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# WATER SAMPLING PLAN FOR THE PUEBLO OF SANTA ANA

Plan for the Pueblo of Santa Ana Water Quality Division of the Department of Natural Resources

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The Pueblo of Santa Ana Department of Natural Resources

Submitted to:

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# Abstract

The Pueblo of Santa Ana's Department of Natural Resources needed improvements to their water sampling methods due to a unique local environment. The goal of this project was to create a water sampling plan comprised of sampling techniques and a water collection device for use during low flow conditions in the Pueblo's rivers. We achieved our goal through research, interviews, and field tests. We created a guide for proper sampling protocols and designed a water optimization device for sampling water.

# Acknowledgements

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We also received help and guidance during our research and interviews from the United States Environmental Protection Agency as well as Anita Steed, Glenn Tenorio, and Tammy Montoya of the Santa Ana DNR, Professor Paul Mathisen of Worcester Polytechnic Institute, and John Cole of PT&C|LWG Forensic Consulting Services. This research and these interactions ultimately helped us finalize almost every aspect of our water sampling plan.

Lastly, we would like to thank our advisors, Professors Michael Aghajanian and R. Creighton Peet, for their continued guidance and helpful comments over the last two terms. This report would not be as well composed if it were not for their feedback on our weekly drafts.

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# Executive Summary

The water in the rivers near the Pueblo of Santa Ana is occasionally unsafe for consumption and recreational use due to upstream pollutants, particularly *E. coli*. In addition to testing the water for *E. coli* as a water quality indicator, the Department of Natural Resources (DNR) also tests for water factors such as temperature, salinity, pH, dissolved oxygen, and turbidity. Being able to reliably and reproducibly sample the river's water to establish that is safe for consuming and for agricultural, ceremonial and recreational purposes is essential. It is especially challenging to collect accurate water samples as there are constantly fluctuating water conditions within the rivers, a unique micro-climate, and other local conditions. Our goal was to determine a water sampling plan for the Santa Ana DNR. This plan included both proper sampling protocols so that more representative and consistent samples could be collected as well as a water optimization and collection device for the Santa Ana DNR to implement and use within the Pueblo's rivers so that water could be better monitored even during seasons of low flow.

In order to achieve our goal, we needed to accomplish several objectives. We began by identifying the current sampling methods in use by the DNR. We then identified river water sampling techniques that would provide the most accurate and representative results. Next, identified water collection systems that could improve sample conditions so that river water samples could be collected during seasons of low flow. When we had an idea of what features of different water collection systems we wanted to incorporate into one system or device, we designed a water optimization device prototype and determined its acceptability for the Pueblo of Santa Ana. Finally, we determined ways to ensure the continuation and implementation of the sampling techniques and collection device we had designed and determined best suited for the Santa Ana DNR.

The identified sampling techniques and specifically the designed water optimization device had to be acceptable to the native culture and be both economically and technologically feasible to implement. Different cultures view the treatment of the environment differently, and we needed to ensure that the water collection device that we designed was acceptable to the Pueblo and did not conflict with any sociocultural values. We also determined and accounted for the ways in which the environment could be affected by our designed device. We determined the resources available,

including manpower, finances, materials, and skills of the workforce, to the Pueblo of Santa Ana for implementing water optimization device and made it feasible in those regards.

We achieved our goal and objectives by using various research methods including: interviews with local experts, interviews with the Santa Ana DNR Water Resources Division (WRD), observation of the Pueblo's current sampling methods, internet research, and field tests of our water optimization device prototypes. By speaking with the local experts we ensured that we were focused on solving the correct problems and they assisted us in identifying factors or problems that we may not have thought about. The Pueblo of Santa Ana's Department of Natural Resources was also a great resource. Not only did they provide us with useful information relevant to our project, but they also allowed us to learn about and observe the current sampling methods that they use. We observed those methods and used that information to help determine where the DNR needed to improve their sampling techniques. Based on the information obtained from all of these methods of research, we provided the Santa Ana DNR with a sampling techniques guide that highlights the most important practices when sampling water during different weather conditions and varying levels of flow in the river. We also provided a user's manual for the water optimization device complete with a construction plan, blueprints, and implementation and maintenance protocols. This device and its user's manual will enable the DNR to take water samples even during very low flow conditions of the rivers. We provided recommendations on the materials to use for fabricating the device as well as several future modifications and additions to further improve the device's functionality for low flow conditions.

# Chapter 1: Introduction

Clean water and knowledge of water quality is necessary for a healthy life. However, due to various factors, such as pollution, lack of funding, lack of maintenance, or difficult environmental conditions, affordable and clean water is not always readily available for many people. Being able to reliably and consistently sample water to establish if it is safe for drinking, agricultural, ceremonial and/or recreational uses is important. It is especially challenging to collect accurate water samples when there are constantly fluctuating river water conditions, unique climates, or other local conditions or circumstances.

The Rio Grande and Rio Jemez are rivers located in New Mexico that have varying water levels throughout the year. Due to the area's unique climate, these rivers are prone to drastically reduced flow during certain times of the year (IBWC, 2015). The water levels in these rivers is further affected by upstream water use for irrigation and by various Native American pueblos and other users. The varying water conditions in these rivers make it difficult to find a reliable method to sample water for testing on a regular basis. The Pueblo of Santa Ana's Department of Natural Resources needs consistent techniques for sampling water under varying conditions in the rivers, as well as a system or device to be used in order to better monitor the Pueblo's rivers during seasons of low flow. The water being sampled and tested is used by the members of the Pueblo for various uses, including irrigation, recreational uses, and, most importantly, for occasional consumption and cleansing during traditional ceremonies.

Several water sampling technique guides have been written (EPA, 1982; Myers, 2003). Due to the variety in types of bodies of water, the guides on best sampling practices also come in a great variety. The EPA, among many organizations, has released many guides detailing how and when to sample water for multiple types of bodies of water. There have also been many systems which have been implemented to improve sampling conditions. They can come in multiple forms, including weirs, dams, and flumes. While their sole purposes are not always to improve the flow of a river, this generally seems to be a result of the implementation of those systems (Campbell Scientific, 2016).

Currently, the Santa Ana DNR staff have methods and techniques for sampling water in the rivers that serve the Pueblo, but they would like to improve their techniques so that the results are more representative and consistent over time. The DNR needs to know which sampling techniques to use under changing conditions and needs a method or device that could improve the flow in the river to improve water sampling monitoring during low flow.

The goal of this project was to determine a water sampling plan which would include both sampling techniques and a water collection and optimization device for the Santa Ana DNR to implement and use to monitor the Pueblo's river water quality. We did this by accomplishing several objectives.

- We identified the Pueblo's water sources and the current water sampling locations and sampling methods used by the Santa Ana DNR.
- We identified water sampling techniques that would provide the most accurate and representative sampling results.
- We identified water collection systems that would improve sample conditions so that samples could be collected during low flow.
- We designed a water optimization device prototype and determined its acceptability for the Pueblo of Santa Ana.
- We determined ways to ensure the continuation and implementation of the sampling techniques and collection device we had determined best suited for the Santa Ana DNR.

We accomplished these objectives using a series of interviews, observations, and field tests along with archival and internet based research. The results of this project were important in aiding the Santa Ana DNR to be able to accurately identify the quality of the water that they use so that they could be aware of any possible dangers related to consumption and recreational use of the river water.

# Chapter 2: Background

The presence of *E. coli* in the Rio Grande and Rio Jemez water that flows through the Pueblo of Santa Ana is used as a water quality indicator by the Water Resources Division (WRD) of the Santa Ana Department of Natural Resources. Sampling and testing surface water for *E. coli* within the Pueblo requires attention to a myriad of factors and issues. In order to explain these factors and issues, this chapter identifies the different factors that should be considered based on the source of water—ground, lake, or river—being collected and sampled. We also describe several systems that alter and control the flow of river water so that the water can be properly sampled for testing during low flow. Finally, we examine the specific rivers that serve the Pueblo including the usage, types of pollution, and the various regulatory agencies of the rivers.

## 2.1 Collecting Surface Water Samples

When collecting surface water samples, there are several different factors to take into consideration. Depending on whether you are sampling groundwater, lakes and ponds, or rivers, these factors may vary.

### 2.1.1 Sampling Groundwater

When sampling groundwater, there are several different sampling procedures that one could follow. These procedures can vary based on the criteria used to determine if a sample is a good representation of the groundwater conditions (Porfet, 2010). Due to the variations in groundwater, there is no method or procedure that can be used for all groundwater sampling. Therefore, when sampling for groundwater one needs to consider a variety of factors when determining which method would work best given the site's conditions. These conditions include the depth of the groundwater well, availability of sampling equipment, and location of the sampling site. While there are many differences in the methods, all of the sampling protocols follow several basic steps: sampling preparations, accessing the groundwater well prior to sampling, measuring the water level, pumping water from the well, and collecting and delivering the water sample to a laboratory.

### 2.1.2 Sampling Lakes and Ponds

When sampling water from a lake, one should collect the sample at a location that is representative of the water in the pond or lake (Musselman, 2012). Generally, this is found at a deeper location and away from any incoming sources of water including streams, springs, or other sources that may be feeding into the lake or pond. If a deep area can be found, it is best to sample the water mid-depth. The sampling location should not be close to the shore because that is generally where debris or other contaminants are more likely to be present.

When sampling lake water, one should make sure that an uncontaminated bottle is being used and that the individual is not contaminating the sample results by contacting the inside of the cap or bottle in a way that will introduce new contaminants (Hilton, 1989). The bottle should be rinsed three times with pond/lake water and after rinsing, the bottle should be submerged below the water level and allowed to fill completely to the top. If possible, a device should be used in order to submerge the sample bottle to avoid contamination of the water with any bacteria that may be on the sampler's hands and also ensuring the safety of the sampler with potentially unsafe water. Once the samples have been taken, they need to be refrigerated and kept cold until they are ready to be tested in a laboratory.

### 2.1.3 Sampling Rivers

When sampling water in a river, there are many different factors to consider. The location chosen to take the sample from may have a great impact on the accuracy of the test results (Myers, 2003). Most importantly, samples should not be taken near the banks of the river. Although this may be the most convenient, it is generally not a great representation of the water in the river. This is due to the possibility of debris that lie along the banks which may corrupt the results. In order to obtain the best results, samples should be collected mid-stream. The depth of the samples collected also has an impact on the results. It is recommended that samples taken from a river be taken at mid-depth. The weather conditions that occur prior to sample collection also have a big impact on the water sample's results. It is not recommended that water samples be collected following a rain event as the rain can cause *E. coli* in the river's sediment to be churned up and could greatly skew and increase the *E. coli* test results.

## 2.2 Water Optimization and Collection Systems

The importance of collecting and testing water samples from the Rio Grande and Rio Jemez is imperative for the Santa Ana DNR because of the various uses of the water from the rivers (A. Steed, personal communication, August 29, 2016). During seasons of low flow, a sample may not always be able to be collected, but the water is still being used. Because of this, a system is needed to control the flow of the river's water in order to collect a sample. There are many systems and methods that have been used in order to control the flow of river water. These systems include dams, weirs, and flumes (Campbell Scientific, 2016).

### 2.2.1 Water Optimization Using Dams

A dam is a common method of water control (FEMA, 2016). Dams create a barrier to an existing body of water and obstruct the natural water flow in order to build up a reservoir of water behind it. The only water that is able to pass a dam is channeled through the body of the dam in a man-made penstock or water outlet. Dams are used for several purposes including flood prevention, the creation of a water supply, generating power, wildlife protection, navigation, recreation, and waste management. Since dams completely block the natural flow of water they allow for maximum control of a water source because the water can be released as necessary and in varying quantities.

There are many different types of dams that can be constructed. One example of a dam is the adjustable height dam built by the Albuquerque Bernalillo County Water Utility Authority (see Figure 2.1). Built in 2005 on the Rio Grande, the dam is 600 feet long and was part of the 400-million-dollar San Juan-Chama Drinking Water Project. Its main purpose is to divert water into a treatment plant (ABCWUA, 2010; Kable, 2016). During times of low flow, the dam can be lowered to avoid diverting too much water. This dam was built fairly recently and is a modern design. Its ability to retract when not in use vastly diminishes its environmental impact.


Figure 2.1: ABCWUA's adjustable height dam
(ABCWUA, 2010)

### 2.2.2 Water Optimization Using Weirs

Another method of water flow control is a weir, which is a partial dam which allows water to build up behind an obstruction, then over flow and continue to flow (Michigan DNR, 2016). They are usually used to measure the flow of a river. They create a temporary reservoir that is meant to overflow so the flow rate of the river can be measured by how fast water is able to overflow the obstruction. They are primarily used for data collection purposes. but a series of weirs can occasionally be used as a ladder for fish to swim upstream by jumping from reservoir to reservoir to get above a dam so that they can continue their trip upstream.

An example of a weir designed by RMC consultants is a natural weir and can be found along the Rio Jemez (R.W., 2016). Part of the Lower-Jemez Fish Structure Project, a series of natural weirs were installed in 2016 to reverse damage caused by previously placed, failing weirs (see Figure 2.2). Constructed using granite, these weirs are designed to resemble naturally-occurring barriers in the river as much as possible, creating a slow flow above themselves while allowing water to escape through a central gap into a small pool below.

Large rocks have also been placed to provide shelter for water creatures while logs covered with root balls, rocks, soil and small pieces of wood were placed in the water parallel to banks and close to eroded areas to strengthen them and provide habitats for plants and animals. Native trees were also planted in the area while invasive species in the area were cut down. The river's course was slightly adjusted to further repair damage from previous weirs and to give vegetation a firmer grip on the river's banks.

Figure 2.2: Natural weir on the Rio Jemez
(R.W., 2016)

Another example of a weir was built in Reclamation District 108 along the western edge of the Sacramento River (Reclamation District 108, 2008). Known as a flashboard weir, it consisted of a series of boards that could be removed from or added to a series of supports to lower or raise the water level behind it, respectively. Later, this weir was replaced by a long-crested weir for more precise and constant water level control. One of the flashboard weir's primary advantages is how most of its footprint (the boards) can be removed when it isn't in use, minimizing unnecessary ecological disruption. Furthermore, it is a very simple and inexpensive design (Lempérière, 2013). On the other hand, this type of weir does have some vulnerability to damage from floating debris. Because of this - along with its inability to precisely control river discharge—it is generally being phased out of use so up-to-date knowledge about it may be limited. An example of a flashboard weir is shown in Figure 2.3.

Figure 2.3: A typical flashboard weir
(MSU, 2016)

### 2.2.3 Water Optimization Using Flumes

A flume can also be used as a method to manipulate the flow of water, but unlike a weir or a dam it does not block the flow of water but instead redirects it to speed it up (Open Channel Flow, 2016). A flume consists of walls that are built out from the bank, which constricts a waterway and thereby improves the speed of the flow. Essentially, a flume funnels slow streams of water into one faster stream. It can be used for navigation, rapid transfer of water or materials down river, data collection, and recreation. As seen in Figure 2.4, a flume concentrates the flow of water and converges it to a middle or "throat" section. The water then diverges, exits the flume, and continues flowing in the river.

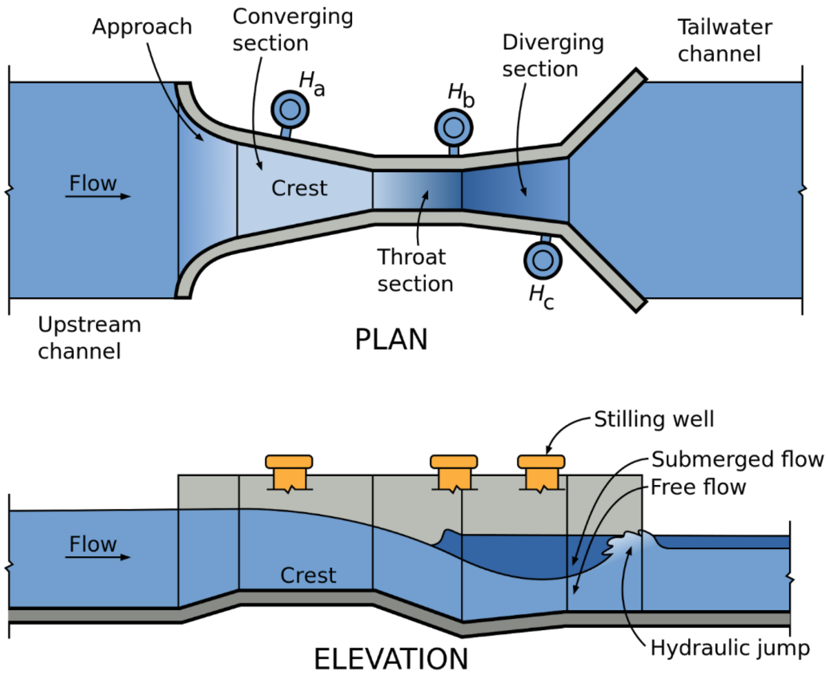


Figure 2.4: Basic Parshall flume diagram displaying the top and side views of the flume (Inductiveload, 2015)

Parshall flumes are typically made from one of four materials - aluminum, fiberglass, galvanized steel and stainless steel. Aluminum flumes have the advantage of being both lightweight and resistant to abrasion and damage from larger physical forces. These flumes are most useful in the measurement of dam seepage, watersheds, and mine dewatering flows. Galvanized steel flumes are highly robust while being the least expensive of the four mentioned. However, these flumes are considerably heavier and the galvanized layer needs to be reapplied periodically due to low abrasion resistance. They are typically used for measuring irrigation and surface water flows in non-remote areas. One of the most optimal materials for Parshall flumes is fiberglass, balancing light weight with low cost along with a certain degree of resistance to chemical damage. On the other hand, the resins required for the use of this material under harsher conditions can significantly drive up the price. This type of flume is useful for a variety of applications and is usually the best choice for sewage-related applications. Lastly, stainless steel weirs are highly resistant to abrasive, chemical, thermal, and physical damage. While they are more expensive than standard fiberglass flumes, they are often more cost effective under the most damaging conditions. Therefore, these flumes are often used as a substitute for fiberglass flumes when harsh conditions drive up the price of the required material.

An example of a Parshall flume is being implemented in South Korea to aid in the measurement of the flow rates of rivers (Kim, Lee & Oh, 2010). Despite their simple design, these flumes can maintain uniform flow rates - which are useful in preventing sediment buildup. Their design is also environmentally friendly, allowing fish and other wildlife to pass through unhindered.

