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Using a Geospatial Analysis Tool to Visualize Water Impairments and Engage Stakeholders in the San Bernardino National Forest

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USING A GEOSPATIAL ANALYSIS TOOL TO VISUALIZE WATER IMPAIRMENTS AND ENGAGE STAKEHOLDERS IN THE SAN BERNARDINO NATIONAL FOREST

A Thesis

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

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Master of Science

in

Earth and Environmental Sciences

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ABSTRACT

High quality water is an important resource that is integral to supporting environmental and human health. It is essential for economic, social and environmental purposes. Impairments to water resources can be attributed to anthropogenic sources that are associated with terrestrial activities including urban development and agricultural activities. Community-Based Participatory Research (CBPR) is an approach that can be used to include community input to improve water management strategies. In the San Bernardino National Forest (SBNF) area in southern California, there are disadvantaged communities that can benefit from a CBPR study to increase water quality in the area. A geovisualization tool will be used to identify community stakeholders in the area's water, identify issues and create a more inclusive and informed community that can make well informed decisions on the area's water management.

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CHAPTER ONE

INTRODUCTION

High quality water is an important resource that is integral to supporting environmental and human health (Zhang, 2010, Pimentel, 2004, Reibel, 2020). Not only is water used for basic necessities such as drinking, bathing and general sanitation to protect public health, it is also essential to support economic (i.e. agriculture, industrial, commercial), social (i.e. public health, cultural), and environmental (i.e. habitat, ecological services, food) purposes (Zhang, 2010, Pimentel, 2004, Reibel, 2020). Of growing concern is the spatially extensive impairments to water resources typically associated with anthropogenic activities and climatic changes (i.e. prolonged droughts, excessive heat, flood conditions) (Arnold, 1996, Sheuler, 1994, Delpla, 2009, Peters, 2000). Anthropocentric sources of impairments are associated with terrestrial activities including development (i.e. industrial, commercial, residential, wastewater facilities) and agricultural activities (i.e. growing crops, raising livestock) that remove natural vegetation from the land (Mallin, 2013, Mallin, 2003, Rothernsberger, 2013, Smith, 2013).

On these landscapes, pollution inputs to surface waters may be variable including pesticides, fertilizers, pet and human waste. Pollution inputs are often conveyed to waterways during storm events across impervious surfaces (i.e. building, roads, sidewalks) and from eroded soils. Some of these pollutants may include pathogens, nutrients (i.e. nitrogen and phosphorus), heavy metals, pesticides, and plastic (Arnold 1996, Brabec, 2002, Dennis, 1987, Wilkinson, 1999, Zabinski, 1997, Huang, 2013, Shaw, 2014, St-Hilaire, 2015). Climatic changes can also pose water quality issues including droughts and floods that may concentrate or dilute contaminants in water (Arnold, 1996, Shuler, 1994, Delpla, 2009, Peters, 2000). Given the diverse sources of water impairments, it is essential to understand the spatial context of impairment so that communities and resources agencies identify site specific strategies to mitigate pollution inputs from entering waterways (Pimentel, 2004). This is especially important in headwater streams because impacts in these reaches can impact water resources downstream.

Although headwater stream quality is important, there is little known about headwater quality and this hydrological feature is often left out of water resource management planning (Edwards, 2015, Wallace, 2015). This creates gaps in knowledge about the extent to which watershed characteristics and activities upstream create impairments throughout the entire hydrological network (Alexander, 2007, Dodds, 2007, Edwards, 2015, Wallace, 2015). Frequent monitoring of headwater water resources can assist with understanding the importance of headwater stream quality, however, communities are rarely informed of such data and how it impacts water resources (Butler, 2015). As a result, geospatial visualization has been used as a tool to assist communities with understanding the spatial context of water resource quality (Dave, 2017, Nyerges, 2014). This approach is action based and oriented as it is an applied research method. Furthermore, it allows communities to be informed to and be active in community-level decisions that support and sustain the economic, social and environmental functions of communities for current and future generations (Burns, 2015, Dave, 2017, Nyerges, 2014).

Despite this advantage, geospatial tools are rarely used to engage communities with understanding the spatial and physicochemical characteristics of water resources making public buy-in for management strategies more complicated. Geospatial visualization coupled with community engagement presents an opportunity to develop a grassroots resource management where scientists and community members can collaborate to determine the best strategies for improving water resource quality (Butler, 2015). Identifying the extent to which human activities impact headwater resources is vital to ensuring water resources are protected for current and future generations. One way to bridge community knowledge gaps, is to apply a Community Based Participatory Research (CBPR) platform to which community members can provide informed feedback in the development and deployment of water-quality centered online mapping tools (Butler, 2015, Pimentel, 2020). Combining community knowledge with field monitoring data may assist with ensuring community decisions about watershed management are informed potentially having a lasting impact and leave a high value to the community (Jankowski, 2009, Levine, 2014, Nyerges, 2013).

Sources of Water Impairments

Water impairments can be sourced from many points in a watershed system. Agricultural disturbances and urban land use have been identified as the primary land types associated with increased sources of pollution inputs that impair surface water resources (Azizullah, 2011). For example, nutrients such as nitrogen and phosphorus from fertilizers used in agricultural processes (i.e. livestock, crops) and on landscaped surfaces (i.e. lawns, parks) can leach into water systems (Ahearn, 2005, Billen et al., 2001, Danz, 2013). Additionally, increases in impairments have also been associated with pathogens (i.e. fecal coliform; e. coli), ammonia and chlorides primarily attributed to septic and sewage systems failures and impervious surface runoff from urbanized areas (Ahearn, 2005, Brabec, 2002, Burkholder, 2007, Chester, 1996, Hatt, 2003, Mallin, 2003). When sewage flow exceeds sewer system capacities, it may overflow and unload directly into surface water bodies. Pathogens such as coliform bacteria may thrive in waterways creating dangerous conditions for humans and wildlife that may rely on those waterways for drinking and sanitation purposes as well as habitat (Barakat, 2016, Koczura, 2015). Once in waterways, these inputs can become concentrated during excessive heat and drought conditions, further causing highly variable spatio-temporal impairments of waterways across the entire hydrological network (i.e. watershed, river basin) (Charron, 2004, van Viet, 2007, Zampella, 2007).

Across hydrological features such as watersheds and river basins, excessive inputs entering waterways can cause pollution to become highly concentrated resulting in dangerous conditions including eutrophication. Eutrophication is the process of nutrients, such as nitrogen and phosphorus which usually originate in fertilizers, being input into the water systems. This excess in nutrients can create Harmful Algal Blooms (HABs) (Le Moal, 2019, McCrackin, 2017). HAB’s are toxic overgrowths of algae in fresh or marine water (EPA, 2020). Algal blooms are becoming more common in the Great Lakes and other regions of the United States due to warm and still waters (Carmichael, 2016, Pearl, 2014). Excessive nutrient input feeds cyanobacteria and creates algal blooms which then depletes oxygen in the water and reduces water clarity (Carpenter, 1998, Verspagen, 2014). When dissolved oxygen is depleted and light is unable to penetrate water depths aquatic wildlife such as fish and aquatic vegetation will struggle to survive (Carpenter, 1998, Paerl, 2014, Verspagen, 2014). Throughout the United States, lakes and reservoirs are experiencing HABs that pose dangers to the ecology and public health of these regions as wildlife will struggle to survive as well as human consumption of this toxic water can cause adverse health effects such as vomiting, rashes, cold and flu symptoms, etc. and, in rare cases, death (Carpenter, 1998, DWP, 2019, Marion, 2017, Paerl, 2014).

The quantity and quality of water resources in headwater streams is especially important because they represent the largest percent of surface water resources across the hydrologic network (Alexander et al., 2007, Dodds and Oakes, 2007, Edwards, 2015, Wallace, 2015). Impairments to headwater streams may cause spatially diverse impacts across the entire hydrological network leading to a reduction in water quantity and quality at the sources and downstream impacting the social, economic and environmental resources for multiple communities threatening their ability to become resilient to such changes overtime (Alexander, 2007, Edwards, 2015, Rasmussen, 2013, Lassaletta, 2010, Wallace, 2015). Water quality and a healthy, diverse downstream environment rely heavily on the conditions of headwater streams. Although significant, headwater streams are often omitted from water resource planning and management highlighting the need to identify and document how impairments in headwaters could potentially impact downstream resources (Xenopoulous, 2017). Much of the sediment, nutrients and organic matter that is present in downstream rivers are transported from headwater streams higher up in the watershed network. If many of the headwater streams are impaired it will impair important water bodies and rivers across vast spatial extents, limiting the availability of safe water resources that support human and ecological health (Lassaletta, 2010, Rasmussen, 2013, Wallace, 2015). Although human-environmental relationships associated with water impairments are well known, studies typically focus on a single body of water or stream and river segments. As a result, there is a need to focus more attention on headwater streams as they represent the largest percentage of stream miles across the hydrological feature and impairments in these segments can result in a multitude of impairments across the entire hydrological network (Alexander, 2007, Edwards, 2015, Ding, 2013, Dodds, 2008, MacDonald, 2007, Lassaletta, 2010, Rasmussen, 2013, Wallace, 2015).

