflict, achieve buy-in from a wide array of stakeholders, and is mostly likely to lead to solutions that are widely supported and can be sustained in the long-run (Lenton & Muller, 2012; U. S. Army Corps of Engineers, 2014). Collaborative problem-solving means that various stakeholders agree to work together to address a particular issue or concern (Environmental Protection Agency, 2008). Collaboration, usually achieved through a process of negotiation, has been relied upon to resolve many of the world's most pressing water conflicts (Cosgrove, 2003), and is "at the center of solving future water conflicts (Cech, 2003, p. 436)."

Furthermore, collaboration is central to nearly all models of conflict resolution. For example the EPA Office of Environmental Justice (OEJ) utilizes the Environmental Justice Collaborative Problem-Solving Model (CPS Model) to bring together multiple parties from various stakeholder groups to develop solutions to address local environmental and/or public health issues (Environmental Protection Agency, 2008). The adaptive collaborative governance model uses an approach which emphasizes inclusion and equity in processes and outcomes, and seeks to engender effective connections among actors (McDougall & Banjade, 2015).

In the past, water policy-making followed a linear process, which generally entailed using past trends to provide a basis for new projects and using previous technologies as a starting point for new projects. As population grew, the infrastructure expanded with it. It was assumed the general public would accept the judgment and expertise of respected institutions and public servants in such matters (Skinner, 2017).

However, with climate change, projected population growth, and political demands for inclusion, it became necessary to develop a more complex form of policy analysis. The linear “evidence informed” approach was no longer adequate. Skinner (2017) examines three case studies in Australia to determine why some recent major decisions in water policy in Australia have been able to retain evidence-based analyses in the face of political imperatives. He finds that successful strategy development is highly dependent on authentic citizen engagement being undertaken within an adequate time-frame (Skinner, 2017, p. 16). Skinner concludes that managing increased complexity while engaging a full range of stakeholders requires a new approach to leadership and governance.

Skinner’s conclusion is supported by other scholars of contemporary policy-making processes, who have argued that “polycentric” institutional arrangements—those with multiple centers of decision making that maintain mechanisms for coordination—can support robust governance of natural resources as well as other public goods (Heikkila, 2017). Also, the degree to which people have competing values and interests is a key political consideration. Such competing values or interests can result in water conflicts, which can be difficult to resolve without formal and costly conflict resolution processes (Heikkila & Schlager, 2012). Also, institutional change inevitably involves questions of competing values. Choices that favor one set of values over another can impose threats to certain groups, which then can lead groups to mobilize to oppose or stymie change (Heikkila, 2017). One of the most effective ways to minimize these potentially damaging responses is to include stakeholders in the decision-making process.

Like all models of conflict-reducing decision-making, IWRM places significant emphasis on the essential role of collaboration. Yet none of these models have developed an adequate specification of the concept. Collaboration can occur in many forms, and some may be superior to others. In this article, we develop a typology of different forms of collaboration, and then analyze a particular collaborative process—the WSAT-- to illustrate how the type of collaboration affects the success of the process.

There are twelve essential questions that must be addressed in the design of a collaborative process, arranged into three categories:

#### Category A: Control over Participants

1. How many stakeholders should be included? How inclusive should the process be? Is there an optimal number of parties in a collaboration? Do the members of the collaborative group have the power to add new members to the group?
2. Should some stakeholders be excluded from the process because they are viewed as less likely to come to an agreement? Do the members of the collaborative group have the power to remove someone from the group?

#### Category B: Control over Procedure

3. How will the collaborative group conduct its meetings? Who will assign roles of leadership, time-lines, writing responsibilities, and sub-group structures?
4. Should a body of outside impartial fact experts be assigned to the collaborative group to assist them in their deliberations? Who makes this decision? Who decides which experts are consulted?
5. Will decisions be made by majority vote, or is a consensus-building approach more suitable? If voting is the preferred decision tool, do all participants have an

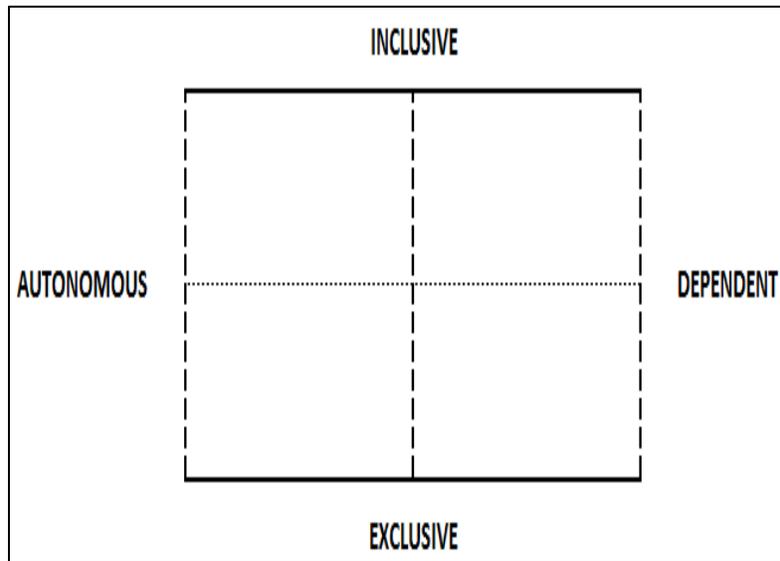
- equal vote, or should some be weighted more/less than others due “investment variables” such as having more at stake, having greater resources, a larger tax liability, etc.
6. Who will be responsible for public relations? Who is authorized to communicate with the public, and solicit and receive comments from the public? How will the deliberative body decide on the extent of transparency and public involvement?

**Category C: Control over End Result**

7. What is the target audience for the collaborative decision-making process? Is the goal merely to advise others, or formulate a legal settlement agreement, or achieve a specific and enforceable political outcome?
8. Should a range of options be the final product, or should the group select one specific outcome?
9. Will there be a process of review and appeal if some stakeholders are displeased by a group decision? Is there are procedure in place in case of deadlock?
10. Is there a process for a minority or dissenting report if some members of the group do not support the final outcome? If a party drops out of the process, how does that effect the efficacy and legitimacy of the outcome?
11. At the end of the collaborative process, who is authorized to speak on behalf of the group?
12. How will the collaborative body communicate its decisions with the public? Will it hold hearings on a draft policy? Will it solicit feedback?

At the heart of this question is the relationship between process and outcome. Clearly, the way the collaborative process is structured directly impacts final decisions. For example, if all decisions are made by a process of majority vote, then the outcome can be heavily influenced by the party that decides who will be included in the deliberations; in other words, an entity external to the collaborative group could “stack the membership” before the deliberative process even begins.

Based on the answers to these questions, we have formulated a basic typology of collaborative processes based on two continua: exclusive/inclusive, and autonomous/dependent (Figure 1). The vertical continuum refers to the extent to which all stakeholders are included in all aspects of the collaborative process, including procedural decisions. The horizontal continuum refers to the degree to which the collaborative body operates as an independent entity with a wide degree of operational freedom, and the extent to which it has the power to make concrete and enforceable decisions.



*Figure 1. Collaborative Typology*

The two continua create a typology of four possible types of collaborative processes:

**A. Autonomous/Inclusive**

This type of collaborative body has general control over its membership, operational procedures, and the end result, and strives to include as many stakeholders as possible.

**B. Autonomous/Exclusive**

This type of collaborative body has general control over its membership, operational procedures, and the end result, but limits access to the collaborative process to only certain parties, to the exclusion of others.

**C. Dependent/Inclusive**

This type of collaborative body has limited control over its membership, operational procedures, and the end result, but strives to include all possible stakeholders.

**D. Dependent/Exclusive**

This type of collaborative body has limited control over its membership, operational procedures, and the end result, and membership is limited to only certain stakeholders.

It must be noted these criteria are continua, and represent a range of possible values. Also, the criteria are subject to practical limitations; no collaborative process

could possibly include all stakeholders, and every deliberative body in a democracy is subject to some form of external control over procedure, role, and authority. However, the typology does create the possibility to place various collaborative processes in a range of possible locations within the boxes formed by the two continua. Also, as a collaborative deliberation proceeds, it may undergo changes that would change its location in the typology.

In this article, we apply the typology to a unique and innovative effort to resolve pressing water supply issues in the state of Utah, using IWRM as our over-arching framework for problem-solving. However, the application of the typology should not be limited to only collaborative processes within IWRM; indeed, if it is valid, then it should be applicable to any collaborative body that operates within a relative open, participatory, democratic form of government.

We hypothesize that the greater the level of autonomy and inclusivity, the higher the probability that the collaborative process will be successful. Conversely, collaborative processes with a low level of autonomy that are not very inclusive have a low probability of success. “Success” is defined as meeting the goal or mission for which the collaborative body was established with the approval of a wide variety of affected stakeholders.

### III. The Governor’s Water Strategy Advisory Team (WSAT)

#### A. Its history and development, and conflicts

In October 2013, Governor Gary Herbert created a “Water Strategy Advisory Team” (WSAT), an entity designated to make recommendations for a 50-year water strategy

(Utah Governor Gary Herbert, 2013) and analyze the water needs of the state with expected growth of 2.5 million people (Envision Utah, 2013). Governor Herbert asked the WSAT to:

- Solicit and evaluate potential water management strategies;
- Frame for public feedback various water management options and the implications of those options; and
- Based on broad input, develop a set of strategies and ideas to be considered as part of the 50-year water strategy (Utah Governor Gary Herbert, 2013).

The team is comprised of elected officials, conservation leaders, water managers, recreational organizations, technical experts, attorneys, and business representatives.

This process was initially led by Envision Utah, which is a nonprofit organization that was formed in 1997 to serve as a neutral facilitator to help make informed decision on how the state of Utah should grow (Envision Utah, 2016a). In 2013, as part of the WSAT and with support of Envision Utah, Governor Herbert initiated the “Your Utah, Your Future” process to examine relevant issues in light of the fact that Utah’s population will almost double by 2050. “Your Utah, Your Future” is a statewide vision that addresses 11 topics, including water (Envision Utah, 2016b). As part of this process, in 2014 Envision Utah developed a public survey that contained questions around various choice and outcome model scenarios (Envision Utah, 2016c). The survey was completed by 52,845 respondents and the final results were released in August 2015. The survey found that water is one of the top concerns for Utah residents and they support reduction of per capita water by 2050 (Envision Utah, 2016c). The results and “scenario preferences” of the public survey were to be utilized by the action teams, including the WSAT.

In September 20, 2016, a draft version of the State Water Strategy Plan was made public for review and comments. However, initially it was unclear if the document was to be submitted to the public. In a public meeting on September 13, 2016 it was announced it was unclear if the draft State Water Strategy Plan would be submitted to public for review, which brought controversy to the process (Emma Penrod, 2016). In April 2017, the WSAT was given an ambitious schedule to complete the State Water Strategy Plan. In this period, the WSAT was tasked with completing the State Water Strategy Plan for delivery of the document to Governor Herbert on July 19, 2017. The draft Water Strategy Plan was open to public review on June 16, 2017 with a ten-day comment period through June 26, 2017 (Envision Utah, 2017).

#### **B. The Switch from Envision Utah control to a group approach**

#### **C. The final report**

The draft Water Strategy Plan was open to public review on June 16, 2017 with a ten-day comment period through June 26, 2017 (Envision Utah, 2017). The Water Strategy Plan will then be presented to Governor Herbert on July 19, 2017. According to media reports, members of the Water Strategy Advisory Team say the report has changed significantly from a previous draft released amid public outcry last fall (Emma Penrod, 2017).

#### **D. Our Survey**

Once the State Water Strategy Plan is finalized and approved by Governor Herbert, a survey will follow to assess the effectiveness of the WSAT process. The proposed study, relying on IWRM as a framework for analysis, will attempt to answer questions regarding the collaborative process in regards to the proposed collaborative typology (Figure 1) as well as the following questions:

1. Was the WSAT collaborative, fair and open?
2. Did the WSAT take a systemic, holistic approach to water resources management?
3. Did the WSAT focus on the interdependency of water resources and other natural resources?
4. Did the WSAT balance social, economic, and environmental goods and services?
5. Did the WSAT recommend a bottom-up, stakeholder-driven process rather than a top-down approach to resolving water conflicts?
6. Did the WSAT recommend a comprehensive, multi-dimensional approach to problem-solving?
7. Did the WSAT balance short-term gains with long-term impacts?
8. Did the WSAT consider inclusivity and equality for all stakeholders and segments of society in the development and administration of water policy?
9. Did the WSAT process, as facilitated by Envision Utah, improve water planning and help prepare Utah for future water demands?
10. What is your overall assessment of the WSAT and the final report issued by Envision Utah?

The study will obtain answers to these questions by accessing five sources. First, we will develop a questionnaire that will be sent to all 38 members of the WSAT, asking each team member to evaluate the WSAT experience by answering the ten questions posed above. Second, we will send the same questionnaire to a selection of water stakeholders who were not on the WSAT. This will include water managers, interest groups, elected officials, academics, and water attorneys, in order to assess their opinions of the WSAT effort. Third, we will conduct in-person interviews with the three co-chairs of the WSAT, and the employees of Envision Utah who facilitated the process. Fourth, we will evaluate all of the written material that was produced by the process, including the final report. And fifth, we will use secondary sources such as articles, published research, and government reports/analyses that were used by the WSAT during its deliberations or were referenced or utilized by team members.

**IV. Conclusion**

We predict that throughout the development of the State Water Strategy Plan, the WSAT moved across our developed typology (Figure 1). For example, initially the WSAT was in the collaborative process frame of dependency and exclusion, then moved to a position closer to autonomy and inclusion, and then recently moved back toward the extremes of dependency and exclusion. Furthermore, we predict the minimal public engagement and review will impact the effectiveness and buy-in of the State Water Strategy Plan.

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## Appendix B

Interdisciplinary Social Sciences in Hiroshima Japan

*July 28, 2017*

# Water Strategy Advisory Team: A New Approach to Water Management

Dr. Daniel McCool

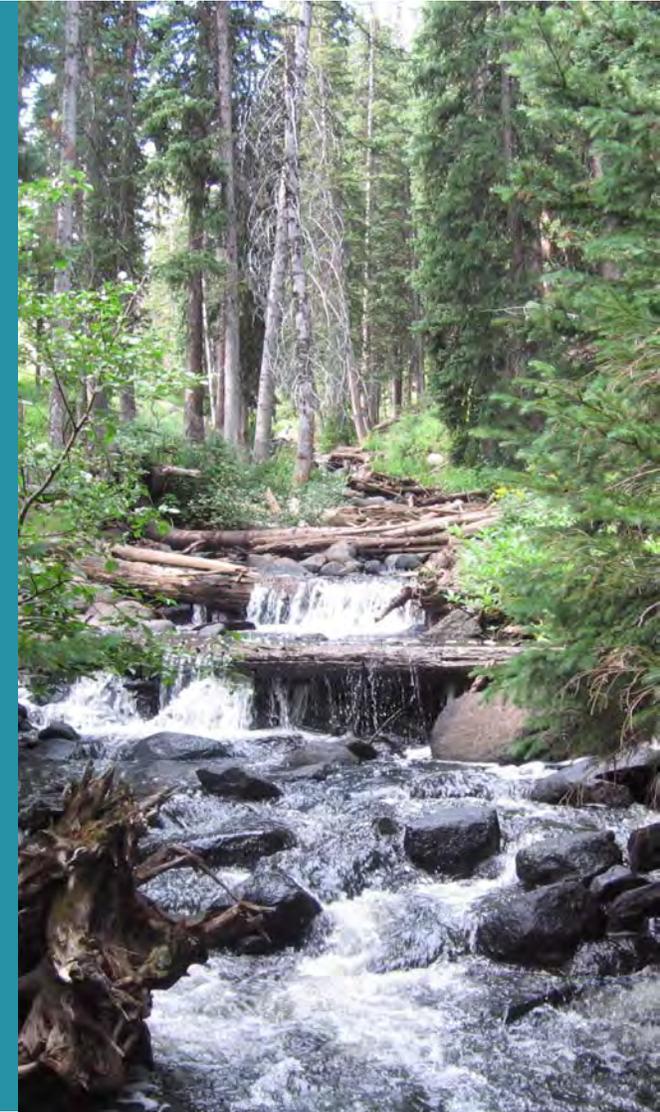
Professor, University of Utah

Marian Hubbard-Rice

PhD Candidate, University of Utah



Twelfth International Conference on Interdisciplinary Social Sciences  
July 28, 2017



# Introduction



## Utah Future Water Challenges

- Projected double population by year 2060
- Climate Change
- Increased Recreation and Use
- Increased Energy Extraction



# Introduction

## Water Strategy Advisory Team



# Water Strategy Advisory Team (WSAT)

## Created by the Governor in 2013 to:

- Solicit and evaluate potential water management strategies.
- Frame various water management options and the implications of those options for public feedback.
- Based on broad input, develop a set of recommended strategies and ideas to be considered as part of the 50-year plan.

Administered and facilitated by  
Envision Utah



# State Water Strategy Plan

Part of nonprofit public-private partnership  
*Your Vision, Your Future*



## Introduction

### State Water Strategy Plan



- **2014**-Public survey that contained questions around various choice and outcome model scenarios.
- **September 2016**-DRAFT Water Strategy Plan made public for review and comments.
- **April 2017**-WSAT given ambitious schedulable to complete State Water Strategy Plan.
- **June 16, 2017**-Draft Water Strategy Plan open to public for 10 day review.

# State Water Strategy Plan

## Introduction

## State Water Strategy Plan



**The Salt Lake Tribune**  
(<http://www.sltrib.com>)

### Newly finished 50-year water plan marks a new era, Utah governor says

By EMMA PENROD The Salt Lake Tribune  
Published: July 19, 2017 11:10PM  
Updated: July 19, 2017 10:46PM

**Environment • Governor accepts 50-year proposal that includes contentious project at Bear River.**

Gov. Gary Herbert on Wednesday heralded the completion of the state's new 50-year water management plan, a document four years in the making.

In a public appearance with his personally appointed, 40-member team of water advisers, the Republican governor accepted the completed blueprint, which maps strategies for water conservation as the state's population grows and calls for the construction of big-ticket water projects at Lake Powell and the Bear River.

The document's development has not been without controversy, with part of the drafting process done in meetings that were not disclosed to the public, prompting an outcry. And that's not the only flashpoint in the 106-page water-management blueprint, compiled with help from Envision Utah.

Herbert offered high praise for the strategy's authors, calling their effort unprecedented and holding it up as a "model of cooperation and collaboration for the rest of nation."

Disagreement over a few of the document's chapters — particularly those regarding water development and conservation — forced advisers into intense deliberations just weeks before the governor's deadline for the completed report.



Utah Gov. Gary Herbert

# Purpose of Research



## Research Assessment WSAT

- Extent WSAT met its objectives.
- Value as a template that could be used by other states and jurisdictions.

**Examined through:  
Integrated Water Resources Management Framework**

# Framework



## Integrated Water Resources Management

A process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems[1].

1. Global Water Partnership, *Integrated Water Resources Management*. 2008: Stockholm.

# Framework



## Integrated Water Resources Management

### Collaboration is at the center of IWRM[1, 2]

- Potential to reduce conflict
- Achieve buy-in from a wide array of stakeholders
- Mostly likely to lead to solutions that are widely supported
- Can be sustained in the long-run

1. Lenton, R. and M. Muller, *Integrated water resources management in practice: Better water management for development*. 2012: Routledge.
2. U. S. Army Corps of Engineers, *Building Strong Collaborative Relationships for a Sustainable Water Resources Future: Understanding Integrated Water Resources Management*. 2014.

# Design of Collaborative Process



## Category A: Control over Participants

1. How many stakeholders should be included? How inclusive should the process be? Is there an optimal number of parties in a collaboration? Do the members of the collaborative group have the power to add new members to the group?
2. Should some stakeholders be excluded from the process because they are viewed as less likely to come to an agreement? Do the members of the collaborative group have the power to remove someone from the group?

# Design of Collaborative Process



## Category B: Control over Procedure

3. How will the collaborative group conduct its meetings? Who will assign roles of leadership, time-lines, writing responsibilities, and sub-group structures?
4. Should a body of outside impartial fact experts be assigned to the collaborative group to assist them in their deliberations? Who makes this decision? Who decides which experts are consulted?
5. Will decisions be made by majority vote, or is a consensus-building approach more suitable? If voting is the preferred decision tool, do all participants have an equal vote, or should some be weighted more/less than others due “investment variables” such as having more at stake, having greater resources, a larger tax liability, etc.
6. Who will be responsible for public relations? Who is authorized to communicate with the public, and solicit and receive comments from the public? How will the deliberative body decide on the extent of transparency and public involvement?