## 2.3 The Rivers Serving the Pueblo of Santa Ana

The Pueblo of Santa Ana is located in central New Mexico north of Albuquerque (Santa Ana Pueblo, 2010). The land of the Pueblo has been occupied by the Santa Ana tribe of Native Americans since the late 1500s. A part of the Rio Grande valley includes reservation land, and water from both the Rio Grande and Rio Jemez flows through the Pueblo. After providing an overview of these rivers and what they are used for, we discuss the governmental regulations relating to these rivers.

### 2.3.1 The Rio Grande and Rio Jemez

The main river that runs through New Mexico, and particularly the Pueblo of Santa Ana, is the Rio Grande (Metz, 2010). The Rio Grande begins in the high mountains of southern Colorado, flows through New Mexico, serves as the international boundary between the United States and Mexico, and flows into the Gulf of Mexico (see Figure 2.5). Originating from the Continental Divide, the Rio Grande is fed by springs and snow melt from the San Juan Mountains. The amount of rainfall entering the river in the northern mountains varies from that of the rest of the river and the drainage area, from about thirty-five inches per year to less than ten inches per year, respectively (Lowe, 1952, p. 1021).


Figure 2.5: Map of the Rio Grande
(Musser, 2010)

The Rio Grande is not a "normal" river—it has no streams and no runoff (A. Steed, personal communication, April 6, 2016). There is very little rainfall nearby, as it flows through a desert climate, and there is never enough water present in the river for industrial or commercial use. The Rio Grande is referred to as a "losing" river because it loses about ninety percent of its water by the time it reaches the Gulf of Mexico. This is due to the use of river water for agriculture and for other uses within pueblos and settlements along the river.

The Rio Grande, along with the Rio Jemez, which is one of its tributaries, are the main sources of irrigation water for the Pueblo of Santa Ana (A. Steed, personal communication, April 6, 2016). The people of the Pueblo have moved over time and Santa Ana now has two villages: (1) the "old village," also referred to as Tamaya, and (2) the current reservation settlement area where most of the Santa Ana people live. The land where the native people live now is where their ancestors used to farm due to the proximity of the Rio Grande and Rio Jemez. Because the three main villages of the Pueblo—Rebahene, Ranchitos, and Chicale—are all farming communities, this particular area is now a prime location for the Pueblo residents. The Rio Jemez meets the Rio Grande just upstream of the majority of the Pueblo's farmland and the area which is now inhabited by most of the tribe's people. The map in Figure 2.6 below shows where the Santa Ana people are currently settled, the old village of Tamaya, and the Rio Jemez and Rio Grande. The Rio Grande can be seen flowing right through this area allowing for the continuation of the Pueblo's agricultural practices.


Figure 2.6: Map of the Pueblo of Santa Ana and its rivers
(Google Inc., 2016)

### 2.3.2 River Water Usage

Due to the Pueblo of Santa Ana being mainly a farming community, the water from the Rio Grande and Rio Jemez is mainly used for irrigation (Lowe, 1952, p. 1022). Due to the arid climate and cultural preferences of the Santa Ana people living within the river's watershed, the most common crops grown include cotton, corn, squash, and beans. The water is also used for municipal water supply, watering livestock, and limited recreational fishing in the reservoirs. In addition to these uses, water from the Rio Jemez is occasionally consumed for ceremonial cleansing purposes, which are kept as a private pueblo tradition (A. Steed, personal communication, August 29, 2016). This consumption largely takes place at the old village of Santa Ana, or Tamaya, as seen in Figure 2.7 below.


Figure 2.7: Aerial photo of Tamaya and the Rio Jemez
(Google Inc., 2016)

### 2.3.3 Why the Rivers Are Polluted

There are a variety of reasons as to why the waters of the Rio Grande and Rio Jemez are polluted. According to the Environmental Protection Agency (2016), the leading source of water quality problems is from nonpoint source pollution (NSP), which is due to storm water runoff. NSP sources of particular concern in the area include primarily bacteria from wildlife and livestock feces as well as occasional leakage from wastewater treatment systems (A. Steed, personal communication, April 6, 2016). The main wildlife sources of pollution include elk, deer, and geese. High levels of these sources of pollution cause varying levels of *E. Coli* in the rivers.

Another source of pollutants on the Rio Grande are known as legacy pollutants (A. Steed, personal communication, September 22, 2016). Legacy pollutants are typically industrial chemicals that have remained in the environment, in this case the Rio Grande, long after they were introduced to the environment. Los Alamos National Laboratory is located near the Rio Grande and was the main source for legacy pollutants. The main pollutant that still occurs in test results is polychlorinated biphenyl, or PCB, which were used in electrical transformers along with other industrial applications (GGI, 2010). Due to environmental concerns, the use and production of PCBs stopped in 1997, but they are still present in the environment in low concentrations and therefore present an occasional risk to ecosystems and human health.

Pueblos upstream of Santa Ana, including the San Felipe and Cochiti Pueblos, use lagoons for collecting and storing wastewater (A. Steed, personal communication, August 29, 2016). These lagoons are located next to the rivers. A failure or a break in a lagoon system can cause waste water pollution in the rivers. In the past, towns and pueblos along the Rio Grande would dump sewage directly into the river. Even now, there are occasional sewage spills into the river that cause widespread pollution (Satija, 2013).

Storms and flash floods also contribute to pollution in the rivers (Winter, et al., 1998). Though they can also cause runoff of pollutants, the major concern related to such flooding is the uptake of bacteria from the sediment in the rivers.

A main pollutant that makes its way into the Rio Grande and Rio Jemez due to the variety of sources is *Escherichia coli* or *E. coli*. *E. coli* is a common type of bacteria found in the digestive systems of humans and animals (Lewis, 2016). Though most strains of *E. coli* are not harmful, they do indicate the presence of other contaminants in the rivers (Perry, 2011). *E. coli* can survive in the underwater sediment of rivers for several months. When storms and flash floods occur, bacteria such as *E. coli* that were "dormant" in the sediment can be taken up in the water flow and reintroduced into the water used for irrigation or other purposes. Other common sources of fecal contamination and *E. coli* include agricultural runoff from fields fertilized with manure.

### 2.3.4 Regulation of the Rivers

The Rio Grande is a binational watershed that covers 335,000 square miles and provides a source of water to parts of southwestern United States and parts of Mexico (IBWC, 2015). Due to this, not only are there United States agencies and organizations in New Mexico that regulate Rio Grande water usage, but the International Boundary and Water Commission (IBWC) also plays an important part. According to their *Strategic Plan*, the IBWC oversees boundary preservation, water conveyance, water quality, and resource management through a partnership between the United States and Mexico. A number of treaties and agreements between the two countries have made this possible (Drusina, 2011).

There are many other partners and organizations that assist with improving coordination and collaboration between federal agencies and community organizations. On the federal level these include, the United States Environmental Protection Agency (2015), the United States Geological Survey, and the United States National Park Service among others. Local and tribal partners include the City of Albuquerque, Ciudad Soil & Water Conservation District, and the Pueblo of Santa Ana. These organizations and several others also organize restoration projects along the Rio Grande and have developed a national wildlife refuge. These organizations not only help to regulate and improve water quality, but they also determine where the water goes. They determine where dams are built and how much water is allocated to each pueblo along the Rio Grande.

There are several dams along the rivers for flow regulation, irrigation, and flood control (USBR, 2007). The main dam along the Rio Grande is the Cochiti Dam, located about thirty miles from the Pueblo of Santa Ana (A. Steed, personal communication, April 6, 2016). The Cochiti Dam, a project by the United States Army Corps of Engineers, is used along the Rio Grande for flood and sediment control. The dam, and the resulting Cochiti Lake that has built up behind the dam, assist in regulating heavy runoff and ensure a steady flow in the Rio Grande year-round. The Jemez Canyon Dam, located along the Rio Jemez, created the Jemez Canyon Reservoir (USBR, 2007). The Jemez Canyon Dam is used to operate control floods, store water from spring and summer runoff, and release water without causing flooding downstream.

Unlike the Rio Grande, the Rio Jemez, and particularly the Jemez Canyon Dam, have very little governmental control (A. Steed, personal communication, October 12, 2016). The United States Army Corps of Engineers is the primary source of regulations along the Rio Jemez. Primarily, they are in charge of the channel of the Jemez Canyon Dam. They are also in charge of flood control structures along the river and they also issue permits for disturbance or construction along the river.

The Rio Jemez's headwaters are located in the Valles Caldera in northern New Mexico, approximately fifty miles from the Pueblo of Santa Ana. The Pueblos of Jemez, Zia, and Santa Ana are the pueblos along the Rio Jemez before it flows into the Rio Grande. Since the Pueblo of Santa Ana is the last pueblo along the Rio Jemez, the amount of water flowing through the river when it reaches the Pueblo is variable. The amount depends on the season and the river's usage for irrigation water upstream of the Pueblo of Santa Ana. Because of this, especially during the irrigation season, there is typically no flow in the Rio Jemez by the time it reaches the Pueblo of Santa Ana. Although the Rio Grande is the main source of irrigation water for the Pueblo, the Rio Jemez is the sole source of water used for ceremonial purposes serving the old village of Tamaya for feast days.

Over the past thirty years, the Water Resources Department of the Santa Ana DNR has been working towards the adjudication of the Rio Jemez's water and the Pueblo's rights to the water (A. Steed, personal communication, September 6, 2016). The litigation and proceedings are an ongoing, private matter between pueblos along the Rio Jemez and the US Federal Government.

## 2.4 Summary

The main rivers that serve the Pueblo of Santa Ana are the Rio Grande and Rio Jemez. These rivers are located in an area with an arid desert climate and are prone to flash floods and extreme weather conditions that cause the rivers to dry up after the irrigation season. These conditions make it difficult to accurately and consistently sample the water quality in the rivers. Most of the water diverted from the rivers is used for irrigation. The reliance of pueblos bordering these rivers for irrigation water, despite its tendency to become polluted, makes it imperative that a reliable, efficient, and reproducible water sampling method be identified for the Santa Ana DNR. Along with consistent sampling protocols, the possibilities of using systems such as dams, weirs, and flumes may assist in the control of river water during seasons of low flow, allowing for more representative samples of the river's water to be taken. Because these systems control the flow of river water, they may also assist the DNR in collecting a sample of water when it may otherwise not be possible. In the next chapter we detail the methods we used to achieve our project's goal and objectives.

# Chapter 3: Methodology

The goal of this project was to determine a water sampling plan for the Santa Ana DNR that would ensure accurate and representative results obtained from testing for *E. Coli* and other river water factors. This goal included the identification and selection of both sampling techniques and a water optimization device. In order to accomplish this goal, we achieved several objectives: (1) we identified the Pueblo's water sources and the DNR's current water sampling locations and sampling methods; (2) we identified water sampling techniques that would provide the most accurate and representative results; (3) we identified water collection systems that would improve sampling conditions; (4) we designed a device to optimize river flow and determined its acceptability for the Pueblo of Santa Ana; and (5) we determined ways to ensure the continuation and implementation of the sampling techniques and the collection device that we had determined were best suited for the Santa Ana DNR. This chapter explains the methods we used to achieve our goal and each of our objectives.

## 3.1 Identify Water Sources, Sampling Locations, and Sampling Methods

We began by identifying the water sources that are used by the Pueblo of Santa Ana. We also identified the surface water sampling locations and current sampling methods used by the Santa Ana DNR. We were able to learn how Pueblo of Santa Ana members use water from the Rio Grande and Rio Jemez throughout their Pueblo lands. We were also able to identify locations where the DNR collects water samples and why samples are collected in those areas. This also allowed us to see firsthand how samples are collected and to then evaluate the validity of the DNR's methods of sample collection. We also conducted a formal interview with both the DNR's Water Resources Division Manager and Technician to discuss these methods and reviewed several maps of Santa Ana, the areas surrounding Santa Ana, and the rivers that flow through the Santa Ana reservation. In the following sections we will explain the details of these methods.

### 3.1.1 Observations of Current Sampling Methods

Through observations, we were able to identify the current water sources that serve the Pueblo of Santa Ana. We were also able to identify sampling locations and sampling methods in use by the Santa Ana DNR by directly observing their current practices. This included visiting their regular sampling locations along the Rio Grande and Rio Jemez at the time when DNR staff were taking water samples. In addition to observing the DNR's routine sampling locations and methods, we traveled upstream of these locations on the Rio Jemez and sampled water there to determine the difference in *E. coli* levels along the river.

### 3.1.2 Interview with DNR Water Resources Division Manager and Technician

In order to discuss the sampling methods used by the DNR, we conducted an interview with the Water Resources Division Manager and a Water Resources Technician of the Santa Ana DNR following the interview protocol found in Appendix B. In this interview, we focused on gathering information about the current methods of sampling and testing of the surface water that serves Santa Ana. We obtained information regarding where water samples may and may not be collected from along the rivers. This information was important because members from the Santa Ana DNR cannot collect water samples along the rivers when they are on reservation land belonging to another pueblo. The interview contained questions focused on how and when samples are collected. We also obtained information regarding the considerations taken when collecting samples during certain conditions such as low water levels, ripples present in the river flow, and braiding of river water flow. This was important in order to determine if samples collected by the DNR are done based on scientifically valid protocols, for convenience, or for other reasons. We used these interviews in tandem with our observations, outlined in section 3.1.1, of the DNR's sampling methods and sampling locations to determine their current sampling methods.

### 3.1.3 Reviewing Geographic Maps

We reviewed and studied several physical maps of the Pueblo's land, water sources, and sampling locations along the rivers. These maps included several provided by the DNR, as well as current and historic imagery from Google Earth. We used these maps to gain a better understanding of the land belonging to the Pueblo of Santa Ana and its residents. We also used the maps to determine the course of the rivers as they flow through the Pueblo and the change in flow over time. In addition to our observations, these maps allowed us to geographically pinpoint where the DNR's sampling sites were along the two rivers. These maps also showed where the DNR is allowed to collect water samples and where they are not, due to the borders of other pueblos.

## 3.2 Identify Alternative Sampling Techniques

We identified water sampling techniques that can provide accurate and representative sample results. We were able to find sampling techniques that would allow the Santa Ana DNR to obtain more accurate and representative results of *E. coli* and other water factors through modifying their current sample collection methods. We did this by researching how to properly collect water samples as well as identifying ways to sample river sediment for times when there is no water present in the rivers, particularly in the Rio Jemez.

### 3.2.1 Sample Collection

We searched the internet and researched reference guides in order to determine the most accurate practices for sampling surface water. This involved taking into consideration any potential environmental and climate limitations, economic factors, and cultural standards or traditions of the Pueblo of Santa Ana. Following our research, we then provided the Santa Ana DNR with a list of measures to be considered in different conditions when obtaining surface water samples.

### 3.2.2 Sediment Testing

We researched sediment testing in order to determine if it would be a viable alternative to direct water sampling given the Santa Ana DNR's needs. Due to the climate in the area of the Pueblo of Santa Ana, lack of water in rivers for sampling is a problem in some of the sample sites along the rivers, particularly the Rio Jemez. Therefore, sediment testing could possibly be an option and be conducted in those areas where surface water is lacking.

## 3.3 Identify Water Optimization and Collection Systems

We identified water collection systems that could possibly be implemented by the Santa Ana DNR when there is a low flow of water in the rivers. The identified system needed to both funnel and concentrate the water from one or more braids and also collect that water as it flowed through the system. The systems identified needed to allow for sample collection using small sample bottles and also the use of a hydrolab, the device the DNR uses to test for certain factors of river water such as temperature, salinity, pH, and turbidity. To achieve this objective, we conducted research into possible systems that could be used or modified based on need and the specific conditions present in the rivers during low flow.

### 3.3.1 Designing a Water Optimization Device

We designed a water optimization device and determined its acceptability for the Pueblo of Santa Ana. In order to find out how to improve current sample collection conditions, we researched EPA guides to identify optimal surface water sample collection conditions. When we determined optimal sample conditions, we then did internet research on various systems and devices and how they manipulate river water flow. The systems and devices we identified would not only manipulate water flow in the river, but it also had to allow for DNR employees to collect water samples and test them for *E. coli* and other factors when it would be otherwise impossible to collect a sample for testing due to low water levels. We identified these systems and examples of them not only to be used as possible solutions, but also to create our own device based on particular aspects of the systems that we found would best suit the DNR's purpose.

## 3.4 Designing a Prototype and Determining its Acceptability

After identifying possible systems that could create stable and consistent sample collection conditions, we analyzed these methods to ensure that they would be useful for the DNR and acceptable to the Pueblo. In addition to analyzing each system, we designed our own model device that incorporated certain features of some of the systems we had identified. We analyzed the device ensuring that it would meet several criteria: (a) be useful and simple to implement for Santa Ana DNR employees, (b) be non-intrusive to the environment and lands of the Pueblo, and (c) be culturally acceptable and respectful of the traditions of the Pueblo of Santa Ana. This model and prototype had several iterations that were modified to meet our criteria and that would function well in the field under appropriate conditions. To find out if the device we designed and prototyped would meet these criteria and work in the field, we modeled, modified, and then field tested the device and also held an interview with a tribal member who is a Water Resources Technician for the DNR to get his opinions on the device's functionality and appropriateness.

### 3.4.1 Designing the Prototype

Once we identified the several types of systems that could be used, we began to design a device of our own. This included consideration of the materials that could be used by the DNR and would work best in the environment and the climate of the area. We also designed the device based on whether it needed to be temporary or semi-temporary. The design was also made to ensure that the device would be manual and therefore not require much, if any, electricity or power.

### 3.4.2 Modeling and Modifying the Prototype

Once we had determined the design of the device, we created a simplified model. This model included the materials that the device would require. It also showed how the device would assist in collecting water samples during months of low flow in the rivers. We tested the model of the device which then allowed us to determine any possible limitations of the device, which allowed for further modifications and other solutions to any problems that might arise in the implementation of the device.

### 3.4.3 Interview with DNR Water Resources Technician

After we had identified, modified, and modeled a device to improve sample collection, we needed to ensure that the device would be appropriate and feasible to implement for the Santa Ana DNR. In order to do this, we conducted an interview with a Water Resources Technician of the DNR following the interview protocol found in Appendix C. The Water Resources Technicians are the individuals who collect water samples, and would be the individuals using the device we designed and proposed. The interviewee was able to inform us how simple or complex the device would be for the DNR to use. Since the interviewee is also tribal member of the Pueblo of Santa Ana, he also helped us determine if the device would be intrusive to the environment or land and if the device would be culturally acceptable. This interview allowed us to gain first-hand feedback from an individual who would be using the device we designed and who would be directly affected by it. This interview ultimately allowed us to determine if the device we had designed, modeled, and modified needed any further modifications in order to be proposed and implemented within the Pueblo of Santa Ana.