Many lakes and water bodies across the nation experienced algal blooms the past few years that caused issues such as eutrophication, hypoxia and potential harm to human health, across the United States (Azizullah, 2019, Carpenter, 1998, Paerl, 2014, Verspagen et al., 2014). According to the California Water Resources Department, many water bodies across the state are experiencing harmful algal blooms (*California Harmful Algal Blooms (HABs) Portal, 2020*). Departments are often instructed to close lakes to any recreational activities and advise people to avoid contact with the lake water (DWP 2019). Human contact with toxic green algae may cause health issues such as vomiting, rashes, mouth ulcers, and cold/flu symptoms (DWP, 2019, Falconer, 1999). Climate change may make these algal blooms more common. These algal blooms thrive from warm weather as the cyanobacteria prefer warmer and still waters (EPA 2019). When toxic algal blooms expand they can create dead zones which happen when the water is depleted of dissolved oxygen and any wildlife in the water die, intensifying water quality issues (Paerl, 2014, Carmicheal, 2016). Many recreational freshwater fishing sites around the United States are not well-monitored or managed for fish consumption, catch and release, or even harmful contaminants that may be in the water or fishes (Pulford, 2017). Sites like the

North American Great Lakes do have advisories for harmful chemicals in the water and fish, although they are usually only restrictive to the most harmful toxin (Gandhi, 2017). These algal blooms are harmful not only to people who are in contact with the lake water and wildlife but it can also be harmful because some people may depend on these water bodies for sustenance.

Application of Geospatial Technologies for Collaborative Water Resource Management

There are two primary methods for water management but they both pose challenges. The first is the top-down approach which focuses on technical solutions but it does not account for uncertainties such as floods or droughts (Gaymer, 2014, Ludwig, 2013). The second is the bottom-up approach which focuses more on the socioeconomic vulnerabilities of the local community by community members but does not focus as much on technical solutions (Gaymer, Ludwig, 2013). Within these governance structures, there are often limited opportunities for community-based involvement including the distribution of detailed water resources data, a clear understanding of how regional, state and federal policies impact water resources quantity and quality, and short and long term risk to water access including drinking and recreational waters. As a result, both of these methods need to be reevaluated to create a more functional process for managing water that is inclusive of continuous community input (Bullard 2000, Crow 2019).

One way to resolve this gap in inclusion is the use of geospatial technologies, such as online mapping tools that display the spatial context of water resources, and related education and outreach strategies that could result in more collaborative and comprehensive management strategies that enable communities to become more resilient to climatic changes that reduce the quantity and quality of water resources (Dave, 2017, Hacker, 2017, Jankowski, 2009, Kearns, 2003, Levine, 2004) . This is especially true in areas experiencing rapid population growth coupled with extreme and prolonged drought conditions, such as the Southern Californian region.

Participatory geographic information systems (PGIS) is an emerging approach to include community input to improve water management strategies. This is a sector of GIS that involves the inclusion of community knowledge through programs such as Google Earth or ArcGIS Explorer which allows users to spatially identify known water resource issues. The results of such processes can expand resource and regulatory agency knowledge that informs decision makers. Rulemaking is a very important aspect of conserving environmental resources, such as water (Brown, 2017, Jankowski, 2009). Many states throughout the United States have systems in place to allow public participation in the rulemaking process but there is little participation due to the fact that many citizens lack the knowledge to participate in the rulemaking process (Crow, 2016, Brown, 2014, Brown, 2017, Levine, 2014, Vajjhala, 2005). Having a system that is easily accessible and understandable by citizens can also assist with ensuring that resources (i.e. financial and staff time) are prioritized to address the most pressing issues that support a more comprehensive approach to resolving human-environmental relationships related to water resources that can be sustained for generations to come (Brotosusilo, 2019, Kuntiyawichai, 2017). *Figure 1* shows an interactive ArcGIS map of the City of Zwolle in Switzerland. This city is one of the greenest cities in the country and is doing research with their residents to combat climate change in their community. The interactive map is part of a larger initiative called the Smart Zwolle Hub where residents can access open data such as air pressure, humidity, particulate matter and nitrogen levels are constantly being collected by sensors placed throughout the city (Zwolle, 2019). The interactive map is where residents can visualize where and when the data was collected by the sensors. Each sensor is a point where users can click and see more data collected by the sensor.

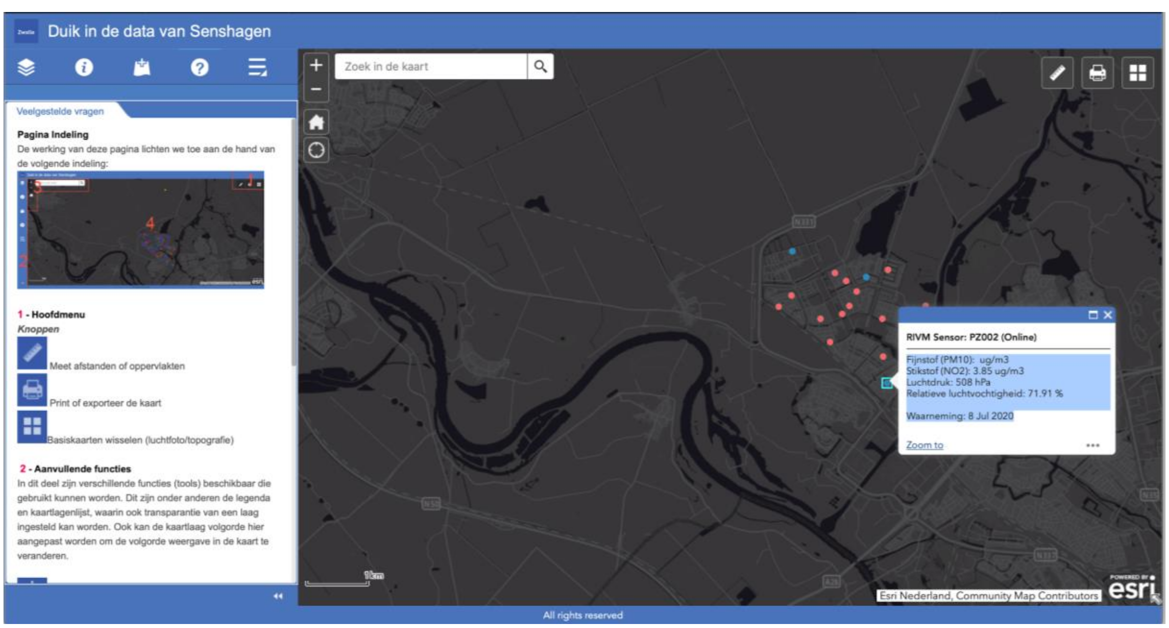


Figure 1. An ArcGIS interactive map of Zwolle, Switzerland.

There are concepts that need to be identified before beginning a PGIS study. First, the community educational needs must be identified. Identification of community needs is very important to the study as the PGIS platform must fit the needs (Nyerges, 2014). Otherwise, data may not be relevant as a user may not fully comprehend the platform. A way to anticipate what the community needs are by identifying the concerns of the community through meetings prior to the development of the platform. This may provide a window into what the community values and how the platform should be designed. Another concept that needs to be identified is the ease of access and understandability of a platform. A PGIS platform must be relatively easy for a community member to access as well as user friendly and understandable. For a study like this one, it may be beneficial to use a web-based platform as it would be more accessible and user friendly to individuals that want to participate (Dave, 2017, Nyerges, 2014, Vajjhala, 2005).

Studying the changes and trends that a water body goes through throughout the years can help in the conservation of clean water by educating the public. PGIS serves as an avenue for community participation but it also serves as an avenue for the community to come together with a well-informed decision when it comes to policymaking in the area. Although, the question of whether the data input by the community is valid or not is an ongoing challenge to this process. Data is only valid when the right people do the research in the correct way by being informed about the process through clear objectives, goals, training and education (Brown, 2017).

California Water Resources and Participatory GIS

Historically, California's economic growth has been attributed to the availability of water. The California Department of Water Resources states that the southern portion of the state experiences a larger scarcity of water than the northern portion due to a more arid climate. California attains its water from three main sources. The central valley's main economic driver is agriculture and receives water that is pumped from the Mount Shasta Region. The State Water project is an infrastructure project of dams, aqueducts, power and pumping plants that supply water to the whole state (*CWS,* 2020). The main sources of water for the State Water project are rainfall, snowpack, runoff, water storage facilities and are supplied by 29 contractors throughout the state (*CWS,* 2020).