# Design of Collaborative Process



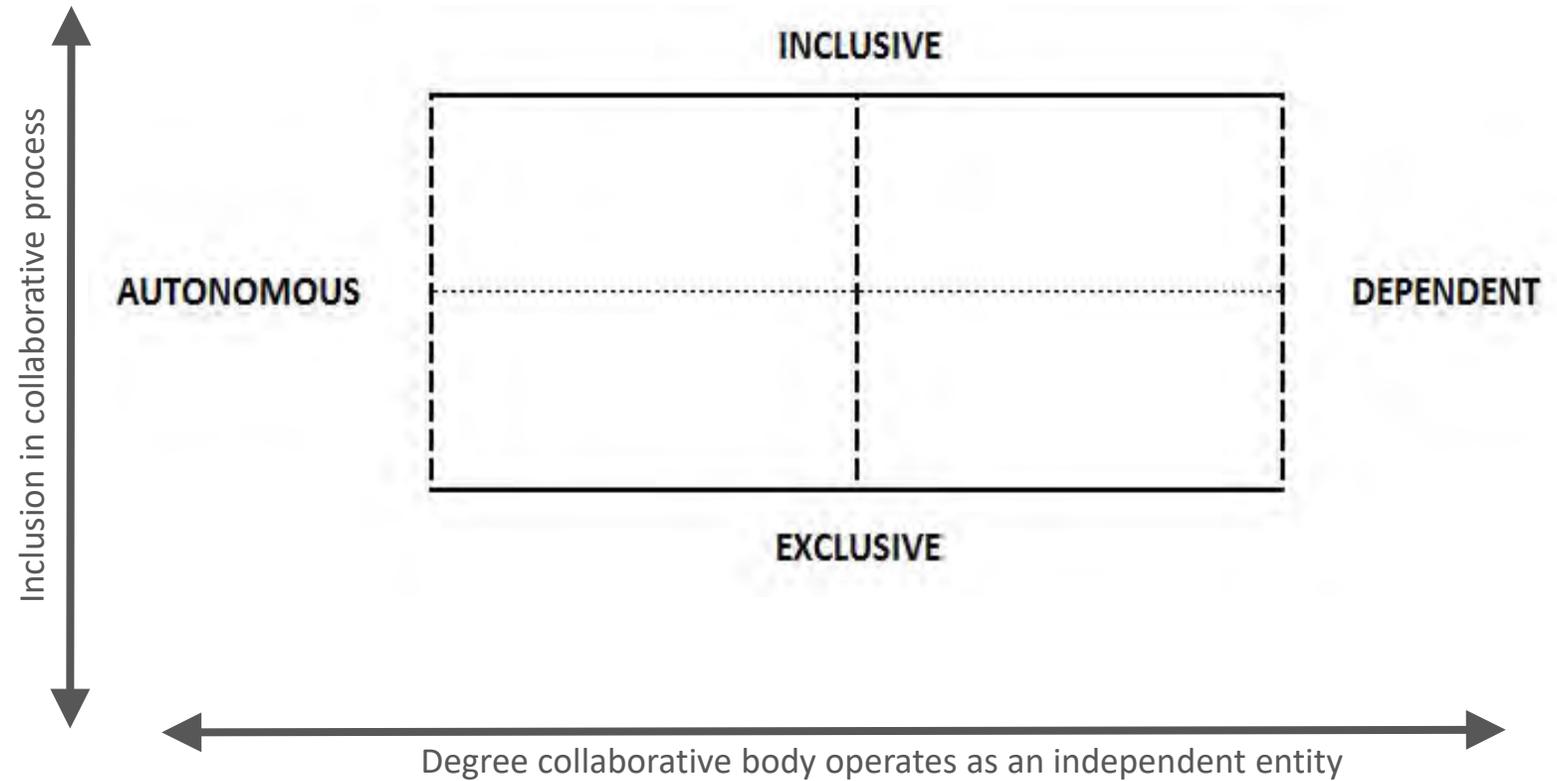
## Category C: Control over End Result

7. What is the target audience for the collaborative decision-making process? Is the goal merely to advise others, or formulate a legal settlement agreement, or achieve a specific and enforceable political outcome?
8. Should a range of options be the final product, or should the group select one specific outcome?
9. Will there be a process of review and appeal if some stakeholders are displeased by a group decision? Is there a procedure in place in case of deadlock?
10. Is there a process for a minority or dissenting report if some members of the group do not support the final outcome? If a party drops out of the process, how does that affect the efficacy and legitimacy of the outcome?
11. At the end of the collaborative process, who is authorized to speak on behalf of the group?
12. How will the collaborative body communicate its decisions with the public? Will it hold hearings on a draft policy? Will it solicit feedback?

# Typology of Collaborative Process



## Collaborative Typology



# Collaborative Bodies

## Autonomous/Inclusive

General control over its membership, operational procedures, and the end result, and strives to include as many stakeholders as possible.



# Collaborative Bodies

## Autonomous/Exclusive

General control over its membership, operational procedures, and the end result, but limits access to the collaborative process to only certain parties, to the exclusion of others.



# Collaborative Bodies

## Dependent/Inclusive

Limited control over its membership, operational procedures, and the end result, but strives to include all possible stakeholders.



# Collaborative Bodies

## Dependent/Exclusive

Limited control over its membership, operational procedures, and the end result, and membership is limited to only certain stakeholders.



# Research Application



## Hypothesis

The greater the level of autonomy and inclusivity, the higher the probability that the collaborative process will be successful.

Collaborative processes with a low level of autonomy that are not very inclusive have a low probability of success.

“Success” is defined as meeting the goal or mission for which the collaborative body was established with the approval of a wide variety of affected stakeholders.

# Research Application



## Research Survey

- Survey to assess the effectiveness of the WSAT process.
- Utilize the IWRM as a framework for analysis.
- Survey will attempt to answer questions regarding the collaborative process in regards to the proposed collaborative typology.
- The study will obtain answers to these questions by accessing five sources.

# Research Application



## Research Survey

1. Questionnaire that will be sent to all members of the WSAT.
2. Same questionnaire to a selection of water stakeholders not part of WSAT.
3. In-person interviews with the three co-chairs of the WSAT, and the employees of Envision Utah who facilitated the process.
4. Evaluate all of the written material that was produced by the process, including the final report.
5. Utilize secondary sources such as articles, published research, and government reports/analyses that were used by the WSAT during its deliberations or were referenced or utilized by team members.

# Questions



**Dr. Daniel McCool**  
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## Appendix C

Water Strategy Advisory Team: Questionnaire



## The Water Strategy Advisory Team-Assessment of the Process

### 1. SECTION A- PARTICIPANTS

**In this first section of the survey we would like to ask questions about participation in the Governor's Water Strategy Advisory Team.**

1. Was the process of selecting team members fair and appropriate?

Yes

No

Provide additional information below if you would like to expand on your response.

2. Were some people excluded you feel should have been members of the group?

Yes

No

Provide additional information below if you would like to expand on your response.

3. Was the Water Strategy Advisory Team balanced and did it accurately represent all stakeholders?

Yes

No

Provide additional information below if you would like to expand on your response.



## The Water Strategy Advisory Team-Assessment of the Process

### 2. SECTION B- PROCEDURE

**In this second section of the survey we would like to ask questions about procedures employed by the Water Strategy Advisory Team.**

1. Were the meetings conducted in a fair and impartial manner?

Yes

No

Provide additional information below if you would like to expand on your response.

2. Were outside experts utilized effectively?

Yes

No

Provide additional information below if you would like to expand on your response.

3. Were decisions made by majority vote?

Yes

No

Provide additional information below if you would like to expand on your response.

4. Did the WSAT leaders utilize a consensus-building approach?

Yes

No

Provide additional information below if you would like to expand on your response.

5. Was the public involved or engaged in the decision-making process?

Yes

No

Provide additional information below if you would like to expand on your response.



## The Water Strategy Advisory Team-Assessment of the Process

### 3. SECTION C- END RESULTS

**In this third section of the survey we would like to ask questions about the end results of the Governor's Water Strategy Team.**

1. Was the target audience clearly identified?

Yes

No

Provide additional information below if you would like to expand on your response.

2. Was the range of options in the final report inclusive?

Yes

No

Provide additional information below if you would like to expand on your response.

3. Did the group have sufficient autonomy to produce an end product that reflected a group consensus?

Yes

No

Provide additional information below if you would like to expand on your response.



## The Water Strategy Advisory Team-Assessment of the Process

### 4. SECTION D- INFORMATION ABOUT YOURSELF

**We have a few concluding questions to make sure our survey is representative of a variety of viewpoints and perspectives. Please remember that all answers are completely confidential and you have the right to not answer any question.**

1. Are you a native Utahn?

Yes

No

2. How many years have you lived in Utah?

3. Are you originally from the Salt Lake Valley?

Yes

No

4. How would you describe the place where you grew up? Please check one.

On a farm

Rural or small town

Suburban area

Urban Area

5. Do you or any of your relatives currently farm?

Yes

No

6. In what sector are you employed?

Government

Politics

Water Provider

Agriculture/farming

Mining/energy extraction

Professional/scientific

Research

Recreation

Nonprofit

Other (please specify)

7. What year were you born?

8. Are you male or female?

Male

Female

9. Please indicate level of education completed:

Less than high school

High school diploma

Some college

Vocational/technical degree

4 Year college degree

Graduate degree

Professional doctorate degree (for example: Ph.D., MD, JD)

10. Please choose the term that best describes your political orientation:

Very Liberal

Liberal

Moderate

Conservative

Very Conservative

11. Please indicate your household income (before taxes) in 2016:

Less than \$25,000

\$25,000-\$49,999

\$50,000-\$74,999

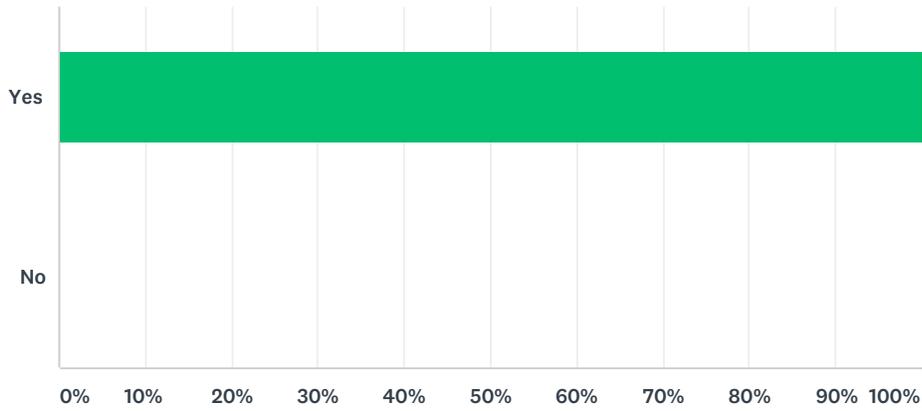
\$75,000-\$99,999

\$100,000 or greater

**Appendix D**  
**Water Strategy Advisory Team (WSAT)**  
**Questionnaire Summary**

# Q1 Was the process of selecting team members fair and appropriate?

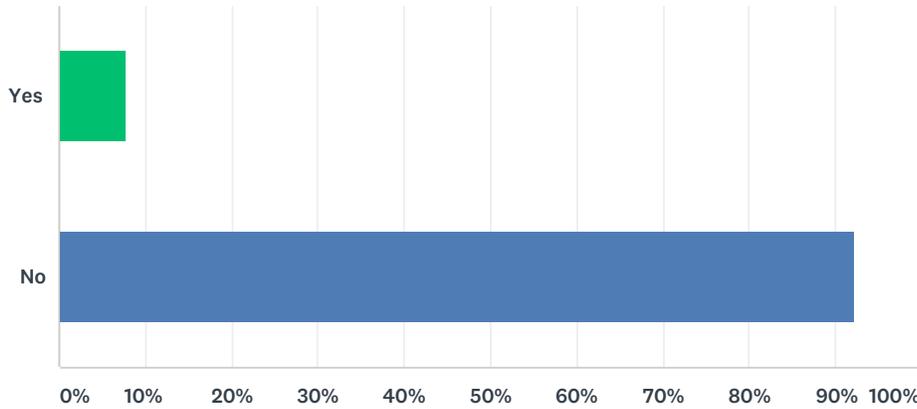
Answered: 13 Skipped: 2



ANSWER CHOICES	RESPONSES	
Yes	100.00%	13
No	0.00%	0
TOTAL		13

## Q2 Were some people excluded you feel should have been members of the group?

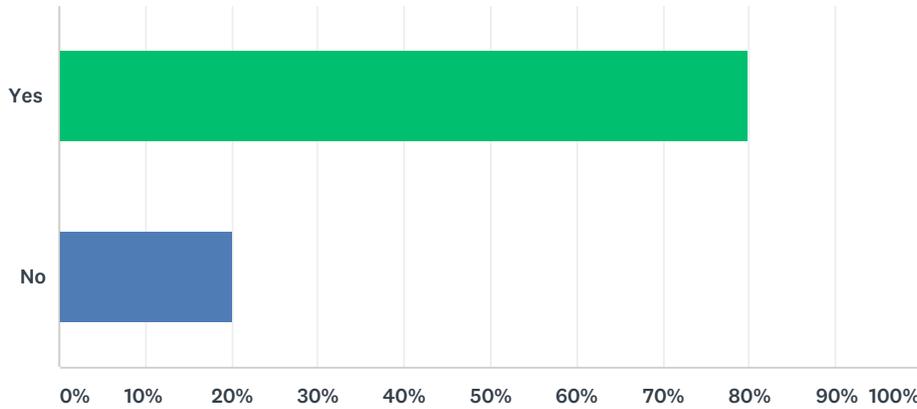
Answered: 13 Skipped: 2



ANSWER CHOICES	RESPONSES	
Yes	7.69%	1
No	92.31%	12
TOTAL		13

### Q3 Was the Water Strategy Advisory Team balanced and did it accurately represent all stakeholders?

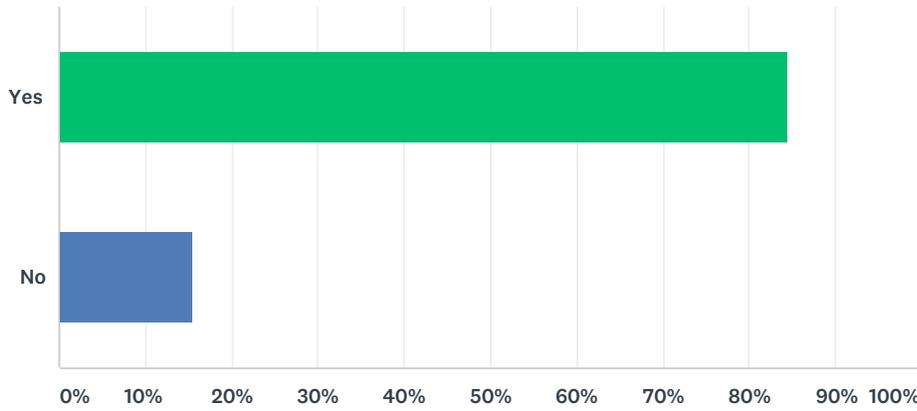
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	80.00%	12
No	20.00%	3
TOTAL		15

### Q4 Were the meetings conducted in a fair and impartial manner?

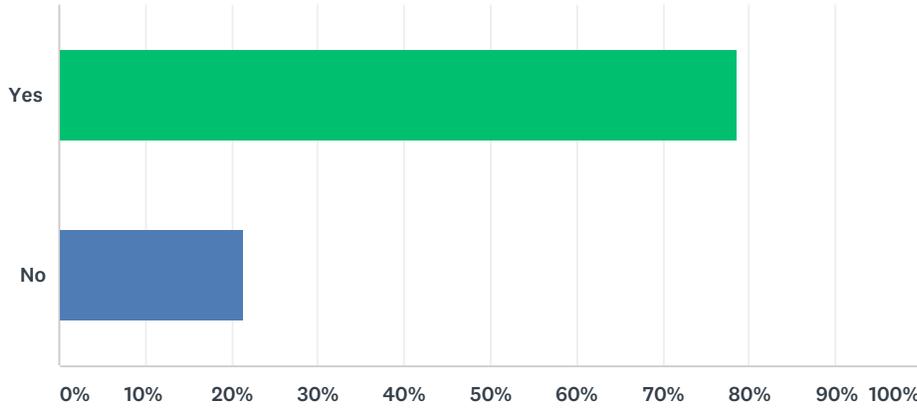
Answered: 13 Skipped: 2



ANSWER CHOICES	RESPONSES	
Yes	84.62%	11
No	15.38%	2
TOTAL		13

### Q5 Were outside experts utilized effectively?

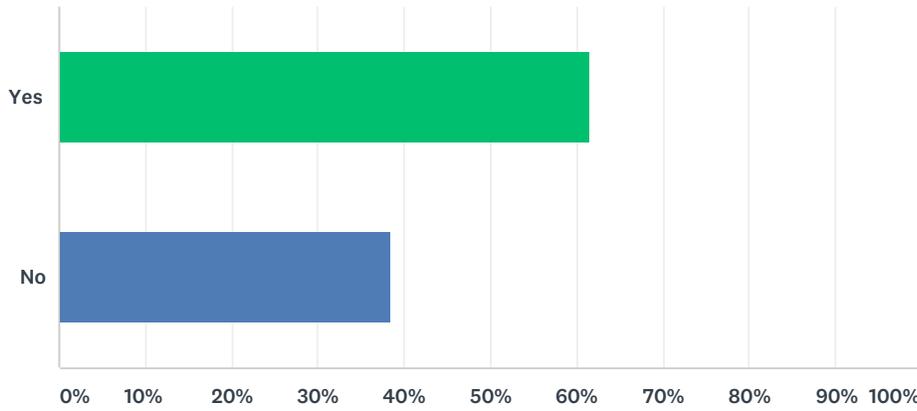
Answered: 14 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	78.57%	11
No	21.43%	3
TOTAL		14

### Q6 Were decisions made by majority vote?

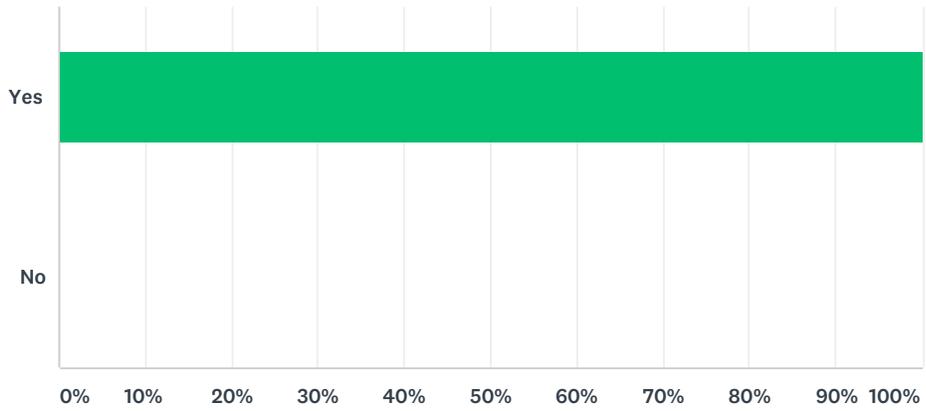
Answered: 13 Skipped: 2



ANSWER CHOICES	RESPONSES	
Yes	61.54%	8
No	38.46%	5
TOTAL		13

### Q7 Did the WSAT leaders utilize a consensus-building approach?

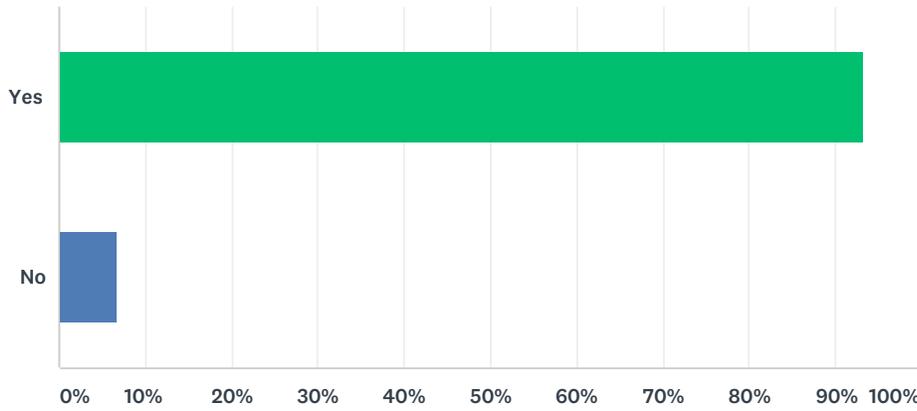
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	100.00%	15
No	0.00%	0
TOTAL		15