## 3.5 Determining a Way to Ensure Continuity of the Methods

Once we had identified the best sample collection techniques and strategies as well as a device to be used to concentrate a low flow of river water, we identified ways to ensure proper implementation and use of our proposed methods. We identified the best way to present documentation regarding the techniques and device in order to ensure continuity and reliability into the future. In order to determine the best way to present our proposed recommendations, we needed to consider who would be implementing them. We created two sets of deliverables: (1) a guide displaying the proposed sampling protocols, and (2) a construction and implementation plan for the proposed water collection device.

### 3.5.1 Sampling Protocols and Techniques Guide

In addition to presenting the members of the Santa Ana DNR with an overview of our recommendations for improving sample collection, we created a pamphlet regarding ideal sampling protocols and techniques for those involved in water quality monitoring for the Pueblo. This pamphlet was presented to our sponsor as a reference for current and future employees to utilize when sampling water. This pamphlet covered topics ranging from where to collect samples along the rivers to conditions under which a sample should be taken. In addition to written descriptions of certain protocols, images and graphics were also included to help explain the protocols.

### 3.5.2 Water Collection Device Construction and Implementation Plan

In order to ensure proper implementation of the water collection device, we needed to determine the information that was necessary to present in order for the device to be implemented. We gathered feature details, such as dimensions and materials, as well as other information needed in order for current and future water resources employees of the DNR to use the guide for fabrication and implementation of the device. In addition to this plan, we provided our three-dimensional prototype that we had designed as a visual representation of the device. We also created a simulation with similar conditions the device would be used for and demonstrated the prototype of our device to the Water Resources Division employees.

## 3.6 Summary

In order to provide the Santa Ana DNR with the best possible water sample collection plan, we focused on several factors including feasibility and ease of use, impact on the environment and land, and compatibility with the Pueblo's culture and traditions. To account for these factors and to identify the Pueblo's water sources, sampling locations, and current sampling methods, we used direct observations and conducted interviews with the Santa Ana DNR staff. We also researched reference guides to identify sampling techniques that would provide the most representative and accurate sample results. In addition, we identified and researched water collection systems that would improve conditions for collecting samples and testing water during conditions of low flow. We modeled and modified our own prototype of the device to be implemented and simulated field tests to determine viability. We used an interview with a DNR staff member to ensure our design would be feasible for the DNR and also be culturally and environmentally acceptable to use within the Pueblo. In the following chapter, we discuss the results we obtained from completing these methods.

# Chapter 4: Results and Analysis

The goal of this project was to determine a water sampling plan which included both sampling techniques and a water optimization and collection device for the Santa Ana DNR to implement and use to better monitor the Pueblo's river water quality. In this chapter, we present the results of our research according to our objectives we have identified to achieve this goal. We discuss the Santa Ana DNR's current sampling methods, identify appropriate water sampling protocols, and describe water optimization devices. We also describe and explain the prototype and model we designed specifically for the Santa Ana DNR to help improve water sampling through water optimization.

## 4.1 Identification of Water Sources, Sampling Locations, and Sampling Methods

Our first objective was to identify the Pueblo's water sources as well as the DNR's sampling locations and methods. We eventually used this information to identify sample collection protocols as well as systems that could be used to concentrate and collect water for monitoring and sampling during low flow situations and at what locations these methods would be needed.

### 4.1.1 The DNR's Existing Sampling Methods

We followed Water Resources Division employees when they went to take water samples. Depending on the sample location, employees would wade into the river to collect a sample, lower a device (see Figure 4.1) into the river to collect samples from a bridge, or collect the sample from the river bank. Typically, the DNR employees used the latter two methods. Despite the various sample locations, samples are typically taken from the part of the river with the most flow and the most depth. This is more easily determined at some locations than others. For example, during the time of our observations, sample locations along the Rio Jemez had variable flow. This flow was usually low and braided across the river's path into different small stream braids. In these areas, a sample would be collected from the braid with the most flow.

At all sample locations, two sample containers are used to collect river samples. At most of the sites that we observed samples were either collected off of a bridge or a high bank. A simple device created by the DNR in order to collect samples is used (see Figure

4.1). This device also allows for sample collection without coming into contact with the water or the sample bottle during sample collection. The two bottles are secured onto the device, the caps are carefully removed from the bottles, the device is lowered off of the bridge or bank into the river, and samples are collected. On days when samples are collected, more than one sample location is visited. Two brand new bottles are used to collect samples at each location so that there is no contamination between samples. Following collection, the bottle caps are replaced and the sample bottles are kept in an ice chest until they are tested in a laboratory. The water from these two sample containers is tested for *E. coli* and total coliforms and then the most probable number (MPN) of *E. coli* is calculated. This testing of *E. coli* serves as a water quality indicator and when levels are found to be above the Pueblo's water quality standards, the public is alerted and notified to take proper precautions with regards to consumption and recreational uses of the river's water.


Figure 4.1: Water sampling device (left). Device being lowered off of San Ysidro bridge (right).

In addition to collecting water samples to test for *E. coli* in the water, the water is tested and monitored with a hydrolab (see Figure 4.2). The hydrolab used has several probes that test and monitor river water factors such as temperature, pH, and turbidity. In order to use the hydrolab and test for these various factors, there must be at least four inches of water present so that the probes are completely submerged. In between sample locations and uses of the hydrolab, the probes of the hydrolab are cleaned with tap water to remove any sediment that may have built up on them during use.


Figure 4.2: The hydrolab

Our interview with the DNR confirmed our observations and gave us further information regarding their river sampling and monitoring procedures. The summary of this interview can be found in Appendix B.

Samples are collected in three locations along both the Rio Grande and Rio Jemez (see Figure 4.3). As the rivers flow through the Pueblo of Santa Ana, there is an upstream sample site, a downstream sample site, and a sample site in between these two. These three general locations allow for analysis of the water in the rivers as it enters the Pueblo, as it flows through the Pueblo, and as it leaves the Pueblo. This enables the DNR to determine the quality of the water coming to, flowing through, and leaving Santa Ana and to monitor what is happening to the water of the rivers on its path through the Pueblo. These particular sample locations allow for comparison of the water quality and the determination if the Pueblo is causing a positive or negative effect on the river water.

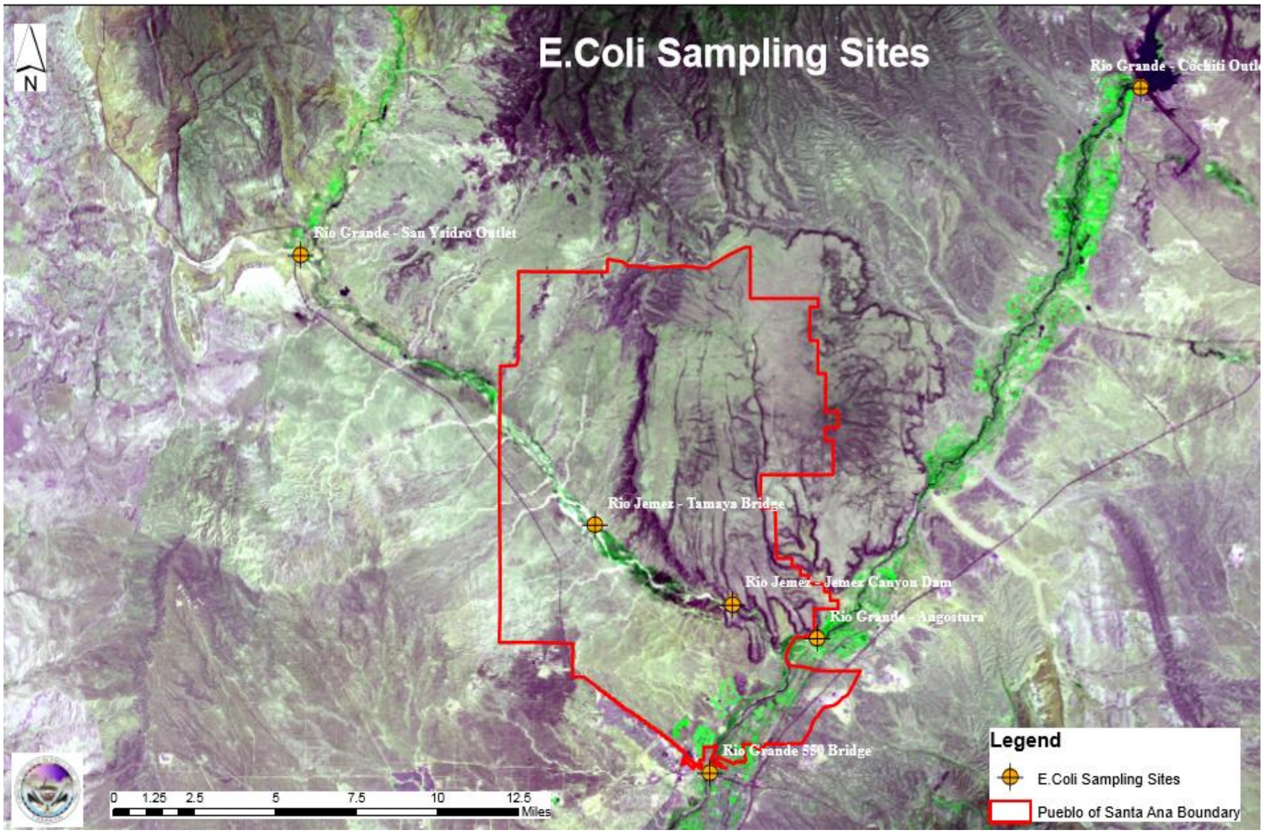


Figure 4.3: Map displaying the DNR's sampling sites
(A. Steed, personal communication, September 5, 2016)
Note: there is an error in this map-the San Ysidro sampling site is along the Rio Jemez, not the Rio Grande.

Since there is variable flow in both of the rivers, when the DNR samples, they usually collect water from the channel of the main flow in the rivers. This is the channel that most of the water flows through, particularly in a braided river. The sample is taken from the middle of that channel's main flow and typically at a medium depth. Collections are not taken in areas where there are ripples in the water at a sample location. Ripples indicate a shallow area of water or the presence of a barrier in the river's flow.

Water samples are collected on a monthly basis, though there is no strict schedule. In the months following the irrigation season, the flow of the rivers is reduced and samples are only collected and tested when there is enough flow and water is actually present in the rivers. This is done so that the samples yield representative results. When results from *E. coli* tests are higher than the acceptable EPA and DNR levels, water samples are collected weekly until *E. coli* levels in the rivers decrease to acceptable levels for consumption and recreational use. Pueblo members are made aware by a notice from the DNR when the water is unsafe for contact or consumption due to *E. coli* levels being too high.

Though *E. coli* is the main pollutant of concern in the rivers, it is not the only factor that is tested and monitored. The DNR also tests for typical factors monitored on most rivers, such as, temperature, pH levels, specific conductivity, total dissolved solids (TDS), turbidity and dissolved oxygen concentration. The DNR reviews this data, which is representative of the river's ecosystem at the time of sampling, and also reports it to the EPA. Year to year these data are reviewed for comparison and to determine the overall changes in the rivers' conditions, including whether there have been negative impacts from the Pueblo's practices.

In addition to our personal observations and interview, we also reviewed and studied several geographical maps to view pueblo boundaries and sample sites as well as the path of the river over time. As seen in Figure 4.3, the Rio Jemez is sampled as it flows through the Jemez Pueblo at a site prior to Pueblo of Santa Ana, at a midpoint of the reservation in Tamaya (the traditional village of the Pueblo of Santa Ana), and at a point just prior to the Rio Jemez flowing into the Rio Grande. Because the upstream sample site is within the area of the Jemez Pueblo, the Santa Ana DNR staff collect water samples from the river off of a state highway bridge, which is state property and therefore not legally part of the Jemez Pueblo. These maps also show the sample locations along the Rio Grande at the Cochiti Dam upstream of Santa Ana, at Angostura—which is where the water is diverted into the Albuquerque Main-the main source of irrigation water for the Pueblo—and under the Route 550 Bridge as the Rio Grande exits the Pueblo of Santa Ana. At the sample sites that we visited, we were able to see the variable flow of the rivers.

Along with observations of the rivers' flow, these maps allowed us to determine locations where our water collection device would be most necessary. Based on our observations of the Rio Grande, we determined that a water collection device would not be necessary for sampling from that river as there was always enough water flowing for sampling protocols to be used. A device would be necessary on the Rio Jemez during seasons of low flow, however. The particular locations this device would be used include the

Tamaya Bridge (the middle sampling location) and the Jemez Canyon Dam (the sampling location upstream of the where the Rio Jemez flows into the Rio Grande). These two particular locations along the Rio Jemez experience low to no flow during the dry season and a water collection device could be utilized when there is low flow in these locations to concentrate the river water into one area so it could be properly collected and tested.

## 4.2 Identification of Proper and Alternative Sampling Techniques

After conducting research on water sampling techniques and alternative methods of sampling, we gathered and condensed the water sampling techniques into simple, easy to follow tips on how to collect a reliable water sample. We also concluded that at this time sediment testing is not a viable option for the Pueblo of Santa Ana due to the newness of the field and the cost of conducting these tests.

### 4.2.1 Sample Collection

Through our internet research and review of an EPA water sample collection techniques guide and a geological survey, we identified techniques that should be followed for sampling surface water (EPA, 1982). These included:

- Where to collect surface water.
- How to collect surface water.
- When to collect surface water.

<u>Where to collect</u>

During our observations of the current sampling practices the DNR uses, we noticed that samples are typically collected based on methods of convenience. We also saw that debris occasionally collects along the banks of the rivers. Collecting a sample from the center of the river would avoid contaminating the sample. Collecting from the center of the river would also make it easier to find a portion of the river that is deep enough to collect a water sample that is below the surface and can therefore also avoid any debris floating on the surface that may be in the river (see Figure 4.4). While shadowing the DNR employees we also collected samples from under a bridge and noted that swallows tend to build their nests in these areas, which leads to elevated bacteria levels. Collecting samples on the upstream side of the bridge prevents contamination from any wildlife that may live under the bridge.

The climate in Santa Ana also occasionally caused the rivers to be completely or nearly dry. When sampling in these conditions it is important to try to collect a sample from an area where the water is mixing with as many braided streams as possible so that all of the river water is being accounted for. The following is a list of the most important practices regarding where to collect water samples from a river.

- Collect samples from the middle of the river.
- Sample from the upstream side of a bridge.
- Collect samples where the water is mixing.
- Collect samples five centimeters under the surface of the river's water but not along the river bottom.

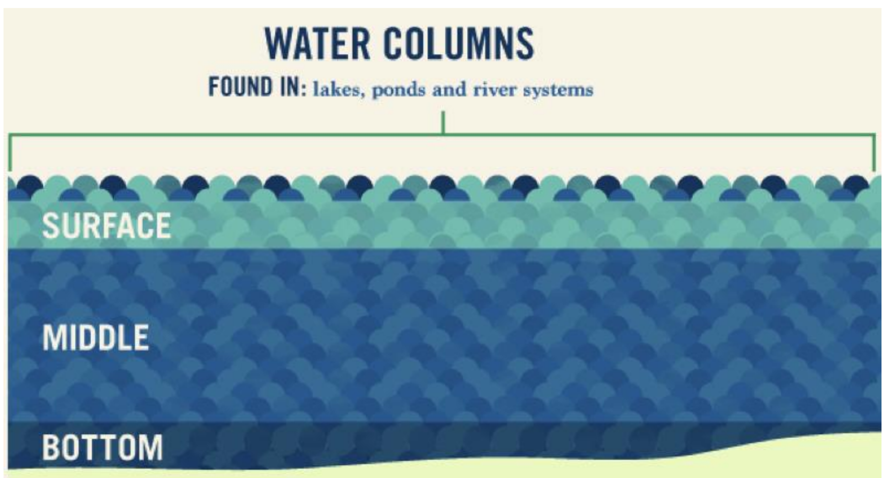


Figure 4.4: River water column diagram
This shows the middle section where water should be collected.
(Cork, 2014)

<u>How to collect</u>

When collecting samples, it is important to avoid contaminating them. In order to collect the cleanest sample possible, the sample collection container should be facing upstream so that the bottle is collecting water that has not yet been contaminated by the sampler's presence. It is equally important that the sampler stand downstream of the collection bottle so that they are not contaminating the water before it is able to be collected. While collecting the sample it is also important to avoid touching the collection bottle to the river bottom because this churns up sediment, which can also contaminate the sample. In the event that multiple samples are being collected for different types of tests it is important to collect the samples from the same location in the river at the same time so that all of the tests can be compared because they are testing water that was collected under the same conditions. Finally, it is important to immediately put any samples collected on ice so that any contaminates in the water do not break down before the samples can be tested in a laboratory. This is a concise list of these practices in terms of how to collect river water samples:

- Face the collection bottle upstream.
- Stand downstream of the collection bottle.
- Do not touch the sampling bottle to the riverbed.
- Collect all samples from the same location at the same time, if multiple types of tests are being used.
- Put samples on ice immediately after collection.

#### When to collect

Due to the unique climate and therefore vast variety of weather conditions in the areas surrounding the Pueblo of Santa Ana, it is important to collect the samples under calm weather conditions. Samples should not be collected during a rainstorm or when there are heavy winds at the collection location or they should be noted if they are. Both of these weather events churn up sediment in the river water and contaminate any samples that may be collected. The exception to this rule is when the rivers are so dry that rainwater is the only water that will be present in the river. If rainwater runoff is the only water present in the river, then it can be collected as a representative sample of the water that is found in the river. Overall, these protocols should be followed regarding when river water samples are collected:

- Do not collect samples after a rain event.
- Do not collect samples on or after a windy day.

### 4.2.2 Sediment Testing

Due to the dry climate in the area of Santa Ana, there is not always water readily available for sampling in a river. One possible solution to this problem is sediment testing. While sediment testing can be used under or around a flowing river, it can also be used as a last resort in a dry riverbed to see what bacteria the water might have contained before it dried out.