Drinking water and recreational fishing are important factors of the California economy (Davis, 2013). Keeping water clean is essential for recreational fishing. Although, that is not the case in California, as bioaccumulation is a large concern. Bioaccumulation is the accumulation of contaminants such as methylmercury (a neurotoxin), Polychlorinated biphenyls or PCBs (multi-use industrial grade chemicals), and other toxic chemicals (Davis, 2013, Le Moal, 2019). This poses a threat to human health as many communities may rely on fishing for sustenance. Additionally, climate change has also had a significant impact on water availability in California. Historically, California has had drought periods, although in recent years, climate change has caused the extension of these drought periods and the limitation of water supply. Drought periods can also be an issue for water quality as a decrease in water supply may concentrate already existing contaminants in water bodies (Delpla, 2009).

As community-based research plays a larger role in developing scientific knowledge, it can be very helpful to inform community residents where their water comes from, the quality of their water and what is going into their water, particularly in socio-economically disadvantaged communities (Jankowski, 2009, Brown, 2017). According to the California Public Utilities Commission, a disadvantaged community is defined by areas, specifically in California, that suffer from a combination of economic, health and environmental burdens. These burdens include poverty, high unemployment, water and air pollution, presence of hazardous waste, and high rates of asthma and heart disease (*CPUC*, 2020). These communities also include all tribal lands, households whose incomes are below 80 percent of the area median income, and census tracts where combined household incomes are less than 80 percent of the area median income. These disadvantaged communities often experience a higher level of health risks in their homes and places of work compared to more affluent communities (Bullard 2000). For example, the US Census, the median household income for San Bernardino County in 2018 was about $60,000. Many times, these communities do not have the fiscal resources to develop GIS processes that facilitate the tracking of their water sources. Usually more affluent communities have GIS capabilities that allow them to better understand their water sources and make informed decisions as a united community on how they want their own water managed; as another community's water management plan may not fit their needs (Jankowski 2009, Butler, 2015). Water quality is always changing which is why it is important to help disadvantaged communities who may not have GIS resources to study and understand their water quality issues.

In attempting to resolve these knowledge gaps, the California Department of Water Resources (CA DWR) has created a web map tool called the DAC (i.e. Disadvantaged Communities) Mapping Tool that is very helpful in visualizing different aspects of this water issue (California Department of Water Resources, 2020). It is designed to assist with Integrated Water Resource Management, Jerry Brown's Sustainable Groundwater Management Act, and the California Water Plan. This map has multiple layers that can be turned off and on ranging from watershed systems in California, Proposition 1 IWRM funding areas, and Disadvantaged Community information. This is a useful tool for interested parties who want to know more about California's disadvantaged communities and their water resources, although it does take a level of water knowledge and California's demographics to understand how to use this tool on a deeper level (DWR, 2019).

Similarly, a tool was created by the National Oceanic and Atmospheric Administration (NOAA, 2010) called the California Ocean Uses Atlas. This tool focuses on the California ocean and what those waters are being used for. At first glance the map shows a heat map with blue being areas of the ocean that are least used and red for areas that are being most used, usually shown on the coast (NOAA, 2010). This tool categorizes ocean uses by three general categories: Non-consumptive, Fishing, and Industrial/Military. With a point ID tool, a user could click anywhere on the ocean and get more specific water uses such as shipping, wildlife viewing and commercial fishing. In relation to coastal recreation, the Beach Report Card was developed to track the water quality at beaches along the coasts of California, Oregon and Washington. Beachreportcard.org is very user friendly as it uses an A-F grading system to classify weekly water quality reports and facial expressions such as a happy face or a sad face to classify yearly water quality reports (HTB, 2018). Users can search for a beach they may want to visit and see if it is safe to be in contact with the water. They could then make an informed decision if they want to visit the beach or not (HTB, 2018). This tool is not only for the general population but also for anyone interested in data, such as researchers as the website also shows the raw data used to grade water quality in a chart. This tool is more of a Participatory GIS tool as it potentially engages more of the community.

Study Purpose and Objectives

To engage communities in understanding the spatio-temporal characteristics of water resources in their community, this study has three main objectives, all with the central goal of informing community stakeholders about the quality of water resources in their community. Objectives include (1) Identify stakeholder needs related to water quality data, (2) explore ways of applying geovisualization tools to an online setting to meet stakeholder needs and (3) understand the extent to which impaired water resources (i.e. using a headwater watershed and lake context) are spatio-temporally impacting the various socio-economic (i.e. DACs vs. non-DACs) and environmental characteristics of local communities. Developing such knowledge may assist communities with becoming more informed and engaged in water resource planning, management and conservation efforts.

Study Site

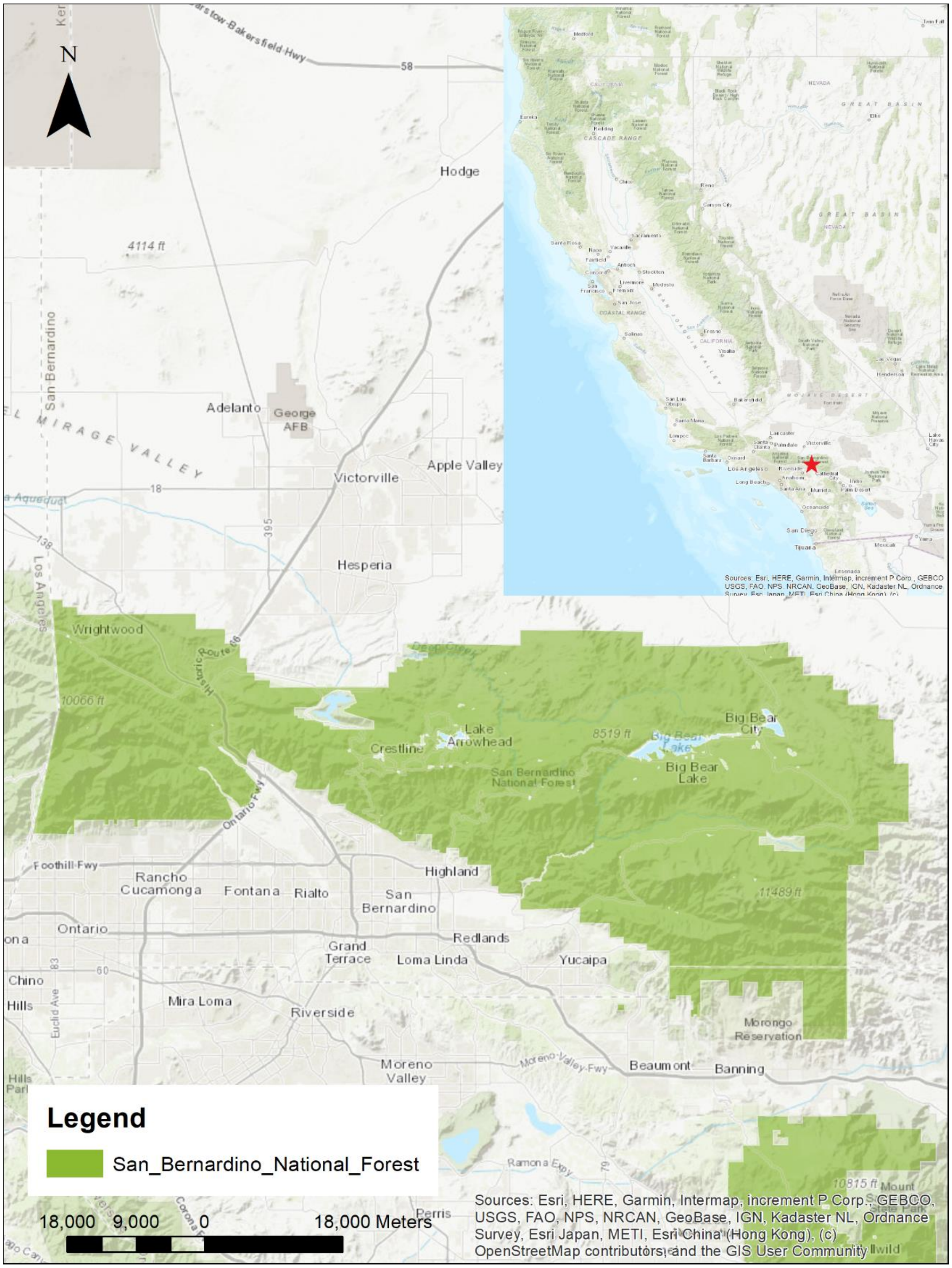


Figure 2. Map of California with the San Bernardino National Forest marked.