### Q8 Was the public involved or engaged in the decision-making process?

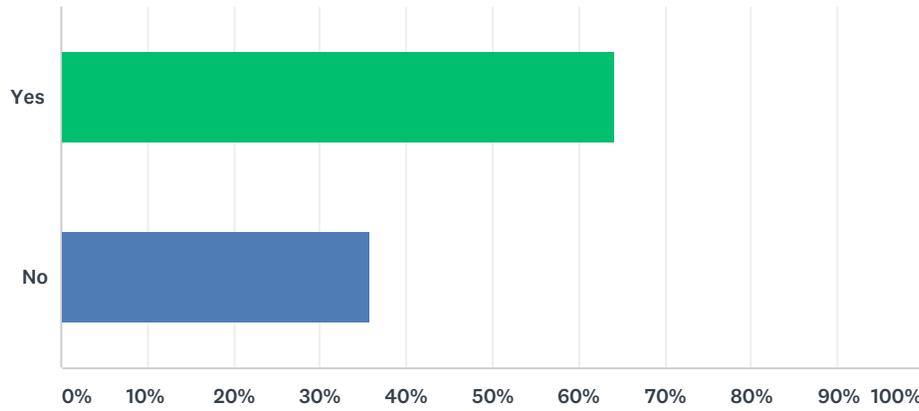
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	93.33%	14
No	6.67%	1
TOTAL		15

### Q9 Was the target audience clearly identified?

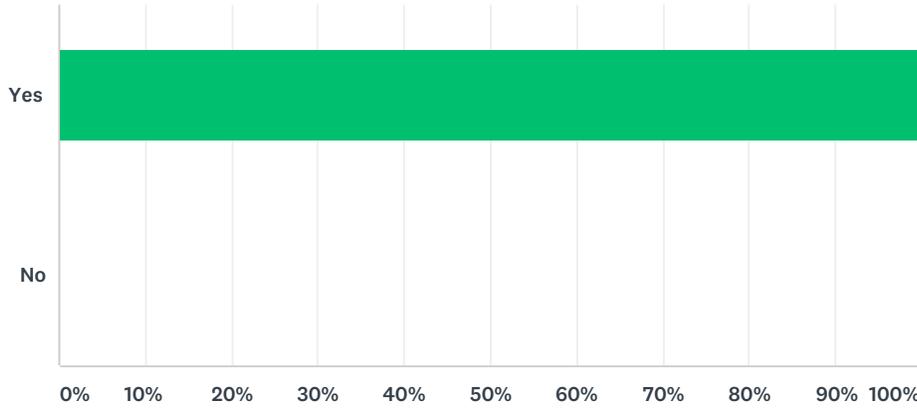
Answered: 14 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	64.29%	9
No	35.71%	5
TOTAL		14

### Q10 Was the range of options in the final report inclusive?

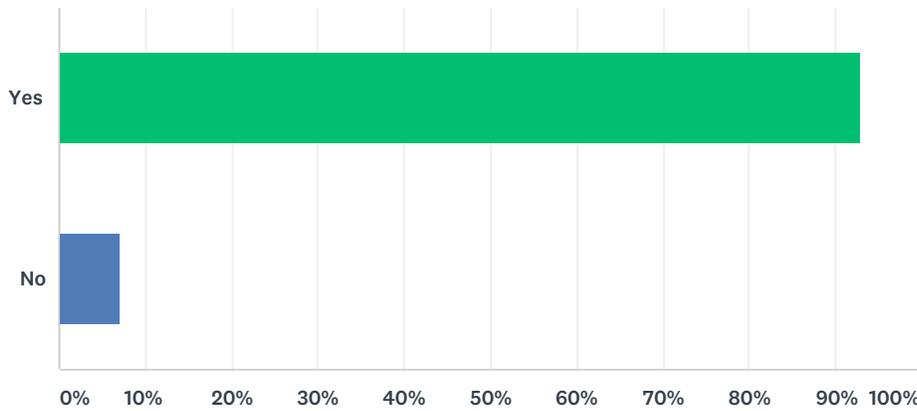
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	100.00%	15
No	0.00%	0
TOTAL		15

### Q11 Did the group have sufficient autonomy to produce an end product that reflected a group consensus?

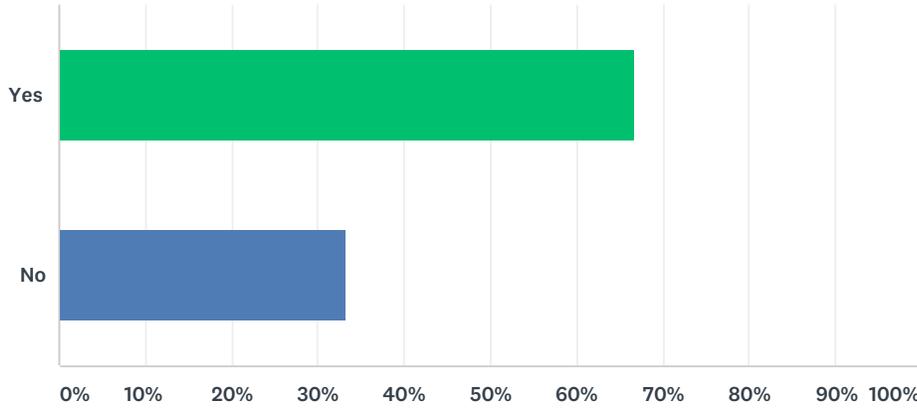
Answered: 14 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	92.86%	13
No	7.14%	1
TOTAL		14

### Q12 Are you a native Utahn?

Answered: 15 Skipped: 0



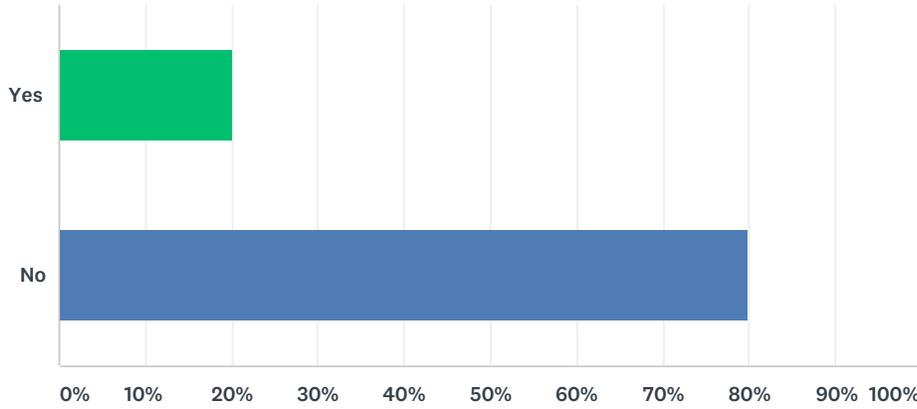
ANSWER CHOICES	RESPONSES	
Yes	66.67%	10
No	33.33%	5
TOTAL		15

## Q13 How many years have you lived in Utah?

Answered: 14 Skipped: 1

### Q14 Are you originally from the Salt Lake Valley?

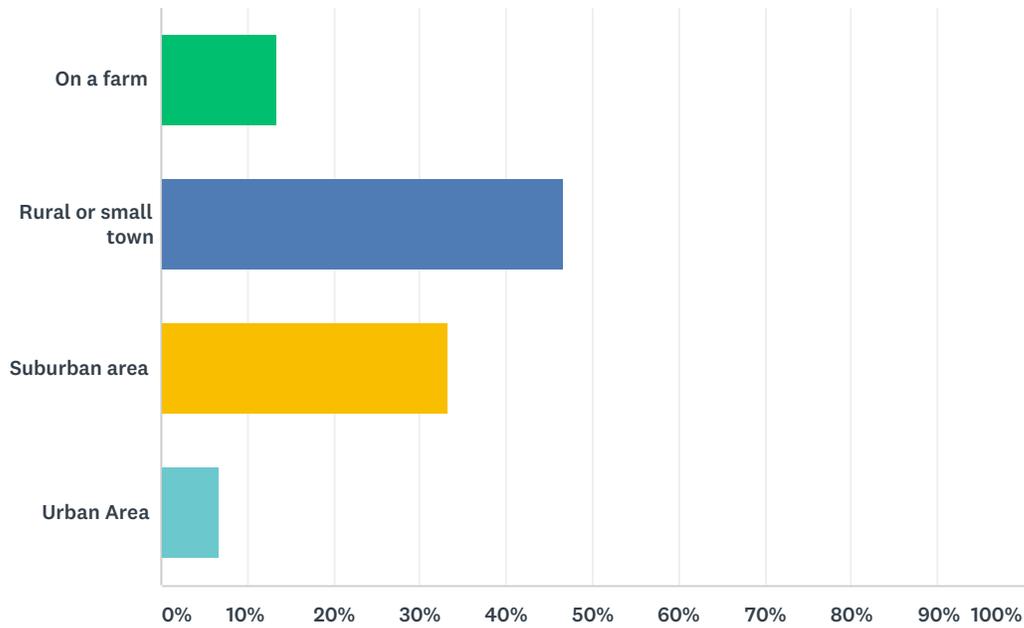
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	20.00%	3
No	80.00%	12
TOTAL		15

### Q15 How would you describe the place where you grew up? Please check one.

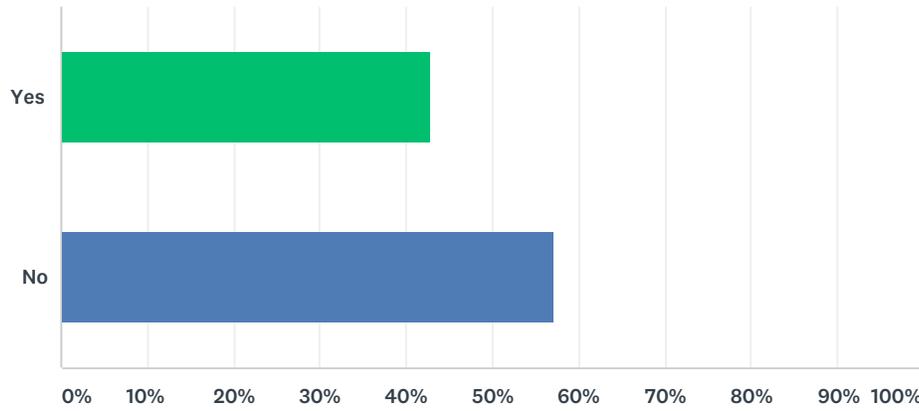
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
On a farm	13.33%	2
Rural or small town	46.67%	7
Suburban area	33.33%	5
Urban Area	6.67%	1
<b>TOTAL</b>		<b>15</b>

### Q16 Do you or any of your relatives currently farm?

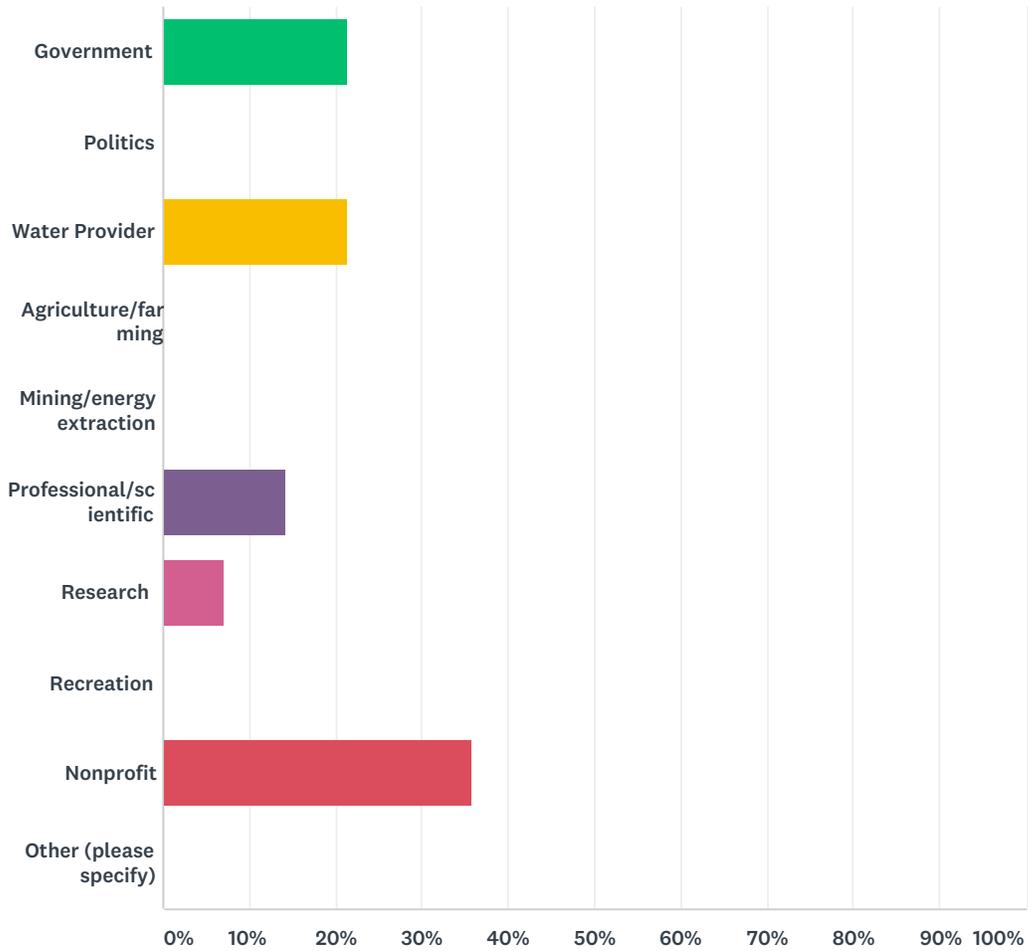
Answered: 14 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	42.86%	6
No	57.14%	8
TOTAL		14

### Q17 In what sector are you employed?

Answered: 14 Skipped: 1



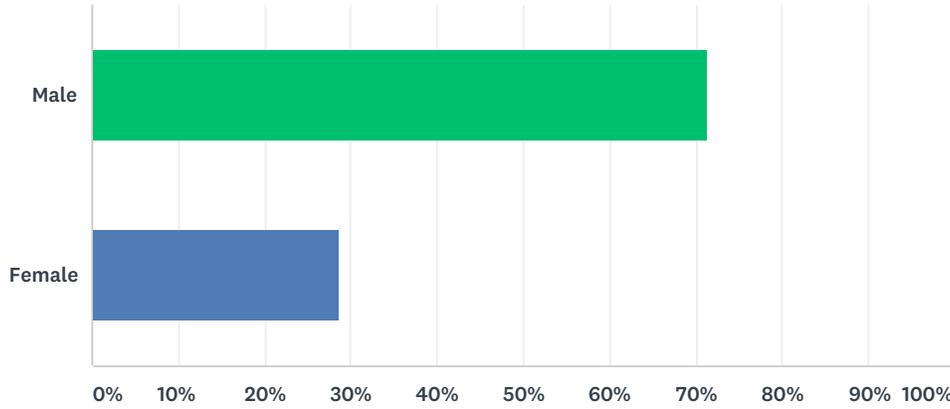
ANSWER CHOICES	RESPONSES	
Government	21.43%	3
Politics	0.00%	0
Water Provider	21.43%	3
Agriculture/farming	0.00%	0
Mining/energy extraction	0.00%	0
Professional/scientific	14.29%	2
Research	7.14%	1
Recreation	0.00%	0
Nonprofit	35.71%	5
Other (please specify)	0.00%	0
<b>TOTAL</b>		<b>14</b>

## Q18 What year were you born?

Answered: 12 Skipped: 3

### Q19 Are you male or female?

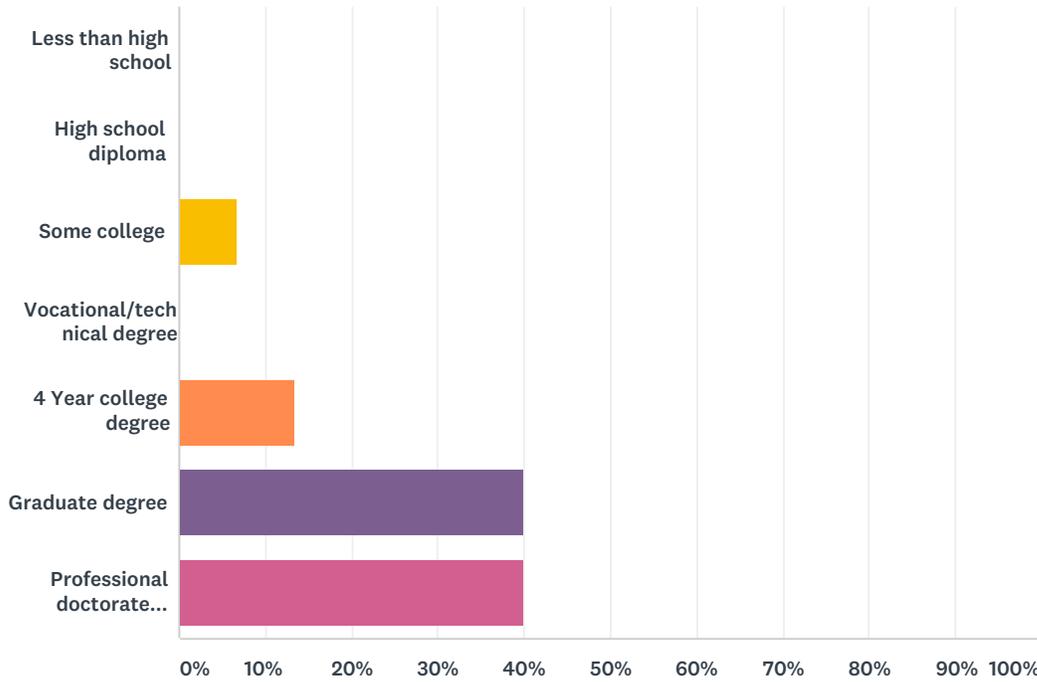
Answered: 14 Skipped: 1



ANSWER CHOICES	RESPONSES	
Male	71.43%	10
Female	28.57%	4
TOTAL		14

## Q20 Please indicate level of education completed:

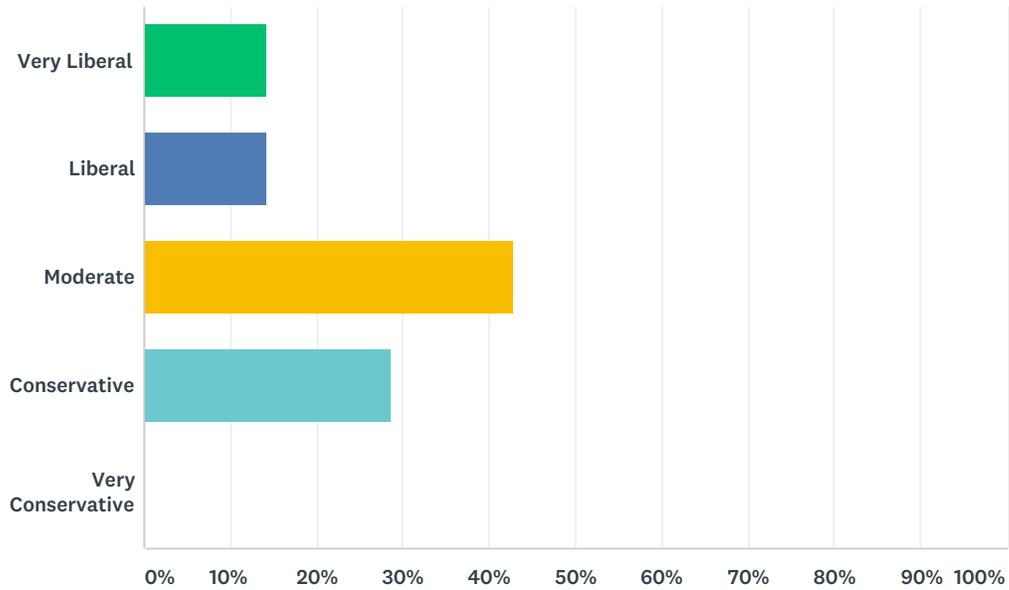
Answered: 15 Skipped: 0



ANSWER CHOICES	RESPONSES	
Less than high school	0.00%	0
High school diploma	0.00%	0
Some college	6.67%	1
Vocational/technical degree	0.00%	0
4 Year college degree	13.33%	2
Graduate degree	40.00%	6
Professional doctorate degree (for example: Ph.D., MD, JD)	40.00%	6
<b>TOTAL</b>		<b>15</b>

