Beaver Instinct:

Nature's Contribution to the Restoration of the Santa Fe River Ecosystem

An Interactive Qualifying Project Proposal submitted to the faculty of

WORCESTER POLYTECHNIC INSTITUTE

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Abstract

This Interactive Qualifying project assessed the impact of beavers on the Santa Fe River and surrounding community. To do this the group gathered data from the Santa Fe Girls' School. This data provided a panoramic view of the impact of beavers. During the time they collected data, a colony of beavers moved into a location upstream of their site and then moved out two years later. We also gathered information from the Santa Fe Indian School. We took measurements at their data collection sites both upstream and downstream of the beaver habitat. Using this information, the group assessed the impacts of beaver habitats on the surrounding ecosystem. We found that beaver ponds help revitalize aquifers. Then the group assessed the impact of beaver habitats on human activities. The analysis showed no direct consequences from the beaver habitat on the Santa Fe Airport. Three have been no wildlife strikes at the Santa Fe Airport since the time the beavers arrived. In response to the needs of the community, we created an education platform for the sharing of information on the Santa Fe River. It is designed to facilitate easy communication between educators and students studying the Santa Fe River. We also created a video aimed at dispelling the negative sentiments of locals about beavers by describing their positive impacts and providing ways of managing beaver flooding.

Authorship

The members of this team provided equal contributions for the different sections of this report, and every student deserves an equal share of credit as authors. The following describes the contributions of each student during this Interactive Qualifying Project. Jennifer Gill focused on researching the Santa Fe River, its past and the current issues relevant to this project. She is also responsible for the group's GIS maps as well as the abstract and executive summary. She also researched beaver habitat requirements for assessing possible beaver host sties. Allison Grocela focused on researching the reasons for water quality testing and the educational platform. She worked on developing the Santa Fe Teachers' Coalition website as well as writing the result and analysis section for the website. Christopher Huston researched information on beavers focusing on the services they provide to their own ecosystem and also to humans. He researched various water quality tests and appropriate testing methods. He also performed and wrote the analysis on the water quality data. Lastly, Carlos Sarria focused on researching the impacts of the beavers on the Santa Fe Municipal Airport and the surrounding area. He wrote all sections related to the airport.

Executive Summary

The story begins in 1996 with the tree planting campaign started by the WildEarth Guardians, a group dedicated to protecting and restoring wildlife, wild places, and wild rivers in the American West. They began by completing a restoration project on the land in the La Cieneguilla Land Grant Area. WildEarth Guardians received permission to remove non-native, invasive trees such as Russian Olives and Salt Cedars, but also, reintroduced native species such as Cottonwood and Willow trees that require much less water. The vegetation spread upstream, all along the river. These new plantings of Cottonwoods and Willows attracted a colony of beavers to that section of the Santa Fe River. They have built their dams along Paseo Real adjacent to the Santa Fe Airport, as seen in the two pictures below. The orange ellipse is an outline that shows where the beaver colony is located. The green outline shows the extent of the flooding their dams have caused. This picture shows how close the beavers are to the airport runway (right side of picture). The green thumbtacks in figure 2 show all of dams the beavers have created. The two red thumbtacks indicate the locations where we collected data.

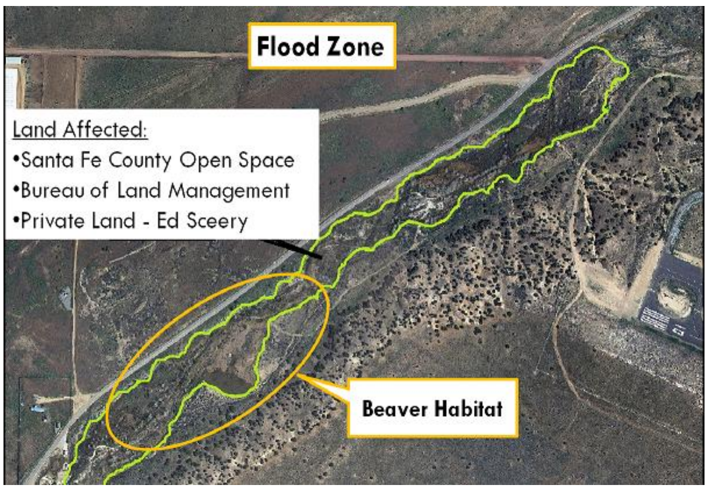

Figure 1: Aerial Photo of Beaver Flood Zone and Habitat. Google Maps.

Figure 2: Aerial Photo of Beaver Dams. Google Maps.

The colony's proximity to the airport has stirred up controversy within the community. Private land owners are concerned that the flooding caused by the beavers devalues their property. Airport officials are concerned that the wetlands created by the beavers pose a threat to air traffic safety. The wetlands attract waterfowl, which are very dangerous to airplanes. They are large enough to damage engines so severely that it is unsafe to land. On the other hand, scientists and ecologists and optimistic that the beavers presence will help the health of the river and recharge the aquifers.

These conflicting opinions led to the need for a thorough and objective assessment of the beavers' impact on the Santa Fe River ecosystem and surrounding community. Our mission was to gather relevant information about beavers and present it in a fair and balanced manner so that others can make their own judgments about the beavers. Our first objective was to assess the impacts of the beavers on the environment. The team collected historical data from the Santa Fe Girls' School. They have been collecting water quality data, as well as stream flow, and aquifer levels since 2005. When they began their study, there were no beavers in the area. In March 2008, beavers began to colonize and dam near the site where the Girls' School collects their data. In March 2010 the beavers left the area to seek other habitat. During the time when the beavers were there, the aquifer level steadily rose. When the beavers left there was a sharp downward spike in the aquifer level. This data proves that the beavers have a positive impact on aquifer levels.

The group also traveled out to an active beaver colony just upstream of the SFGS site. We collected water quality measurements both upstream and downstream from the beaver dams. The data we collected was inconclusive because of the limited amount of time we had. Four weeks is not an adequate amount of time. But, it is a beginning for schools to continue monitoring the beaver's impact on the Santa Fe River.

Below is an aerial photo that shows the three data collection locations.

Figure 3: Ariel Photo of Data Collection Locations. Google Maps.

The second objective of our project was to assess the impact of the beavers on human activities. One of the main concerns about this particular beaver colony is its proximity to the airport. The beavers themselves are not the problem. It is the wetlands that attract birds that pose a threat to air traffic safety. A Wildlife Hazard Assessment of the Santa Fe Airport began in Fall 2010. This was not in response to the beaver colony, but rather a nationwide mandate that all commercial airports had to comply with. When the assessment is completed in Fall 2011 the airport will put together a Wildlife Management Plan based on their findings. The group found no evidence to support that flooding or the wetlands have a direct consequence on the airport. There have been no bird strikes since the beavers have been on the land near the airport.