The San Bernardino National Forest (SBNF) area is a mountainous region in San Bernardino County north of the Inland Empire in Southern California. It contains about 676,000 acres of forest ranging from coniferous, juniper, chaparral forests as well as semi-arid desert regions (USDA, 2020). Elevation ranges from 11,499 feet at the highest peak and 440 feet above sea level (USDA, 2020). Many reservoirs are fed by the surrounding watersheds of the four major mountain ranges in the forest which include the San Gabriel, San Bernardino, San Jacinto and Santa Rosa mountains. Climatically the forest has a very moderate climate ranging from cool summers and snowy winters in the mountainous region and hot-dry summers in the lowland and desertic regions (USDA, 2020). The national forest also contains two headwater basins that eventually drain into the Santa Ana River and Mojave River Basin. Recreational activities include hiking, backpacking, camping, ski and snowboarding, horseback riding, fishing, boating and picnicking (USDA, 2020).

Creating an interactive webGIS mapping tool where professional scientists can input information about water quality in the SBNF and community members can provide feedback would be of high community value. The feedback would be related to what information community members find useful and how it can be better presented in a way that is user friendly and understandable by the whole community; not just members that have prior understanding of water quality data in the region. Data collected by Dr. Alford and her graduate students from the various sites in the San Bernardino National Forest area will be included. The sites that will be included, shown in *Figure 1* as red points, are Lake Gregory (LG1, LG2, LG4), Heart Rock (HR1), and three sites in Lake Arrowhead, including Little Bear Creek (LBC), Orchards Creek (OC), and Burnt Mill Creek (BMC).

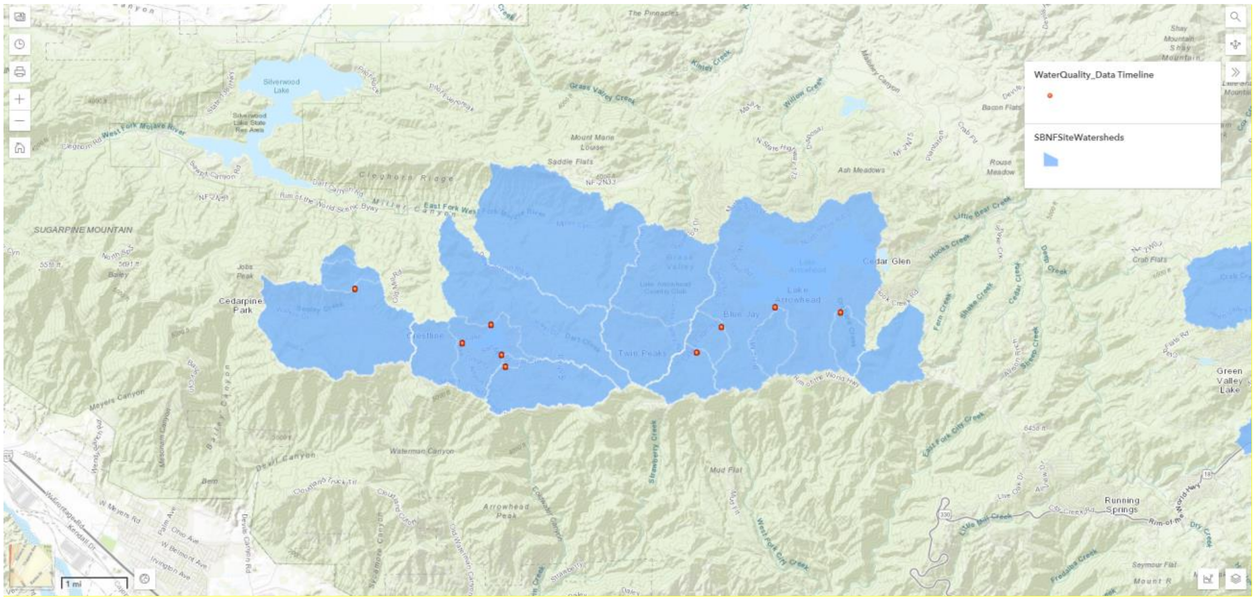


Figure 3. Map of testing sites and watersheds in San Bernardino National Forest.

CHAPTER TWO

METHODS

Water Quality Sampling

Sampling occurred bi-weekly for seven water quality metrics measured *in situ* with Vernier LabQuest 2 instrument probes including temperature (℃), dissolved oxygen (DO) (mg/L), pH, conductivity (µS/cm), ammonium (NH_4^+) and nitrate (NO_3^-) ion-selective electrodes (mg/L), and turbidity sensor (NTU). Additional grab samples were collected for total coliform (TC) (MPN/100mL), and Escherichia coli (*E. coli*) (EC) (MPN/100mL). Samples for bacteria (i.e. total coliform and *E. coli*) were collected separately in sterilized IDEXX 100mL bottles and analyzed using U.S. EPA approved IDEXX methods (IDEXX, 2018).The sampling periods that were observed were from April 2108 through August 2020. During the dry seasons of May through September, these sampling sites were tested bi-weekly whereas in the wet season of October through April, the sites were tested weekly. This data is applied to this project as the data was acquired by other researchers for other projects. The EPA approves the measurement of coliform bacteria as most probable number (MPN), although IDEXX (2018) states that MPN is synonymous with colony forming units (cfu). For this project, cfu was used as the primary form of measurement for coliform bacteria and were measurements were recorded as such on an excel spreadsheet.

Table 1. Exceedances levels set by various governmental agencies.

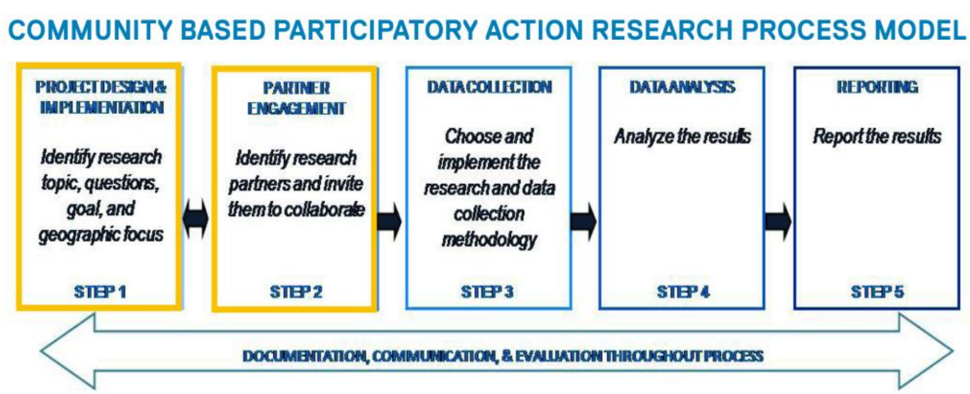
Water Quality Metric	Standard	Source
Temperature (C)	< 25C	CA State Water Board
Dissolved Oxygen (DO) (mg/L)	>4 mg/L	CA State Water Board, Lahontan Region
pH	6.5-8.5	CA State Water Board, Lahontan Region
Turbidity (NTU)	<100 NTU	CA State Water Board (Fact Sheet)
Conductivity (uS/cm)	150-500 Range <336 ms/cm (Average)	EPA (Range) CA State Water Board (Average)
Nitrate (NO3-) (mg/L)	0.8-2.5 mg/L	San Bernardino Mountains Hooks Creek Objectives
Ammonium (NH4+) (mg/L)	0.02-0.4 mg/L	EPA Aquatic Life Criteria
Total Coliform (TC) (cfu/100mL)	1,000 cfu/100mL	CA State Water Board Objectives
e. Coli (cfu/100mL)	<126 cfu/100mL	EPA Recreational Standards
Enterococcus (cfu/100mL)	<35 cfu/100mL	EPA Recreational Standards

Geodatabase Development

The data used to build the GIS database and resulting maps will be downloaded from various sources including the US Geological Survey, State of

California, US Census, Environmental Protection Agency geospatial portals. Some of these data sets include topography, population, forest boundaries, precipitation and climate for the region. The data will assist in developing GIS based layers that will further allow for the development of interactive online tools. These tools will include details about water quality sampling points, topography, socio-economic demographic data and land use cover. The map will also include a timeline where a user could visualize changes and trends in water quality as well as compare to similar water bodies. With this trend data the user will be able to see how the region's water measures up to EPA standards and how it changes throughout wet and dry seasons.

There is a five-step model in conducting a community-based participatory study (Figure 3). This model can easily be applied to a GIS study as well. The first step in the process would be identifying the community that we want to participate in this research and what the overall goal of the study is. In this case, the disadvantaged community in the San Bernardino mountains is the community



to focus on and the goal is to create an interactive webGIS mapping tool that community members could view and provide feedback on.

Figure 4. A process model of a CBPAR study (Burns, Cooke, and Schweidler, 2011)

Stakeholder Outreach and Feedback

Community stakeholders, shown in Table 1, will be identified using online search tools that explore local, regional and state agencies and non-profit organizations that are directly involved in representing the social, economic and environmental issues surrounding water for Crestline, Lake Arrowhead and surrounding unincorporated areas.