As sediment testing is a relatively new field, there hasn't been much research on the methods, and therefore the accuracy of it has been questioned (P. Mathisen, personal communication, April 19, 2016) (see Appendix E). Sediment toxicity testing is a more developed field but that is only used for identifying chemical compounds such as metals or nutrients.

Since the Pueblo is primarily interested in *E. coli* testing, the sediment toxicity testing would not be appropriate. Thus, basic sediment testing would be the only viable option as an alternative to their current testing methods that rely on flowing water. However, after consulting with Worcester Polytechnic Institute Professor Paul Mathisen, an environmental engineering and water resources expert, we learned that sediment testing is a complex and costly process that is currently inconsistent with the Pueblo's desire for a simple and low cost testing method. At this time, sediment testing does not appear to be a viable option for the Pueblo.

## 4.3 Identification of Water Collection Systems

Given the conditions that often occur in the rivers of the Pueblo of Santa Ana, we decided that Santa Ana needed a system that could not only funnel streams of water that were normally too shallow to test into a more substantial and testable body of water, they also needed one that was portable and therefore adaptable to the changing river conditions as well as being low cost (A. Steed, personal communication, September 14, 2016). Our search for the best system ended with a design that incorporated elements from a number of existing systems.

### 4.3.1 Potential Systems

The systems we found to be best suited for the DNR and the objectives of our project included some combination of the following systems:

- Parshall flume - a structure that funnels water into a narrower, faster stream (see Figure 2.4).
- Drop weir structure - a dam-like structure with a central gap that allows water to flow down into a small reservoir before being released back into a channel (Development Planning and Research Associates, Inc., 1983) (see Figure 4.5).

Figure 4.5: A drop weir structure system used for irrigation.
(USBR, 2015)
Note: While the system displayed bears strong similarities to the system we are referring to, it is not the same in that it is designed to aid in irrigation rather than sampling - therefore it is not designed to minimize contamination of water samples like the system of interest to us.

We determined that the best device for our project would be a hybrid of these two systems in which river water would enter through a funnel like the opening end of a Parshall flume. From there, the water would flow through a central gap over a partial barrier and then drop down and collect into a small, box-shaped reservoir. In this part of the device, water would be deep enough to be sampled using small bottles and tested with a hydrolab. The water would then exit over a lip as in a drop weir structure. For, our final design, we wanted the device to be small and light enough to be portable so it could be placed onto any braid of the river being tested to funnel its shallow flow into a deeper, easier-to-sample volume.

## 4.4 Designing and Determining the Acceptability of the Water Optimization Device

After examining several different types of water collection systems, we identified the elements that best met the Pueblo's needs. From these systems, we designed a device incorporating certain aspects of some of the systems. We then designed a Water Optimization Device (WOD) and finally, determined its cultural acceptability and ease of use through an interview with a DNR Water Resources Technician.

### 4.4.1 Modifying the Water Optimization Device

After determining that aspects of both a Parshall flume and a drop weir structure would best suit the DNR's needs, we designed and built a prototype combining the elements from both collection systems. In order to do this, we took into account several modifications and considerations for this device including:

- Dimensions
- Mobility
- Materials

Modifications to the flume portion of the WOD were needed to ensure that the low flow from a braid in the river would be funneled to the drop box portion. We determined that the flume would need to extend from the box no more than 30 inches and that the opening should be about 30 inches wide (G. Tenorio, personal communication, September 26, 2016). This would allow for the device to be fairly compact as well as allow for as much low flow to be funneled and collected as possible. The optimal convergence angle for flumes is typically 12.5° (see Figure 4.6) (Merkley, 2004).

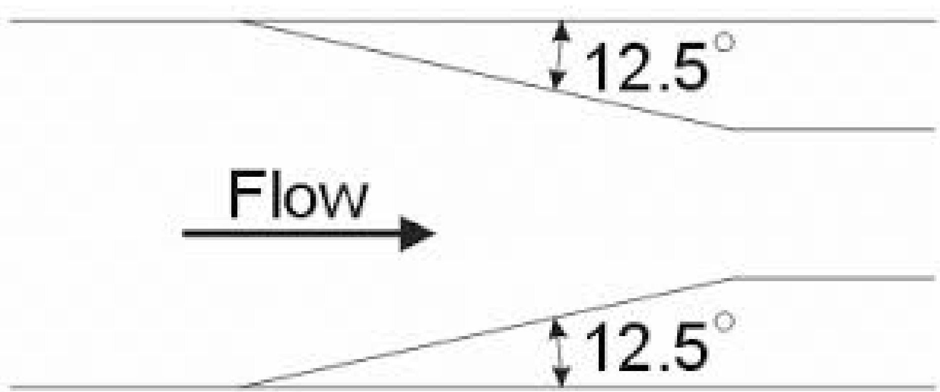

Figure 4.6: Diagram showing optimal flume angle.
(Merkley, 2004)

Though the 12.5° angle is optimal for flumes, we geometrically determined that this small angle would cause one of two thing for our design:

- In order to design a device that would extend out 30 inches from the box, the flume opening would be approximately 21 inches, which is too small as it should be about 30 inches.

- In order to design a device that would have an opening of about 30 inches, the flume would extend over 50 inches from the box, which greatly exceeds 30 inches and would cause the device to be too large.

We decided to calculate an angle that would take into account both the measurement of 30 inches extended from the box and an opening of approximately 30 inches. Using simple geometry and to consider both of these measurements, we calculated that the angle for the flume opening should be about 20° (see Figure 4.7). This angle allowed for the flume portion of the device to meet both measurement requirements.

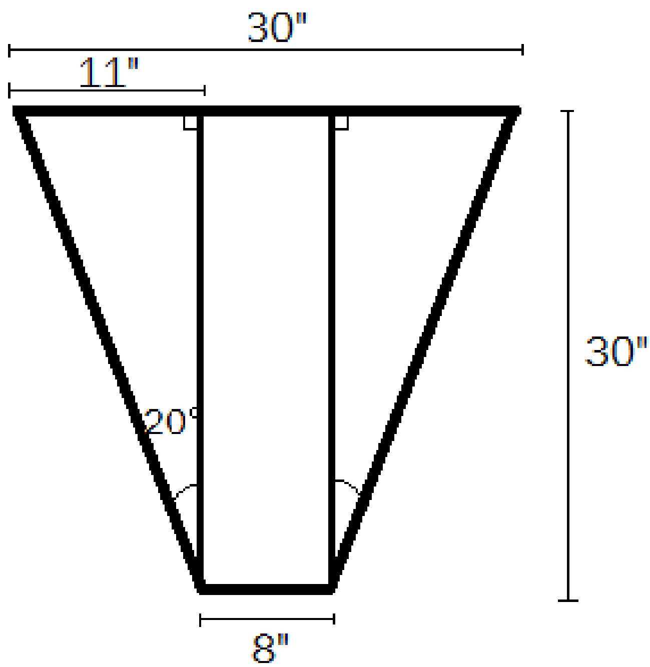

Figure 4.7: Geometric flume diagram for our device' design.
This diagram shows the measurements used to geometrically derive the flume angle.

The design allowed for water to build up in the flume portion before flowing through a V-notch into the drop box portion. Water then needed to fill the box to a certain level to allow for use both by the hydrolab and for water bottle sample collection. Due to these uses that the device would be utilized for, we determined that its dimensions were a crucial factor to consider. The hydrolab is about four inches in diameter so the width of the drop box portion of the device needed to be greater than that in order for the hydrolab to fit into the box vertically. Water samples also needed to be collected from water that would fill the box, so we determined that the box portion should be at least eight inches in width (G. Tenorio, personal communication, September 20, 2016).

The hydrolab probes also need to be submerged in at least four inches of water in order for all of the factors to be tested. Therefore, the box portion needed to be at least four inches deep. Water would be flowing into and then out of the water collection box. The opening, designed as a V-notch, allowing for water to flow into the box needed to be higher than the opening allowing water to flow out. This would ensure that the water would flow seamlessly through the device and not backflow. This also meant that the box should be deeper than four inches to allow for water to flow in and flow out while also allowing four inches of water to collect within the box.

We also viewed and studied Google Earth Pro images-both current and historic. With this, we focused in on one of the sample locations-Tamaya Bridge. We viewed historic stills of the area over time (see Figure 4.8).


Figure 4.8: Historic aerial photos of the Tamaya bridge sampling site
top left: 1996; top right: 2006; bottom left: 2013; bottom right: 2015
(Google Inc., 2016)

In viewing these photos, it became evident that, along with the variable flows that we had observed in the Rio Jemez in particular, the river itself has taken a varied course over time. There has been increased sediment build up over time, and the braids and streams of water have constantly changed. From this we determined that any water collection system or device we propose must be temporary because the braid of the river with the most flow is constantly changing. In other words, installing permanent infrastructure in a river that is braided would not enable water to be collected when the water flows and braids elsewhere in the river. Also, since sediment levels have greatly built up in the river over time, any permanent structure would also build up a lot of sediment behind and within it. This would therefore significantly degrade any device's effectiveness over time.

Due to both our prior field observations and studying of maps of the Rio Jemez, we determined that modifications to the WOD in order to make it temporary were necessary. Having observed the river's low flow and change in course, even at one particular sample location, it was essential that the device be temporary and portable so that it could be used wherever it was needed in the rivers. Also, as mentioned in 4.1.3, because the water of the Rio Jemez carries a lot of sediment, any permanent system or device would build up sediment around and behind it over time, and it would then not serve its purpose to funnel and collect water. Thus a temporary option would best suit the DNR's purposes.

Since a temporary, portable device was determined as the best option, materials used to fabricate the WOD needed to support that requirement. Flumes and drop weir structures can be fabricated from various materials based on their application (Open Channel Flow, 2016). These materials include wood, aluminum, copper, galvanized steel, plastic, and concrete. We considered each of these materials based on the following factors:

- Cost and ease of fabrication
- Weight and mobility
- Risk of Contamination
- Maintenance and decontamination
- Wear and corrosion
- Risk of introducing chemicals to the water

Following communication with John Cole, a failure analysis expert (the summary of this correspondence can be found in Appendix E), we determined that ranking each material according to each factor on a scale of one to five, one meaning that it was not a good option and five meaning it would be the best option, would be the best way to determine what material the device should be fabricated with. We have summarized the results in Table 4.1. In Appendix E, a more comprehensive table has been provided and gives overall pros and cons for each material according to some of the factors we considered.

Table 4.1 Summary of Material Analysis

| Material | Wood | Plastic | Aluminum | Copper | Galvanized Steel | Concrete [mortar mix] |
|---|---|---|---|---|---|---|
| Cost / Ease of fabrication | 4 | 2 | 4 | 3 | 3 | 3 |
| Weight & mobility | 5 | 5 | 5 | 5 | 5 | 2 |
| Risk of cross-contamination | 1 | 5 | 5 | 5 | 5 | 1 |
| Maintenance / decontamination | 1 | 5 | 5 | 5 | 5 | 2 |
| Wear/corrosion | 4 | 5 | 5 | 5 | 5 | 4 |
| Risk of introducing chemicals | 5 | 5 | 5 | 5 | 3 | 5 |

Based on discussion with Mr. Cole and the material analysis summarized in Table 4.1, we determined that aluminum would be the best material for device fabrication. Overall, aluminum scored highest in all categories for factors that we took into consideration. Aluminum is a very lightweight metal that is inexpensive and simple to bend and work with for fabrication. Since it is an inert material, it will not interact with the river water. This means it will not introduce any chemicals to the environment, and when maintained properly, it will not cause cross-contamination between locations and samples. If maintained and decontaminated properly it will also not wear or corrode very quickly over time. Most building and construction materials degrade overtime due to corrosion, rot, decay, and weathering (Kalzip, 2009). Aluminum has a natural ability to resist these factors better than most other materials. Because it is used for everyday products like ladders, gutters, house siding, boats, airplanes, etc. using it for the fabrication of the device will allow the device to be used for a long period of time if maintained and used properly for its purpose.

### 4.4.2 Modeling and Testing the Water Optimization Device

After determining what was necessary for a device to funnel and collect river water during low flow, we began to sketch and design models of our ideas. The first iteration of the device was a very simplified flume made from readily available materials in the Pueblo (see Figure 4.9).

Figure 4.9: First Prototype of the WOD

We designed the WOD to simply improve the flow of the river by concentrating the flow in the hope that it would assist the DNR employees in being able to sample water in low flow circumstances. While the prototype did improve the flow, it did not take into consideration that the hydrolab would need around 4 inches of water depth to work. The improved flow was also useful in mixing of the water when going through the flume such as for use with bottles.

The second iteration of the WOD was designed to address the issue of testing with the hydrolab. We combined the ideas of a simple flume and drop-weir structure and constructed a model of a device that could both improve flow and also allow for testing the water with the hydrolab (see Figure 4.10).

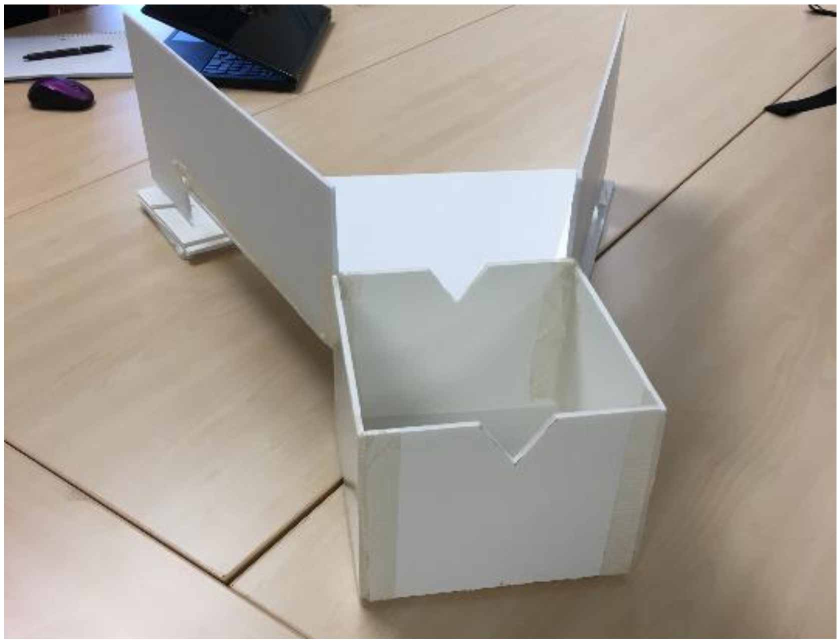

Figure 4.10: Second prototype of the WOD

While we were unable to test the prototype in a river due to no flow in the Rio Jemez, we used a hose and replicated a river's flow to see how the device would function (see Figure 4.11). Although using a hose to replicate the river's water and putting the model on dry soil could not perfectly replicate the Rio Jemez, we were able to learn a lot from the field test. The addition of the box allowed for testing using the hydrolab with less than an inch of flow. The water took a little bit longer to fill up in the box than we had expected, but that was due to the base of the flume being too far below the notch. We also noticed that some water was flowing under the device, which also contributed to the box taking a long time to fill.


Figure 4.11: Testing of the second prototype

As the time did not allow for us to construct an improved model, we made the changes to the design using the 3D design tool, SketchUp. The final model for our product addressed the issues brought up in the testing of the first two iterations (see Figure 4.12).

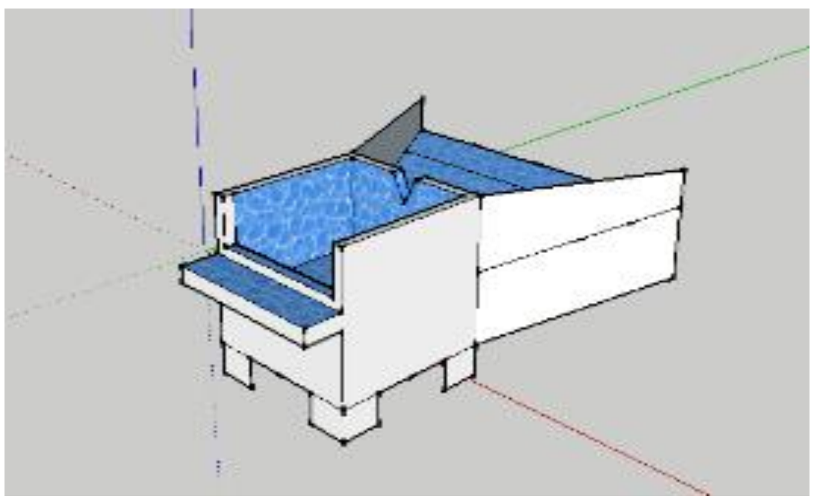
Figure 4.12: 3D Rendering of Second Design

In order to prevent leakage of water underneath the device, we added flashing to the entrance of the flume and feet on the corners so that the device could easily dig into the riverbed and be secure. We raised the base of the flume and put it at an incline so that it improved the flow of the river and the box would be able to fill up more quickly (see Figure 4.13).

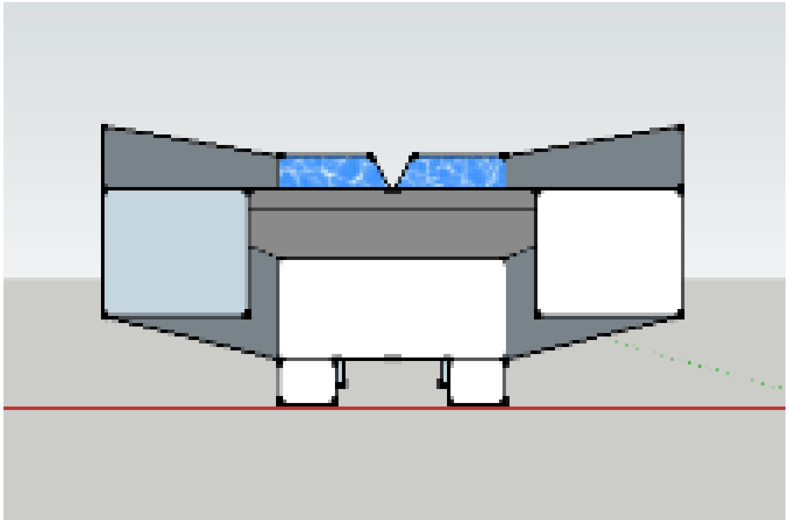

Figure 4.13: Water entrance view (looking downstream) of the WOD model
This view shows the incline incorporated into the flume portion of the design.