Our final objective was to develop an educational platform for the continued monitoring of the effects of beaver colonies on the Santa Fe River and the surrounding ecosystem. There are several different schools in the city of Santa Fe that travel to the river to engage their students in some sort of outdoor educational project. The group worked with two teachers who wished to create some sort of communication between educators. We created a website, Santa Fe River Teacher's Coalition, to facilitate the sharing of information and aid in the coordination of outdoor activities. The website features an automated spreadsheet with a streamlined data entry form. Students and teachers can use this database to monitor the Santa Fe River. They have the ability to create visualizations of the data they have collected but also the data others have collected. This website unites teachers so that they can better educate their students about the river and its importance. In the future, this platform will provide a comprehensive history of the Santa Fe River for continuous monitoring, as well as act as a support for new teachers who are interested in starting an outdoor education program at their school. Additionally, we created a video aimed at dispelling the negative sentiments of locals about beavers by describing their positive impacts and providing ways of managing beaver flooding.

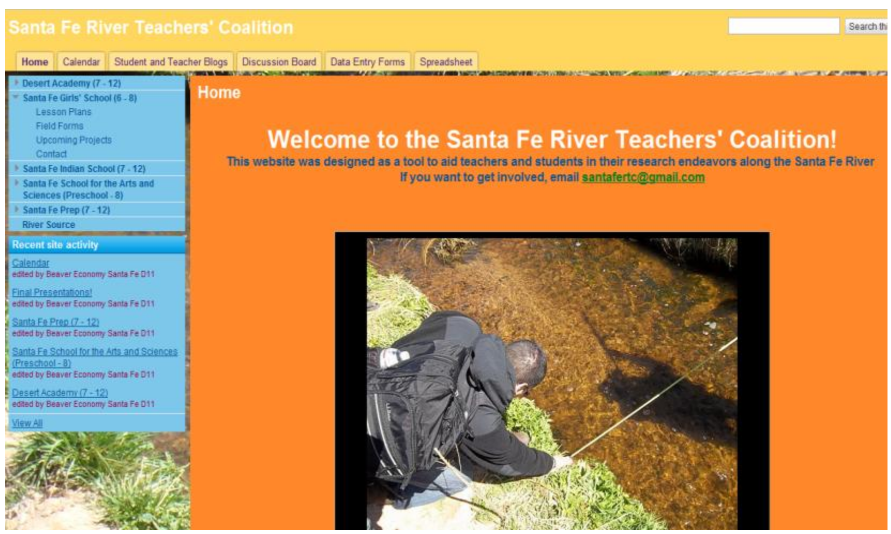

Figure 4: Snapshot of Santa Fe River Teachers' Coalition Website

The Santa Fe River has always been an important part of the city and that mindset will continue long into the future. This desert community places high value on water because it is such a scarce resource. In the future this resource will only become less available and more precious. Consequently, it is important to begin educating the next generation about the importance of natural resources. The Santa Fe River Teacher's Coalition is the first step in expanding outdoor education programs and educating the future generation.

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1. Introduction

The connection between the health of the human economy and the functioning of natural ecosystems has been an integral part of life ever since our species evolved.[1] The human population is growing at a rate of over 78 million people each year, resulting in rapid expansion and near constant confrontation between humans and wildlife for natural resources.[2] Over 83 percent of the total land surface on the earth is directly influenced by human activities, as can be seen in Figure 5.[3] It is estimated that by 2050 "ten billion hectares of natural ecosystem will be converted to agriculture" to provide goods to an estimated nine billion people.[4] Within the past few decades, scientists and organizations have started studying the concepts of *ecosystem services* in order to reduce any harmful effects resulting from this conflict. Ecosystem services are functions of ecosystems that are valuable to society and provided at no cost to those dependent on them.[5] One important example is free pollination services provided by species such as bats, bees, birds and butterflies.

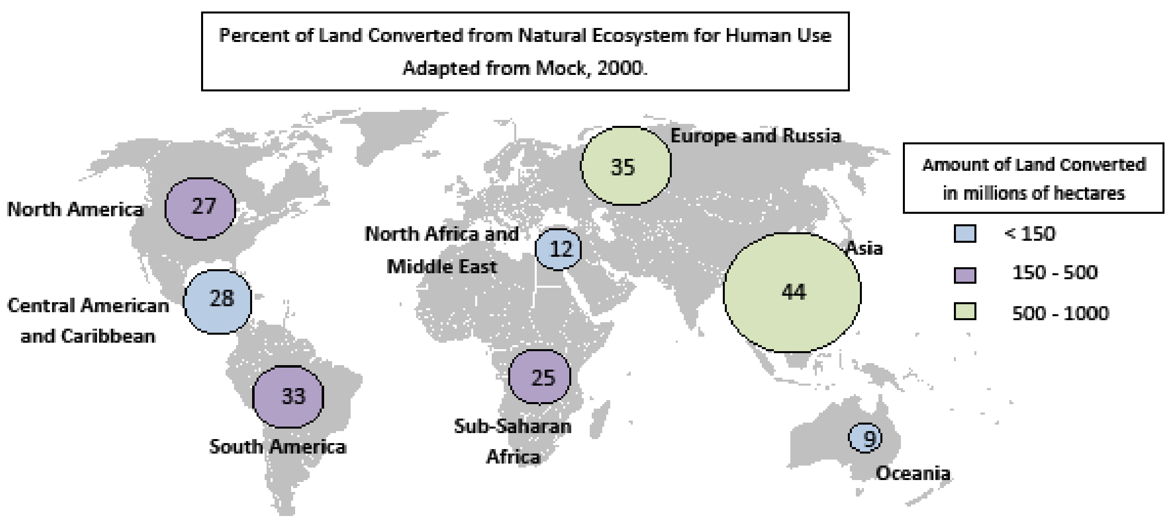

Figure 5: Widespread Conversion of Natural Ecosystems

The Southwest area of the United States is currently experiencing one of the worst droughts in 60 years.[6] Since 1999, the Santa Fe River has been dry an average of 220 days each year.[7] In 2007, American Rivers named the Santa Fe River the most endangered river in the United States because of continued water extraction. In order to revive the river, a local organization, WildEarth Guardians, decided to plant

[1] (Day et al. 2009, 321 <last_page> 331)
[2] (Population Reference Bureau)
[3] (National Geographic)
[4] (Goldman 2010, 15 <last_page> 23)
[5] (McAfee)
[6] (The University of Arizona 2010)
[7] (Southwest Hydrology 2010)

cottonwood and willow trees, both native to the region, along the riverbanks. Trees can provide ecosystem services, and in this case, were intended to improve the water flow and quality of the river in addition to enriching the soil and providing erosion protection.[8] An unforeseen effect of the transplanting was the migration of a population of beavers to within city limits that was attracted to the cottonwood trees. The beavers instinctively built a network of dams as their habitat. Scientists suspect that beaver dams could be linked to recharging aquifers, creating natural reservoirs that could be used during dry weather. If these assumptions prove to be true, the services provided by the beavers could be put to use as a natural way to rehabilitate the Santa Fe River.