Table 2. Stakeholders in the SBNF area and their mission

Organization	**Location**	**Mission**
Crestline Lake Arrowhead Water Agency	Crestline, California	Governmental public agency providing water across the San Bernardino Mountains
Silverwood Lake State Park	Silverwood Lake, California	Recreational Lake in the San Bernardino Mountains
Mojave Water Agency	Apple Valley, California	Region water provider for towns in the High Desert including, Barstow, Lucerne Valley, Victor Valley, Yucca Valley and surrounding communities

Santa Ana Watershed Project Authority	Riverside, California	A joint power authority composed of five member agencies: Eastern Municipal Water district, Inland Empire Utilities Agency, Orange County Water District, San Bernardino Valley Municipal Water District and Western Municipal Water District.
US Forest Service	Nationwide	Governmental agency protecting forest land across the US
Lake Arrowhead Community Services District	Blue Jay, California	Provides water and wastewater services to the Lake Arrowhead area
Arrowhead Lake Association	Lake Arrowhead, California	To protect, operate, and improve Lake Arrowhead and ALA properties, to provide reasonable and safe recreational facilities in a a fiscally responsible manner, with appropriate planning for the future.
Crestline Water and Sanitation Districts	Crestline, California	Provides sanitation services for the Crestline communities.
San Bernardino Valley Municipal Water District	San Bernardino, California	Provides water services to the San Bernardino Valley

San Bernardino County Parks and Recreation	San Bernardino, California	San Bernardino County Regional Parks is dedicated to providing County residents and visitors with opportunities to host and participate in innovative and diverse recreational and educational events, while protecting the County's natural, cultural, historical, and land resources. The Department continues to improve and ensure the availability and integrity of open space activities for all ages and communities.
San Bernardino County Public Health Department	San Bernardino, California	Working in partnership to promote and improve health, wellness, safety and quality of life in San Bernardino County.
Southern California Mountain Foundation	San Bernardino, California	A non-profit for the San Bernardino Mountain area that supports youth development through conservation initiatives integrating environmental education, training and hands-on service projects. Protecting natural resources through adult and family-led programming. As well as providing interpretive services that focus on outdoor recreation, responsible use, and stewardship of

		our natural environment.
Urban Conservation Corps	San Bernardino, California	The Southern California Mountains Foundation Urban Conservation Corps offers young men and women the chance to better their lives. Corps members serve in the Southern California Mountains and become employable citizens through hard work in environmental conservation. Meaningful projects build valuable workforce skills that increase job readiness.
Big Bear Discovery Center	Big Bear, California	Our goal is to ensure your visit here is enjoyable and heightens your awareness to become a more knowledgeable and responsible caretaker of the San Bernardino National Forest.
Children's Forests	Nationwide	Places where kids and families are connecting with the outdoors.

Save our Mountains Association	Rim Forest, California	SOFA supports our local Chambers of Commerce in enhancing our mountain community through sensible economic development, tourism, and positive governmental relations. We share the core values of preserving the quality of life; integrity and hard work; excellence in reputation and productivity as a team. If you care about these issues, we urge you to add your support to this highly dedicated group of grassroots activists and volunteer your time, energy and expertise to help maintain our irreplaceable forest.
San Bernardino Mountain Land Trust	Lake Arrowhead, California	We acquire forest open space and wildlife habitat on private land inholdings within the San Bernardino National Forest in order to ensure lasting public benefit of the natural mountain environment.
Mojave Resource Conservation District	Victorville, California	The Mojave Desert Resource Conservation District is committed to the development of a land stewardship ethic that promotes long-term sustainability of the region's rich and diverse natural resource heritage.
Lahontan Regional Quality Board	Victorville, California	To preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and to ensure proper water resource allocation and efficient use, for the benefit of present and future generations.

Cal Trout	Statewide	At California Trout, we work to ensure resilient wild fish thrive in healthy waters for a better California. It's our belief that abundant wild fish indicate healthy waters and that healthy waters benefit all Californians. With more than sixty large-scale, "boots on-the-ground" conservation projects underway, in tandem with public policy efforts in Sacramento, our six regional offices work tirelessly to advance our cause through a three-pillared approach to conservation.
San Bernardino County Public Works	San Bernardino, California	To enhance the quality of life for our diverse communities by developing and maintaining public infrastructure, and providing a variety of municipal services that complements our natural resources and environment.
Skypark	Skyforest, California	SkyPark at Santa’s Village promotes clean living, an active lifestyle and conservation in a fun and interactive exchange with the environment.
Arrowbear Water District	Arrowbear Lake, California	The mission of the Arrowbear Park County Water District is to provide the highest quality water, sewer, and fire protection services to the community of Arrowbear Lake in the most economical and efficient manner possible. Our goal is to accomplish our mission with the highest standards of integrity, ethics, accountability, and transparency. As public servants we pledge to provide prompt and

		courteous service to the community we serve.
Running Springs Water District	Running Springs, California	Has the duty of supplying and maintaining water service, providing fire and emergency medical care services and operating wastewater collection and treatment facilities for the residents, users and taxpayers of this area.
San Bernardino Valley Audubon Society	Running Springs, California	SBVAS strives to bring people to their natural environment. Focusing on birds and other wildlife, we hope to conserve natural resources in the Southern California's "Inland Empire," specifically San Bernardino, Riverside, and Imperial Counties.
Rim of the World Recreation and Parks District	Rim Forest, California	To help enrich and fulfill the lives of the citizens through the provision of facilities and programs that will provide and enhance creative, wholesome and imaginative leisure time living patterns.

Inland Empire Resources Conservation District	Redlands, California	A public agency that focuses on open space preservation, wildland rehabilitation, and outreach/education within 1300 square miles of northwestern Riverside and southwestern San Bernardino counties.

Due to ongoing COVID restrictions, a virtual approach will be taken to communicate with organizations. This includes email and phone correspondence where respondents will be asked to outline their priorities related to water resources. Throughout the process of developing the online platform, stakeholders will be able to provide feedback to ensure the platform, as much as possible, assists with their individual objectives related to water resources in the study area. The CSUSB Institutional Review Board (IRB) has been contacted to ensure an IRB is not warranted, which they indicated was not needed for this information communication with stakeholders.

Geovisualization Tools

Geovisualization tools will be used to analyze and interpret the information that is being input into the platform in a way that is easy to visualize and understand for people living in the community (Jankowski, 2009). The Department of Water Resources' Disadvantaged Communities tool is also embedded in the application as this community in particular, as well as individuals who recreate and visit, can be heavily impacted by impaired water in the area. The data could then be reported to the community and stakeholders therefore creating a more inclusive and informed community that can make decisions on their water resources together.

CHAPTER THREE

RESULTS AND DISCUSSION

With prolonged drought conditions, coupled with surface water resources that support numerous human and environmental uses across the San Bernardino National Forest, amplifies the need to understand the spatial and temporal aspects of water quality so that trends and sources of impairments can be identified and mitigated. This study observed water quality data including water quality measurements of temperature, dissolved oxygen, pH, conductivity, ammonium, nitrate, turbidity, total coliform, and E. coli. Each parameter indicates physicochemical properties of monitoring sites at a given time as well as trends over time in relation to wet and dry seasons and prolonged drought (Ahearn 2005, Billen, 2001, Burkholder 2002). For example, conductivity is an indicator of increased dissolved solids present in the water body such as salts and wastewater effluent, whereas dissolved oxygen and nutrient concentrations, can indicate conditions conducive to supporting harmful algal blooms (Carmichael 2015, Falconer 1999, Ahearn 2005, Mallin, 2009). Additionally, increases in bacterial concentrations may indicate waste from wildlife, pets and infrastructure failures that are adversely impacting water resource quality (Mallin 2003). Essential to this study was identifying ways to illustrate data trends to inform community stakeholders and resource managers so that more informed decisions about the quality of water resources can be identified and mitigated. At a sampling site, if a point is green, the sampling site meets regulatory standards

(Table 1). If the point is red, then the sampling site is not meeting regulatory standards. The points on this geovisualization tool showcases how the area experiences trends in water impairments, especially throughout the wet and dry seasons as well as allows users to link these impairments to specific watersheds. This way stakeholders, educators and residents in the area are able to create rehabilitation plans more specific to each watershed as a one size fits all remediation may not be successful for every watershed. Examples of these scenarios are shown in the figures 4, 5, and 6.