## Q21 Please choose the term that best describes your political orientation:

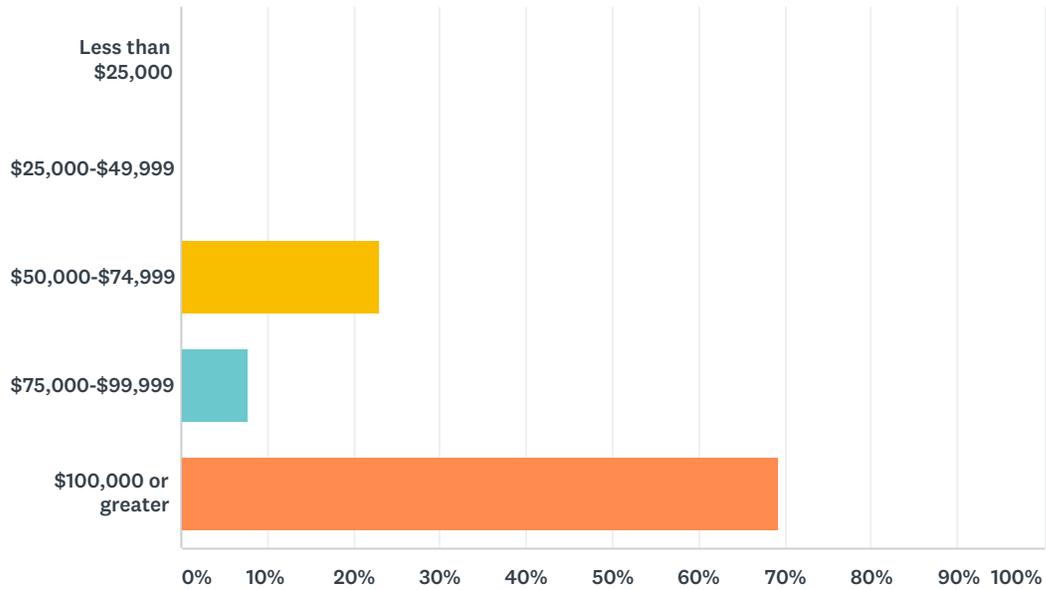
Answered: 14 Skipped: 1



ANSWER CHOICES	RESPONSES	
Very Liberal	14.29%	2
Liberal	14.29%	2
Moderate	42.86%	6
Conservative	28.57%	4
Very Conservative	0.00%	0
<b>TOTAL</b>		<b>14</b>

## Q22 Please indicate your household income (before taxes) in 2016:

Answered: 13 Skipped: 2

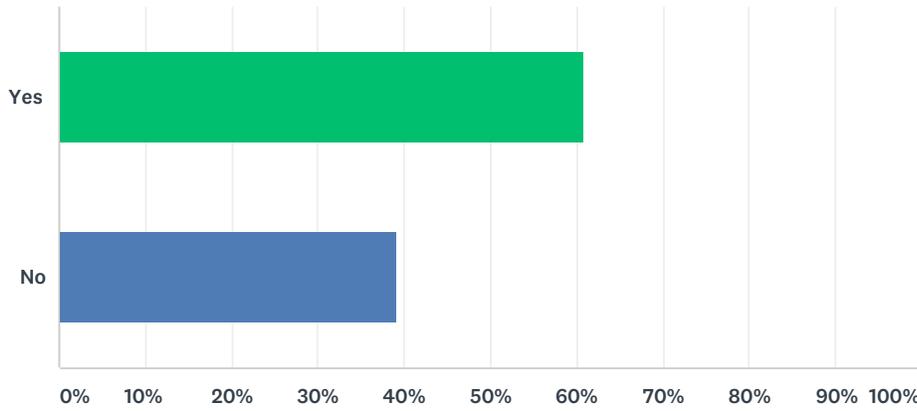


ANSWER CHOICES	RESPONSES	
Less than \$25,000	0.00%	0
\$25,000-\$49,999	0.00%	0
\$50,000-\$74,999	23.08%	3
\$75,000-\$99,999	7.69%	1
\$100,000 or greater	69.23%	9
<b>TOTAL</b>		<b>13</b>

Appendix E  
Non-Water Strategy Advisory Team (WSAT)  
Questionnaire Summary

# Q1 Was the process of selecting team members fair and appropriate?

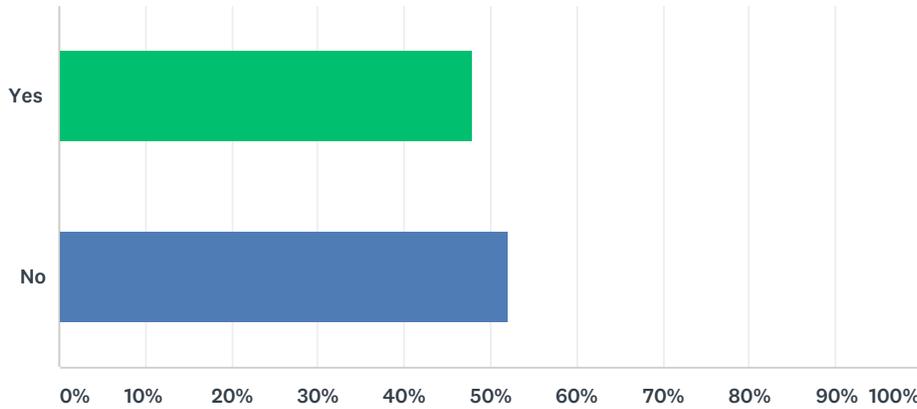
Answered: 23 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	60.87%	14
No	39.13%	9
TOTAL		23

## Q2 Were some people excluded you feel should have been members of the group?

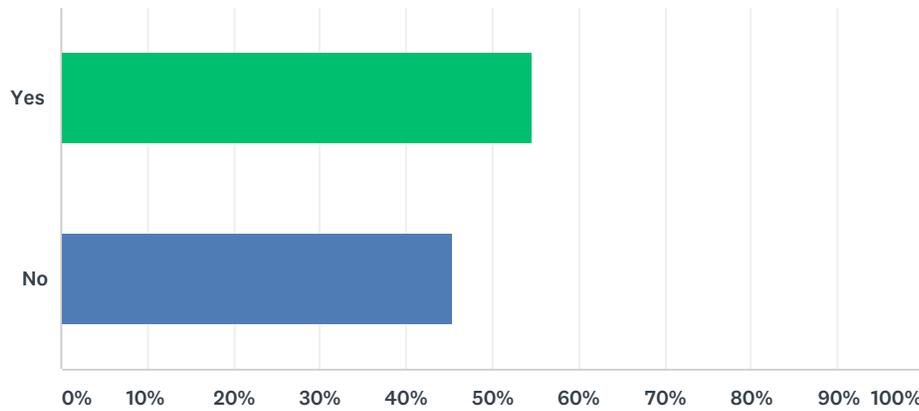
Answered: 23 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	47.83%	11
No	52.17%	12
TOTAL		23

### Q3 Was the Water Strategy Advisory Team balanced and did it accurately represent all stakeholders?

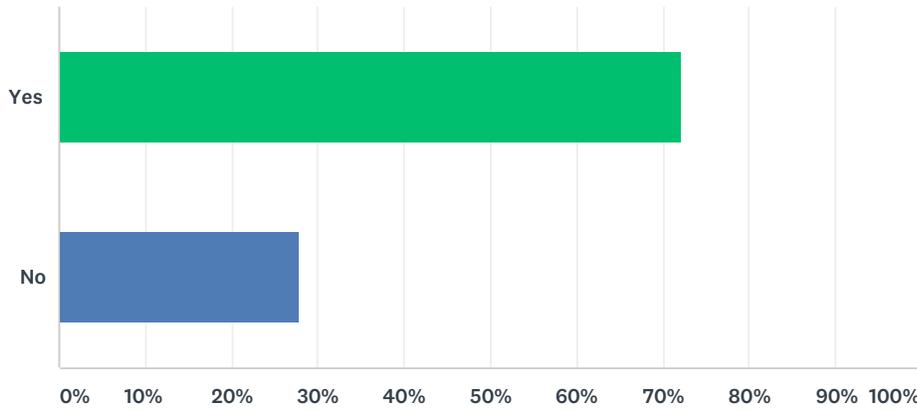
Answered: 22 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	54.55%	12
No	45.45%	10
TOTAL		22

### Q4 Were the meetings conducted in a fair and impartial manner?

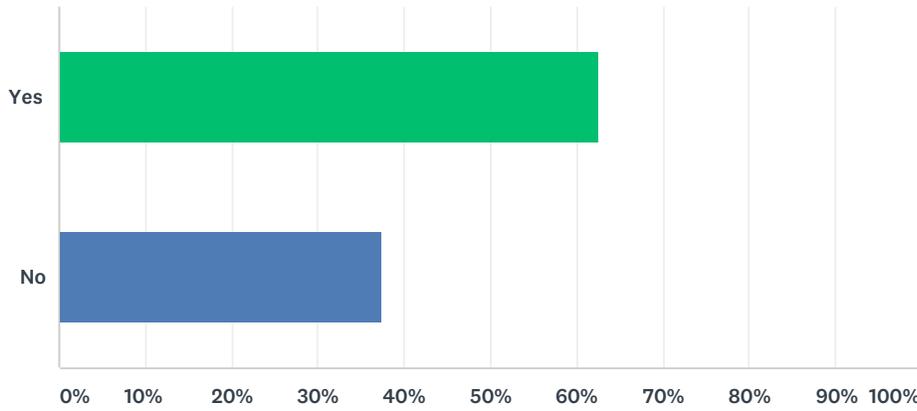
Answered: 18 Skipped: 5



ANSWER CHOICES	RESPONSES	
Yes	72.22%	13
No	27.78%	5
TOTAL		18

### Q5 Were outside experts utilized effectively?

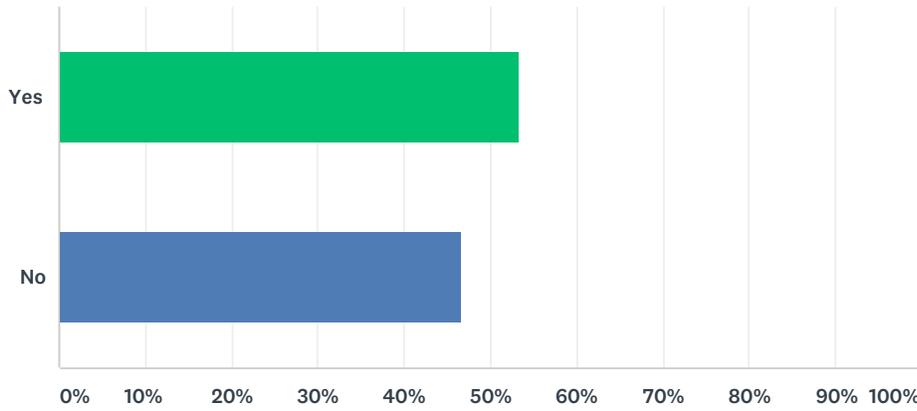
Answered: 16 Skipped: 7



ANSWER CHOICES	RESPONSES	
Yes	62.50%	10
No	37.50%	6
TOTAL		16

### Q6 Were decisions made by majority vote?

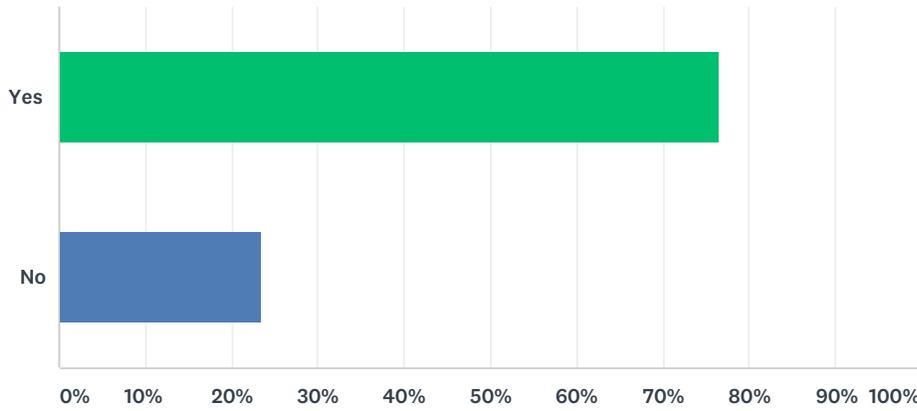
Answered: 15 Skipped: 8



ANSWER CHOICES	RESPONSES	
Yes	53.33%	8
No	46.67%	7
TOTAL		15

### Q7 Did the WSAT leaders utilize a consensus-building approach?

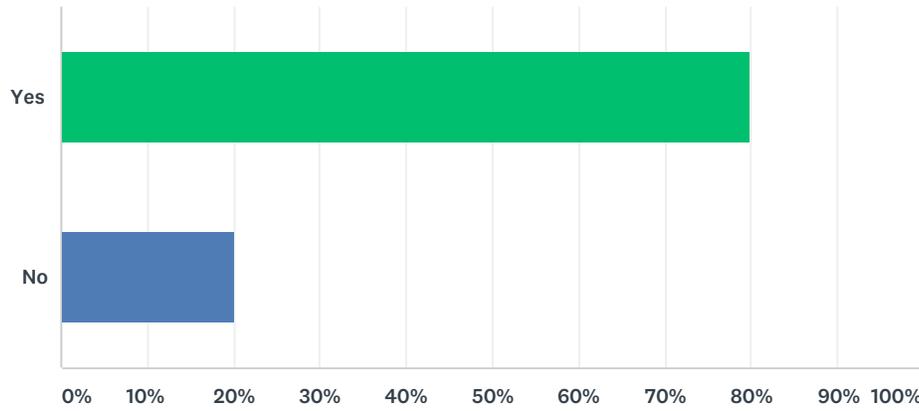
Answered: 17 Skipped: 6



ANSWER CHOICES	RESPONSES	
Yes	76.47%	13
No	23.53%	4
TOTAL		17

### Q8 Was the public involved or engaged in the decision-making process?

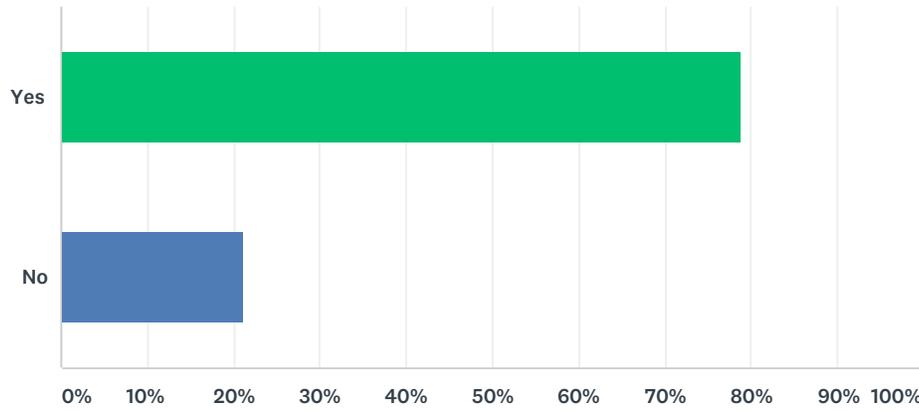
Answered: 20 Skipped: 3



ANSWER CHOICES	RESPONSES	
Yes	80.00%	16
No	20.00%	4
TOTAL		20

### Q9 Was the target audience clearly identified?

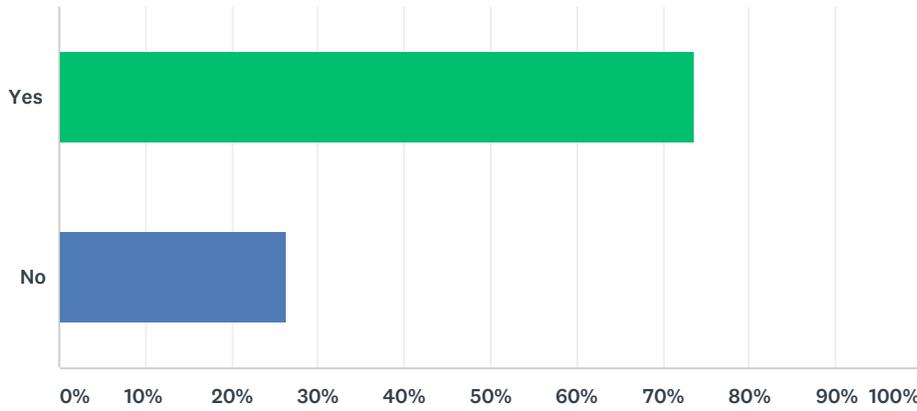
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
Yes	78.95%	15
No	21.05%	4
TOTAL		19

### Q10 Was the range of options in the final report inclusive?

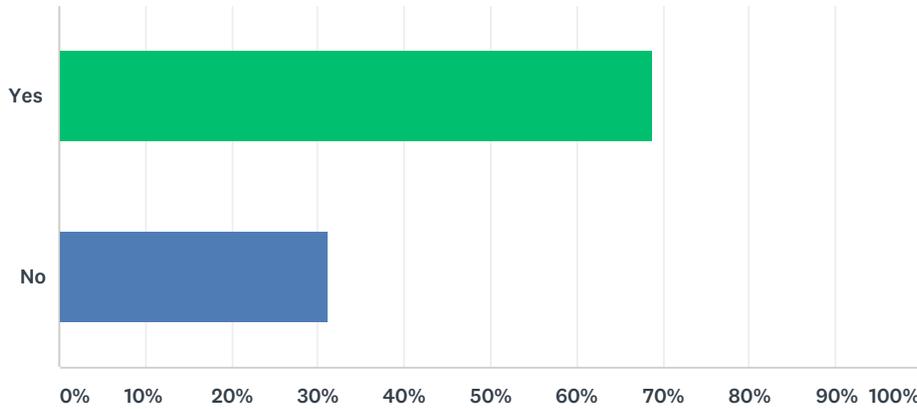
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
Yes	73.68%	14
No	26.32%	5
TOTAL		19

### Q11 Did the group have sufficient autonomy to produce an end product that reflected a group consensus?

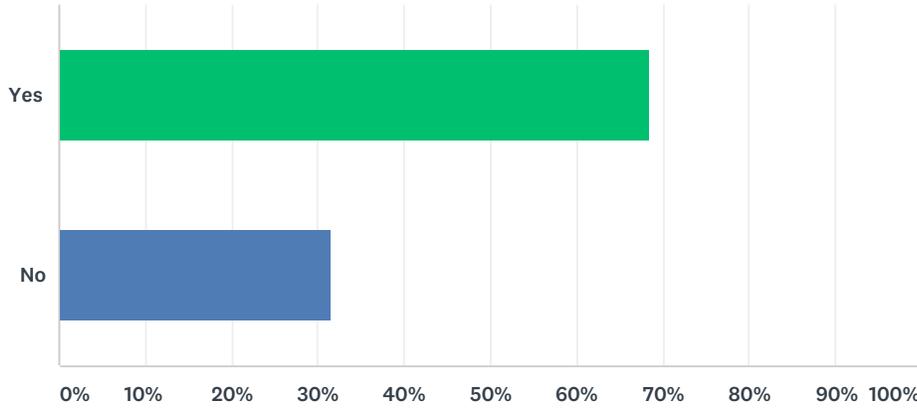
Answered: 16 Skipped: 7



ANSWER CHOICES	RESPONSES	
Yes	68.75%	11
No	31.25%	5
TOTAL		16

### Q12 Are you a native Utahn?

Answered: 19 Skipped: 4



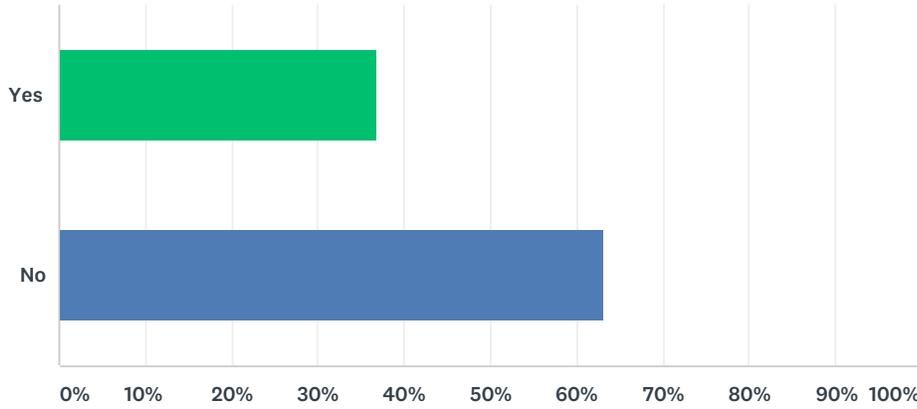
ANSWER CHOICES	RESPONSES	
Yes	68.42%	13
No	31.58%	6
TOTAL		19