Beavers are considered to have a positive influence on the riparian habitats, yet some local citizens and private landowners believe otherwise. Dam building can cause damage, including tree cutting and flooding to nearby crops and roadways.[9] In addition, new species of birds are attracted to the developing wetlands, giving Santa Fe Municipal Airport officials a reason to be concerned about the increased risk of bird strikes on aircraft. These concerns have resulted in an ongoing conflict between local residents and the beavers. Some people have removed beavers from the river by trapping and killing them. Because beaver activities can improve water quality and enhance habitats for many other species, scientists and organizations have developed non-lethal solutions to this conflict. An example of a non-lethal solution is flow devices which prevent flooding by guiding water flow from areas with high water levels to those with lower levels, allowing beavers to continue building dams with less negative impacts on the land.[10]

Organizations in Santa Fe have focused much of their attention on educating the community about the current condition of the Santa Fe River. For example, River Source provides educational programs for both middle school and high school students, with the goal of teaching them how to appreciate and take care of the land. In addition, the Santa Fe Indian School added new material to their curriculum that educates students about the significance of cooperating with natural ecosystems. Educational programs are beneficial, but they are not the only means by which organizations can help protect the river. There are opportunities for local organizations to research and utilize the impacts of beavers for restoration of the river, but a lack of time and resources has prevented them from moving forward.

The societal and environmental impacts of beavers on the Santa Fe River are still unknown and there is a need to investigate their presence. The goal of this project is to assess the impacts of beavers on the ecosystem and surrounding community. By gathering previously collected data concerning beavers on the river and taking our own measurements, we will be able to identify the changes that have occurred because of the beaver settlement. The outcome of our project is a website that will allow for the continued monitoring of the river. The website can be used as an aid for student and teachers participating in outdoor education

[8] (WildEarth Guardians)
[9] (Animal Protection of New Mexico 2008)
[10] (Animal Protection of New Mexico 2008)

programs in the Santa Fe area. Another outcome is an informative video aimed at dispelling the negative sentiments of locals about beavers by describing their positive impacts and providing ways of managing beaver flooding.

2. Background

The city of Santa Fe, New Mexico was founded in1609 by the Spanish conquistador Don Pedro de Peralta. This new settlement was an amalgamation of Spanish settlers, Franciscan missionaries, and the Pueblo Indians. At the time of the Spanish settlement there were approximately 100,000 natives living in the pueblos. By 1680, Spanish settlers numbered 2,500 and were forced out of their settlement by the natives. The Pueblo Indians had control of Santa Fe until Don Diego de Vargas conquered the city in 1692. The Spanish maintained a diplomatic relationship with the Pueblo Indians for the remainder of their time spent in Santa Fe. In 1821, Mexico gained its independence from Spain and Santa Fe became the capital of the province of New Mexico. This transition opened up further possibilities for trading goods. On August 18, 1846, during the early part of the Mexican American War, Santa Fe was seized by the Americans. Two years later, as part of the Treaty of Guadalupe Hidalgo, New Mexico was ceded to the United States and in 1912 New Mexico became the forty-seventh state.[11]

2.1 History of the Santa Fe River

The city of Santa Fe was founded next to the Santa Fe River because of the great advantages provided by living close to water. During the Spanish Colonial era up until the mid-twentieth century, the river was used for the irrigation of 1,000 acres of farmland.[12] When the Spanish resettled the city of Santa Fe in 1693, farming became an integral part of their livelihood. The landscape in Santa Fe was favorable for growing crops such as beans, onions, oats, and wheat. To the settlers, this was more important than finding gold. Farmers settled along the river, outside of the city, to be close to water. This left them vulnerable to raids from northern tribes, as well as bears who were hunting for food. There was a proposal to move the city to the south side of the river so that it could be protected from attacks. The farmers, however, did not want to leave their ranches and so the move never happened.

The landscape of the river has played an important role in shaping the city.[13] During times of steady water flow, people used the river for fishing, swimming, and ice-skating in the winter. Today, there is no longer a consistent flow in the river and residents can no longer use the river for recreation or other activities.[14] The river is used to fulfill water needs for the city of Santa Fe which leave no water for the river itself.

[11] (Anonymous, 1-6)
[12] (Smith 2007, 8-8-11)
[13] (Cheek 2008)
[14] (Smith 2007, 8-8-11)

2.1.1 Geography and Landscape

The Santa Fe River originates in the Sangre de Cristo Mountains north of the city of Santa Fe. The river itself is relatively small, stretching only forty-two miles before meeting the Rio Grande.[15] There are two reservoirs upstream of the city, McClure and Nichols, which are circled in Figure 6. These reservoirs can hold 3,939 acre-feet of water for the city.[16] An acre-foot is approximately 325,852 gallons of water. Unfortunately, the reservoirs prevent the water from flowing freely throughout the city.

Figure 6: Map of the Santa Fe River

2.1.2 Aquifers in Santa Fe

Water flowing through the Santa Fe River is absorbed by plants before it can seep into the ground. Excess water not utilized by plants is pulled by gravity into the subsoil, and eventually into underground aquifers. An aquifer is a geological formation that stores water.[17] The Santa Fe River is underlain by two types of aquifers. The first is a hard rock aquifer, where water is stored in the fractures or cavities in the rock. The second type is a gravel bed or sandstone, where water is stored in the pores of the formation. The relationship of aquifers and rivers can be seen in Figure 7.

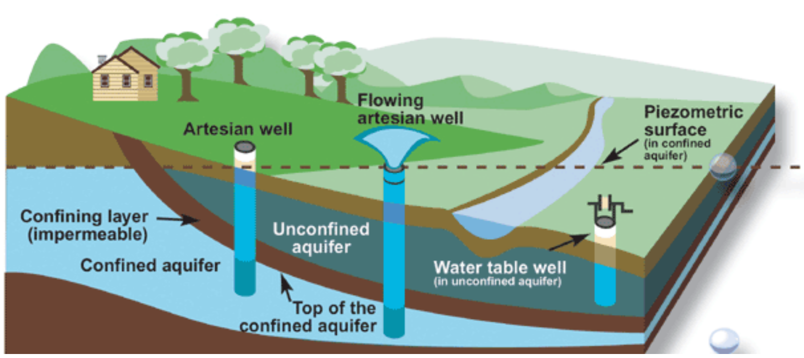

Figure 7: Aquifer System. Source: USGS

[15] (Smith 2007, 8-8-11)
[16] (Amy Lewis, Amy C. Lewis Consulting and Claudia Borchert, City of Santa F 2009, 1)
[17] (Grant and Williams 2009)