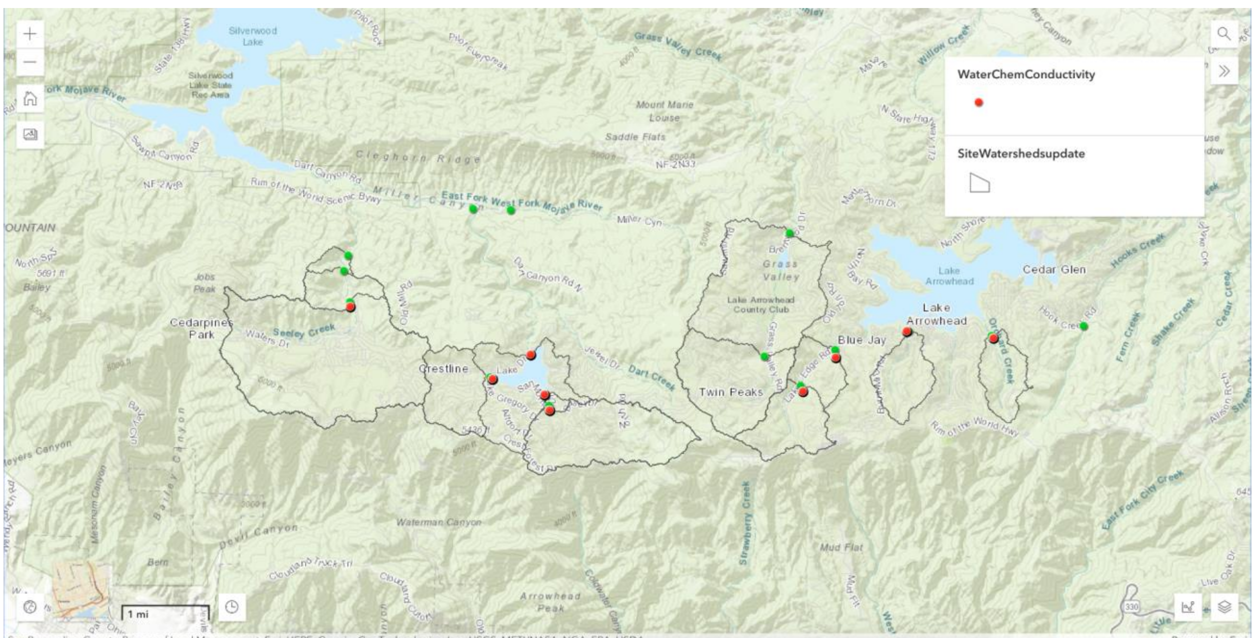


Figure 5. Depicts the map and sampling sites during a time of high conductivity

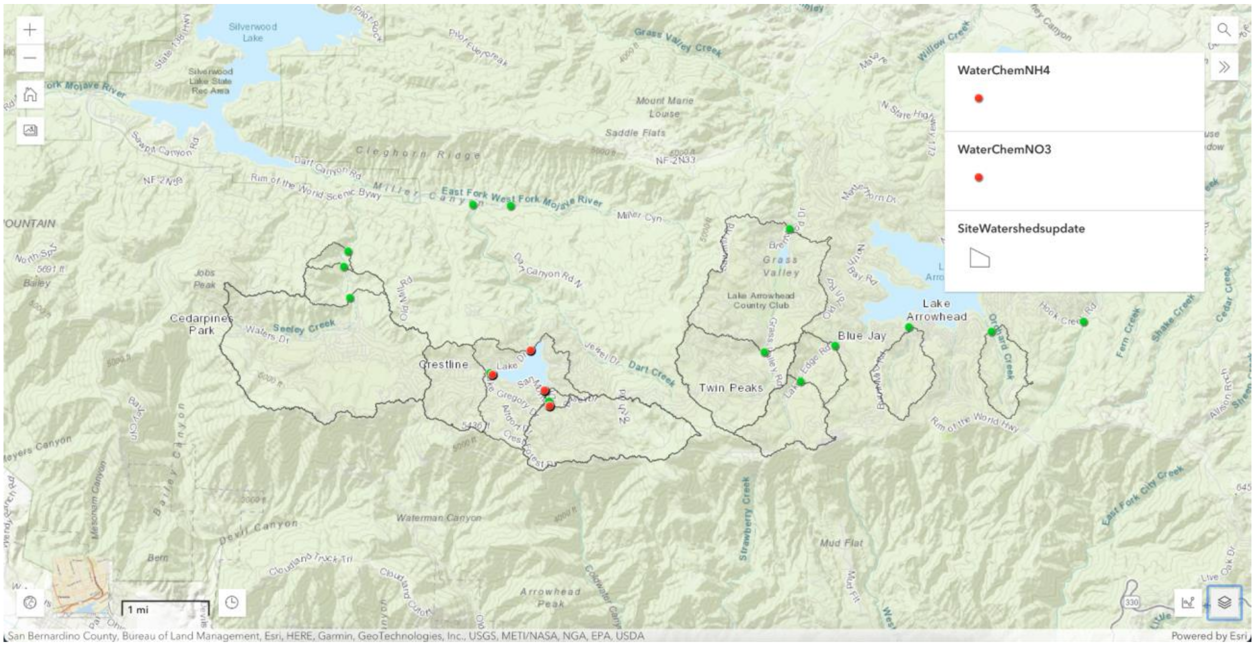


Figure 6. Detection of parameters that indicate possible sources that create algal bloom conditions.

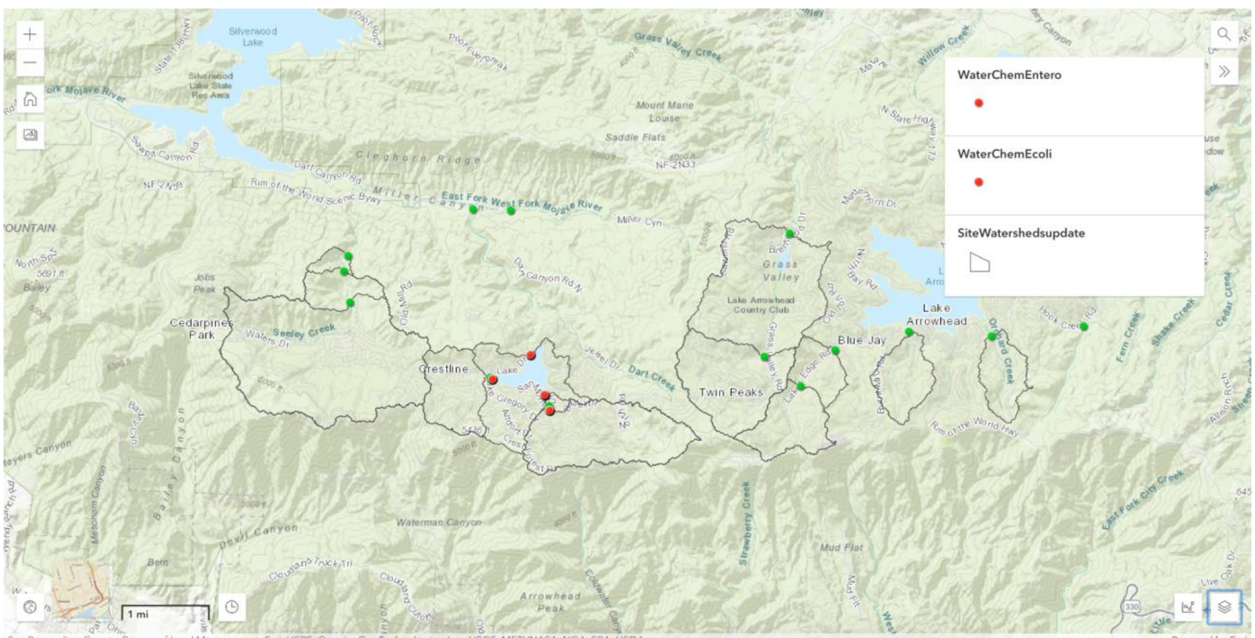


Figure 7. Detection of parameters that indicate possible sources of a sewage leak.

Descriptive Statistics, Parameter Trends and Watershed Characteristics

Descriptive statistics were calculated for all of the water quality parameters. These include mean, median, standard deviation and variance. Although the focus is on the high exceedances and the variance as this gives insight on the frequency and level of exceedance a testing site is experiencing those exceedances throughout the sampling period. This data in Table 3, is used to inform the Arc GIS mapping applications and public facing online mapping tool. Exceedance levels are set by the federal government and many of the trends seen in these tables are well over the exceedance levels and can be seen on the application as red points (USDA, 2020).