## Q13 How many years have you lived in Utah?

Answered: 19 Skipped: 4

### Q14 Are you originally from the Salt Lake Valley?

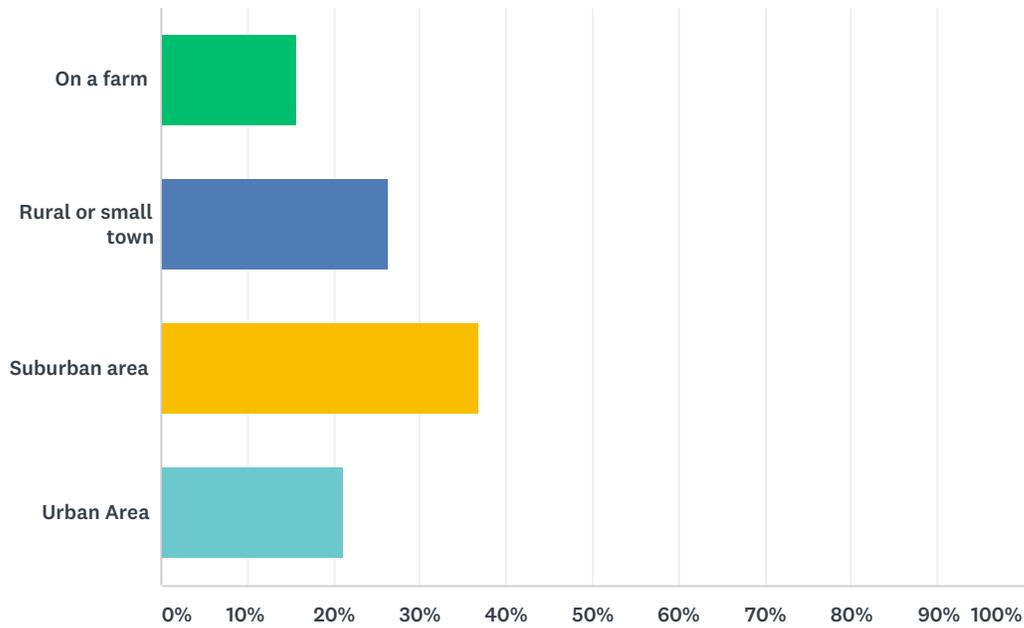
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
Yes	36.84%	7
No	63.16%	12
TOTAL		19

### Q15 How would you describe the place where you grew up? Please check one.

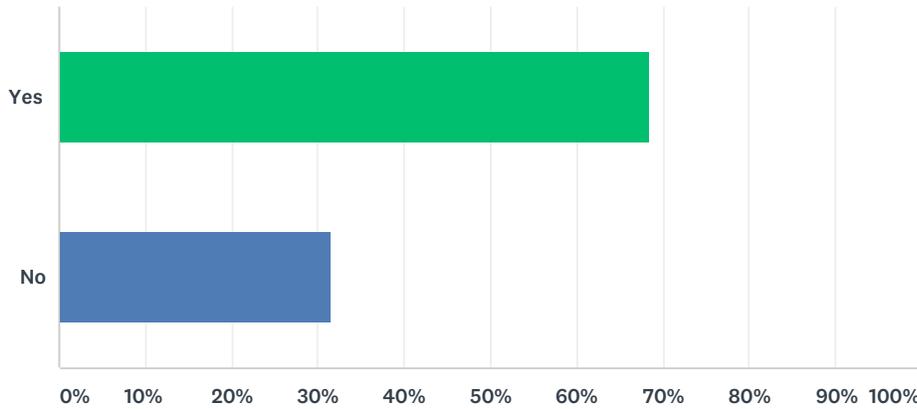
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
On a farm	15.79%	3
Rural or small town	26.32%	5
Suburban area	36.84%	7
Urban Area	21.05%	4
TOTAL		19

### Q16 Do you or any of your relatives currently farm?

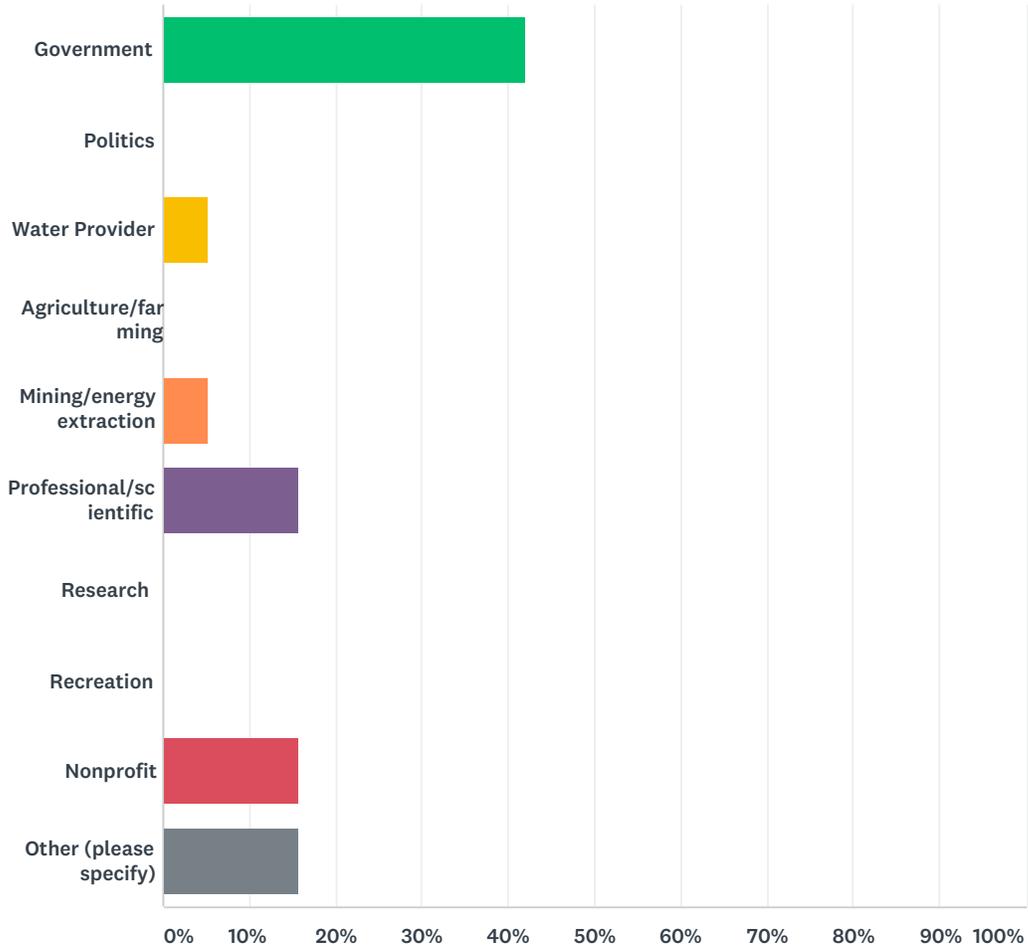
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
Yes	68.42%	13
No	31.58%	6
TOTAL		19

### Q17 In what sector are you employed?

Answered: 19 Skipped: 4



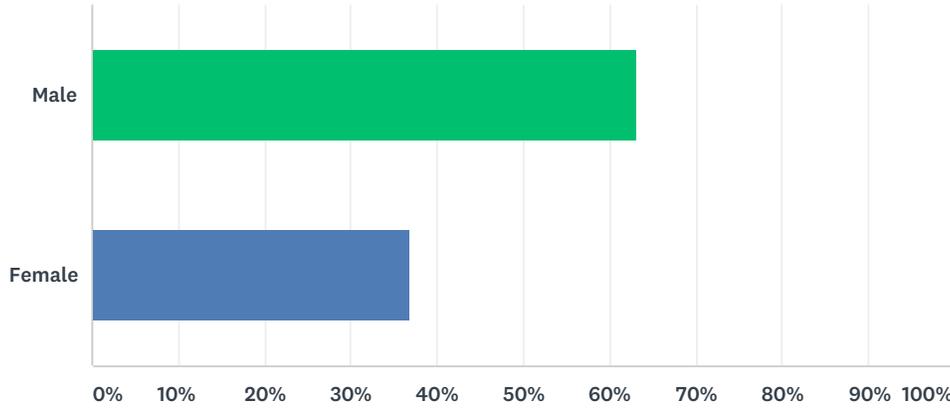
ANSWER CHOICES	RESPONSES	
Government	42.11%	8
Politics	0.00%	0
Water Provider	5.26%	1
Agriculture/farming	0.00%	0
Mining/energy extraction	5.26%	1
Professional/scientific	15.79%	3
Research	0.00%	0
Recreation	0.00%	0
Nonprofit	15.79%	3
Other (please specify)	15.79%	3
<b>TOTAL</b>		<b>19</b>

## Q18 What year were you born?

Answered: 17 Skipped: 6

### Q19 Are you male or female?

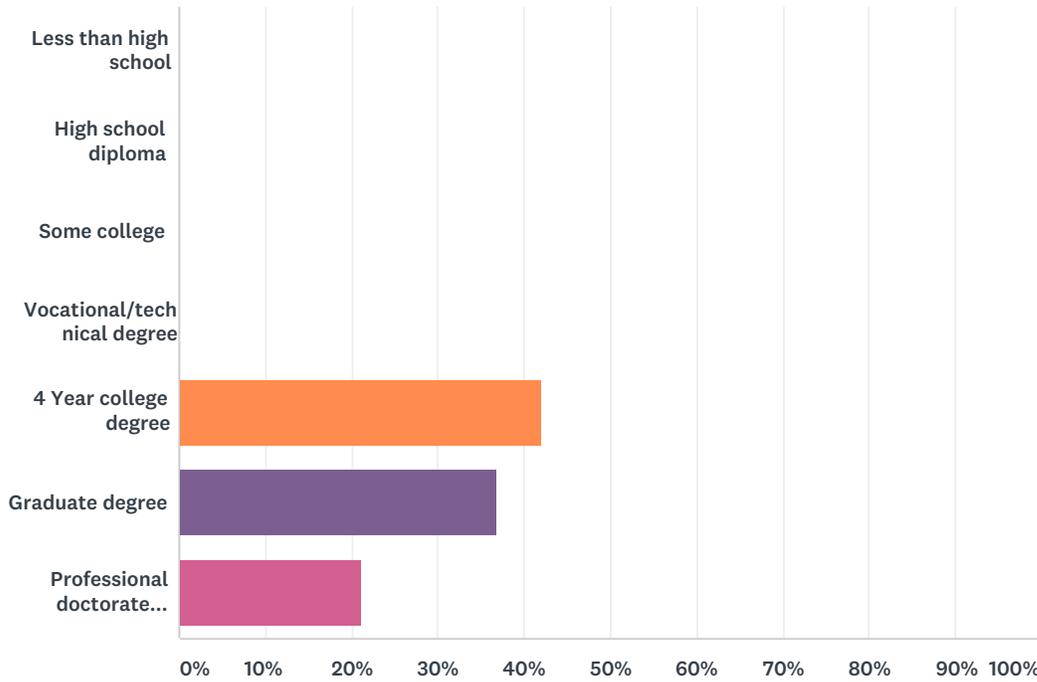
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
Male	63.16%	12
Female	36.84%	7
TOTAL		19

### Q20 Please indicate level of education completed:

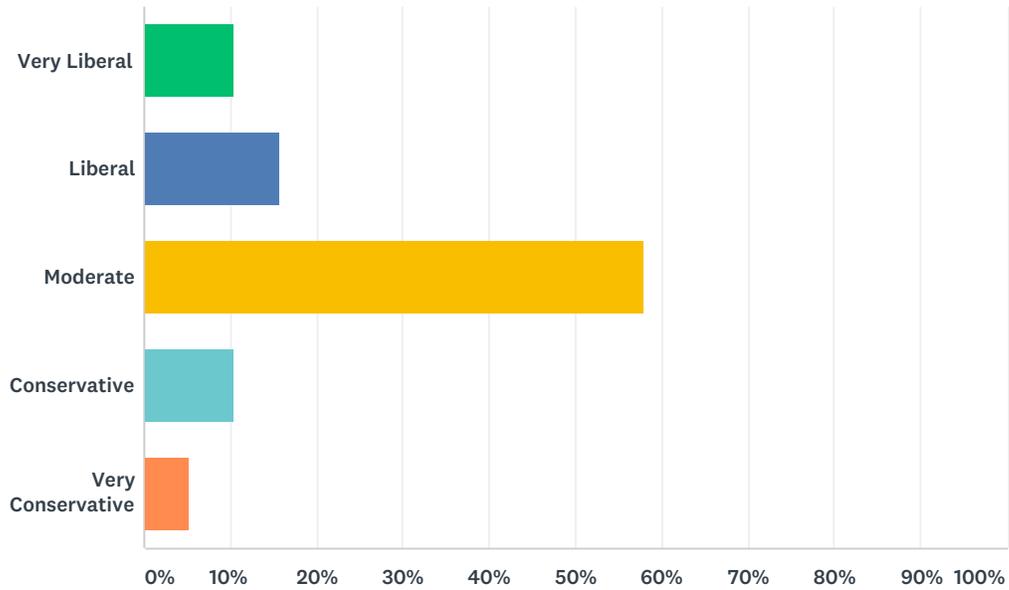
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES	
Less than high school	0.00%	0
High school diploma	0.00%	0
Some college	0.00%	0
Vocational/technical degree	0.00%	0
4 Year college degree	42.11%	8
Graduate degree	36.84%	7
Professional doctorate degree (for example: Ph.D., MD, JD)	21.05%	4
<b>TOTAL</b>		<b>19</b>

## Q21 Please choose the term that best describes your political orientation:

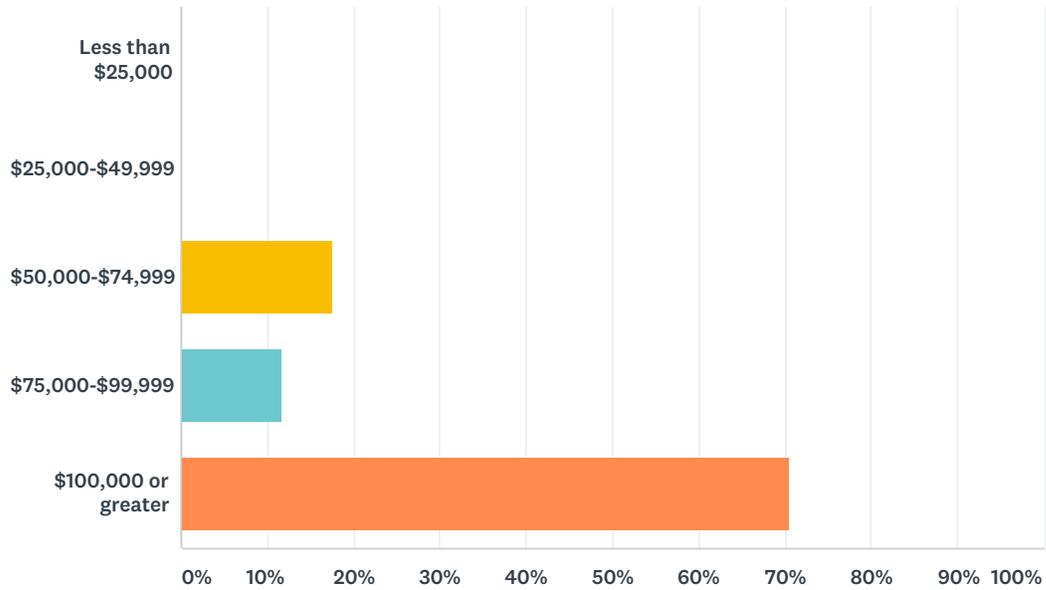
Answered: 19 Skipped: 4



ANSWER CHOICES	RESPONSES
Very Liberal	10.53% 2
Liberal	15.79% 3
Moderate	57.89% 11
Conservative	10.53% 2
Very Conservative	5.26% 1
<b>TOTAL</b>	<b>19</b>

## Q22 Please indicate your household income (before taxes) in 2016:

Answered: 17 Skipped: 6



ANSWER CHOICES	RESPONSES	
Less than \$25,000	0.00%	0
\$25,000-\$49,999	0.00%	0
\$50,000-\$74,999	17.65%	3
\$75,000-\$99,999	11.76%	2
\$100,000 or greater	70.59%	12
<b>TOTAL</b>		<b>17</b>

# Researching Optimal Methods for Educating Hydrologists and Future Water Managers Using USGS National Water Census Data Portal

## Basic Information

<b>Title:</b>	Researching Optimal Methods for Educating Hydrologists and Future Water Managers Using USGS National Water Census Data Portal
<b>Project Number:</b>	2016UT208S
<b>USGS Grant Number:</b>	G16AP00110
<b>Sponsoring Agency:</b>	U.S. Geological Survey
<b>Start Date:</b>	3/4/2016
<b>End Date:</b>	1/3/2018
<b>Funding Source:</b>	104S
<b>Congressional District:</b>	None
<b>Research Category:</b>	None
<b>Focus Categories:</b>	
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	

## Publications

1. Nelson, Jake; Ames, Daniel P.; and Blodgett, David (2018) "Open Hydrology Courseware Using the United States Geological Survey's National Water Census Data Portal," Open Water Journal: Vol. 5 : Iss. 1 , Article 1. Available at: <https://scholarsarchive.byu.edu/openwater/vol5/iss1/1>
2. Nelson, Jacob D., 2017, "Open Hydrology Courseware Using the United States Geological Survey's National Water Census Data Portal, MS Dissertation," Department of Civil and Environmental Engineering, College of Engineering, Brigham Young University, Provo, UT, 43.

**Researching Optimal Methods for Educating  
Hydrologists and Future Water Managers  
Using the USGS National Water Census Data Portal**

**FINAL REPORT**

2016UT208S

by

Jacob D. Nelson  
Daniel P. Ames

Culminating as a MS thesis by Jacob D. Nelson

2017

Open Hydrology Courseware Using the United States Geological Survey's National Water  
Census Data Portal

Jacob Daniel Nelson

A project submitted to the  
faculty of Brigham Young  
University  
in partial fulfillment of the requirements for the  
degree of Master of Science

Daniel P. Ames, Chair

E. James Nelson

A. Woodruff Miller

Department of Civil and Environmental  
Engineering Brigham Young University

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## ABSTRACT

### Open Hydrology Courseware Using the United States Geological Survey's National Water Census Data Portal

Jacob Daniel Nelson  
Department of Civil and Engineering,  
BYU

Master of Science

The United States Geological Survey (USGS) is the primary U.S. government agency for water data collection and dissemination. In this role, the USGS has recently created and deployed a National Water Census Data Portal (NWC-DP) which provides access to streamflow, evapotranspiration, precipitation, aquatic biology and other data at the national level.

Recognizing the value of these data sets for hydrologic science education, this paper presents an effort to bridge the gap between pencil and paper-based hydrology curriculum and the USGS NWC-DP resource. Specifically, we have developed an R package, National Water Census Education (NWCEd), and five associated laboratory exercises that integrate R and web services based access to the NWC-DP datasets. Using custom functions built into the NWCEd, students are able to access unprecedented amounts of hydrologic data from the NWC-DP which can be applied to current hydrology curriculum and analyzed using new R software.

Keywords: hydrology, education, software, R, National Water Census Data Portal

## **ACKNOWLEDGEMENTS**

I wish to acknowledge the United States Geological Survey (USGS) for funding and participation in the development of this project under award number 200251-00001-176 (G16AP00110). I wish to thank David Blodgett of the USGS and Dr. Dan Ames of Brigham Young University for their guidance and mentorship throughout the development of this project. I would especially like to thank Dr. Dan Ames for providing me the opportunity to advance my knowledge in principles of hydrology and programming through working on this project. I would like to thank Melanie Latham for her help in editing the laboratory exercises. I would also like to thank Shawn Crawley, Bryce Anderson, Zhiyu Li, Xiaohui Qiao, and Sarva Pulla, who work in the BYU Hydroinformatics lab, for helping me understand programming development through using GitHub and for their encouragement and support. I would also like to thank my family for their support and encouragement while completing this project.

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## **PROBLEM DESCRIPTION AND NEED**

As the hydrologic scientific community continues to adopt new technology, there becomes a need for educators to incorporate new technology and techniques into their curriculum (Thompson et al. 2012; Wagener et al. 2012). In hydroinformatics courses in particular, there is great potential to use online tools and data to aid the educational experience (Popescu et al. 2012). In comparison to pencil-and-paper-based laboratory assignments, data-driven laboratory exercises with interactive modeling and visualization components can improve learning and better help prepare students to enter the profession (Sanchez et al. 2016).

Standalone interactive technology based tools can also reduce the need for in-classroom or instructor-led instruction, thereby increasing learning (Ruddell and Wagener 2013).

While there exists a plethora of new software which could be implemented in university classrooms, research has shown that many educators struggle or are averse to amending their curriculum. Several roadblocks can contribute to this problem, including “a lack of access to easily adoptable curriculum materials and a lack of time and training to learn constantly changing tools and methods” and that implementing new technology “should emphasize conceptual learning, and should be used to complement rather than replace lecture-based pedagogies” (Merwade and Ruddell 2012). Indeed, in hydrologic research, reusable code and data should always be made available so that scientific results can be reproduced (Hutton et al.). Such availability of code and data is equally important in the classroom.