2.1.3 Issues Facing the Santa Fe River

In 2007, American Rivers classified the Santa Fe River as America's Most Endangered River. Santa Fe's growing population has naturally led to an increased demand for water.[18] On average, Americans consume between eighty and one hundred gallons of water daily.[19] Despite the fact that Santa Fe citizens consume much less than the national average, the growing population still leads to increased water demand which has left the river dry for the majority of the year, except for in the spring, when melting snow runs into the river.[20]

The local government has made a serious effort to establish a long-term plan for recovering and restoring water flow in the Santa Fe River. The river's flow is inhibited due to the two large reservoirs, Nichols and McClure, which provide water to citizens of Santa Fe. So much of the water is being held upstream that the river is dry more than 50% of the year. After disappearing soon after the reservoirs, water reappears in the Santa Fe River downstream of the Municipal Wastewater Treatment Plant in the Southwestern part of the city. As a consequence of citizen pressures, the municipal government has agreed to release 1000 acre-feet of water out of the city's reservoir in 2010. The goal of this water release is to bring healthy vegetation back into the city. Recently, new plants have been placed along the river, reaching downstream into the community of Agua Fria. The president of the Agua Fria Village Association is extremely supportive of this project, and has been working on his proposal for the continued release of water. His hope is that enough water will be available to reach his community, keeping local vegetation hydrated and the population satisfied.[21]

[18] (Smith 2007, 8-8-11)
[19] (Perlman 2011)
[20] (Smith 2007, 8-8-11)
[21] (Matlock 2011, A-1)

2.2 Santa Fe River and the Community

The Santa Fe River and surrounding wetlands have undergone extreme changes throughout the last century. The river went from being a permanent flowing stream at the beginning of the twentieth century, see Figure 8, to being a weak, seasonal flow remaining dry most of the year with very little vegetation, see Figure 9.[22] The growing problems facing the Santa Fe River have caught the attention of both government and local organizations. An effort from local environmentalists to revive this once thriving ecosystem led to a very noticeable improvement after a significant tree planting campaign by WildEarth Guardians fifteen years ago. This project consisted of removing nearly 4,000 non-native trees that were using three times more water than native trees, and planting native cottonwoods and willow trees.[23] These native trees not only decrease evaporation, but also provide flood protection, shelter and food for local fauna.

Figure 8: Santa Fe Watershed in 1926. Source: SFWA

After transplanting trees along over two miles of the Santa Fe River downstream of the city's wastewater treatment plant, WildEarth Guardians saw dramatic changes in this section of the river. New wildlife found a home in what used to be an arid and relatively lifeless terrain. Because of these new plantings beavers migrated to this area of the Santa Fe River. The beavers started building dams and lodges which quickly flooded parts of the land around the river.[24] Figure 10 shows an aerial image prior to the start of the WildEarth Guardians' rehabilitation program. Notice the lack of vegetation and wetlands on either side of the river. Fourteen years later, see Figure 11, there are trees on both sides of the river. The green outline along the river shows the extent of the current flood zone due to beaver damming. The flood zone information was provided by Mark Ericson. The land that has been flooded includes Santa Fe County Open Space Land, Bureau of Land Management Land, and the private land of Ed Sceery.[25]

Figure 9: Santa Fe Watershed During Dry Season. Source: SFWA

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[22] (Southwest Hydrology 2010)
[23] (WildEarth Guardians)
[24](Matlock and Saturno 2008, A-1)

[25] WildEarth Report

Figure 10: Aerial Image of a Section of the Santa Fe River (1996)

Figure 11: Aerial Image of Same Section of Santa Fe River (2010)

2.3 Beavers

The North American beaver, *Castor canadensis*[26], is a complex and interesting species of rodent. These creatures live in groups of eight to ten, called colonies. The average lifespan of a beaver is twenty to thirty years, and they can weigh anywhere from thirty to sixty pounds when full grown.[27] They are the second largest rodent in the world and the largest rodent in North America.[28]

2.3.1 Beaver Behaviors

Beavers are herbivores, eating mainly bark and the soft inner flesh of trees.[29] They favor poplar, beech, alder, maple, birch, aspen, cottonwood and willow trees. Beavers cut down trees by chewing on the tree trunks with their large front teeth. Because their teeth continue to grow throughout their life, they must chew on trees to keep their teeth sharp and at a reasonable size.[30] One beaver can knock down a five-inch willow tree in less than three minutes.[31] Besides utilizing trees for nutrition, beavers also use them to build their homes. Apart from trees, beavers will also eat roots, and if available, water plants that grow in the area.[32] Grass and other aquatic foliage are staples in their diet during the spring.

Figure 12: Beaver cutting down a tree. Source: Steve Greer, Photo.net

The two types of homes beavers construct are burrows and lodges. Beavers construct burrows on the banks of rivers or lakes. The entrance to a burrow is located underwater as a security measure against predators. The second type of home is a lodge. Lodges are located in the middle of a body of water, usually a pond or swamp. By using mud or similar substances, the beavers secure logs and branches to form a dome. The top of the dome contains an air vent, so that air can circulate throughout the lodge. The entrance to a lodge is located underwater, but is deep enough so that the water will not freeze during the winter.[33] If there is not enough water to build a lodge home, beavers will build a dam, raising the water level to provide a natural barrier from predators and to ensure access to their food cache in the winter time, which is located

[26] (National Geographic)
[27] (National Geographic)
[28] (New Hampshire Public Television 2010)
[29] (New Hampshire Public Television 2010)
[30] (Animal Planet)
[31] (Donna Graham)
[32] (New Hampshire Public Television 2010)
[33] (Donna Graham)

underwater near the entrance to the burrow.[34] Beavers build their homes near small lakes, ponds, rivers, streams and marshes because of their aversion to the sound of running water.[35] The sound of running water will initiate the building of a dam in order to stop the water flow. If beavers notice a leak but it makes no sound, they will not try to stop the flow.[36]

Since beavers are mammals, they give birth to live young. The baby beavers, which are called kits, are born after a three-month gestation period. A typical litter is between 1 and 4 kits, depending on the food available in the area. Each kit usually weighs about one pound when they are first born.[37] Within one day, the kits develop the capability to swim. Unlike some other animals, both of the parents take care of the newborn kits. Beavers will not go off on their own until after their second year. They stay and help take care of the new kits during this time.[38] After the second year, the two-year-old beavers will travel elsewhere in search of a mate. Young beavers will travel until they find a suitable area in which to make their home and find a mate. Usually this involves the beaver travelling up to thirty miles, but could be as far as one hundred forty eight miles.[39]

Figure 13: Types of Beaver Homes

2.3.2 The Role of Beavers in Ecosystems

Beaver behaviors can be beneficial for surrounding ecosystems. One of their most well known behaviors is dam building. Dams cause water levels to rise, creating wetlands. These wetlands are an ideal habitat for numerous organisms, including insects, fish, birds and various species of small mammals.[40] New species that are attracted to the wetlands increase the biodiversity of the area, and the developing wetlands are able to act as a natural reservoir.