Table 3. Descriptive statistics for Lake Arrowhead tributaries testing site

Little Bear Creek 1	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	0.321	8.339	193.818	8.916	6.624	15.203
Median	0.309	7.400	207.000	9.020	6.605	6.200
Var	0.021	10.539	4758.198	1.153	0.233	924.843
Std. Deviation	0.144	3.246	68.980	1.074	0.483	30.411
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.371	1.676	532.521	221.753	197.691	
Median	0.200	1.200	325.500	124.600	156.500	
Var	0.136	7.210	237444.538	70407.295	27503.737	
Std. Deviation	0.369	2.685	487.283	265.344	165.843	
Little Bear Creek 2	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	0.367	7.177	177.157	9.580	6.553	11.515
Median	0.296	5.700	141.500	10.100	6.455	10.150
Var	0.048	13.292	25066.868	1.558	0.181	81.528
Std. Deviation	0.219	3.646	158.325	1.248	0.425	9.029
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.500	0.955	599.490	128.317	59.529	
Median	0.300	0.800	159.500	20.350	24.300	
Var	0.281	0.414	634965.677	31182.243	3643.549	
Std. Deviation	0.530	0.644	796.847	176.585	60.362	
Burnt Mill Creek	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	0.575	6.505	180.275	9.931	6.700	14.785
Median	0.568	5.150	173.550	10.025	6.755	8.800
Var	0.055	13.579	1519.160	0.701	0.201	461.400
Std. Deviation	0.235	3.685	38.976	0.837	0.448	21.480
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.395	1.275	356.845	39.718	22.117	
Median	0.350	1.300	129.100	4.100	16.200	
Var	0.107	0.317	131345.645	11787.022	421.926	
Std. Deviation	0.327	0.563	362.416	108.568	20.541	
Orchard Creek	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	0.305	7.421	176.605	10.095	6.682	13.100
Median	0.308	5.800	166.600	10.330	6.500	10.400
Var	0.024	9.410	1231.565	1.254	0.289	152.593
Std. Deviation	0.154	3.067	35.094	1.120	0.538	12.353
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.537	1.853	628.936	34.418	25.567	
Median	0.500	1.900	261.300	17.300	20.650	
Var	0.170	0.843	667513.631	4545.402	664.539	
Std. Deviation	0.413	0.918	817.015	67.420	25.779	
Deep Creek Headwaters	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	0.985	7.817	160.200	8.758	6.592	5.956
Median	0.927	6.700	162.000	9.560	6.830	5.900
Var	0.191	25.278	3854.676	5.091	1.550	12.049
Std. Deviation	0.437	5.028	62.086	2.256	1.245	3.471
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.308	0.765	62.320	27.571	7.800	
Median	0.200	0.800	36.550	16.100	4.650	
Var	0.121	0.411	2730.760	1045.646	63.412	
Std. Deviation	0.347	0.641	52.257	32.336	7.963	

Table 4. Descriptive Statistics for Heart Rock and Lake Gregory testing sites.

Heart Rock	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	0.368	5.363	42578.705	877.051	66.050	64.318
Median	0.327	3.685	261.300	10.025	6.755	12.049
Var	0.068	35.956	3364.044	8055517.656	29993.844	19186.815
Std. Deviation	0.260	5.996	154272.556	2838.224	173.187	138.516
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.375	4.749	1021.636	71.471	43.583	
Median	0.308	1.900	803.750	38.900	18.850	
Var	0.077	40.999	623076.167	12208.992	4470.522	
Std. Deviation	0.277	6.403	789.352	110.494	66.862	
Lake Gregory 1	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	N/A	13.300	211.400	9.700	7.000	22.500
Median	N/A	12.300	199.700	9.670	6.840	14.400
Var	N/A	49.200	8532.300	3.400	0.600	606.300
Std. Deviation	N/A	7.000	92.400	1.900	0.800	24.600
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	1.100	3.000	952.000	131.800	22.200	
Median	0.500	1.700	770.100	23.100	6.200	
Var	3.100	11.800	684684.600	71728.600	3218.700	
Std. Deviation	1.800	3.400	827.500	267.800	56.700	
Lake Gregory 2	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	N/A	12.500	190.600	9.000	6.800	20.400
Median	N/A	11.300	191.700	8.890	6.700	13.800
Var	N/A	39.800	1790.800	3.400	0.400	808.800
Std. Deviation	N/A	6.300	42.300	1.800	0.600	28.400
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.900	2.600	676.400	50.800	25.400	
Median	0.300	1.600	344.800	9.650	6.300	
Var	3.200	7.300	513917.200	10082.700	3435.400	
Std. Deviation	1.800	2.700	716.900	100.400	58.600	
Lake Gregory 3	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	1.000	59.600	66.500	50.600	58.300	69.900
Median	1.125	7.800	155.400	9.730	6.850	5.200
Var	0.300	8.400	1955.300	2.000	0.200	236.600
Std. Deviation	0.600	2.900	44.200	1.400	0.500	15.400
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	87.000	121.400	201.400	65.200	113.500	
Median	0.200	2.450	202.350	20.600	54.700	
Var	2.000	20.300	229921.800	11889.900	37271.300	
Std. Deviation	1.400	4.500	479.500	109.000	193.100	
Lake Gregory 4	Flow (m/s)	Temp (C)	Conductivity (ms/cm)	DO (mg/L)	pH	Turbidity (NTU)
Mean	N/A	13.884	185.153	9.046	7.057	45.132
Median	N/A	12.300	187.700	8.950	6.850	22.200
Var	N/A	56.150	1682.979	3.001	0.603	10129.511
Std. Deviation	N/A	7.493	41.024	1.732	0.776	100.645
	NH4 (mg/L)	NO3 (mg/L)	Total Coliform	E Coli	Enterococci	
Mean	0.595	4.637	969.568	75.857	35.787	
Median	0.300	3.800	648.800	8.100	16.800	
Var	1.110	10.250	750831.950	57127.722	3258.450	
Std. Deviation	1.054	3.202	866.506	239.014	57.083	

For example, Lake Gregory Testing Site 1 (LG1) is a popular lake that is an outlet for three different watersheds in the area. Many residents and visitors use this lake to enjoy recreation such as swimming, fishing and boating. These activities can be dangerous when the water becomes impaired and potentially toxic. Many of the testing categories for LG1 have a high variance meaning the site goes through much fluctuation. Lake Gregory's site 1 Total Coliform, E. Coli and Enterococci categories are exceeding regulatory standards. The average level of total coliform at LG1 is at 952 MPN which is very close to the maximum set by the CA State Water Board, although, the variance of this category is at 684684.600 MPN which means there are times where the levels of the Total Coliform exceeding regulatory standards by 199% (Table 3). During the wet season which is from October to April, bacteria are exceeding regulatory standards when algae tends to bloom making it unsafe for residents to use for recreation and fishing. Especially after a heavy rain event, algae may form after non-point sources of pollution in the watershed have runoff into Lake Gregory causing the algal blooms as also observed by Carmichael (2016), Le Moal (2019), and Verspagen (2014). As seen in various other studies regarding non-point sources of pollution, it is seen that after precipitation events, concentrations of pollution inputs are often elevated in receiving water bodies as the pollution is carried down as runoff, either from rain or snowmelt, from higher points in the watershed to lower points where streams, rivers, lakes and oceanic water features are located (Azizullah, 2011, Davis, 2013, Ding 2013). Lake Gregory experiences much of the same phenomena as during the October through April sampling periods; the region experiences precipitation events that exacerbate pollution in the lake system as pollution is carried from higher elevations in the watershed headwaters and is carried through streams that flow into Lake Gregory.

Heart Rock (HR1) is a very important stream system that supports the community with drinking water as well as a recreational site as it traverses the forest landscape terminating into Silverwood State Park Lake and Recreational areas. High variances in nitrate and ammonium occur during the wet season, which is from October to April. Similar to what Davis (2013) observed, during the wet season is when more pollution can be observed at the testing sites as it is carried by precipitation events to the water bodies (Davis, 2013). This pollution is observed as increased concentrations of nitrates, ammonium, and decreased dissolved oxygen levels. In this area pollution is present throughout the year but during the wet season when there are precipitation events is when it gets carried down through subsurface and surface waterways to the Heart Rock stream system. There is also a sewage line that runs through the area that at times may experience leakage. At this site, many of the pollutants that cause these spikes in bacteria are non-point pollutants which are pollutants that get carried to the stream when there is rainfall or snowmelt. These non-point pollutants can be sourced from sewage leaks, chemical spills, urban runoff (Alexander, 2007, Carpenter, 1998). Throughout the year this stream system experiences high incidences of bacteria and is highly unsafe for hikers in the area as well as use for drinking water. The average total coliform level for this site is at 1021.63 MPN which is 2% over the standard set by the California water boards. The average for E. Coli is 71.47 MPN which is under the EPA standard for E. Coli but for Enterococci the level is at 43.5 MPN which is exceeding the regulatory standard of 35 MPN by 22% (Table 3). Heart Rock has multiple sites on the stream that are tested, which is beneficial because there is a section of the stream that is impaired, the web application tool could help in identifying if the whole stream or a section of the stream is contaminated.