We also opened up the exit side of the box more to improve outflow. An issue that was raised in the first iteration was the incising of the river due to the flow out of the structure. We added a lip to the structure to prevent the incising (see Figure 4.14).

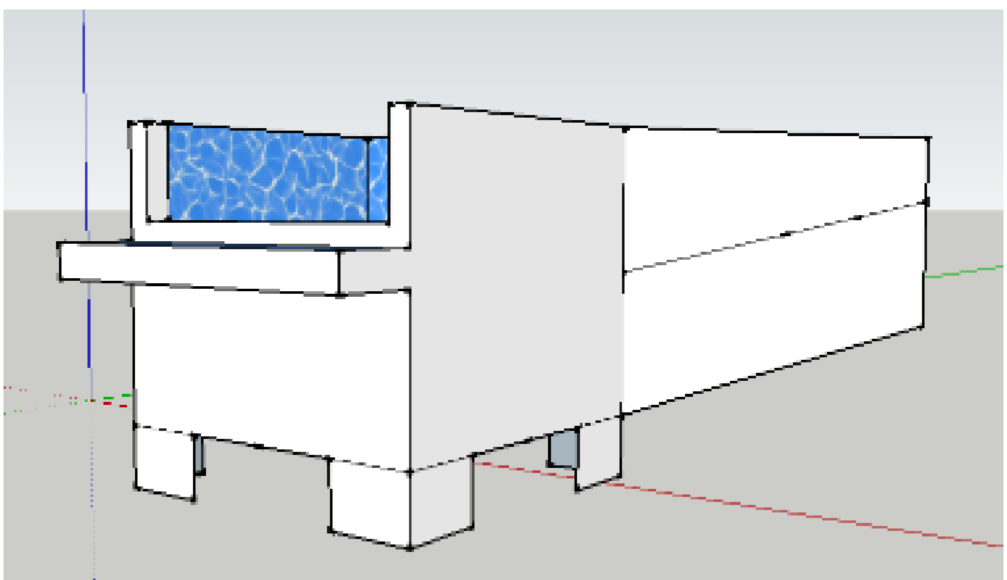

Figure 4.14: Water exit view (looking upstream) of the WOD model
This view shows the lip designed to prevent incising as well as larger opening.

The final model of the WOD was designed to both improve the flow from the river's braids and allow for testing with the hydrolab even when there is only an inch or two of river flow.

### 4.4.3 Interview with DNR Water Resources Technician

After we finalized the second design of the WOD, we needed to ensure its cultural acceptability as well make certain that our design took into consideration all of the DNR's needs and was ready for fabrication. Through our interview we learned that our design for the WOD would not have any negative cultural or environmental impacts. The material chosen for fabrication of the design, aluminum, was also approved. Mr. Tenorio also requested a few modifications be made to the design which he thought would improve its functionality (see Figure 4.15). We changed the design and shape of the feet on the box to allow for the WOD to more easily sit into the riverbed and stay in place. We also raised the base of the flume to be only a quarter of an inch away from the V-notch. This would allow for the drop box portion to fill up more quickly with water. We also discussed creating and providing a separate recommendation for longer walls of the flume to allow for water from several braids to be collected at once.

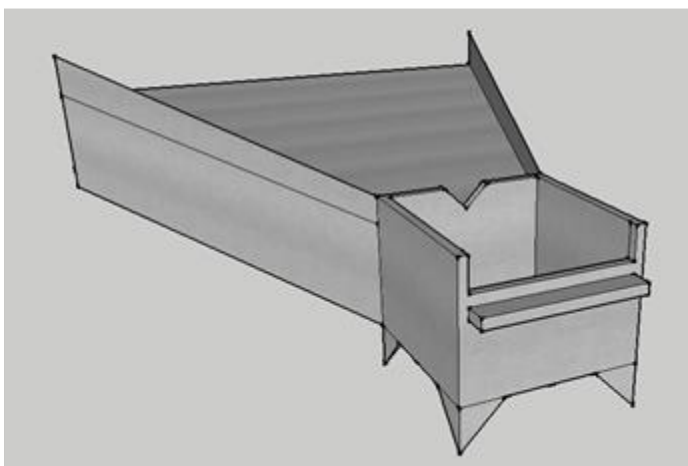

Figure 4.15: Final Design of the WOD

## 4.5 Determining a Way to Ensure Continuity of the Methods

In order to ensure that the techniques and technology that we had identified can be used by the DNR and passed on to others within the DNR, we created a pamphlet that contained an explanation of the proper sampling techniques as well as a blueprint, construction plan, and implementation plan for the sampling device that we have proposed.

### 4.5.1 Sampling Protocols and Techniques Guide

Using information from an EPA water sampling field guide and the US Geological Survey national field manual for collection of water-quality data, we created a pamphlet in order to pass on the information to the Santa Ana DNR in an easy to read and follow format. The guide summarized the necessary information into simple-to-follow tips that included information on where, when and, how to collect a water sample, specifically in terms of the Pueblo's river conditions. This pamphlet includes some methods that the DNR already uses however, this pamphlet was written so that if the DNR has a change in staff, a new employee would be able to learn how to collect a water sample correctly and reliably from the rivers.

### 4.5.2 Water Optimization Device Construction and Implementation Plan

In addition to the sampling guide, we created a plan for constructing the water optimization device that provided the DNR staff with the following:

- Blueprint of the device
- Construction plan for the device's fabrication
- Explanation on how to implement and use the device.

The blueprint we provided of the device included a diagram with all the necessary parts/pieces needed for fabrication. Our construction plan included the dimensions of those parts as well. A materials list was also provided to ensure that the proper materials would be used in the fabrication and construction of the device.

This plan also included instructions for the device's implementation and use. It explains the steps involved in setting up the device and the locations and situations in which it would be used. We also included how to collect water samples and how to use the hydrolab with the device in place. Proper procedures for cleaning and decontaminating the device following its use were also included.

To further ensure the proper implementation of our water optimization device by current and future users, we demonstrated the model we had created in the DNR's yard, as described in 4.4.2. The details of this demonstration included how to position the WOD to funnel as much water as possible, how to avoid contaminating the water being tested, and how to clean and maintain the device.

## 4.6 Summary

We observed that the DNR occasionally collected water samples using techniques that were convenient but not necessarily valid for accurate sampling, which may have led to sample results that are not representative of the water in their rivers. We also learned that during seasons of extremely low flow, there are times when samples cannot be collected. Through our data collection and analysis, we found proper river water collection techniques and designed a water optimization device (WOD) to collect and test water during the seasons of low flow. An important concern was whether these methods would be culturally acceptable and easy to use by the DNR. Based on all necessary criteria, we designed a model that would be culturally acceptable and best suit the DNR's need for collecting water during these low flow seasons. We have recommended that the DNR follow the sample collection protocols displayed and explained in the Water Sampling Protocols Guide pamphlet (found in Appendix F). This will help to ensure that a representative and reproducible sample is collected when possible. We also recommend that the DNR fabricate, implement, and use the water optimization device (WOD) we designed for use during low flow in the rivers. The WOD will funnel and collect river water during seasons of low flow and allow for water samples to be collected and the hydrolab to be used when it would otherwise be impossible.

# Chapter 5: Conclusions and Recommendations

The purpose of this project was to create an improved water sampling plan for the Santa Ana DNR. Though the water that the DNR samples is mainly used for irrigation, it is also used for recreation and occasionally as drinking water for traditional, ceremonial purposes. Because of this, collecting representative and accurate samples of river water on a regular basis for testing of the presence of *E. coli* is imperative for the health and wellness of the members of the Pueblo of Santa Ana. During this project we produced two main deliverables which provide (1) specific water sampling techniques for the Rio Grande and Rio Jemez and (2) a user's manual for the modified flume-drop weir device we designed for low flow water sampling.

## 5.1 Project Conclusions

Our team reached several conclusions on how to collect water samples from the Rio Grande and Rio Jemez. We also designed a device that will allow for funneling and collection of river water during seasons of low flow which will optimize sampling and testing, particularly on the Rio Jemez.

### 5.1.1 River Sampling Protocols

We identified several ideal sampling techniques for where, when, and how to collect a proper river water sample. These included:

<u>Where to collect a river water sample:</u>

- Samples should be collected from the middle of the river and, where applicable, in an area where two stream braids are mixing.
- Sample from the upstream side of a bridge.
- Samples should be collected five centimeters under the surface of the river but not along the river bottom.

<u>When to collect a river water sample:</u>

- Samples should not be collected after a rain event nor on or after a windy day when possible.

<u>How to collect a river water sample:</u>

- The collection bottle should be facing upstream and the individual collecting the sample should stand downstream of the collection bottle.
- The sampling bottle should not touch the river bottom.
- If multiple samples are being collected from a location, they should be collected at the same time and immediately put on ice.

### 5.1.2 Water Optimization Device (WOD)

We also designed, modeled, and modified a water optimization device to be used during low flow seasons on the Rio Jemez. The design of our device incorporates the funneling feature of a flume as well as the water collection aspect of a modified, closed off drop weir system. We designed and modified this model because its water funneling ability can concentrate and collect a low flow of river water from a braid of the river. This water can then build up and collect into the modified, closed off weir system we designed. By incorporating certain aspects from both of these systems into one design for our device, we were able to provide the Water Resources Division of the Santa Ana DNR with a device that will allow them to collect water samples for *E. coli* testing and test for specific factors of the river's water with the hydrolab. Because the design of the device allows for this, the DNR will be able to do two things they would otherwise be unable to do when the water is too low to otherwise collect and test: (1) they will be able to report test results to the EPA and (2) they will be able to alert and advise the members of the Pueblo of Santa Ana when *E. coli* levels are too high and the river's water is unsafe for recreation or for consumption.

## 5.2 Future Recommendations

In addition to our conclusions for water sampling protocols and our WOD, we also have several recommendations for the DNR. These will assist in the implementation and use of our deliverables as well as extend the ability and possible uses for the WOD.

### 5.2.1 Recommendation for Improved Water Sample Collection Techniques

The Santa Ana DNR should review the water sampling techniques guide that we created and have provided (see Appendix F). After familiarizing themselves with the new sampling techniques they should implement them consistently to insure valid sampling results. While the DNR does have a simple device to collect water samples when standing on a bridge or a high bank, we recommend they invest in a water sampling pole (see Figure 5.1). This will aid in their ability to collect a sample from the middle of a river when standing on or near the river's edge. This will assist in following the technique regarding collecting a sample from the middle of the river as opposed to the side of the river. This pole should be used regularly in order to collect a sample from as close to the middle of the river as possible and to collect the most representative sample possible. In order to fill two sample bottles for testing, this would have to be done twice since this type of sampling pole only allows for on sample bottle to be attached at a time.

Figure 5.1 Water sampling pole
Using the sampling pole to collect as a sample from midstream (left). A close up of the end of the sampling pole with sample collection bottle attached (right).
(Macdonald, 2014; Nasco, 2016)

### 5.2.2 Recommendation for Construction and Modification to the WOD

In order to construct and implement the water optimization device the DNR should review the user manual we have developed and have provided in Appendix G. This guide includes three-dimensional diagrams, including dimensions and measurements, of water optimization device. This guide also lays out how to implement, use, and maintain the device.

We recommend that the WOD be fabricated at a sheet metal shop and we have included a descriptive list of possibilities in the Albuquerque, New Mexico area. Based on the information provided in Table E.1, we recommend that the WOD be fabricated using at least fourteen-gauge aluminum. Also, this device should be constructed using rivets and silicone or epoxy to connect and attach the various parts.

One possible future modification to WOD that we recommend is the addition of adjustable, removable extensions to the flume portion of the device (see Figure 5.2). These extensions should be attached using a three-point pin hinge, or the like. We have included further details regarding this recommendation in the WOD user's manual. These hinges may be attached to the device at the time of fabrication or in the future if they are in fact needed.

This will allow for the collection of multiple braids or a larger area of river water during low flow when necessary.

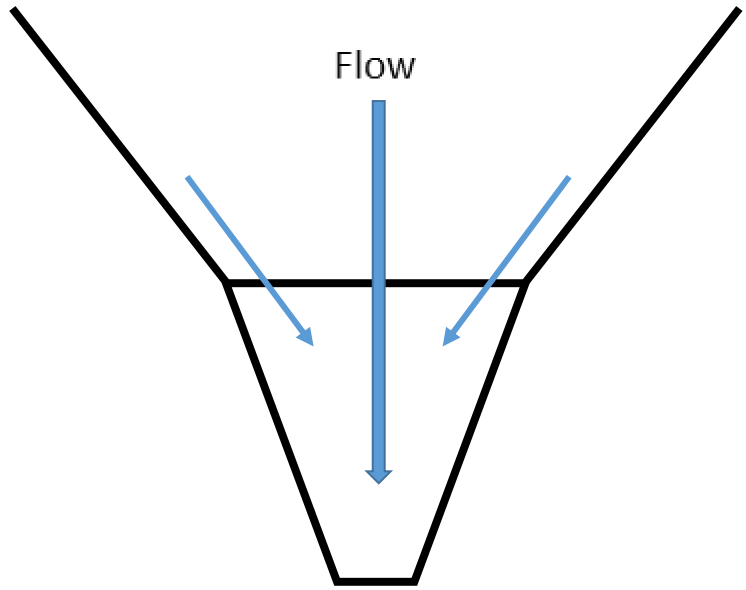


Figure 5.2: Diagram of future modification to the WOD
Note: This is not to scale.

## 5.3 Summary

The overall results of this project have provided the Water Resources Division of the Santa Ana DNR the means to collect representative samples of the Pueblo's river water as well as collect samples and test the river's water despite low flow conditions. We believe that this project has been able to help the Water Resources Division to more consistently sample and monitor the Pueblo's river water. Overall, this will assist them in their main goals to both report test results to the EPA and alert and advise members of the Pueblo when the river's water is unsafe for recreation or consumption.

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# Appendix A – The Sponsor

The Pueblo of Santa Ana (2016) is a federally recognized tribal entity which possess a culture, religion, and way of life that hold harmony with nature in high regard. The Pueblo of Santa Ana's government is a combination of two different influences, one being religious from indigenous cultural society, and the second derived from Spanish influence. On the religious side, the most important role is the cacique, the head of the Pueblo and the most sacred position in the Pueblo. The cacique serves for life and is not required to support himself or his family and is instead supported by the Pueblo. The responsibilities of the cacique include: keeping order in the Pueblo, authorizing communal rituals, and appointing other officials. The second part of the Pueblo's government system is comprised of officials who were imposed upon the Pueblo by Spanish authorities and influences. These officials included a governor, a lieutenant governor, captains, and church officials. Each position is appointed annually by the cacique. This part of the government is aided by a counsel of advisors that is made up of former office officials.

The Natural Resources Department (DNR) of the Pueblo of Santa Ana (2016) was created by the tribal government in order to develop and implement programs to protect, preserve, and enhance the natural resources for members of the tribe. Initially formed in 1996, the Santa Ana DNR has since been expanded and has five core divisions: (1) Bosque Restoration Division, (2) Environmental Education Division, (3) Geographic Information System/Information Technology Division, (4) Rangeland & Wildlife Division, and (5) Water Resources Division. The divisions of the DNR provide information and options to the Pueblo for management of their natural recourses. The DNR employs tribal members for monitoring and support and also has an internship program which provides training and work for the members of the Pueblo.

The Water Resources Division (WRD) itself has five specific programs: Watershed Protection, Safety of Dams, Water Quality, Water Rights, and Hydrology (Santa Ana Pueblo, 2016). The WRD is involved with support for water rights of the Rio Jemez and Rio Grande. The Water Quality Program, which is in part funded by the United States Environmental Protection Agency with a Clean Water Act grant, works alongside the Pueblo's government to plan and protect water resources and takes part in environmental education to make the youth and elders of the Pueblo aware of issues surrounding water quality. The Water Resources division has collaborated and partnered with some of the following organizations in the implementation of their many programs: The United States Environmental Protection Agency, the United States Fish and Wildlife Services, and the Bureau of Indian Affairs.

# Appendix B – Interview with DNR Water Resources Division Manager and Technician

## Protocol:

Date: __________________________
Location: _______________________
Interviewee Names: ________________
Interviewer Name: ________________

- This interview was conducted in person at the Santa Ana DNR Building
- Our team had already met with the DNR Water Resources Division Manager and Technician prior to the interview, so we did not have to introduce ourselves.
- All team members had to opportunity to ask questions during the interview, but one team member (Avik) was designated to make sure the interview progressed.
- One group member (Stephanie) took notes from the interview
- This interview was a question, answer, discussion format.

## Topics:

- How often do you sample and test the river water?
    - When tested samples come back with concerning levels of *E. coli*, what do you do as follow up, if anything?
    - What is the typical procedure when this happens?
- Along with taking samples of water to test and monitor *E. coli* levels, what else do you monitor?
    - How often?
    - What do you do with this data?
- Where along the river do you sample the water? [Could you show these areas on a map for our use?]
    - Why do you sample in these specific locations?
- Where along the river can samples not be taken?
- When sampling and testing the water in an area of the rivers where there is a consistent flow, where do you test and take samples (e.g. in the middle/sides of the river in terms of width; top/bottom in terms of depth)? Why?
- When there is braiding in the river, where do you sample and test?
    - Do you take a sample from one area or in multiple areas at the same location along the river when this occurs?
- When there are ripples in the water, how do you test and take water samples (i.e. with or against the ripples)?
- What other things should we consider [i.e. land, environment, Pueblo culture, and traditions] when considering sampling locations and alternative sample collection methods/devices?

## Interview Summary:

Date: Wednesday, September 21, 2016
Location: Department of Natural Resources Break Room
Interviewee Names: Tammy Montoya (WRD Technician) and Anita Steed (WRD Manager)
Interviewer Name: Avik Muralidharan

- This interview was conducted in person at the Santa Ana DNR Building
- Our team had already met with the DNR Water Resources Division Manager and Technician prior to the interview, so we did not have to introduce ourselves.
- All team members had to opportunity to ask questions during the interview, but one team member (Avik) was designated to make sure the interview progressed.
- One group member (Stephanie) took notes from the interview
- This interview was a question, answer, discussion format.