One specific challenge in technology-augmented learning is in the incorporation of web based data resources, such as those provided by the United States Geological Survey (USGS), into an introductory hydrology course. The USGS has made many attempts to make their data holdings accessible to the general public and to scientists through, for example, the National Map ([www.nationalmap.gov](http://www.nationalmap.gov)) (Simley and Carswell Jr 2009), South Florida Information Access Data Exchange ([http://www1.usgs.gov/csas/obis-usa/data\\_search\\_and\\_access.html](http://www1.usgs.gov/csas/obis-usa/data_search_and_access.html)), the Geo Data Portal (Blodgett 2011), and Biodiversity Information Serving Our Nation (BISON) (<https://bison.usgs.gov/#home>) (Hanken 2013). In 2001, the USGS released a public web interface for their National Water Information System (NWIS) called USGS Water Data for the Nation (<http://dx.doi.org/10.5066/F7P55KJN>). This website includes simple tutorials on navigating the website interface and methods for downloading hydrologic data. Many of the web-based data sources provided by the USGS have either examples or primers on how to use their tools, but no additional resources which could be integrated with or support current hydroscience curriculum.

The Consortium of Universities for the Advancement of Hydrologic Science, Inc (CUAHSI), has made extensive efforts to increase the academic use of USGS and other water-related, web-based data sets by educators through various initiatives, webinars, and conferences (<https://www.cuahsi.org/Posts/Cyberseminars>) (CUAHSI 2012; Keim et al. 2014; Morsy et al. 2016; Tarboton et al. 2014; Tarboton et al. 2011). These efforts have generally focused on the CUAHSI Hydrologic Information System (Ames et al. 2009; Tarboton et al. 2009), which has included USGS NWIS datasets since its inception. CUAHSI resources include training modules

that provide step-by-step instruction on how to access many datasets through CUAHSI's HydroClient and how to create data visualizations in Microsoft Excel and RStudio (Brazil 2016a; Brazil 2016b).

Another data portal has been developed by the USGS called the National Water Census Data Portal (NWC-DP) (<https://cida.usgs.gov/nwc/>). This portal provides public access to large amounts of hydrologic data, collected through the USGS's National Water Census (NWC) research program (<https://water.usgs.gov/watercensus/water-budgets.html>). The NWC is responsible for the collection of precipitation, evapotranspiration, and stream runoff data. Along with NWC data, web-based tools are available in the portal to provide a means whereby the data can be analyzed. NWC-DP provides support for making informed decisions affecting water availability and usage (<https://water.usgs.gov/watercensus/>). The NWC-DP, however, does not have an educational component to instruct users how to access the associated tools and data.

## **RESEARCH OBJECTIVES**

Missing in these efforts to communicate USGS water resources data to educators and students, is an interactive, code-based set of educational materials that integrates scripting for data access, retrieval and analysis with basic hydrologic principles. In this paper, we present the development of the National Water Census Education R package (NWCEd) and corresponding open courseware educational laboratory exercises which serve to fill this gap.

The remainder of this paper is organized as follows. The methods section presents a description of the development of the NWCEd package and its associated functions. A discussion on the development of five educational laboratory exercises is provided, including established learning objectives for the materials. The Results section discusses how the NWCEd technology supports the content of each of the laboratory exercises. An analysis of the correspondence between laboratory content and the established learning objectives is also included. The conclusion provides recommendations for future research with regards to the effectiveness of laboratory exercises in improving learning.

## **METHODOLOGY**

The National Water Census Education R-package (NWCEd) and associated laboratory exercises serve as tools which introduce hydroscience students to USGS hydrologic time series datasets, processing and analysis tools, and hands-on learning activities. This section describes the NWCEd, its associated package components and functions, and external R-packages required for complete NWCEd functionality. Discussion is also provided on the creation of the laboratory exercises.

### **Documentation**

The NWCEd R-package was developed in RStudio (RStudio-Team 2015) and contains several custom R functions, preloaded data tables, NWC-DP screenshot images, and HTML and

R Markdown (.Rmd) files of the laboratory exercises. Much of the documentation was generated automatically using Roxygen2 (<https://cran.r-project.org/web/packages/roxygen2/vignettes/rd.html>), including seven Markdown (.Rd) files describing the custom-made R functions and the NAMESPACE file which contains the list of functions made available through the package. The documentation also includes a manually created README file which provides instructions for installing the NWCEd package, laboratory content, required external R packages, links for viewing the laboratory exercises in a web browser, and licensing information (<http://water.usgs.gov/software/help/notice/>). Complete NWCEd documentation and source code is available at <https://github.com/NWCEd/NWCEd>.

### Custom NWCEd R-package Functions

One of the primary objectives of the NWCEd package is to allow users to access hydrologic time series datasets from the NWC-DP in RStudio. To do this, we created custom functions to retrieve the respective datasets from a USGS THREDDS server (<http://doi.org/10.5065/D6N014KG>). The process is outlined in Figure 1 below.

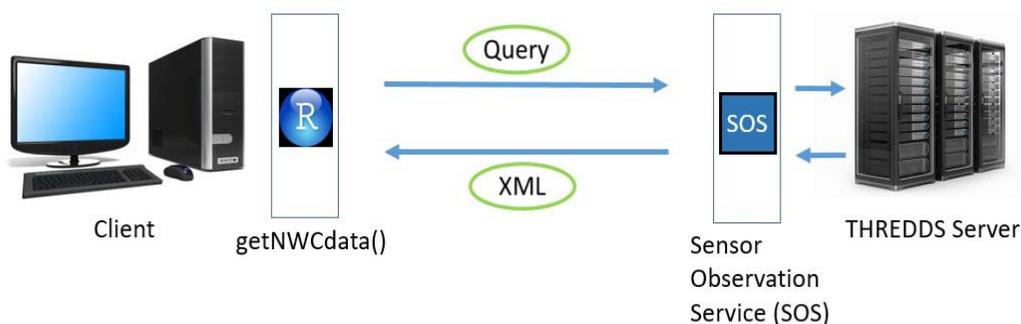


Figure 1: The getNWCdata retrieves hydrologic data from USGS servers and returns an RStudio data table to the user.

The user builds a query for a desired hydrologic dataset based on a user-selected hydrologic unit code (HUC) using the getNWCdata function. Using an HTTP protocol, the query is sent to a Sensor Observation Service (SOS) web service (Jirka et al. 2012). The SOS web service retrieves the desired dataset and returns it to the user formatted as XML text (Erl 2004). The getNWCdata function then parses the XML file into an RStudio data table view.

Another function, getNWCWatershed, extracts watershed geometry information from a USGS server in a similar way as the getNWCdata function. A query is built using the getNWCWatershed function and is sent using an http protocol. The query interacts with the web feature service (WFS) (Peng and Zhang 2004). The WFS interacts with GeoServer to obtain a polygon feature associated with the specified HUC. A GeoJSON text file (Butler et al. 2008) containing the watershed boundary coordinates is then returned to the user and converted to a map representation for visualization. To improve visualization, the polygon fill option is turned

off, subsequently displaying only the boundary of the watershed. The boundary is then laid over a base map provided by the external Leaflet R package (Graul 2016) which allows users to zoom in and out, as well as pan around the area of their desired watershed.

A Log-Pearson Type III function was developed for the purpose of teaching concepts related to hydrologic probability distributions and return periods. This function, called Lp3, implements the method described by Oregon State University (<http://streamflow.engr.oregonstate.edu/analysis/floodfreq/#log>). The Lp3 function receives two arguments: a user-named variable containing previously downloaded NWC-DP data, and a dataset type such as “prcp” for precipitation or “streamflow” for streamflow data. The Lp3 function then returns a Log-Pearson Type III distribution plot. Other functionality has been provided in the NWCEd package including the annualize function which converts time series datasets from daily time series to annual time series, and the getNWISsite which verifies the location of an NWIS gage.

Table 1 lists other external open source R packages used in this project together with each specific, respective function. A description of the application of these packages in the project is provided later under the Laboratory Exercises Development section.

Table 1: NWCEd works in concert with functionalities provided by external R packages.

Package Name	Functionality Incorporated
datasets	Preloaded datasets
devtools	Install NWCEd from GitHub
dplyr	Data manipulation
foreach	Looping
ggplot2	Plotting
gridExtra	Grid graphics
iterators	Iterating
leaflet	Interactive map
psych	Summary statistics
scales	Graphical aesthetics
stats	Statistics functions

Each of these packages are hosted on the Comprehensive R Archive Network (CRAN) website (R-Core-Team 2016). The packages are downloaded from CRAN into an instance of RStudio using default RStudio functions. The NWCEd package is downloaded from GitHub into an instance of RStudio using the functionality of the devtools package as listed in the table above. An illustration of the relationship between the local instance of RStudio and GitHub, CRAN, and the NWC-DP is provided as Figure 2 below.

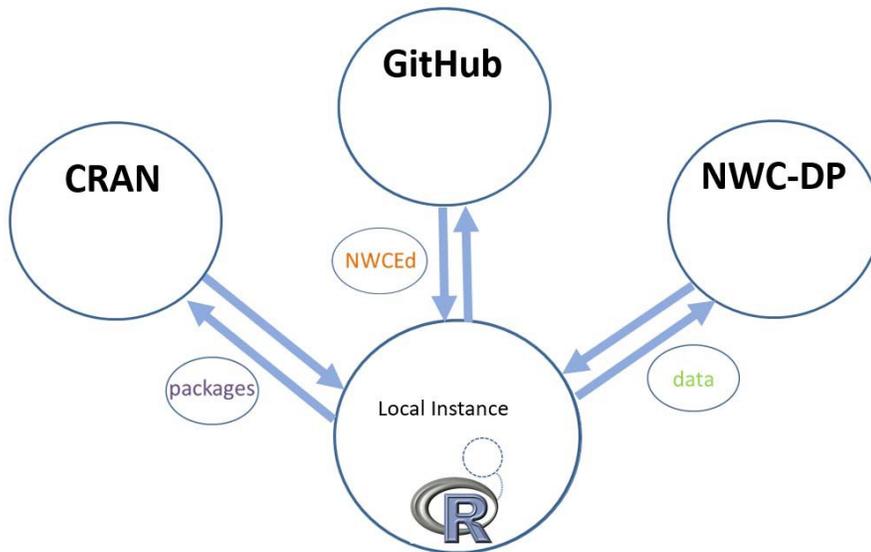


Figure 2: NWCEd, external R packages, and data from NWC-DP is downloaded into a local instance of RStudio.

## Laboratory Exercises Development

A core goal of this work was to develop a set of laboratory exercises that expose the

National Water Census data and web services to hydrology students and educators. These exercises were developed in RStudio. The raw content for these labs was written in html, R Markdown, and Javascript in order to achieve the desired interactive functionality. The knitr package was then used to read each of the languages and convert the contents into interactive html pages (Xie 2016).

The labs have many shared, built-in features, including layout, image display, and interactive buttons. The specific layout of the lab documents comes from an R Markdown document template. The template used for the NWCEd labs was an html template. The “cerulean” theme was selected which corresponds to the blue font of the labs. An interactive table of contents is also a common layout feature. This feature allows the user to click on the desired section within a given lab and automatically be relocated within the document to the specified location.

Each of the five labs are set up to instruct students on how to use the NWC-DP. This is done by including several screenshots of the NWC-DP as part of the content. Relative paths for these images were coded in R Markdown into the raw document, and knitr was used to generate the images into the html documents with varying formatting styles.

Another feature of the labs is the ability to toggle code blocks, hints, and answers to questions on and off using Javascript code. A simple function was included in the raw document which defaults the toggle settings to “none”, meaning that the information is not shown. The user can then click the blue toggle buttons to reveal the hidden information.

The plotting capabilities of the ggplot2 package (Wickham 2009) were used extensively throughout the development of the third, fourth, and fifth labs. The library was used to produce boxplots, histograms, probability and fitted distributions, time series, and double-mass curve plots. Knitr was then used to convert ggplot2 code, written in R Markdown, into the desired plots embedded into the html pages. More information regarding the use of the plots will be given in the Results section.

## Laboratory Content

We selected content for the labs to coincide with topics discussed in the commonly used college textbook, Hydrology – Water Quantity and Quality Control (Wanielista et al. 1997) while incorporating the use of RStudio and data from the NWC-DP. The hydrology concepts discussed in the labs include locating metadata for hydrologic datasets and tools provided by the NWC-DP, graphing analysis methods for hydrologic datasets, water balances, double-mass curve analyses, and Log-Pearson Type III distributions. Other concepts mentioned include common statistics terms such as range, skew, and kurtosis and an introduction to simple R functions in RStudio. Table 2 below provides a comprehensive summary of the content contained in each of the labs.

Table 2: The content of the laboratory exercises associated with NWCEd was summarized with the associated NWCEd functions.

Lab #	Material Description	NWCEd Functions
Lab 1	<ul style="list-style-type: none"> <li>• Accessing the NWC-DP</li> <li>• NWC-DP Water Budget tool</li> <li>• Introduction to HUC's</li> </ul>	
Lab 2	<ul style="list-style-type: none"> <li>• Accessing the NWC-DP</li> <li>• NWC-DP Water Streamflow Stats tool</li> <li>• Downloading stats results</li> </ul>	
Lab 3	<ul style="list-style-type: none"> <li>• Accessing ET/ precipitation data from NWC-DP</li> <li>• Analyzing and plotting box plots, histograms, and density curve plots in R</li> <li>• Writing exercises</li> </ul>	<ul style="list-style-type: none"> <li>• getNWCData()</li> <li>• annualize()</li> </ul>
Lab 4	<ul style="list-style-type: none"> <li>• Analyzing time series and bar plots in R using NWC-DP data</li> <li>• Water balances</li> <li>• Double-mass curve analysis</li> </ul>	<ul style="list-style-type: none"> <li>• getNWCWatershed()</li> <li>• getNWCData()</li> <li>• annualize()</li> </ul>
Lab 5	<ul style="list-style-type: none"> <li>• Using a Log Pearson Type III model to analyze NWC-DP data in Excel</li> <li>• Using a Log Pearson Type III model to analyze NWC-DP data in Rstudio</li> <li>• Writing exercises</li> </ul>	<ul style="list-style-type: none"> <li>• getNWCData()</li> <li>• Lp3()</li> </ul>

The content for each of the labs was developed to support three learning objectives for the hydroscience students. The first learning objective is understanding how to access hydrologic datasets and associated metadata from the NWC-DP. The second objective is learning how to

analyze datasets from the NWC-DP using both numerical and graphical methods in R. The third objective is to practice effective communication of data analysis through the use of graphs. An assessment of the correspondence between learning objectives and the provided lab content are provided in the Results section.

## **PRINCIPAL FINDINGD AND SIGNIFICANCE**

The NWCEd package functions and external R-package functions serve to support the hydrology concepts presented in the NWCEd laboratory exercises. This section describes the relationship between the lab content and the technology incorporated into the labs. Also included in this section is an analysis of the effectiveness of the lab content in meeting the established learning objectives as described previously.

Lab 1 and Lab 2 were designed specifically to instruct students how to navigate through the NWC-DP to access USGS hydrologic datasets. Step-by-step instructions were laid out in Lab 1 and Lab 2 for choosing the desired datasets according to a user-specified HUC or a user-specified USGS stream gage. Lab 1 walks the user through NWC-DP features while Lab 2 teaches the user how to access associated metadata, how to access statistical tools for running analyses in the portal, and how to download the results into Microsoft Excel as shown in Figure 3 below. There is no interactive R technology incorporated into these two labs.

While the first two labs do not have any supporting R code, the other three labs are heavily supported through R technology. These labs assume students have a working knowledge of R and RStudio. Lab 3 focuses on graphical methods in R for analyzing hydrologic data. The graphical methods discussed include box plots, histograms, and density plots.

Box plots were discussed to teach students how to identify outliers in datasets, as well as how to analyze the spread of the data. The cars dataset from the built-in datasets R package was also used in connection with ggplot2 to provide a box plot with non-uniform spread. This allowed students to more easily visualize the attributes of the dataset. In addition, ggplot2 was used to provide labels to the box plot which corresponded to the content discussed in the lab. The R package gridExtra was applied during the box plot section of Lab 3 to compare box plots side by side (Baptiste 2016).

A discussion on using histograms to analyze hydrologic data was also presented in the content for Lab 3. The ggplot2 and gridExtra packages were used to compare several histograms of evapotranspiration data side by side, each with varying band widths as shown in Figure 4 below.



Figure 5: La Pine gage location link.



Figure 6: Webpage displaying metadata.

Move your cursor over the plotted data. You will notice that actual data points are displayed below the plot similarly to data plots generated using the Water Budget tool. There are two identical tables below the streamflow data plot, each with unchecked boxes and a list of statistic group names. See Figure 7 below.

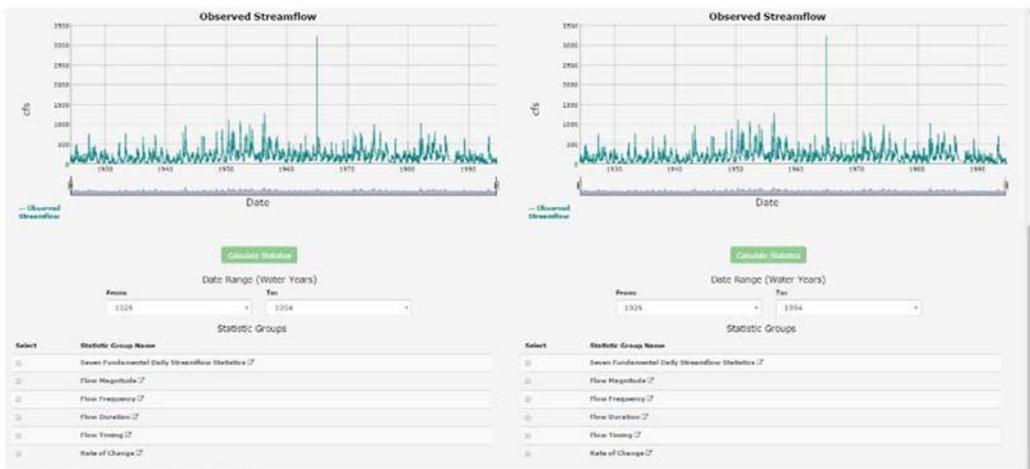


Figure 7: Statistic group tables link.

Figure 3: Lab 2 instructs users how to access and run statistics on streamflow data from the NWC-DP.

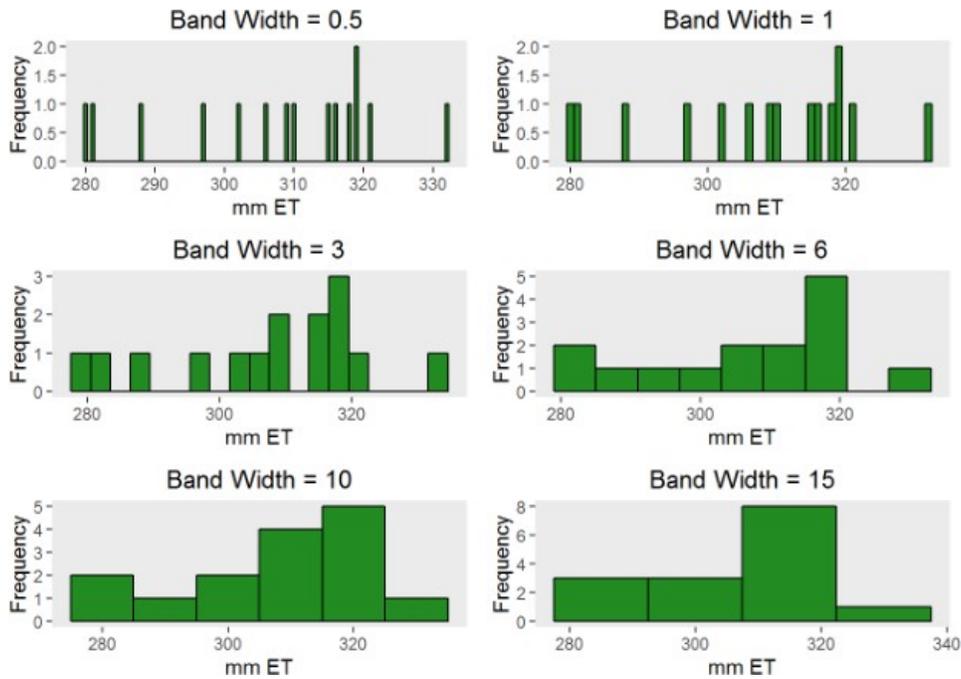


Figure 4: Histogram bandwidths are compared in Lab 3.