Wetlands help to reduce the amount of sediment runoff in rivers and streams, resulting in less erosion. This allows soil to hold on to more nutrients that are utilized by local vegetation.[41] Along with

[34] (Beavers: Wetland and Wildlife)
[35] (New Hampshire Public Television 2010)
[36] (Riley Woodford)
[37] (New Hampshire Public Television 2010)
[38] (New Hampshire Public Television 2010)
[39] (New Hampshire Public Television 2010)
[40] (Donna Graham)(New Hampshire Public Television 2010)
[41] (Richard T. Woodward, Yong-Suhk Wui 2001)

wetlands, dams help restrict water flow which further helps to ease effects of erosion, which in turn helps reduce flooding levels.[42] Dams also act as a natural water filtration system that helps purify water in streams and rivers.[43] Once the water moves through this natural system, there is less of a need for an intensive purification process at a treatment plant. This results in reduced costs and efforts for treatment facilities.

2.3.3 Beaver Presence and the Santa Fe River

Beavers have lived in the Southwest region of the United States for centuries, located in almost every permanent river and stream prior to the arrival of Europeans.[44] However, during the 18th and 19th centuries, they became victims of the fur trade and were pushed to the point of near extinction. In order to prevent extinction, the U.S. government developed policies concerning their hunting season as well as their reintroduction to former habitats.[45]

See Figure 14 for a map depicting the current location of the beaver colony in relation to the Wastewater Treatment Plant and the Santa Fe Municipal Airport. The beaver's location with respect to the Santa Fe Airport is troubling. Airport officials are concerned that the wetlands they have created pose a threat to airport safety.

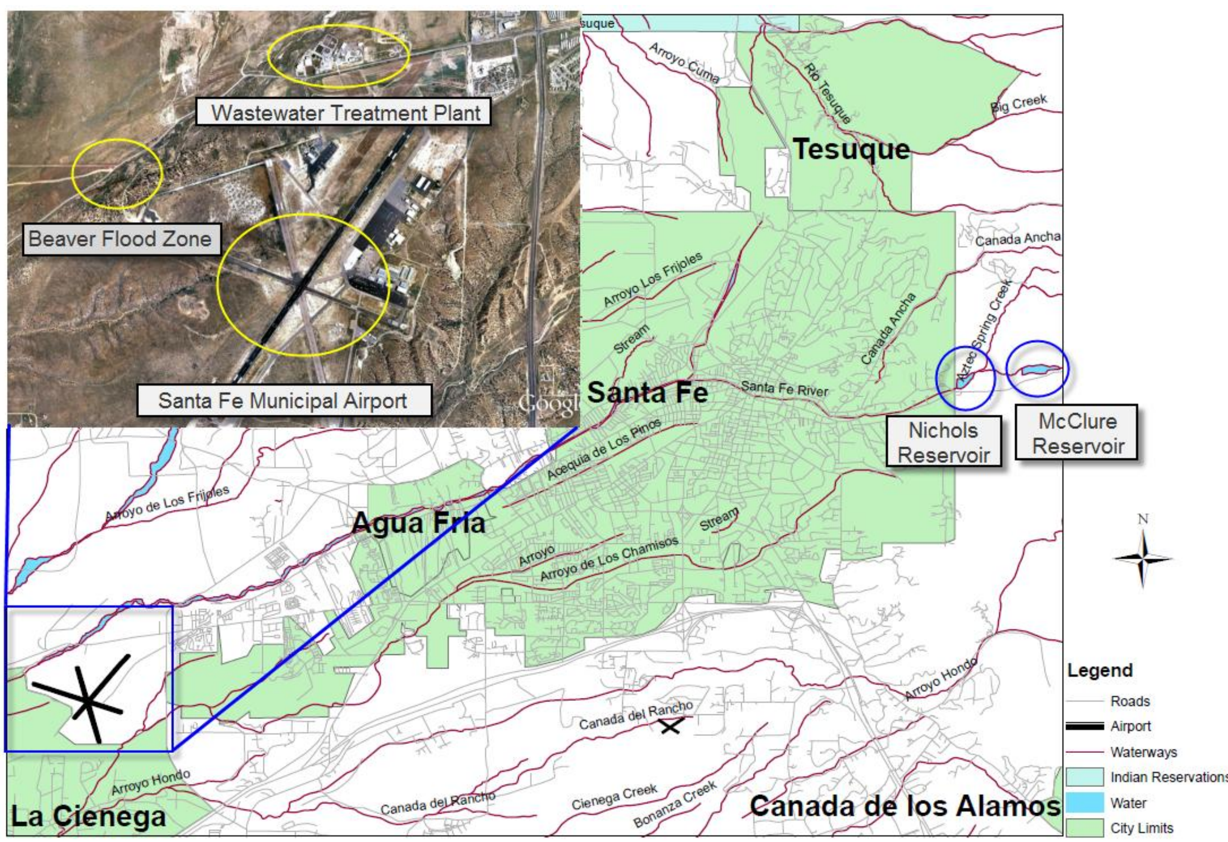

Figure 14: Map of the Santa Fe River, Reservoirs, and Airport

(New Hampshire Public Television 2010)
44 (Animal Protection of New Mexico)
45 (Feldhamer, Thompson, and Chapman 2003)

2.3.4 Understanding Ecosystem Services Provided by Beavers

Every ecosystem provides functions attributed to the habitat, and biological processes of the ecosystem. *Ecosystem services* portray the benefits that the human population derives from ecosystem functions.[46] The term emerged in the early 1980s to describe a structure for understanding ecosystem processes in terms of human well-being[47]. Many private and international environmental agencies have begun creating policies for the conservation of these services, replacing the protection of endangered species and wilderness as a focus. The 2005 Millennium Ecosystem Assessment warns that humans are overusing ecosystem services. The four main categories of ecosystem services are provisioning services, regulating services, cultural services, and supporting services.[48]

Provisioning services are the products obtained from ecosystems, including food, water, timber, and fiber. Regulating services acquired from ecosystem processes include the regulation of climate, floods, disease, waste, and water quality. Humans obtain cultural services from the ecosystem through recreation and aesthetic experiences, including social relations and aesthetic values. Supporting services include biomass production and soil formation, which are necessary for the production of all other ecosystem services.[49]

The services provided by beavers fall into the regulatory services category. Dams act as a natural water filtration system and wetlands help to reduce the amount of sediment runoff from flowing rivers. Dams also create wetlands which attract new species, increasing biodiversity in ecosystems. Without these services provided by beavers, the human population would need to find a way to perform these services themselves.