## Topics:

- How often do you sample and test the river water?
  Water is sampled monthly. There is no strict schedule and samples are generally collected when there is good flow.
  - When tested samples come back with concerning levels of *E. coli*, what do you do as follow up, if anything?
    The results of the monthly *E. coli* tests indicate whether weekly samples need to be collected and tested. If *E. coli* test results come back high, then water samples are collected and tested weekly - this applies to both the Rio Grande and the Rio Jemez. Once results from the *E. coli* tests come back to acceptable levels, normal monthly sampling is resumed.
  - What is the typical procedure when this happens?
    First, the conditions (i.e. weather, rain events) prior to the collection of the sample are evaluated as these could alter the results of the *E. coli* test. Then an advisory is sent out to the members of the Pueblo recommending that they do not drink or come into contact with the water.

- Along with taking samples of water to test and monitor *E. coli* levels, what else do you monitor?
  The hydrolab has probes that test for and monitor a variety of river water factors. These include temperature, pH levels, specific conductivity, total dissolved solids (TDS), turbidity and dissolved oxygen concentration. These are all common factors that are typically monitored on most rivers.
  - How often?
    These factors are tested and monitored monthly along with *E. coli* sample collection. When *E. coli* testing needs to be done weekly, they typically also test and monitor these factors. [Generally, whenever water samples are collected, these factors are also tested and monitored.]

- What do you do with this data?
  This data is reviewed and reported to the EPA as information regarding the river's ecosystem. The data regarding the Rio Grande's temperature is of particular concern to the EPA because temperature is an indication of industrial pollution so the EPA uses this data to monitor yearly changes.
  The data is also recorded and monitored by the Santa Ana DNR. The data is loaded into graphs for comparison from year to year to see the overall changes in the rivers and also any improvements to certain conditions.

- Where along the river do you sample the water? [Could you show these areas on a map for our use?]
  Along both rivers, samples are collected along the northern and southern boundaries of the rivers on Pueblo lands as well as somewhere in between/within the Pueblo boundaries (therefore, there are 3 locations per river).
  Map of sample locations can be found in Appendix E.
  - Why do you sample in these specific locations?
    The specific locations are upstream and downstream, and at a middle point along the rivers. These locations are also chosen because they are accessible-collection sites are either on Pueblo of Santa Ana land or in a "public area" and not on other pueblo lands.

- Where along the river can samples not be taken?
  Samples can no longer be taken at the Jemez canyon dam as there is usually low flow or no flow at all.

- When sampling and testing the water in an area of the rivers where there is a consistent flow, where do you test and take samples (e.g. in the middle/sides of the river in terms of width; top/bottom in terms of depth)? Why?
  The channel of the river where the main flow of water is typically where a sample is collected. Samples are typically collected in the middle of the river and usually at medium depth (if there is enough flow). Samples are collected as deep as possible, as long as the sample bottles are completely full.

- When there is braiding in the river, where do you sample and test?
  [As stated above] samples are collected from the braid with the greatest and deepest flow of water.
  - Do you take a sample from one area or in multiple areas at the same location along the river when this occurs?
    No, only one sample is collected from each sample site regardless of the number of streams.

- When there are ripples in the water, how do you test and take water samples (i.e. with or against the ripples)?
  Sample collection is typically avoided in areas where there are ripples present. The presence of ripple indicates shallow water and/or barriers under the surface. Ripples reflect that water is going over a sort of "sandbar" or another sort of barrier.
  So, samples are typically taken in areas of good flow and free of ripples or other barriers.

- What other things should we consider [i.e. land, environment, Pueblo culture, and traditions] when considering sampling locations and alternative sample collection methods/devices?
  The Water Resources Division of the DNR serves the Pueblo of Santa Ana (in terms of offering information on water quality). The WRD is also concerned with reporting to the EPA in terms of water pollution and other river water factors
  We also need to consider the traditional uses of the river's water by the Pueblo.

# Appendix C – Interview with DNR Water Resources Division Technician

## Protocol:

Date: ___________________________
Location: ________________________
Interviewee Names: _______________
Interviewer Name: ________________

- This interview was conducted in person at the Santa Ana DNR Building
- Our team had already met with the DNR Water Resources Technician prior to the interview, so we did not have to introduce ourselves.
- All team members had to opportunity to ask questions during the interview, but one team member (Zebulon) was designated to make sure the interview progressed.
- One group member (Sydney) took notes from the interview
- This interview was a question, answer, discussion format.

## Topics:

- In your opinion, is the water optimization device (WOD) feasible for implementation and use for the DNR?
    - If not, what aspects need to be changed?
- In your opinion, are there any aspects of the WOD that will harm the environment?
    - In what way?
- In your opinion, are there any aspect of the WOD that are not culturally acceptable?
    - In what way?
- Are the materials that we have determined best suited for this device appropriate?
- Are there any other aspects of the WOD that have not been mentioned that are of concern to you?
- Based on the designed water optimization device discussed, are there any aspects of the device that are need to be further modified?

## Interview Summary:

Date: Monday, October 3, 2016
Location: Department of Natural Resources Break Room
Interviewee Names: Glenn Tenorio (WRD Technician)
Interviewer Name: Zebulon Shippee

- This interview was conducted in person at the Santa Ana DNR Building
- Our team had already met with the DNR Water Resources Technician prior to the interview, so we did not have to introduce ourselves.
- All team members had to opportunity to ask questions during the interview, but one team member (Zebulon) was designated to make sure the interview progressed.
- One group member (Sydney) took notes from the interview
- This interview was a question, answer, discussion format.

## Topics:

- In your opinion, is the water optimization device (WOD) feasible for implementation and use for the DNR?
  Yes, this is a feasible device.
    - ~~If not, what aspects need to be changed?~~

- In your opinion, are there any aspects of the WOD that will harm the environment?
  To my knowledge, no, not at all.
    - ~~In what way?~~

- In your opinion, are there any aspect of the WOD that are not culturally acceptable?
  No
    - ~~In what way?~~

- Are the materials [aluminum] that we have determined best suited for this device appropriate?
  To my knowledge, I would not know. If it can meet the demands of what it would be used for-then yes. In the proposal, you may want to include what the other options are and explain why aluminum is the best option.

- Are there any other aspects of the WOD that have not been mentioned that are of concern to you?
  No

- Based on the designed water optimization device discussed, are there any aspects of the device that are need to be further modified?
  You may want to include a recommendation for the option of longer "wings" or walls on the flume portion so that more braids of water can be captured and collected.
  Also, I think that design should be changed to ¼" between the V-notch and the base of the flume.

# Appendix D – Transcript of Interview with Professor Mathisen

Date: Tuesday, April 19, 2016
Method of Contact: In-Person Interview on WPI campus
Interviewee Name: WPI Professor Paul Mathisen
Interviewer Name: Avik Muralidharan

**Avik**: First off, thank you for taking the time to speak with me.

**Professor Mathisen**: Anytime, it sounds like an interesting project.

**Avik**: What is your level of experience with water quality testing methods? Specifically, for irrigation water?

**Professor Mathisen**: I probably haven't sampled for irrigation water specifically, I sampled a lot for water quality though. I do both groundwater and surface water testing and the applications would usually be for protecting ecosystems but also for reservoirs.

**Avik**: Okay so you're definitely well versed with water quality testing methods in general. In addition to salinity, E. coli, and ion toxicity, what are other variables would you consider monitoring?

**Professor Mathisen**: Well certainly in terms of metals, if they were concerned about heavy metals, sometimes they call it the RCRA8 which would be the major heavy metals that people are most concerned about. The other thing is there are these metals that would be of a real concern because you put them in there and they use it for irrigation and it can quite often get taken by your plants and up in the soil. The other thing that's of concern also is the nutrients, nitrogen and phosphorus, which probably would be okay for irrigation I guess.

**Avik**: Yeah it definitely is a tad bit different because the water that's being tested is for irrigation. So do you have any tips or pointers on how to direct our research for testing water quality in a dry climate?

**Professor Mathisen**: So I've had to go out West but not to test water quality specifically. I will say though that there is a rain after the river is dry, the rain water that flows into the river will definitely be highly contaminated because there's a lot of stuff that's built up. Usually when we're looking at dry weather conditions, if there's water in a stream, primarily it's contributed by groundwater. It's what you call a base flow and that's usually fairly steady in terms of the nature of the flow. Now if they're changing the upstream flow conditions, if they have a dam or a reservoir that could change things around.

**Avik**: They do have a reservoir upstream actually, which is government controlled. So do you know anything about how to test for the sediment?

**Professor Mathisen**: There are ways to do that but it is more expensive and it hasn't been looked into a lot so it's accuracy is questionable. You also have to consider that the water that is trapped underneath has potential to be highly contaminated. The process is fairly complex in terms of the conditions out there. Sometimes there's this thing called the PH, there's just overall a lot of different parameters. In the long term when you have something like highly contaminated E.Coli, there could be pathogens and it's an indicator of those pathogens and can be harmful for people working in the fields, etc. I'm not sure if that helps

**Avik**: Oh okay, that's definitely very helpful. We were not sure how it would compare in terms of cost and obviously we'll probably be working with a budget so that information is definitely useful.

**Professor Mathisen**: Yeah the other thing is that it is pretty expensive to try to get the details of the sediments and it's a complicated process. They will take the sample soil and put it in like an acid and leach off all the stuff that's inside. And then it all goes in a solution and then they will analyze that. Like we can do that here but it's definitely expensive. It probably won't be something that you'll be able to do out there. You might be able to find information on a lot of watershed associated out there and they will set up water quality monitoring programs and they try to get the people of the watershed to do that. As a part of that there's a training process and they might have water quality kits and the kits would be fairly easy to manage.

**Avik**: Okay so sediment testing sounds quite a bit more complicated and like you said much more expensive. We are researching different testing methods for both the water and river sediments. Can you recommend any areas that we should look for or any areas we should avoid while testing (mud vs dry dirt, middle of the stream vs the shore, fast moving water vs slow)?

**Professor Mathisen**: For them, if they have a water supply you'd probably want to know where the source is. If you're trying to get the most accurate representation of the entire river, then usually the middle of the stream is the best place to test. I'm not sure I'd recommend going out and sampling in the middle of the stream as there are tremendous safety protocols and stuff. But that usually gives you an indication of all the stuff in the stream. If you were to go on the edge you might be getting a flow but it also might be just what you see locally. If you go from one bank to another you might see a lot of changes. Think of it this way, say you have runoff from a storm. When run off comes in you get a highly variable result because when there's in dry weather all this stuff accumulates on the ground like dog poop, trash etc. but then it rains. Then immediately you have this thing called the first flush, where the water will run off.

**Avik**: We're almost out of time but is anything that we missed that you think we should consider or talk about?

**Professor Mathisen**: I mean we covered quite a bit, I'm sure I told you way more than you need. You might try to go back over and think about it and how this discussion fits into your scope. There are certainly constraints that you have and I guess one of the things to think about, and it sounds like you have thought about, are the goals you're trying to accomplish and what resources fit into that. The other thing is that if you go to measure water quality, it's very variable and you recognize that clearly. Quite often what you have to do is understanding the water quality.

**Avik**: So like understanding what the source of the pollution is, what is it, where it came from etc.?

**Professor Mathisen**: Yes, exactly it's very much what's upstream, the climate, you've mentioned all this before. The reality is that you won't be able to answer all the questions and that's okay. I'd even recommend checking out some river studies on like the Charles River. The methods used might be a little advanced so I'm not sure how relevant the information will be.

**Avik**: Any information is helpful so we'll definitely check that out. Would it be okay if we reached out to you if we had any follow-up questions?

**Professor Mathisen**: Yeah if you have any questions just let me know.

**Avik**: Okay great. Well thank you for taking the time to speak with me!

**Professor Mathisen**: No problem, it sounds like a fun project.

# Appendix E – Summary of Correspondence with John H. Cole, Failure Analysis Expert

Date: Saturday, October 1, 2016
Method of Contact: Phone call correspondence
Interviewee Name: John H. Cole (PT&C | LWG Forensic Consulting Services Senior Project Engineer)
Interviewer Name: Stephanie Silvestris

## Summary:

- This interview was conducted via phone call correspondence.
- On behalf of the team, Stephanie had sent an email to Mr. Cole with a description of our project as well as a description of the device we were designing. The table within this appendix was also sent, blank, for reference as to what we were looking to discuss.
- Phone correspondence was made and we discussed possible alternatives to the design of our water optimization device. These included:
  - the use of prefabricated materials and products for fabrication
  - the option of t-ducts or sheet metal reducers to assist in funneling river water
  - the use of a drainpipe, Tygon® tubing, or other sort of piping to connect the flume portion to the collection box portion
  - the use of a bulkhead connector to connect the flume, some sort of piping, and the collection box together for the seamless flow of water
  - the effectiveness of a large plastic or metal dustpan in place of a fabricated flume
  - the use of a prefabricated aluminum box for the water collection box
- We also discussed materials that the water optimization device could be fabricated with. This included:
  - Wood
  - Plastic (readymade and prefabricated)
  - Aluminum
  - Copper
  - Galvanized steel
  - Concrete [mortar mix]
- While discussing the pros and cons of the different materials for the application of our project we also discussed several factors of each. The factors included:
  - Cost and ease of fabrication
  - Weight and mobility
  - Risk of cross-contamination
  - Maintenance and decontamination
  - Wear and corrosion
  - Risk of introducing hazardous chemicals to the water
- Mr. Cole ranked each material and corresponding factor on a scale of one to five (1-not a good option; 5-the best option). As seen in Table E.1. In addition to these rankings, explanations were provided for most.

Table E.1: Material Analysis

| Material | Wood | Plastic (readymade) | Aluminum | Copper | Galvanized Steel | Concrete [mortar mix] |
|---|---|---|---|---|---|---|
| Cost / Ease of fabrication | 4/5-depends on type and size | 5-if fabricated from ready made parts<br>(2-if custom) | 4-need tools to fabricate | 3-more expensive but easy to fabricate | 3-no welding, harder to fabricate and work with | 3-low cost, but not easy to fabricate and produce |
| Weight & mobility | 5 | 5 | 5 | 5 | 5 | 2-if thick<br>4-if produced thin (but then very fragile and not durable) |
| Risk of cross-contamination | 1* | 5-seal joints, clean between uses [not porous] | 5-inert (may be susceptible to acid in water) | 5 | 5 | 1* |
| Maintenance / decontamination | 1-if untreated | 5 | 5 | 5 | 5<br>(may have some sort of reaction with the cleaning solution) | 2-dependent on the durability of the sealant; if the sealant chips |
| Wear / corrosion | 5-very durable<br>3-if thinner wood | 5-not going to corrode or breakdown | 5 | 5 | 5-if decontaminated and dried post use | 4-durable if its produced thick<br>2-not very durable if thin |
| Risk of introducing chemicals to water | 5- doesn't interact | 5-exosure to water won't introduce anything | 5-inert | 5 | 3/4-zinc oxide release (may not react) | 5-non reactive/inert once solid |

*unless coated with varnish or polyurethane (would then score a 4)

# Appendix F – Deliverable: Water Sampling Protocols Guide

## Sampling Guide

A guide with proper water sampling protocols for the Santa Ana DNR's Water Resources Division

By: Sydney Garcia
Avik Muralidharan
Zebulon Shippee
Stephanie Silvestris

## Contact Information

The Pueblo of Santa Ana
Department of Natural Resources
Water Resources Division

Address: 02 Dove Rd.
Santa Ana Pueblo, NM, 87004

Telephone: 505-771-6710

Web Address:
www.santaanadnr.org

Presented by:
WPI

## When

**Do not collect samples 24 hours after a rain event**

- Rain events will churn up excess sediment, which can elevate bacterial test results. If there is constantly water in the river a sample should not be collected within 24 hours of a rain event. [Note: It is okay to collect a water sample after a rain event if it is being collected during the dry season because rain may be the only water flowing in the river.]

**Do not collect samples on a windy day**

- Similar to a rain event, wind will churn up sediment which can elevate results from a bacterial test.

## Where

**Sample from the middle of the river**

- Biotic factors grow along the banks of the river, which can elevate bacterial levels.

Figure 1: Collecting a Sample from Midstream (Macdonald, 2014)

**Sample from the upstream side of a bridge**

- A bridge can elevate bacterial levels so collecting upstream prevents sample contamination.

## Where

**Samples should be collected 5cm under the surface of the river, but not along the river bottom**

- A layer of bacteria exists on the surface of the river and along the river bottom. Testing in between the surface and river bed will give the most accurate results.

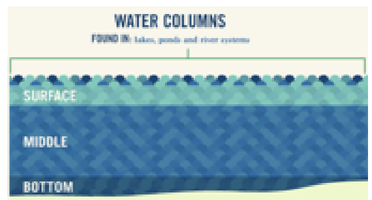



Figure 2: River Water Column (Cork, 2016)

**Collect samples where the river water is mixing**

- Collecting from a stagnant puddle will only give results for that puddle. A sample collected in an area of mixing accounts for the river as a whole.

## How

**Collect all samples from the same location at the same time**

- This will allow different test results to be comparable.

**Sample with the collection bottle facing upstream**

- This will prevent contamination from the sampling device.

**Stand downstream of the collection bottle**

- Standing down stream will prevent the sampler from contaminating the sample.

**Do not allow the collection bottle to come into contact with the river bottom**

- This will churn up sediment, which in turn increases bacteria levels.

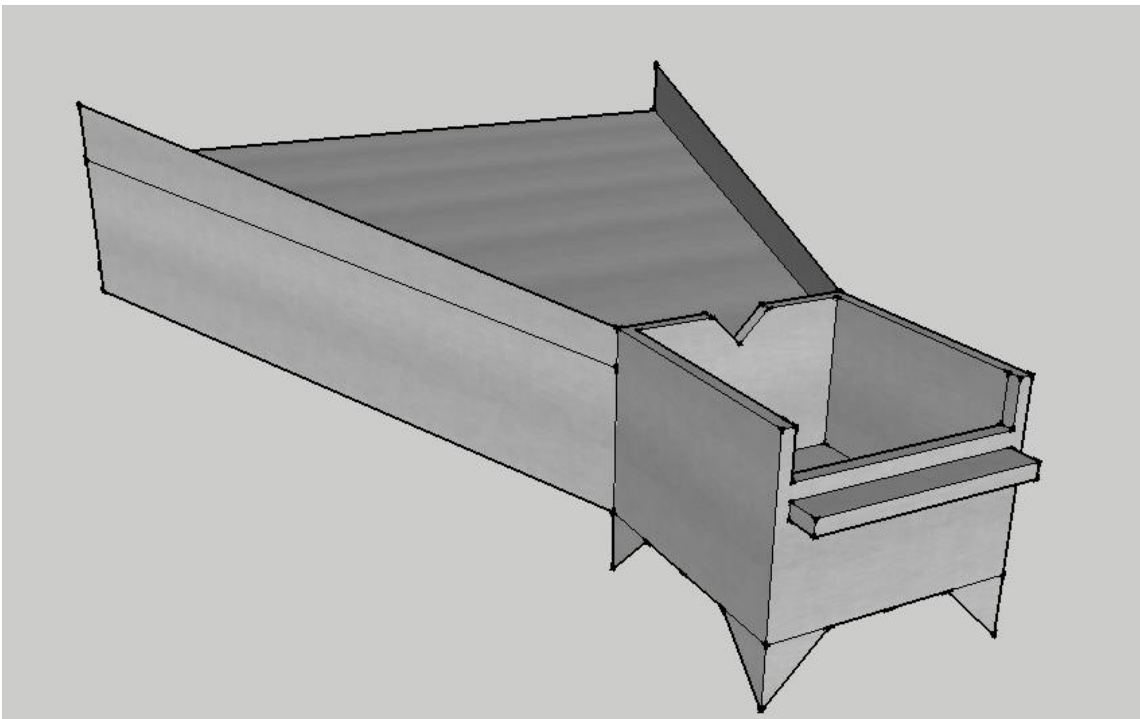
**Immediately place collected samples on ice**

- This will keep contaminants from breaking down during transit.