With all of the histograms plotted side by side and effectively labeled, students are able to see the effect that band width has on histograms. This example is expected to help students make more informed decisions about how they represent their data.

Lab 4 content teaches general principles related to water balances. An interactive map is used to support the water balance concept by allowing the students to view the physical nature of their watershed with the `getNWCWatershed` function from the `NWCED` package and the `leaflet` package as described previously. Time series plots produced using `ggplot2` allow students to view actual datasets from the `NWC-DP` and track the current state of the water balance for their selected watershed. Figure 5 below contains a time series plot from Lab 4 containing evapotranspiration, precipitation, streamflow, and calculated water storage levels.

Lab 4 also uses the `dplyr` package (Wickham 2016) in tandem with `ggplot2` to produce a color-filled histogram with bars above the axis referring to positive storage and bars below the axis referring to a loss in storage. By using different plot types, students' awareness and understanding of a water balance can be increased, as well as their methods to communicate water balance information in the future.

Numerical analyses are introduced in Lab 4 with the use of double-mass curves. To support the concept, an equation and its variables are presented to educate students on how the analysis is to be done numerically. A series of plotted curves are also used to graphically describe the process. The series of plotted curves is presented below in Figure 6.

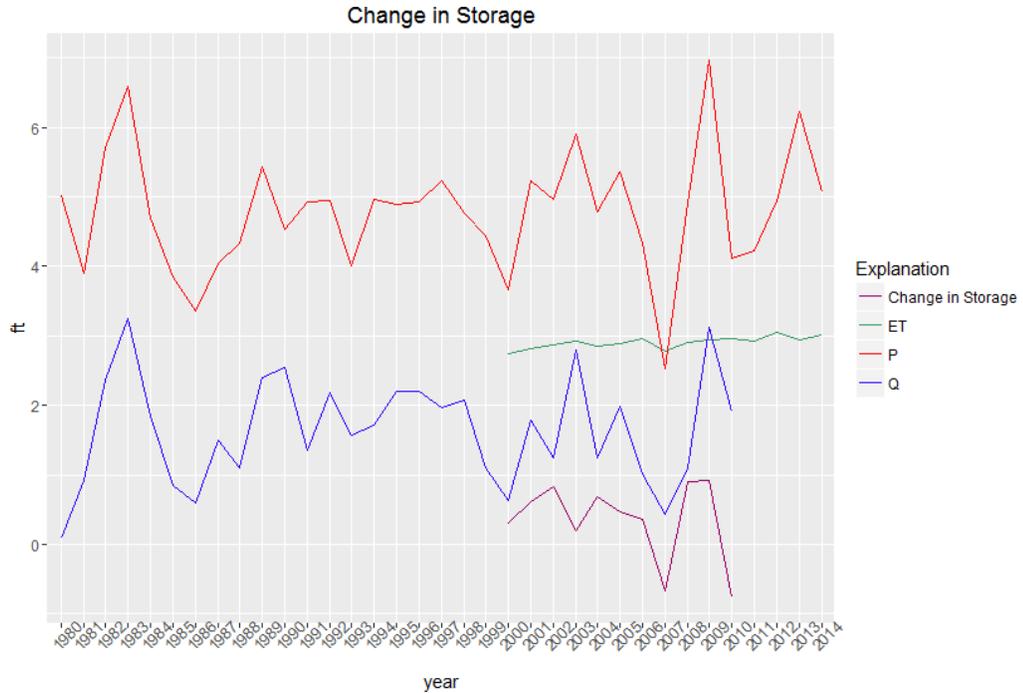


Figure 5: Lab 4 instructs users how to visualize NWC-DP time series data to improve the understanding of the water budget concept.

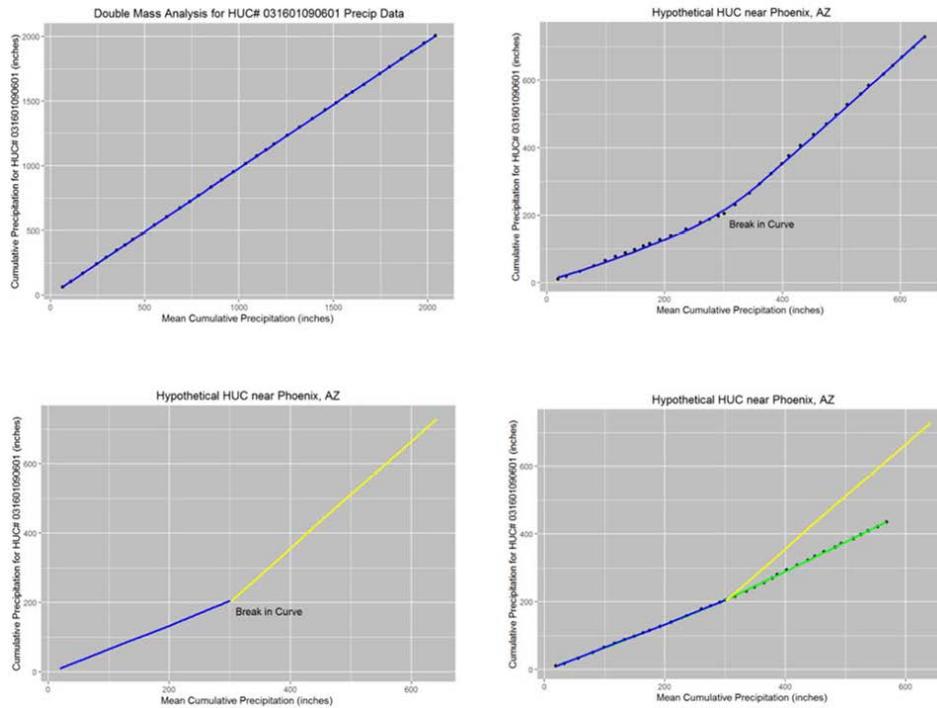


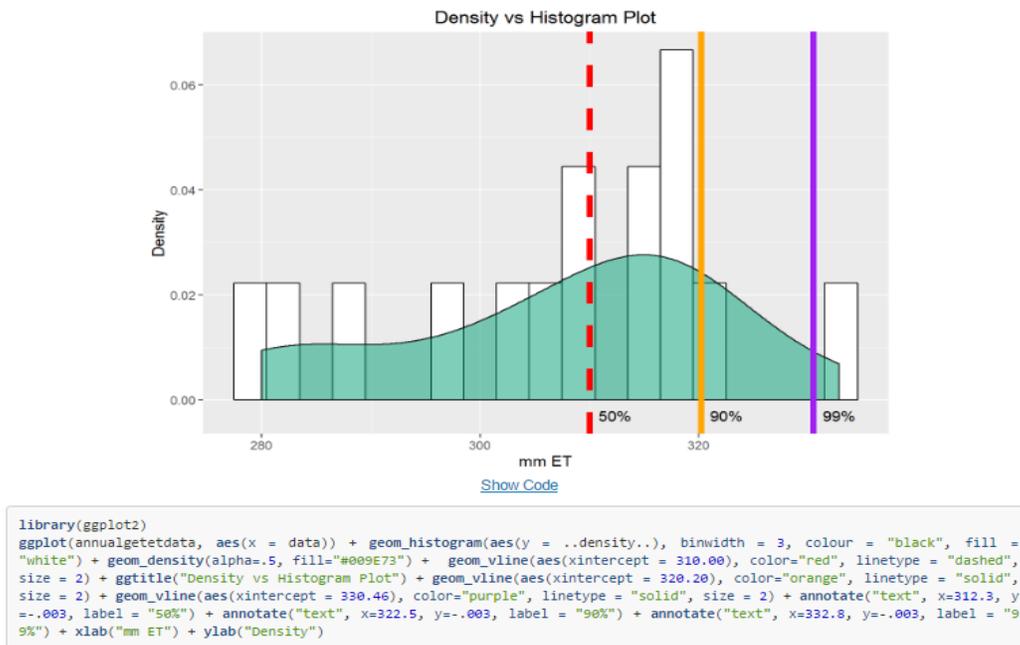
Figure 6: Double-mass curve analysis is visualized in Lab 4 using NWC-DP data.

The use of different colors helps students better visualize the adjustment they have made to their dataset to correct for error. Showing only the final, corrected line would not adequately help students recognize the significance of the adjustment to the data. Plotting the curves in sequence along with both the uncorrected and corrected data together improve the understanding of the method used to perform the adjustment as well as the significance of the change made.

Lab 5 incorporates Microsoft Excel and its PivotTable feature in a step by step tutorial on calculating a Log-Pearson Type III distribution for a hydrologic dataset from the NWC-DP. The datasets from the NWC-DP are very large, which makes the steps for performing the distribution challenging. After walking the students through the lengthy process, the lab then shows students an alternative method using the custom Lp3 function in the NWCEd package.

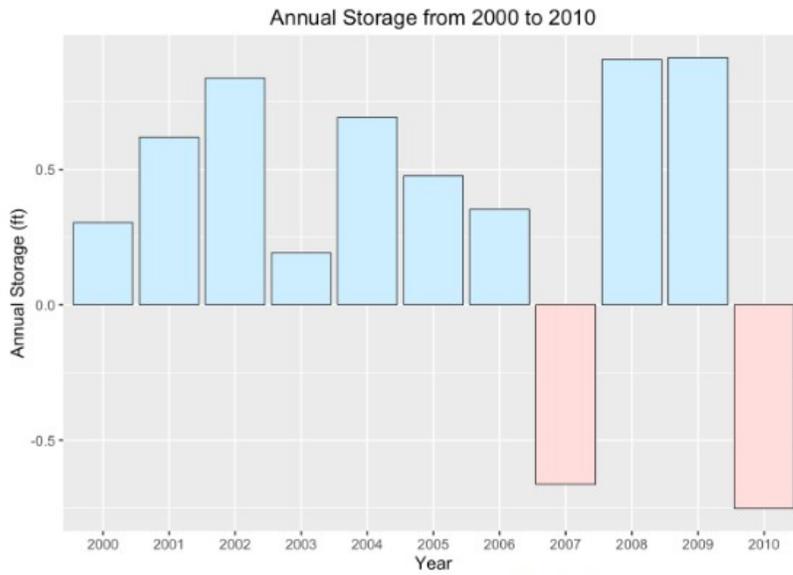
This process allows students to learn the individual steps of calculating a distribution before using R functions to perform the same calculation. This process also helps students see the benefit of using the Lp3 function in that students are able to download large datasets directly into their instance of RStudio and then perform the analysis, saving them time.

It is important to note that for each of the features of the labs described above, there is a viewable block of code which can be copied and pasted directly into an instance of RStudio. This allows for the reproduction of each graph, interactive map, and curve shown in the labs. These code blocks allow students to familiarize themselves with the components and functions used to produce the associated content as shown in Figure 7, Figure 8, and Figure 9 below.



This plot shows a density curve plotted on top of the histogram of the annual ET data. A vertical red dashed line indicates the median. As you can see, the hump of the curve is shifted to the right with the tail on the left. This much more clearly describes the distribution of the data. The 90th and 99th percentiles have been plotted with vertical orange and purple lines, respectively. The 90th percentile and 99th percentiles were found to be 320.20 and 330.46 mm ET, respectively. This means that in a given year for our designated watershed, there is a 10% chance of losing more than 320.2 mm of water to ET and a 1% chance of losing more than 330.46 mm water to ET. Lets take a look at the density plot for the annual precipitation dataset.

Figure 7: Code has been provided to reproduce density curve plots, including the manual adjustment of labels and percentile lines.



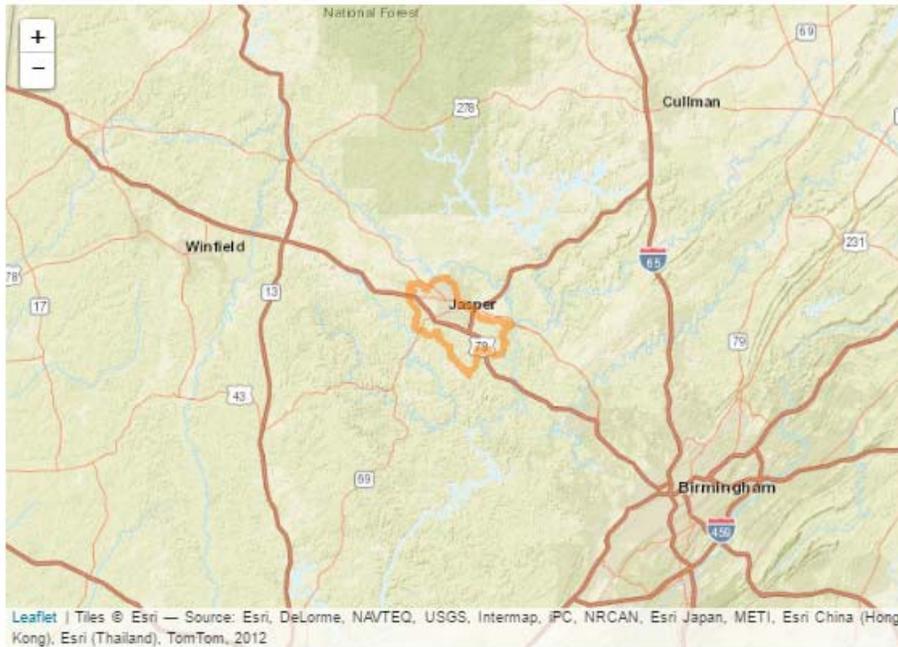
[Show Code](#)

```
library(dplyr)
NWCdata<-getNWCdata(huc="031501070601", local = FALSE)
NWCwatershed<-getNWCwatershed(huc="031501070601",local=FALSE)
areasqft<-NWCwatershed$features[[1]]$properties$areaacres*43560
NWCdata$et$data<-NWCdata$et$data*0.0032808
annual_dataet<-annualize(NWCdata$et, method=sum)
annual_dataet$group<-'ET'
NWCdata$prcp$data<-NWCdata$prcp$data*0.0032808
annual_dataprcp<-annualize(NWCdata$prcp, method=sum)
annual_dataprcp$group<-'P'
NWCdata$streamflow$data<-NWCdata$streamflow$data*60*60*24/areasqft
annual_datastrf<-annualize(NWCdata$streamflow,method=sum)
annual_datastrf$group<-'Q'
annual_union<-merge(annual_dataet,annual_dataprcp,by.x="year",by.y="year")
annual_union<-merge(annual_union,annual_datastrf,by.x="year",by.y="year")
names(annual_union)<-c("year","ET","groupET","P","groupP","Q","groupQ")
annual_diff<-as.data.frame(annual_union$P - annual_union$ET - annual_union$Q)
names(annual_diff) = c('data')
annual_diff$group<-'diff'
annual_diff$year<-annual_union$year

annual_diff = annual_diff%>%
  mutate(pos = data >= 0)

ggplot(annual_diff, aes(x=year, y=data, fill=pos)) + geom_bar(stat='identity', position = 'identity', color='black', size=0.
25)+ scale_fill_manual(values=c('#FFDDDD','#CCFFFF'), guide = FALSE) + xlab("Year") + ylab("Annual Storage (ft)") +
ggtitle("Annual Storage from 2000 to 2010")
```

Figure 8: The code for a histogram with positive and negative bars is provided to introduce an alternative way to visualize water storage.



[Show Code](#)

```
library(NWCEd)
library(leaflet)
# Enter the huc12 to be analyzed like this:
huc12<-"031601090601"
# Get watershed geometry and put it on a map.
NWCwatershed<-getNWCwatershed(huc=huc12,local=FALSE)
coords<-NWCwatershed$features[[1]]$geometry$coordinates[[1]][[1]]
coords<-as.data.frame(matrix(unlist(coords),nrow=length(coords),byrow = T))
names(coords)<-c('lon','lat')
leaflet() %>%
  setView(lng = mean(coords$lon), lat = mean(coords$lat), zoom = 9) %>%
  addTiles("http://server.arcgisonline.com/ArcGIS/rest/services/World_Street_Map/MapServer/tile/{z}/{y}/{x}") %>%
  addWMSTiles(baseUrl = "https://cida.usgs.gov/nwc/geoserver/gwc/service/wms",
              options = WMSTileOptions(format = "image/png", transparent = TRUE, opacity = 1), attribution =
"Tiles &copy; Esri &dash; Source: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2012") %>%
  addGeoJSON(NWCwatershed, weight = 5, color = "#ff7800", fill = FALSE)
```

Figure 9: Code is provided to replicate interactive maps in the user's local instance of RStudio.

Students who are permitted to study and produce their own code for the associated hydrology topics will be prepared for more advanced coursework related to hydrology and hydroinformatics.

We established three learning objectives for the content of the laboratory exercises. Learning Objective 1 is for students to understand how to access the NWC-DP including the associated datasets and tools. Learning Objective 2 is for students to learn how to analyze NWC-

DP data using both numerical methods and graphical methods in R. Learning Objective 3 is for students to practice communicating the results of their analyses using graphs.

The R code and labs were posted to <https://github.com/NWCED/NWCED> and are available for download and use as public domain resources.

## **CONCLUSION AND DISCUSSION**

The NWCEd R package and associated labs were developed to accomplish two objectives. The first was to promote hydrologic data from the NWC-DP. The second was to incorporate new R technology into current hydrology curriculum to better prepare students for future work in hydrology and hydroinformatics.

The NWCEd package contains custom functions which allow users to install hydrologic datasets directly from the NWC-DP into their instance of RStudio for viewing and analyzing.

The NWCEd package works in tandem with several pre-existing packages hosted on CRAN. There are 5 laboratory exercises developed to teach students about hydrology concepts with hands-on examples using NWC-DP data in RStudio.

The NWCEd package and associated laboratory exercises are intended to be used as stand-alone material to support hydrosience courses, such as undergraduate hydrology and hydroinformatics. This design allows educators to have flexibility in selecting lab content that supports their current curriculum. Because the content is self-teaching, instructors do not need to be expert in programming in R. Additionally, the lab content is designed to be used outside of the classroom. This relieves the educator from needing special technology in the classroom.

There exist limitations associated with the laboratory content and NWCEd package. As mentioned previously in this paper, the materials do require a working knowledge of RStudio. It is recommended that educators and students seek open source instruction on downloading and installation of R and RStudio (<https://www.rstudio.com/products/rstudio/download/>). Students must have access to a computer and internet in order to access and use the materials.

There is a need for further research to determine how effective these tools are at educating students on the NWC-DP, data acquisition through the NWC-DP and R, and improving current understanding of hydrology concepts through applying new technology. Continued research is necessary to determine the confidence of students in beginning hydrologic data analysis after completing the materials. It is also recommended that research be conducted to determine how the materials are received and used by hydrology and hydroinformatics educators.

Potential outreach activities for these tools include a CUAHSI webinar. We expect in the near future to post this material on the NWC-DP as well as CUAHSI's website. As an open source project, this material is open to the public to update and reuse and access through GitHub. The USGS is responsible for maintaining the code for the foreseeable future.

## **SOFTWARE AVAILABILITY**

NWCEd, Version 1.0, David Blodgett, Jake Nelson, Software is in Public Domain, Available starting November 15, 2016, Retrievable at <https://github.com/NWCEd/NWCEd>.

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## APPENDIX A

Documentation: <https://github.com/NWCEd/NWCEd/blob/master/README.md>

Lab 1: [https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab\\_1.html](https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab_1.html)

Lab 2: [https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab\\_2.html](https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab_2.html)

Lab 3: [https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab\\_3.html](https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab_3.html)

Lab 4: [https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab\\_4.html](https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab_4.html)

Lab 5: [https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab\\_5.html](https://cdn.rawgit.com/NWCEd/NWCEd/master/inst/Lab_5.html)

# Mapping Didymosphenia in the Logan River Drainage

## Basic Information

<b>Title:</b>	Mapping Didymosphenia in the Logan River Drainage
<b>Project Number:</b>	2017UT204B
<b>Start Date:</b>	3/1/2017
<b>End Date:</b>	2/28/2018
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	UT1
<b>Research Category:</b>	Water Quality
<b>Focus Categories:</b>	Water Quality, Water Quantity, Management and Planning
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Janice Brahney, Bethany Neilson

## Publications

There are no publications.