[46] (Robert Costanza et al 1997, 256)
[47] (Brauman et al. 2007, 67 <last_page> 98)
[48] (McAfee)
[49] (GreenFacts Scientific Board 2010)

2.4 Beaver-Created Wetlands

Wetlands are large areas of land saturated with water either permanently or seasonally. These territories are influential on soil development, as well as the flora and fauna living within them.[50] According to the University of Nebraska, close to 96% of commercial species of fish depend on wetlands, along with 80% of America's bird population.[51] Additional services provided by wetlands are sediment trapping, flood control, and ground water recharge. Figure 15 explains the different zones that make up wetlands. Notice the different types of plants that can live on these lands.

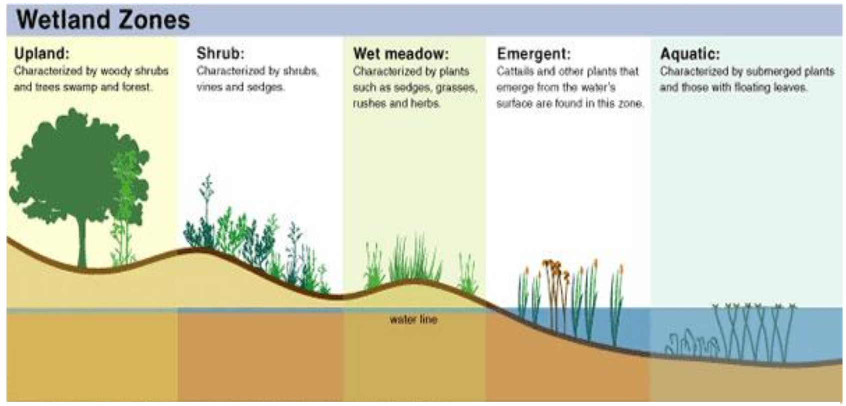

Figure 15: Wetland Zones. Source: Michigan State University

The Southwest of the United States relies heavily on these lands because of the very arid climate, low annual precipitation and developing cities constantly putting stress on the environment. A drought is currently affecting Arizona and New Mexico,[52] which is taking a large toll on rivers, lakes and wetlands. The average precipitation in the last ten years has been 12.58 inches while in 1990 to 2000 it was 20.76[53]. Additionally, the average amount of water available in the city reservoirs has decreased from 2578.8 ac-ft in 1990-1999 to 2435.9 ac-ft in the last ten years. Population has also put more stress on the city's water supply as can be seen in Figure 16. Within the last ten years Santa Fe's population has been increasing linearly, and during very low precipitation from 2000 to 2003, and again from 2008 to 2010 more water needs to be supplied from other sources besides the reservoirs such as underwater wells, or even other rivers like the Rio Grande.

Beaver dams impact ecosystems around the rivers which they are built on. Dams create wetlands that can provide habitats for certain species of fish and plants, as well as increase ground water levels.[54]. Along with impacting ecosystems, the affects of dams can also impact surrounding human activities. Floods caused by dams can affect private or public owned property.[55] Additionally, beavers will take down trees in the area for nutrition and dam construction. This can create controversy regarding the possibility of beavers wiping out the previously planted trees. In addition, the wetlands attract wildlife to areas near the airport, jeopardizing passenger and aircraft safety.

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[50] (United States Environmental Protection Agency 2010)
[51] (UNL Water 2010)
[52] (The University of Arizona 2010)
[53] Weather Underground
[54] (Fish Biology and Fisheries)
[55] (Animal Protection of New Mexico 2008)

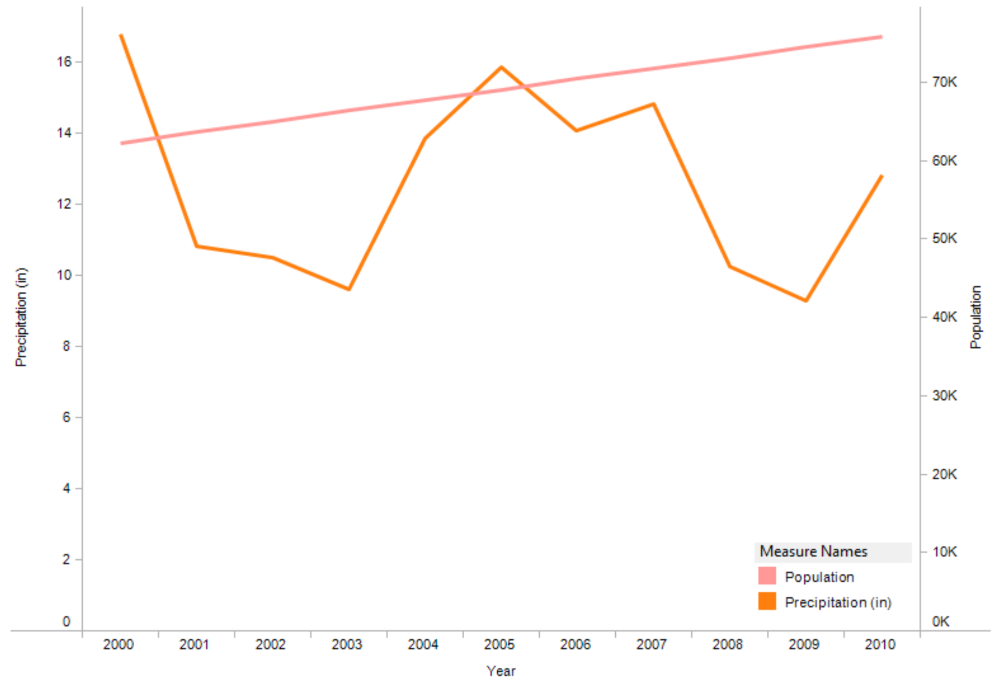


Figure 16: Population and Precipitation for Santa Fe. Source: Weather Underground

2.5 Effects of Beaver Dams on Water Quality

The quality of freshwater is extremely important because humans and other living organisms are dependent on it for survival. While water scarcity receives more attention, water quality is critical because it affects human health, livelihoods, agriculture, industry, recreation, and ecosystem services. Water quality issues are a serious problem in developing countries, where a lack of clean water leads to high morbidity and mortality rates.[56]

Water can be polluted by both human-made and natural sources. Water quality tests can be performed in order to determine the impact of pollution. Water quality is an important aspect of our project. It was important to test the water where the beavers are located because it comes directly from the Wastewater Treatment Plant. For the purposes of our project we have decided to study and analyze the following characteristics in order to accomplish our goals:

1. Stream flow (ft^3/sec)
2. Temperature (°C)
3. Total Dissolved Solids (parts per million or ppm)
4. Turbidity (Nephelometric Turbidity Units or NTU)
5. pH
6. Nitrates (mg/L)
7. Phosphates (μg/L)

Each of these tests is important in helping us further understand the condition of the Santa Fe River and the impact of beavers on its health. Stream flow is the rate at which water passes a given point in a river or stream in cubic feet per second. Beavers build dams to stop the flow of water in a river, which can create a lake or reservoir behind a dam.[57] Taking stream flow measurements upstream and downstream of beaver dams allows for a relatively simple analysis of how dams impact stream flow, and therefore how beavers impact the river.