# Appendix G – Deliverable: Water Optimization Device User's Manual

The following pages include the user's manual we developed for the water optimization device. The user's manual was presented to our sponsor in the following format. Because of this it has its own pagination and presentation.

# Water Optimization Device User's Manual



<u>This User's Manual contains</u>:

-3D diagrams of the WOD
-Measurements and dimensions
-Construction and Fabrication information
-Implementation and Use protocols
-Cleaning and Maintenance protocols
-Future modification information

Written, compiled, and designed by:
Avik Muralidharan
Stephanie Silvestris
[of the 2016 WPI IQP team]

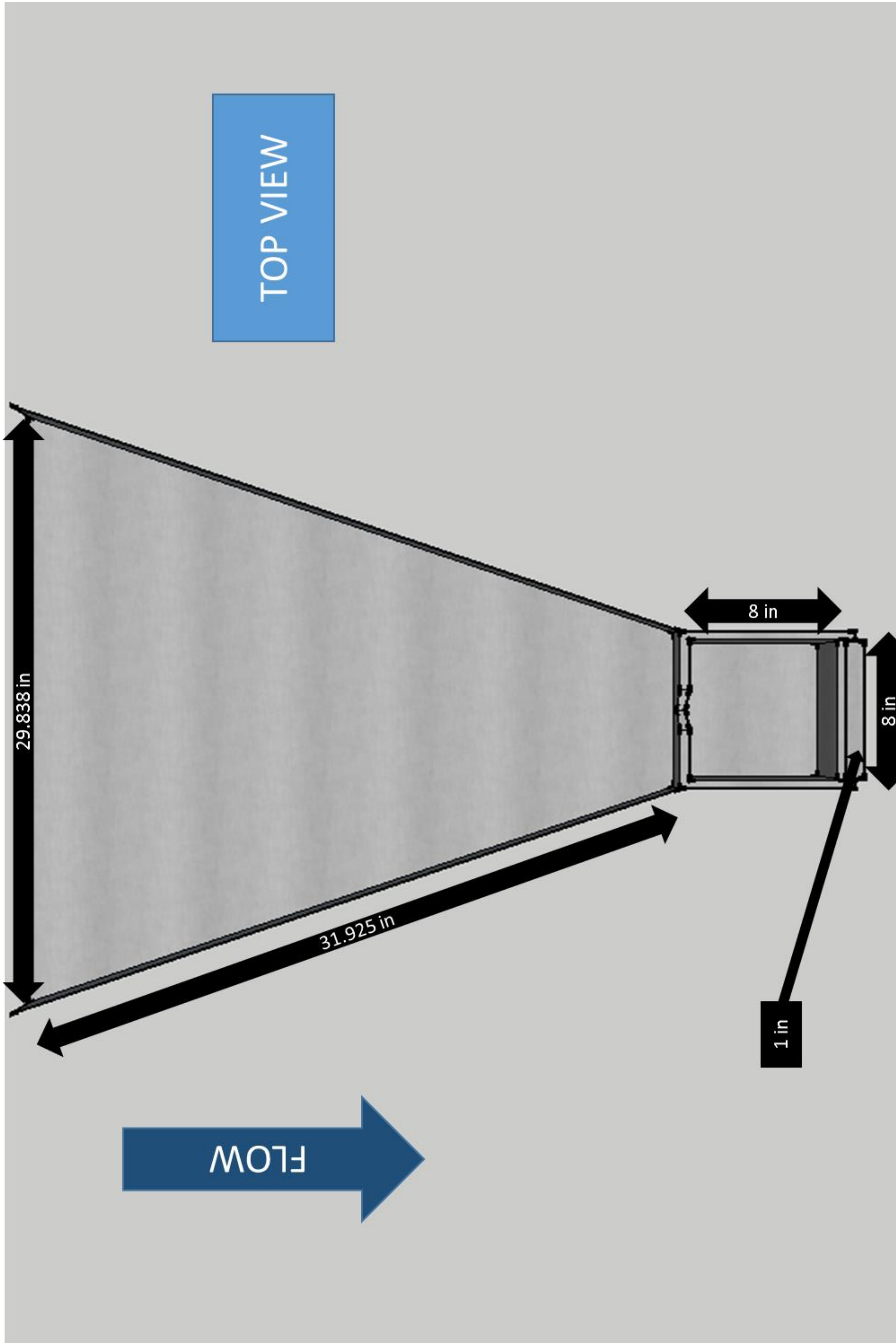
# Table of Contents

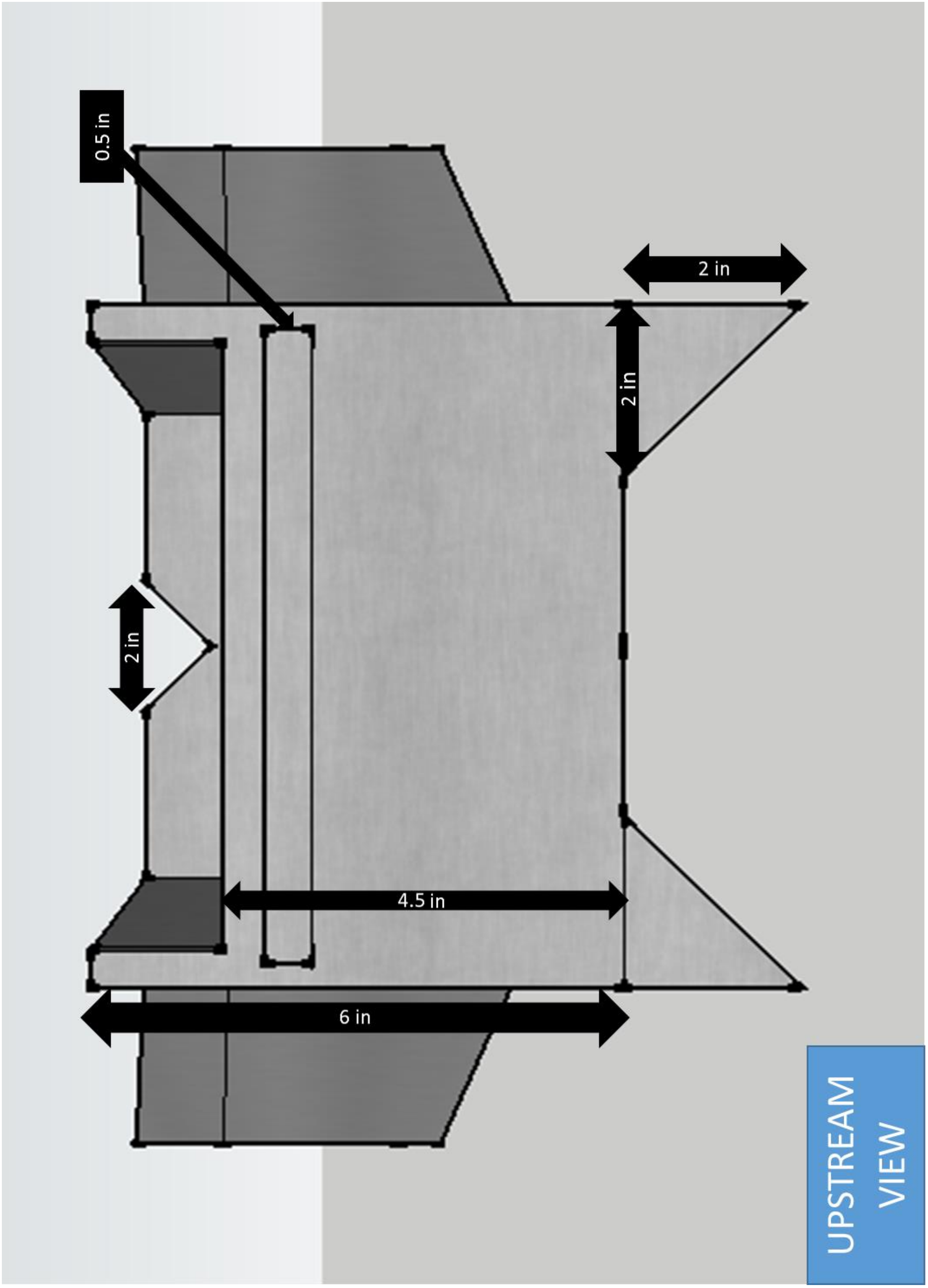
## 3D Diagrams & Device Dimensions

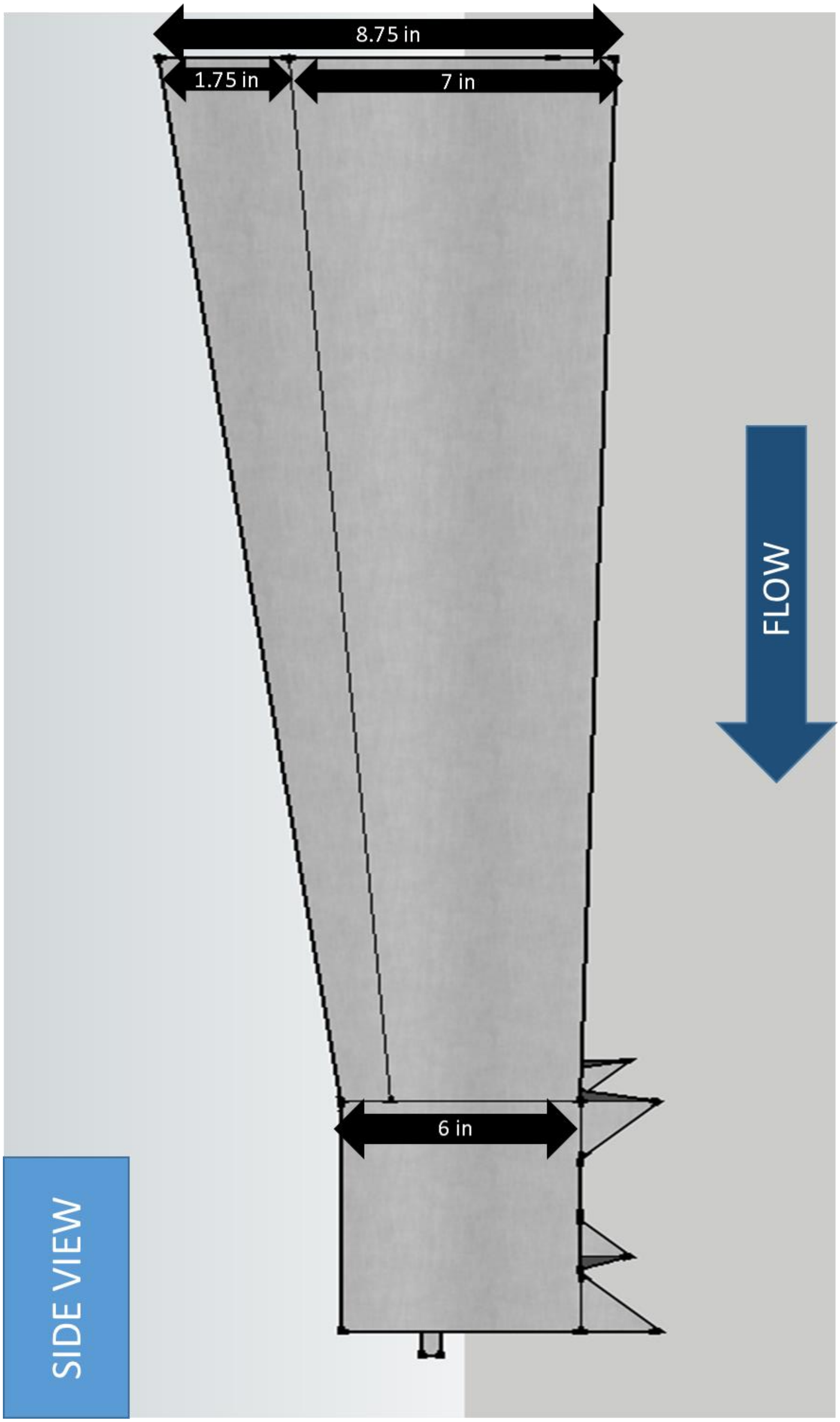
The following pages contain several views of the WOD including:
-top view
-upstream view
-side view
-downstream view
-close-up downstream view

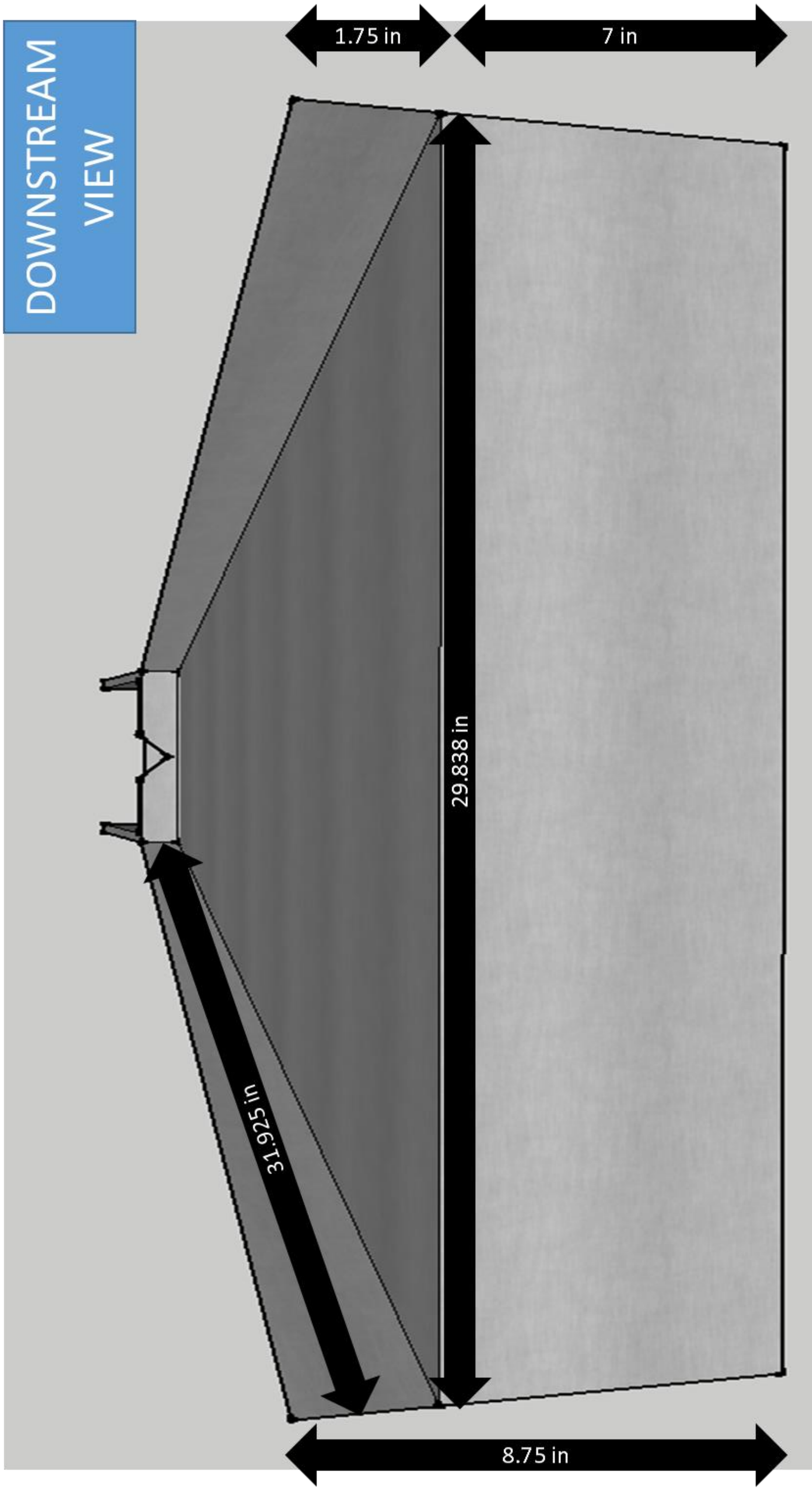
Included in these diagrams are the necessary dimensions for fabrication.