Little Bear Creek is a stream system that is a headwaters to Lake Arrowhead. The area characteristics go from a forested area to small commercial and residential land cover to larger commercial areas. The headwaters of this stream system are heavily forested and experiences much of the precipitation that occurs during the wet season of the year. Study site 2 for Little Bear Creek (LBC 2) has a very high exceedance rate for conductivity and total coliform. Because Little Bear Creek is a head water to Lake Arrowhead, the health of this stream system is very important because it consequently impacts the health of Lake Arrowhead. The trend shows that during the wet season of the year more the parameters for conductivity and coliform bacteria are constantly exceeding regulations. Although during the dry season, there is a buildup of pollution in the headwaters of this system that gets flushed to the stream and eventually the lake during the wet season. The average conductivity level for Little Bear Creek at 177.15 ms/cm falls within regulatory standards (Table 1) but this stream system is also near a gas station which could potentially be why the stream has a high variance of conductivity at 25066.86 ms/cm, exceeding regulatory standards by 194%. The average total coliform level of this stream system is also within the level set by the CA State Water Boards (Table 1) but this category is exceeding regulatory standards by 199% at 634965.6 MPN. Many of the other sites may have exceedances in coliform bacteria but this site is a site that is unique in having exceedances in conductivity which could indicate a high level of dissolved solids in the water such as solids leaching from a facility that uses chemicals.

Each site has a unique purpose and environment which is why it is important for stakeholders to know environmental conditions and the extent to which surface water resources are serving the community related to human-environmental health factors to make sure it is a healthy source of water for drinking water, recreational activities as well as supportive diverse ecological services. In residential communities classified as disadvantaged communities, they often do not have the resources to know how their water sources are impacting them, highlighting an advantage of this study. As each site falls under a different watershed in the area, the environments are different therefore, the solutions to rehabilitating these sites must also be different.

This ArcGIS tool can be used in various different ways. It can be used for both professional and public use. Because of the spatio-temporal nature of the application it is possible to view changes over time as well as predict seasonal changes as more data is collected in future years. The tool can also help visualize trends in regards to geography and spatial location. For example, at the Heart Rock locations, trends such as flow may be identifiable in regards to the location of the stream, how graded it is and what time of year is being seen in regards from the wet season (October through April) or the dry season (May through September). As stated in previous examples of the application one site may be exceeding the federal environmental standards while another may not. This could more proactively support professionals with identifying events that may have happened in specific watersheds such as a sewage spill, formulation of conditions that are supportive of harmful algal blooms and also conditions that impact human and ecological health (Brotosusilo, 2016). As the climate in the region continues to change with increasing prolonged droughts, less frequently, but intense precipitation events, understanding historical to present surface water quality trends will become increasingly necessary to protect dwindling, in both quality and quality, surface water resources (Charron, 2004, Delpla, 2009). Consistent exceedance hotspots in the region include the Lake Gregory sites, Orchard Creek and Heart Rock site 1. Based on the data collected, these three sites have been experiencing exceedances since the beginning of the study starting in April of 2018. Many of these exceedances may be caused by non-point pollution sources from headwaters as the landscape experiences much precipitation at the top of these watersheds, which in turn carries pollution down to the stream outlets (Carpenter, 1998, Mallin, 2009). From the data collected it was observed that during the wet season, which is from October to April is when there are more exceedances occurring at the sites. One solution that can be practiced is rehabilitating areas in the watersheds that have headwater systems. Simply treating areas at the end point of these stream systems will not fully remediate the problem that this area is experiencing with pollution (Rasmussen, 2013, Xenopoulos, 2017). This tool can be helpful in identifying trends the headwaters are experiencing, especially for managers and stakeholders of these stream systems, and possibly predict when a pollution issue may arise if and where there is a precipitation event, for example (Butler, 2015, Dennis, 1987, Jankowski 2009, Kearns 2003).

Stakeholder Input of Tool and Needs

As the application was only a sample for purposes of presenting, many of the suggestions were already loaded into the main application. Many of the stakeholders stated in Table 1 were present in the demonstration of the web application. Many of the stakeholders expressed the helpfulness and usability of the application in their own fields. Some had suggestions such as adding layers that visualized well production data to the application to better facilitate them in using the application in their field.

This application could be helpful to stakeholders in being able to identify areas that need rehabilitation and make these systems safe for consumption and recreation. For example, Lake Gregory has sites that are over regulatory standards for most of the criteria. Much of the impairments as stated before is non-point pollution that comes from higher up in the watershed. One solution is to rehabilitate areas near the headwater streams that feed into Lake Gregory. For example, a solution to rehabilitating Lake Gregory may be different than a solution to rehabilitating the Heart Rock stream sites. A lake system with head water streams may have a rehabilitation plan of constructing or modifying existing storm water run-off structures that would keep and divert non-point pollutants from running off into the headwaters and reaching the lake such as Lee's (2012) findings in a watershed-wide storm water runoff study. A stream system may have a rehabilitation plan of policy enforcing or restricting the use or dumping of certain chemicals or, although perhaps expensive, filtering the water from the stream through a treatment plant such as the ones proposed in Jia's (2013) findings in Chinese stream systems. Once those areas are rehabilitated, it would be easier to rehabilitate Lake Gregory as there would be little to no pollution feeding into the lake. Not only could the tool identify if areas in the San Bernardino National Forest could be rehabilitated but once more data is collected in the future it could also serve as a tool for the public to see if these areas are being successfully rehabilitated and if pollution statistics reach normal levels. Some other additions that were suggested include climatic data such as drought monitoring data collected from the University of Nebraska (National Drought Mitigation Center, 2022). This could be helpful to them as this dataset is highly extensive and could provide more insight on how the climate is changing in the area and seasonal trends that may occur. Some other data that was suggested be included in the application is wildlife corridors, land use, and well production data. Wildlife corridors were also suggested to be loaded on to the application as many of these areas are important habitats for wildlife and it is important to protect it. Land use was suggested as well and could be used to further identify points of potential pollution to the watershed systems. Well production data was something that was not thought of being loaded initially but is a great suggestion as it is important to know how pollution can be affecting wells and the water that residents of the area are using for consumption. This geovisualization tool also includes data gathered from the USGS, US Census and the forest service to further identify the impairments the San Bernardino National Forest faces. The tool also includes a timeline of collected data and shows points where EPA standards for the before mentioned criteria were exceeded.

Meeting with the stakeholders was helpful in being able to see what was important to the community as they are experts in their fields and have different perspectives based on what they focus on in the community. Many of these stakeholders come from backgrounds in social justice, environmental activism, wildlife conservation, public service, county agencies, water agencies, businesses, etc. It is important to get feedback from many different backgrounds so that this geovisualization tool can serve the whole community and not just professionals in the region (Dave, 2017, Jankowski, 2009, Kearns, 2003, Kuntiyawichai, 2017).

This application is also helpful to both identify the issues and needs of the community through environmental justice and decision making (Azizullah 2011, Brabec 2002, Clayton 2000). Equity is a big factor in the San Bernardino National Forest, specifically in the southern side of Lake Arrowhead, and the Lake Gregory and Heart Rock areas. These areas have a lower median household income and as disadvantaged communities many of the individuals in those communities are disproportionately affected by pollution as opposed to other individuals who live in other areas of the San Bernardino National Forest and California that have a higher median income (Bullard 2000, Clayton 2000). This tool could allow people in the disadvantaged regions of the San Bernardino National Forest community to understand and find ways to improve their livelihoods by voting for specific policy that would positively impact their water sources or working with stakeholders that are in positions to make those decisions.

In communication with many stakeholders in the area it seems that a GIS tool, like the one created, can greatly impact the overall quality of water in the watersheds of the San Bernardino National Forest. Being able to visualize all the chronic issues in the watersheds in spatial and temporal forms allows for stakeholders to identify those issues and work to remediate them. Not only will the tool allow stakeholders to identify issues but also anticipate them as many of these issues follow yearly trends or events.

CHAPTER FOUR

CONCLUSION

The goal of this study is to be able to visualize data collected by Dr. Alford and her students to be able to better understand what the needs in the San Bernardino National Forest are. Being able to visualize this data helps stakeholders understand what remediations need to take place in order to impact the community in a positive manner as the community in this area rely heavily on the water systems in place. Much of the community rely on the water for drinking, recreation and fishing. Much of the community in the San Bernardino National Forest is considered disadvantaged and because of this it is more likely that these communities are more impacted by the pollution in the water systems.

There are a few parameters that the water is tested for that tell what kind of impairments the water system is experiencing. These parameters include temperature, dissolved oxygen, ammonium, nitrate, turbidity, conductivity, pH, and coliform bacteria. Different combinations of these parameters and their levels can indicate different impairments.

As Dr. Alford’s students continue to collect data from these sampling sites, the web application will continue to be updated. The next steps for this project, conducted by future graduate students, is to present the web application to community members and make the public aware that a tool such as this web map exists. Creating sustainable partnerships with various stakeholders in the area would also be a goal for the future.

Being able to visualize trends and events that occur in the area in an easy to understand manner such as a timeline map that anyone could use, from professionals in the field, residents, or the K-12 system, could have a positive impact on the community.

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