Temperature has both direct and indirect impacts on many aspects of river ecology. It affects the amount of oxygen that can be dissolved by water, the rate of photosynthesis by algae and aquatic plants, and even the metabolic rates of organisms living in the water. An increase in water temperature can increase the rate of photosynthesis if sufficient nutrients are available.[58] This can be evidenced by a growing algae population on the bottom and banks of a river. Temperature monitoring allows for an analysis of the health of the Santa Fe River and can help determine whether or not the riparian ecosystem is thriving.

[56] (Sultana 2007)
[57] (Waskey)
[58] (Boulton 2011)

Total dissolved solids, or TDS, is the combination of all inorganic and organic substances contained in a liquid that are present in a molecular or suspended form.[59] These substances can include any salt, metal or mineral. The lower the TDS level of water, the more pure it is. We used TDS because it is a quick and inexpensive way to determine water purity. The only true way to measure TDS is to evaporate a water sample and weigh any remaining substances. This is very reliable, yet expensive, and not in the realm of our capability for this project. The level of TDS in the Santa Fe River can help our group determine whether or not the beaver dams are holding sediment.

Turbidity is caused by the presence of suspended and dissolved matter in water, which can make it appear cloudy or muddy. The most common matter found in water is clay, silt, plankton, organic acids, and dyes. Turbidity is not an inherent property of water, but it is a good indicator of the health of water bodies. The following are examples of incongruent uses for turbidity data[60]:

- Regulating and maintaining drinking water clarity
- Determining water clarity for aquatic organisms
- Real-time monitoring that indicates watershed conditions
- Determining transport of contaminants associated with suspended materials

For the purposes of our project, turbidity was analyzed both upstream and downstream of beaver dams in order to conclude how dams affect the amount of suspended and dissolved matter in water.

pH is a primary factor in the chemistry of water systems. It is a measure of how acidic or basic water is and is monitored routinely by organizations such as the Environmental Protection Agency and the U.S. Geological Survey.[61] pH directly affects physiological functions of plants and animals and is an indicator of the health of a water system, in this case the Santa Fe River.[62]

Nitrates and phosphates are both essential nutrients for plants and animals living in aquatic systems. Nitrates are greatly used as a fertilizer and if exposed in excess to the human body can cause disease and even death. The major sources of nitrates in water are runoff from fertilizer, septic tanks, sewage, and erosion of natural deposits. The EPA has determined a maximum contaminant level for nitrates in drinking water, which is 10 mg/L.[63] Phosphates are scarce in more fresh water systems, and even though they are important, a small increase can cause accelerated plant growth, low dissolved oxygen, and death of certain aquatic animals.[64] The EPA has determined that phosphate levels should be below 0.1µg/L for aquatic life to be supported.[65]

[59] (Samborn January 2008)
[60] (USGS 2005, Turbidity 1-55)(U.S. Geological Survery 2011)
[61] (USGS 2011)
[62] (USGS 2008, pH 3)
[63] (EPA 2010a)
[64] (EPA 2010b)
[65] (NCSU Water Quality Group)

3. Methodology

The goal of this project is to assess the impacts of beavers on the Santa Fe River in order to develop an educational platform that can be adapted for use by the Santa Fe Indian School and other schools in the Santa Fe area. To accomplish this mission, three objectives were developed to help us achieve the best final result.

1. To assess the impacts of beaver habitats on the Santa Fe River ecosystem.
2. To assess the impacts of beaver habitats on human activities.
3. To develop an education platform for the continued monitoring of the Santa Fe River ecosystem.

3.1 Assessing Beaver Impacts on the Santa Fe River Ecosystem

The group has utilized several methods to acquire various types of data from both the past and present that will aid in determining the effects of beavers on the Santa Fe River environment.

3.1.1 Assessing Beaver Impacts on Water Quality Data

The group has collaborated with two sponsors throughout the duration of the project in Santa Fe: Rich Schrader from River Source and Mark Erikson from the Santa Fe Indian School. They are both active in the community and are interested in the impacts that the current beaver colony is having on the Santa Fe River. Rich Schrader has provided water quality data collected from the La Cieneguilla area during the past ten years. All of this data is available through a data sharing project at www.watershedwiser.org. The data that is of interest is from three different time periods: before the new trees were planted, after the trees were planted but before the beavers came to the area, and after the beavers came to the area. We will be looking for statistically significant changes from one period to the next in order to determine the effects of each of these events on the water levels. The group began by conducting various water quality tests including:

- stream flow
- temperature
- total dissolved solids
- pH
- turbidity
- nitrate and phosphate levels

Due to limited resources, all tests were performed on site and no results were obtained from a lab. All of the instruments used to take measurements were borrowed from the New Mexico Department of Game and Fish. See Appendix C for details on water quality testing procedures.

3.1.2 Assessing Beaver Impacts on Aquifer Levels

In order to analyze and compare the data, we graphed our data against time. This allowed us to pinpoint the period when the beavers created their habitat, and compare data from before and after that time. All of the water quality was analyzed by looking at data from different sections of the river. This allowed us to compare water quality both downstream and upstream of the dams. The information on flora was based on personal communication and photographic evidence taken by persons who were involved in the initial plantings by WildEarth Guardians.

The group focused on

- Aquifer levels
- Habitats for new wildlife species

Aquifer levels are important because they provide information about the health of the Santa Fe River and the human water supply. The Santa Fe Girls' School has been recording these levels since 2005. Currently, the data suggests that aquifer levels have been rising since the beavers migrated to the Santa Fe River in 2008. If there is a continuous positive trend in this data after conducting and adding our own measurements, we will hopefully be able to use this evidence to further support the thought that the beavers are having a positive impact on the aquifer.

Besides raising aquifer levels, the presence of beavers in the Santa Fe River has thought to stimulate an increase in wildlife species in the area. In order to assess these changes, we will speak directly to employees at WildEarth Guardians, as well as River Source and the Santa Fe Indian School, in order to have a clear understanding of landscape changes around the beaver colony. We are assuming that the combination of the planting campaign by WildEarth Guardians in 1996 and the beaver habitat are changing the landscape for the better.