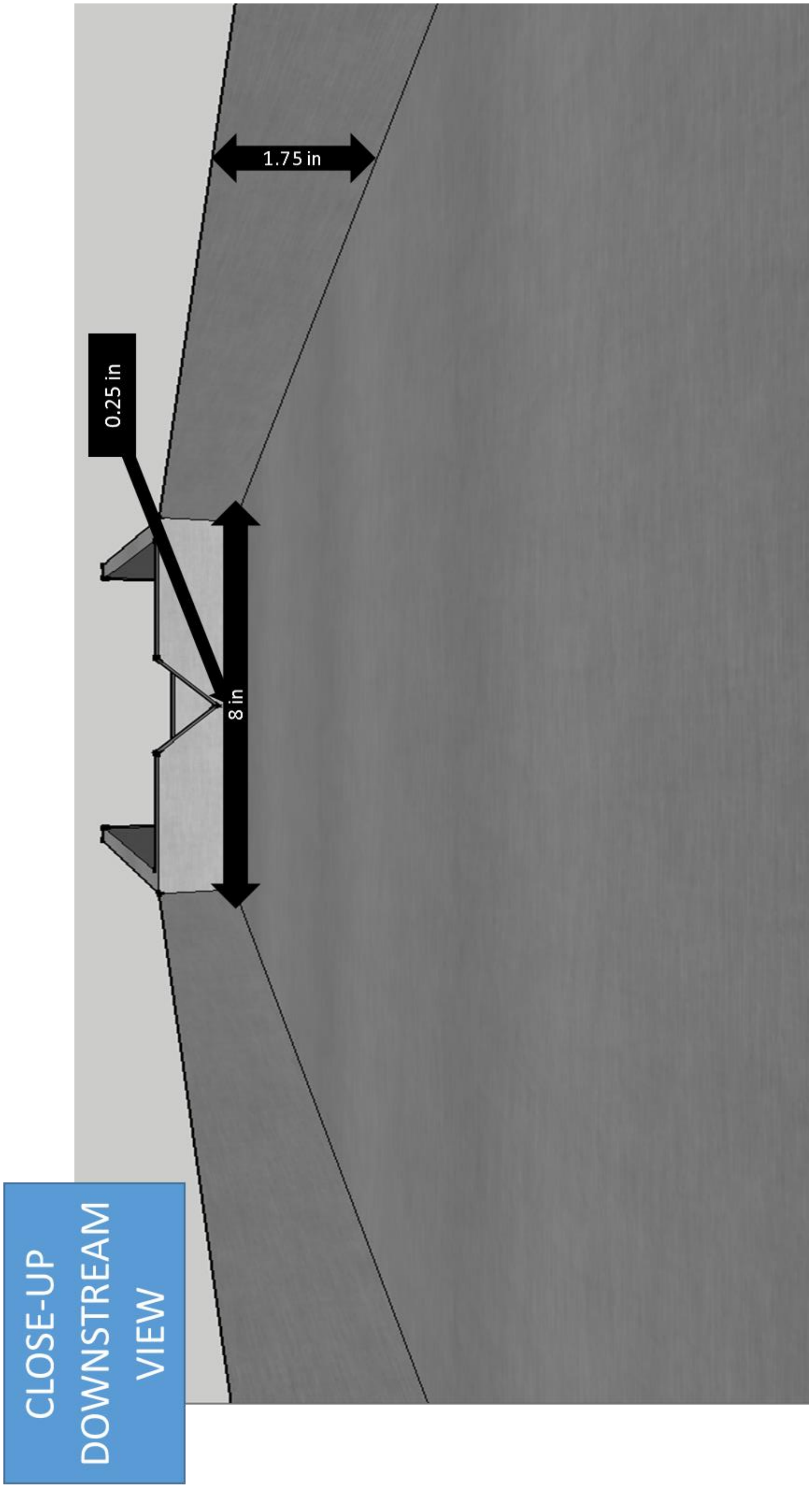
We have also included a 2D diagram of the flume portion of the device depicting the angle.


TOP VIEW
29.838 in
31.925 in
8 in
8 in
1 in
FLOW

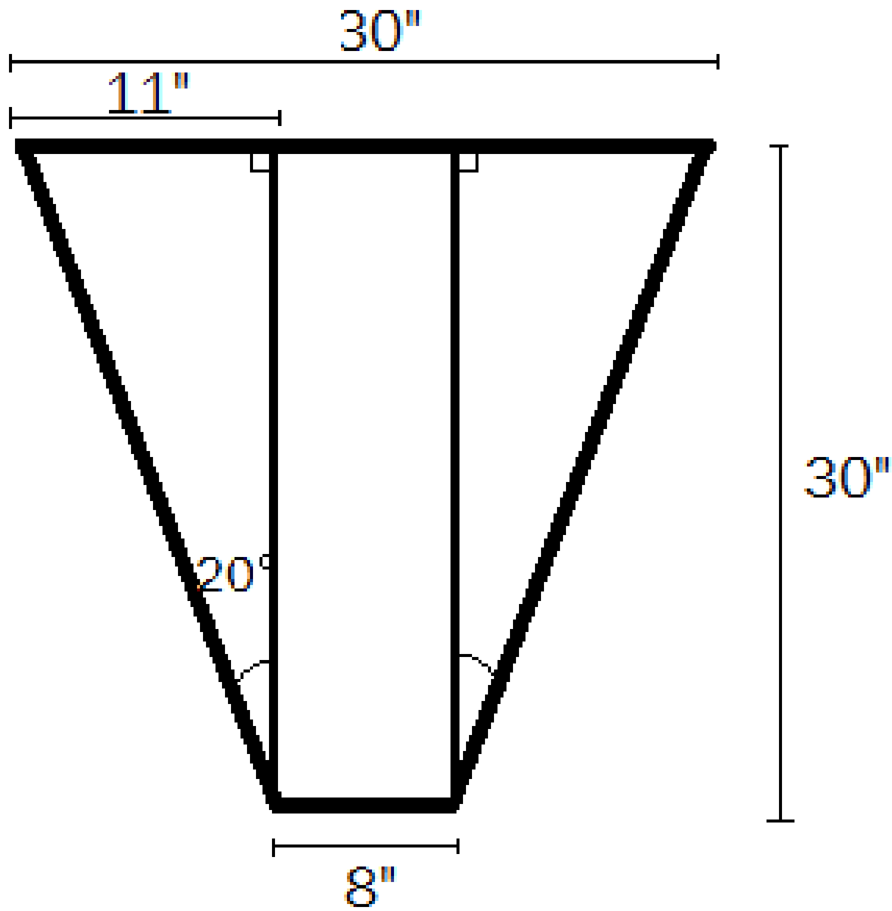

0.5 in
2 in
2 in
2 in
4.5 in
6 in
UPSTREAM VIEW


8.75 in
1.75 in
7 in
FLOW
6 in
SIDE VIEW


DOWNSTREAM VIEW
1.75 in
7 in
29.838 in
31.925 in
8.75 in


CLOSE-UP
DOWNSTREAM
VIEW
1.75 in
0.25 in
8 in

Top view of flume portion with approximate dimensions and angle formulation.




[Dimensions are approximate.]

## Construction and Fabrication information

The material we recommend using for the fabrication of the WOD is **Aluminum** (at least a 14 gauge).

For fabrication of the WOD, the following is a list of local, recommended sheet metal fabrication shops.

1. Taycar Enterprises
   Have been in the business for over 26 years, work specifically with aluminum and have the precision and flexibility to design parts for the aerospace industry
   - 8410 Firestone Lane NE, Albuquerque, NM 97113
     - 14 miles from Santa Ana
   - Phone Number: 505-265-2121

2. Salteydogg
   Have been in metal fabrication business over 35 years, give free estimates, website provides images of their work and appears to be high quality, uses aluminum
   - 2101 Commercial St. NE, Albuquerque, NM 87102
     - 20 miles from Santa Ana
   - Phone Number: 505-244-3644

3. Custom Metal Products
   Have been in the business over 25 years, has many testimonials, works with aluminum
   - 2723 Vassar Place NE, Albuquerque, NM, 87107
     - 18 miles from Santa Ana
   - Phone Number: 505-880-0606

## Implementation and Use Protocols

In order to use the WOD, follow these steps to ensure proper use:

1. Take the WOD to the sampling location.

2. With a shovel, dig a hole **6 inches deep** for the drop box portion of the device. The hole should be in the middle of the <u>largest stream braid</u> and about **8 inches in length and width**.
    a. *Keep the riverbed sediment that was dug out for the hole* ***downstream*** *and to the side of the hole and device. This will ensure that the sediment does not contaminate the water and will also allow the sediment to be replaced in the hole after completion of sampling and removal of the WOD.*

3. Place the WOD's drop-box into the hole and use the feet on the bottom to dig the box in to the river bottom and secure the device.

4. Use some of the riverbed sediment to **pad the outside of the box** so that the water flowing out does not sink in to the hole that has been dug.

5. Push the flume side into the riverbed and pad the **entrance portion of the flume** with river sediment tightly so that water does not go under the WOD.

6. Allow for water to fill up behind the drop box in the flume and then flow into the drop box.
    a. This may take a bit of time depending on the flow of the stream braid (approx. 1-2 minutes).

7. Insert the hydrolab into the box portion of the device so that the water can be monitored and tested.

8. Following completion of the hydrolab monitoring, using sample collection bottles, collect water samples from the river water flowing into the box.

9. Carefully remove the device and dump the remaining water back into the stream. Refill the hole with the river sediment that was set aside.

10. Follow the Cleaning and Maintenance Protocols on the following pages for proper care of the WOD.

## Cleaning and Maintenance Protocols

Since we have recommended that the WOD be fabricated with aluminum, there are several important things to note in terms of cleaning the device after each use. We have provided two options for cleaning the WOD-with regular bleach and with Simple Green.

### SIMPLE GREEN OPTION-

Aluminum is a soft, lightweight metal that is used for a variety of purposes. Simple Green is a brand of all-purpose cleaner and is a safe, all natural alternative for cleaning surfaces (Simple Green, 2016). It is environmentally friendly, biodegradable, and non-toxic cleaner that can be diluted for many uses. Simple Green All-Purpose Cleaner has been used to clean aluminum, both industrial and consumer. Though Simple Green is non-toxic cleaner, it may accelerate the corrosion process of aluminum, if exposed for a very long period of time. Any solution of Simple Green should have contact with aluminum for no more than 10 minutes and should be thoroughly rinsed with water.

#### What is needed:

Spray bottle
1 ounce Simple Green (per 1 cup of water)
1 cup of tap water (for Simple Green solution)
Tap water (for rinsing)

#### Instructions (for Simple Green):

Following each use of the WOD, follow these steps for cleaning and disinfecting.

1. Once the device has been removed from the river, rinse off any remaining sediment with water.

2. In a spray bottle, dilute 1 ounce of Simple Green with 1 cup of water (1:10 ratio). Spray the Simple Green solution on the device

3. Thoroughly rinse off the Simple Green solution from the device with clean water and let dry. Rinse skin that came into contact with the solution.

4. When the device is not in use, store it indoors to keep it out of the elements—sun, rain, etc.

Note: Instead of using a spray solution of Simple Green All-Purpose Cleaner, Simple Green Safety Towels can be used (Simple Green, 2016). These are larger, heavy-duty cleaning wipes that can be used to clean residue and disinfect. Spray the device with water, wipe it with a Simple Green Safety Towels, rinse device and hands after use.

## BLEACH OPTION-

Aluminum is a soft, lightweight metal that is used for a variety of purposes. Bleach is an oxidizing chemical that is used for disinfecting surfaces (Holder, 2012). Bleach can be a harsh chemical when used alone, which can cause permanent damage if used improperly. When bleach comes into contact with aluminum, no immediate reaction will occur as bleach is not strong enough to corrode the metal. Bleach can however change the color of the metal—over time, the aluminum's surface may darken and may turn black. Diluting a small portion of bleach with water (a half cup of regular bleach per gallon of water) will greatly reduce the risk of causing damage to the surface of the device. Also, any bleach solution should not be allowed to set on the surface of the metal for too long and should be rinsed thoroughly with water.

### What is needed:

½ cup bleach
1 gallon of tap water (for bleach solution)
Bucket
Tap water (for rinsing)
Towel
Rubber gloves

### Instructions (for bleach):

Following each use of the WOD, follow these steps for cleaning and disinfecting.

1. Once the device has been removed from the river, rinse off any remaining sediment with clean water.

2. Put on a pair of rubber gloves*. In a bucket, mix 1/2 cup of bleach per 1 gallon of water. Pour or spray the bleach solution on the device or use a clean towel soaked in the solution to clean the device.

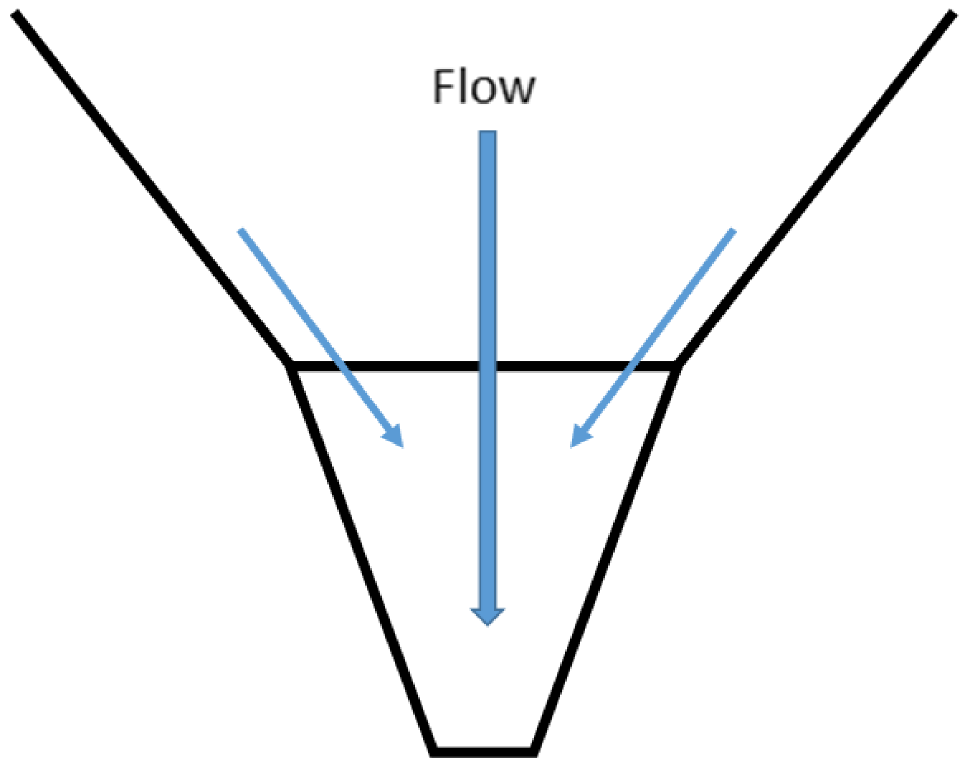
3. Immediately, thoroughly rinse off the bleach solution from the device with clean water and let dry. Also, immediately rinse off any bleach solution that came into contact with skin.

4. When the device is not in use, store it indoors to keep it out of the elements—sun, rain, etc.

*Note: bleach can cause burning, dryness, etc. when comes in contact with skin. Even though this is a mild solution of bleach to water (1:32), the bleach can still cause mild, temporary skin damage. If the solution does come into contact with your skin, rinse immediately.

## Future Modification information

There is one future modification we have recommended for the WOD—adding adjustable, removable wings to extend the walls of the flume. This will allow for a larger area of low flow water to be collected or for multiple small braids of water to converge and be collected.




Top view of the flume portion of the flume a basic design for the flume extensions.

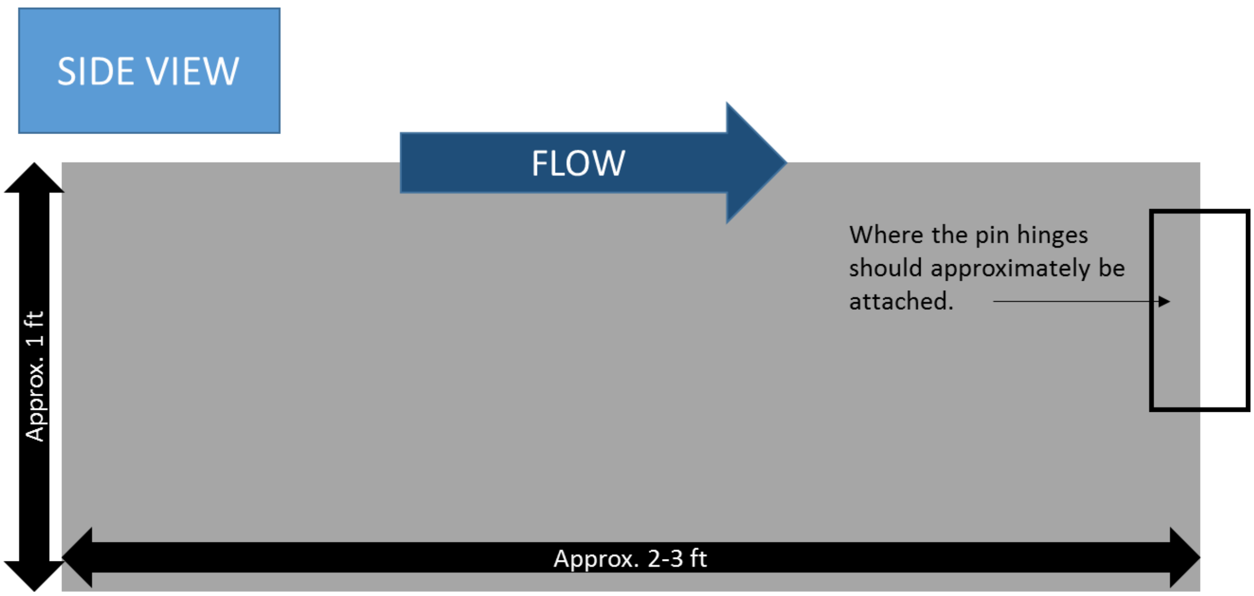
The extended wings should be one foot in height (this will allow for the wings to be attached to the device and also dig into the ground) and at least 2-3 feet long (this dimension is subject to the expertise of the WRD-depending on how much more flow they deem needs to be collected). These wings can be attached with simple three-point pin hinges. They should be attached so that the top is in line with the top of the flume and so that the bottom can dig into the ground.

### Simple Pin Hinge—

A similar pin hinge to this one can be used for the attachment of the flume extensions.

One hinge should be attached to the end of the flume itself and another one should be attached to the extension (as shown in the diagram below).

When the extensions are needed, the hinges should be aligned and the hinge pin inserted to connect the two pieces together (this would be done for both sides of the flume).


Side view of the plan for the sheet metal wing extensions.

This modification can be done at the time of fabrication of the WOD or in the future if the WRD determines this modification is in fact necessary and needed. Two wings would need to be created. Also, two hinges would need to be attached to both sides of the flume and to the ends of the flume extension pieces so that they can be attached. Water may seep through the point of connection of the hinge but due to the nature of the low flow, the amount will not be enough to cause concern.

## References

Holder, S. (2012). Selection and Use of Home Cleaning Products. Las Cruces, NM: New Mexico State University. Retrieved from http://aces.nmsu.edu/pubs/_g/G304.pdf

Simple Green. (2016). Industrial Products. Sunshine Makers, Inc. Retrieved from http://simplegreen.com/industrial/