# Mapping *Didymosphenia* in the Logan River Drainage

Janice Brahney and Bethany Neilson

2017UT204B

## Problem and Research Objectives:

*Didymosphenia geminata* “Didymo” is a stalk forming benthic diatom species that has the potential to bloom, covering large areas of a streambed. In general, diatom community composition is a bell-weather of ambient water quality and environmental conditions. Didymo is extremely nutrient pollution sensitive, occurring in a bloom-state only when ambient phosphorus conditions are below 2  $\mu\text{g/L}$ . In recent decades increases in aggressive bloom-forming behavior of Didymo have occurred in streams across the globe [1, 2]. In the Western US, bloom-forming behavior has been observed in Colorado, Wyoming, Idaho, Montana, and Washington. Based on similar climatic conditions, the species is anticipated to thrive in many Utah rivers [3]. Though native to North America, the increase in bloom forming behavior is perceived as a relatively new phenomenon and the specific conditions that lead to widespread and persistent blooms remain unclear but may be related to water chemistry combined with flow modification, specifically the timing of snowmelt and presence of dams. The presence of Didymo blooms can diminish the recreational and aesthetic value of a stream, and cause infrastructure problems such as the fouling of water intakes. Because Didymo can have significant ecosystem and ecological impacts, the lack of information on distribution, historical occurrence, and habitat alteration represents a significant knowledge gap for the conservation and management of these aquatic ecosystems. To address this knowledge gap we have begun mapping the distribution of diatom species in the Logan River drainage focusing on below dam and spring reaches. Specific goals are to evaluate the environmental controls on the presence or absence of Didymo in the Logan River drainage and to create risk maps for specific stream-reaches given appropriate chemistry and flow conditions.

## Methodology:

At each site, Didymo has or will be identified in streams as cells viable and present, but not in bloom form (DP); present and in bloom form (DPB); or not present (NP). Periphyton samples will be collected from cobble-sized rocks at each of the following locations, (1) the mainstem of the Logan River, (2) at spring sites along the mainstem, (3) in Spawn Creek, a beaver-dam-affected headwater tributary to the Logan River, and (4) Curtis Creek, a historically beaver-affected tributary to Blacksmith Fork. To evaluate community composition over time, we will also sample below First Dam in the Logan River from June to October. Periphyton samples will be digested in 30% hydrogen peroxide solution and mounted using Zrax medium. An Olympus BX51 Differential Interference Contrast microscope will be used for diatom identification and to determine the presence or absence of Didymo not in a bloom-state. Diatom community composition will be related to flow and nutrient conditions. In the Logan River, GAMUT station data will provide flow data. Water samples for nutrient data will be sampled once per week through melt season for the Logan, Spawn, and Curtis creeks. River risk maps in Northern Utah will be developed using a combination of StreamCat and MODIS data.

## Principal Findings and Progress Report:

Due to a delay in funding, the project has been extended until February, 2019. Preliminary data indicates that Didymo is present at all sites sampled in the main stem of the Logan River but is not found elsewhere in the Logan River Drainage or at spring sites. Didymo was not present below First Dam June 18<sup>th</sup>, 2017, but was found from July to October. As this reach is below First Dam, it typically has phosphorus concentrations below detection, creating ideal water quality conditions for Didymo. An increase in Didymo abundance and the development of

colonies was observed throughout the season at this site, suggesting that flow conditions may in part control the occurrence of blooms. While 2017 had extraordinarily high base flows, 2018 is expected to have lower flows due to a lower than average snowpack. Nutrient conditions in the headwater Spawn and Curtis creeks were too high to support the occurrence of *Didymo*, even below beaver dams. The diatom species present in Spawn Creek did indicate otherwise healthy freshwater conditions. The diatoms communities in Curtis Creek have not yet been evaluated. The habitat and biogeochemical effects of beaver dams were evident in Spawn Creek, which produced some additional research directions and outcomes.

# Use of sUAS for Mapping Wetland Flow Paths and Consumptive Use in the San Rafael River, Utah

## Basic Information

<b>Title:</b>	Use of sUAS for Mapping Wetland Flow Paths and Consumptive Use in the San Rafael River, Utah
<b>Project Number:</b>	2017UT205B
<b>Start Date:</b>	3/1/2017
<b>End Date:</b>	2/28/2018
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	UT1
<b>Research Category:</b>	Climate and Hydrologic Processes
<b>Focus Categories:</b>	Water Use, Hydrology, Wetlands
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Alfonso Faustino Torres-Rua, Ian Mark Gowing, Leila HassanEsfahani

## Publications

There are no publications.

# **Use of sUAS for mapping wetland flow paths and consumptive use on the San Rafael River, Utah**

Alfonso Torres-Rua and Ian Gowing  
(2017UT205B)

## **Problem and Research Objectives:**

Tamarisk (*Tamarix* spp.) is one of the main invasive vegetation species in Utah river banks and wetlands. This non-native invasive woody shrub has colonized river floodplains throughout the western US. It develops an extensive root system that has been shown to substantially increase resistance of sediment to erosion. These dense thickets of Tamarisk also increase channel narrowing and the depth to width ratio. Tamarisk has been viewed as an opportunistic invader, colonizing primarily along rivers that have altered flow regimes or on surfaces unsuitable for colonization by native vegetation. Tamarisk colonized the San Rafael, Utah sometime in the 1950s, and eradication efforts have been quite successful, although Tamarisk has proven to be resilient, due to the 2- to 3-year time period between eradication activities in which Tamarisk can develop again. Water managers and decision makers in Utah need information about riverbank or wetland morphological (flow path) changes to historical conditions and amount of consumptive water use related to invasive vegetation as part of their river restoration efforts if changes in flow paths are drastic as Tamarisk eradication (typically by burning) can cause bank erosion and soil displacement. Actual water use (daily and seasonal) by these plants is not well documented because they colonize channel and river banks and develop deep roots with direct access to the water supply. Current unmanned aerial technologies can assist in achieving both of the objectives of this project: monitoring invasive vegetation along with its impact on wetland flow paths and water use impacts. Continuous use of unmanned aerial technologies can be a great benefit to water managers and policy makers, and the flights at local sites may demonstrate its effectiveness and increase confidence among water managers and policy makers.

## **Methodology:**

The project will be executed downstream of Highway 24 to Cottonwood Wash, along the San Rafael River, located in South Central Utah. The project will include two major tasks: field data collection and data analysis. The first task includes two field trips to the Cottonwood Wash region in 2017 and 2018 with sUAS flights along approximately 11 river miles on the San Rafael River, from Highway 24 downstream to Cottonwood Wash. The first sUAS flight should coincide with the spill at Millsite reservoir and the second flight will occur during a period of critically low flow. A Vantage Pro2 weather station will be located

within Hatt Ranch to monitor local weather conditions. The sUAS flight will include optical (visual, near infrared) and thermal sensors. The second task of this proposal involves the analysis of the collected information. Orthomosaics of radiometrically calibrated optical images will be delivered to UDWR. This organization will perform the analysis on wetland flow path changes due to Tamarisk when compared to historical information. The already available surface energy balance models (SEB) will be used to evaluate consumptive water use.

### **Principal Findings and Progress Report**

Due to a delay in funding, the project has been extended to February 2019. A preliminary flight was performed in June 2017 at mid discharge level that shows changes in geomorphology (expanding wetland areas) due to debris creating new water paths within the river corridor. These geomorphological changes are expected to continue in 2018, and two AggieAir flights will be scheduled to track them.

## 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 technical and economic development in the State of Utah. As part of the UCWRR outreach activities supported by USGS 104 funds, we continue to assess and experiment to improve the efficiency and effectiveness of UCWRR outreach activities. Faculty engage 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, provide 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.

### Principal Outreach Publications

Principal outreach items include our website and newsletter, along with other reports. The Water bLog newsletter, which is published semi-annually, highlights a small selection of research projects and their findings from UCWRR affiliated faculty and students. Additional publications from the UCWRR and UWRL appear regularly as technically-reviewed project reports, professional journal articles, other publications and presentations, theses and dissertation papers presented at conferences and meetings, and project completion reports to other funding agencies.

### Short Courses

None of the short-courses conducted were related to USGS funded projects in FY 2017.

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

### Basic Information

<b>Title:</b>	Information Transfer in Support of the Utah Center for Water Resources Research (UCWRR)
<b>Project Number:</b>	2017UT206B
<b>Start Date:</b>	3/1/2017
<b>End Date:</b>	2/28/2018
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	UT1
<b>Research Category:</b>	Not Applicable
<b>Focus Categories:</b>	Education, None, None
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	R. Ivonne Harris, Carri Lyn Richards

### Publications

1. UCWRR, 2017, The Water bLog, Utah Center for Water Resources Research, Vol. 8(1).  
<http://uwrl.usu.edu/research/newsletters/waterblog-2017-jul.pdf>
2. UCWRR, 2017, The Water bLog, Utah Center for Water Resources Research, Vol. 8(2).  
<http://uwrl.usu.edu/research/newsletters/waterblog-2017-dec.pdf>

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

R. Ivonne Harris  
Carri Richards

## **Problem**

The Water Resources Research Act of 1964 established the Utah Center for Water Resources Research (UCWRR). The Center is housed at the Utah Water Research Laboratory at Utah State University in Logan, Utah. The UCWRR fosters interdepartmental research and educational programs in water resources, administers Utah's State Water Research Institute Program funded through the U.S. Geological Survey, and provides university-wide coordination of water resources research.

## **Objectives**

As one of 54 water research centers nationwide, the UCWRR supports and promotes responsible and sustainable water resource management and stewardship as the State of Utah works to "make sure that tomorrow has enough clean water." Utah is home to approximately 50,000 miles of rivers and streams and 7,800 lakes, and this water is an essential resource for the economic, social, and cultural well-being of the State of Utah. The Center plays a vital role in the dissemination of information in support of these goals. A major component of the information transfer and outreach requirements of the UCWRR is the development of appropriate vehicles to disseminate information generated by research projects conducted at the Center. The project provides ongoing updates to the UCWRR web page, with information transfer specifically identified as the key objective. The semi-annual newsletters for the Utah Center feature research projects and their findings, water-related activities in the state, and ongoing work by researchers affiliated with the Center.

## **Methods**

### Web Page

A crucial objective for information dissemination at the UCWRR has been the development of an up-to-date web page, where information can be widely available on the internet. We recently transitioned the UCWRR website to OU Campus as part of the general UWRL website upgrade. Information transfer publications posted on the site include pictures and summaries of ongoing projects and other relevant information. With the website upgrade, the web address for the UCWRR has changed to <http://uwrl.usu.edu/research/ucwrr/>. Figure 1 shows an overview of the website content.

## Utah Center for Water Resources Research (UCWRR)



The UCWRR is one of 54 state water institutes that were authorized by the Water Resources Research Act of 1964. Housed within the Utah Water Research Laboratory, the Center promotes and coordinates the development of research and instructional programs related to stewardship of water quantity and quality through collaboration with federal, state, and local government and the private sector and furthers the training of water resource scientists and engineers.



Current Water bLog Newsletter

Previous Newsletters

**Contact:**

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435-797-3157  
[mac.mckee@usu.edu](mailto:mac.mckee@usu.edu)

### About the UCWRR

The UCWRR actively assists the Utah Department of Environmental Quality (UDEQ), the Utah Department of Natural Resources (UDNR), the State Engineer's Office, all 12 local health departments, and various large water management agencies and conservancy districts within the state with specific water-related problems pertinent to the scope of each.

The UCWRR maintains strong communications and close working relationships with water-related state and local agencies through participation on state boards, activities in conferences and committees, and personal contacts.

### Key Objectives:

- Facilitate water research, outreach, design, and testing elements to support student education and citizen training
- Administer the State Water Research Institute Program funded through the U.S. Geological Survey at Utah State University for the State of Utah
- Foster interdepartmental research and educational programs in water resources
- Provide university-wide coordination of water resources research

Mission & Vision Program Management & Coordination Research Program & Funding Past Projects

Figure 1. UCWRR website at <http://uwrl.usu.edu/research/ucwrr>

## Newsletter

The UCWRR continues to publish the semi-annual newsletter, The Water bLog, which is published electronically via the UWRL/UCWRR web site at:

<http://uwrl.usu.edu/research/newsletter>

The screenshot shows the Utah State University website. At the top, there is a dark blue header with the Utah State University logo and the text 'UTAH WATER RESEARCH LABORATORY'. Below this is a navigation bar with links: 'About', 'People', 'Research', 'Environmental Engineering', 'Hydraulic Services', 'Water Resources', 'Newsroom', and 'Contact'. The main content area is titled 'Water bLog Newsletters'. It features a 'Current Newsletter - December 2017' section with a large thumbnail image of a plant and soil, and a 'Past Newsletters:' section with a grid of smaller thumbnails for previous issues. The current newsletter thumbnail includes a 'Message from the Director' and 'Welcome!' sections. The 'Past Newsletters:' section shows a grid of thumbnails for issues from May 2010 to Dec 2017, each with a 'PDF' link below it.

Figure 2: The Water bLog Newsletter home page (<http://uwrl.usu.edu/research/newsletter>)

The newsletter is disseminated through e-mail to approximately 350 readers. Its main purpose is to highlight research projects and their findings, which often hold interest and value to constituents within the State of Utah, as well as nationally and internationally. The current

version of the Water bLog newsletter presents stories about the effects of copper oxide nanoparticles on plant development and a new method to improve water loss estimates. Other segments highlight the people behind the research, introduce new affiliated faculty members, and report on other recent accomplishments by those associated with the Center.



Photo by Paul McManus

## CuO nanoparticles: impacts of metals and metal ions on soils and plants

**C**opper oxide nanoparticles (CuO NPs) present a conundrum. These NPs can contribute to metal pollution, negatively affecting environmental quality. In fact, intentional or accidental application of CuO NPs on crops or soil can be toxic to plants and can adversely affect both plants and their related beneficial soil microbial ecosystems.

At the same time, CuO NPs can be useful in various medical, food safety, personal care product, and even agricultural applications. For instance, CuO NPs can be used as a beneficial antimicrobial in fungicides for treating plants or as a slow release source of Cu, an essential micronutrient. Preliminary research has even shown potential agricultural benefits from the drought resistance-stimulating properties of NPs.

**Understanding CuO NPs**

For the past 10 years, UWRL researcher Joan McLean has been collaborating with other USU faculty and students to investigate the bioavailability and toxicity of CuO NPs to wheat plants. Their recent work looks at how properties of Utah's agricultural soils specifically influence the bioavailability of CuO NPs to wheat plants.

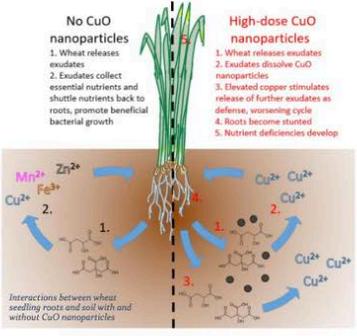
A recently granted 3-year NSF project is extending this research to further explore the interplay of soil chemistry, root exudation, and root biofilm exudation in relation to CuO NP bioactivity in the wheat rhizosphere. Additional USDA funding links past research and the NSF project to improve understanding of how rooting zone

**No CuO nanoparticles**

1. Wheat releases exudates
2. Exudates collect essential nutrients and shuttle nutrients back to roots, promote beneficial bacterial growth

**High-dose CuO nanoparticles**

1. Wheat releases exudates
2. Exudates dissolve CuO nanoparticles
3. Elevated copper stimulates release of further exudates as defense, worsening cycle
4. Roots become starved
5. Nutrient deficiencies develop



Interactions between wheat seedling roots and soil with and without CuO nanoparticles

The Water bLog December 2017

**Pore water effects**

Many factors present in soil or produced by plant roots and associated microbes, including soil pH, salt content, and organic matter content influence the behavior of NPs by altering their surface properties and solubility. In order to test these effects, the research team grew wheat plants for 10 days in sand watered with one of three soil pore waters. The pore waters were extracted from soils in Cache Valley under different agricultural management practices that affect the type and concentration of organic matter. Soil organic matter interacts with copper by forming complexes that will influence CuO NPs and the bioavailability of copper to the wheat plant.

The health of the wheat plant was evaluated by its root length. The presence of the CuO NPs decreased the root length compared to the control (plants grown in deionized water, while the addition of pore water provided protection to the plants).

The concentration of copper in solution increased with the concentration of dissolved organic matter in the soil pore water, but the increase in soluble copper did not increase damage to the root. Copper complexes that formed with organic matter in soil pore water or were produced from plant root growth protected the plants from the adverse effects of CuO NPs.

**PcO6 colonization effects**

In this work, wheat roots were colonized with the bacterium *Pseudomonas chloraphis* O6 (PcO6) to see if it could provide protection for roots in the presence of CuO NPs. Wheat roots colonized with PcO6 showed no significant difference in root length, but the bacterial produced biofilm offered other protective influences. PcO6 may stimulate and prime the defense pathways when the plant is stressed.

Colonized roots showed lower levels of copper uptake at some NP doses. The lower levels of soluble copper detected in the rhizosphere suggest that the bacteria may act as a physical shield limiting the impact of copper on the plant root. It is possible that the PcO6 may consume some metal chelators (citrate and malate) as nutrients, thereby reducing dissolution of copper from the CuO NPs.

Collectively, these data showed that the challenge to the plant imposed by CuO NPs remained dominant but can be modulated by the presence of the root-colonizing bacterial cells.

**What's Next?**

Despite the recent progress, many questions remain:

- What is the solubility of CuO NPs in whole soil?
- How do wheat root exudates interact with metal-containing soil minerals?
- Do CuO NPs, ZnO NPs, or SiO<sub>2</sub> NPs reduce stress experienced by wheat under drought?
- How do NPs interact with wheat roots, PcO6, and root exudates under drought stress conditions?

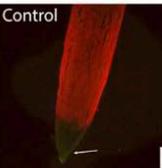
Answering these questions will reveal some of the mysteries in the CuO NP conundrum, including the risk of using CuO NPs in soils, ways that root exudates interact with metal pollutants, and potential beneficial uses of metal NPs to improve crop performance under drought.

In the near future, these are the very things McLean and her colleagues intend to find out.

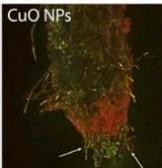
PI: Joan McLean  
Research Professor  
Utah Water Research Laboratory,  
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Students: Paul McManus, Joshua Hortin

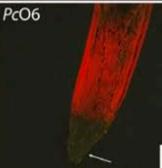
**Control**



**CuO NPs**



**PcO6**



**CuO NPs and PcO6**



Bacterial colonization showed no overall protective effect on morphology, but may have reduced the extent of gene expression associated with plant responses to stress induced by root exposure to CuO NPs

Figure 3: View Current Newsletter at:  
<http://uwrl.usu.edu/research/newsletters/waterblog-2017-dec.pdf>

## Other

Other publications from the UCWRR and UWRL appear regularly as technically-reviewed project reports, professional journal articles, other publications and presentations, theses and dissertation papers presented at conferences and meetings, and project completion reports to other funding agencies. A number of these are available in the USU Digital Commons (<http://digitalcommons.usu.edu/water/>). The annual Mineral Lease Funds Report, submitted to the Utah Office of the Legislative Fiscal Analyst, reports on a wide range of research projects ongoing at the UCWRR and UWRL that specifically benefit the State of Utah (<http://uwrl.usu.edu/research/mlf-reports>).

# USGS Summer Intern Program

None.

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

## **Notable Awards and Achievements**

Faculty Member Bethany Neilson was named USU College of Engineering Undergraduate Student Mentor of the Year and Civil and Environmental Engineering Undergraduate Student Mentor of the Year for 2017.

Undergraduate Student Grants were awarded to Hyrum Tennant (URCO Grant 2017) and Dane Brophy (College of Science Mini-grant) for project-related research.

## Publications from Prior Years

1. 2014UT193B ("Influence of Groundwater/Surface Water Interactions in High Gradient Mountain Streams") - Articles in Refereed Scientific Journals - Gabor, R.S., S.J. Hall, Y. Jameel, M.L. Barnes, T.L. Stout, H. Tennant, M. Millington, A. Gelderloos, D. Eiriksson, B.T. Neilson, G.J. Bowen, P.D. Brooks. 2017. "Persistent urban impacts on surface water quality mediated by stormwater recharge." *Environmental Science and Technology*. 51 (17) 9477–9487, doi:10.1021/acs.est.7b00271.
2. 2014UT193B ("Influence of Groundwater/Surface Water Interactions in High Gradient Mountain Streams") - Articles in Refereed Scientific Journals - Stout\*\*, T.L., M. Majerova, B.T. Neilson. 2017. "Impacts of beaver dams on channel hydraulics and substrate characteristics in a mountain stream." *Ecohydrology*. 10:1 (e1767). doi: 10.1002/eco.1767.
3. 2014UT193B ("Influence of Groundwater/Surface Water Interactions in High Gradient Mountain Streams") - Articles in Refereed Scientific Journals - Niswonger, R., R. Naranjo, D. Smith, J. Constantz, K. Allander, D. Rosenberry, B.T. Neilson, M. Rosen, D. Stonestrom. 2017. "Nutrient Processes at the Stream-Lake Interface for a Channelized vs. Unmodified Stream Mouth: Implications for Cultural-Climatic Eutrophication in a Sub-Alpine Setting." *Water Resources Research*. 53, 237–256, doi:10.1002/2016WR019538.