3.2 Assessing Beaver Impacts on Human Activities

Beavers can have an incredible impact on surrounding human activities, as well as their surrounding ecosystem. There are two groups that may be affected by beaver dams, the airport and property owners. The proximity of the dams to the airport has caused that group to focus on air transportation. A series of methods were used to gather and analyze data in both of these categories.

3.2.1 Assessing Beaver Impacts on Air Transportation

Transportation is another important aspect of our project, particularly air transportation. Since the dams and flood zone are adjacent to the airport, the beavers have an indirect, yet strong effect on aircraft and passenger safety. The group collected data from the FAA concerning the Santa Fe Municipal Airport. Included in this information is the number of flights per year and the number of bird strikes each year. Another important aspect for data collection involved the current Wildlife Hazard Assessment. The group acquired information on types of incidents that would trigger this type of assessment, as well as guidelines provided by the FAA on wildlife attractants near airports.

3.2.2 Living with Beavers

Although the beaver colony is currently impacting human activities in Santa Fe, there are ways to cope with their affects and live with them. As mentioned earlier, beavers provide great ecosystem services for the environment around them. However, an establishment of beavers near the airport may not be the best area. Depending on the result of the Wildlife Hazard Assessment, there may be reason for the beavers to be moved. Since this is an option, the group decided that it would be beneficial to determine the natural requirements for a beaver habitat and an area where they could possibly be relocated to. There is a large amount of area to cover in order to find a suitable habitat for beavers. Therefore, the group decided to focus on one specific area of land and analyze its natural resources and potential for accommodating a beaver colony.

3.2.3 Relocation Opportunities

We have learned through our sponsor Mark Ericson, a teacher at the Santa Fe Indian School, that some of the pueblos might be open to reintroducing beavers on the reservations. There are eight pueblos surrounding the city of Santa Fe. These include: Nambé, Picurís, Pojoaque, San Ildefonso, Ohkay Owingeh, Santa Clara, Taos, and Tesuque. For more information on these pueblos, please refer to Appendix B. In the past, some of these tribes used to have beavers on their land but the beavers have since disappeared, perhaps due to poaching or limited resources. These pueblos would be a good fit culturally because animals can be an important part of a tribe's history. We have been put in contact with Anthony Dorame, also a teacher at the

Santa Fe Indian School, who is very interested in utilizing the works of beavers on his property in Tesuque Pueblo.

3.3 Developing an Education Platform

Once we arrived in Santa Fe we began speaking with our sponsor, Mark Ericson, about a community based education program that he is a part of at the Santa Fe Indian School. During one meeting we learned about an outdoor education program initiated by Will Barnes at the Santa Fe Girls' School and a program at Desert Academy. Each school collects water quality data and observes the environment at different spots along the river. Our group decided that it would be beneficial to put all of this data in one place, so we gathered water quality data from each of these schools, as well the piezometer data from the Santa Fe Girls' School. After talking to each teacher the group realized that the schools were not communicating as well as they could be. Each teacher expressed that they wanted to be able to work with different schools and grade levels, but it never could be worked out. They are in different parts of the city and the distance between them makes it hard to work on projects together. In order to help the situation our group decided that an education platform in the form of a website would be the most useful for these teachers. The website is a place for information sharing, data input, and project collaboration.

3.3.1 Mapping Project Sites

There are currently several schools working on projects along the Santa Fe River. It is great that so many sections of the river are being observed, but the data collection and observation locations are only known by the teachers and students of a particular site. Therefore, the group decided that it would be beneficial to create a map of all the project sites. In order to produce the map, the group visited the sites for The Santa Fe Indian School and the Santa Fe Girls' School, and the locations were recorded using a GPS-enabled phone. There were several points of interest, including the location of all the wells installed by the Santa Fe Girls' School, the location of spots where water quality measurements were taken, and even the location of several dams and wetlands.

Once these locations were recorded a unique identifier was assigned to each school. The unique identifiers are:

- DA (Desert Academy)
- SFGS (Santa Fe Girls' School)
- SFIS (Santa Fe Indian School)
- SFAS (Santa Fe School for the Arts and Sciences)
- SFP (Santa Fe Prep)
- WPIUp (WPI Upstream Site)
- WPIDown (WPI Downstream Site)

These identifiers will be used for identifying collection points in databases and creating the map.

Figure 17: Data Collection Points

3.3.2 Continued Monitoring

After mapping project locations the group needed to figure out a way to allow for continued monitoring of the beaver dams and Santa Fe River ecosystem in general. Two main forms of monitoring were produced, a spreadsheet-based database and a website. The database was created using Google Spreadsheets and is intended to act as a repository for data collected from all schools in the coalition. It contains columns for each type of data collected, as well as the school's identifier, and collection date and time of day. The website was created using Google Sites, and will act as a host for the spreadsheet.

4. Analysis and Results

Our analysis and results are the product of our data collection efforts as well as the research done on the airport. It was difficult to make conclusions about our data because our collection period was too small. Our website will be the key to making more solid conclusions in the future because it will accumulate information over time and all along the river.

4.1 Water Quality Data Analysis

Once all of the historical and present water quality data was collected, it was necessary for the group to perform an analysis of all the data. While performing our water quality tests each week, we discovered that we were using different collection methods than the Santa Fe Girls' School for certain tests. Therefore, combining the analysis and results for these tests was not an option. Separate analyses were performed for each data set.

4.1.1 Santa Fe Girls' School Data Analysis

One of the most important data sets that our team received was the well depth data from the Santa Fe Girls School (SFGS). Over a period of roughly five years, the SFGS has gone to Project Preserve, a data collection site which the Santa Fe River runs right through and abuts private farmland. In March 2008, a colony of beavers moved in. In the picture below (Figure 18) shows Project Preserve, located in the lower left corner. It is located 1.5 miles from the Santa Fe Municipal Airport, which is located in the upper right corner of the picture. Once a week the SFGS travels to this site to take readings from the piezometers, as well as other water quality measurements, including stream flow, pH,

Figure 18: Project Preserve

temperature, turbidity, total dissolved solids, nitrates, and phosphates. The red circle in Figure 19 indicates the site where the water quality tests are conducted.

Figure 19: SFGS Piezometer Locations

The girls collect well depth data from the piezometers that extend across the study area. The piezometers are marked in Figure 19, with each well being represented by a blue numbered pin. After the data is collected the girls calculate the average water level over all of the wells. The well measurement is the distance from the top of the well to the point where water is located. The data for the well depth measurements are displayed in Figure 20. The smaller the measurement, the closer to the surface the water is and the higher the aquifer level. The wells were installed about five years ago and have proven very useful in regards to the effects that the beavers had on the river. When the wells were installed there were no beaver in the area. Then, in March 2008, beavers arrived just upstream of the data collection site. In April 2010, the beavers were forced out of the area due to the destruction of their dams. During the time when the beavers were present, there was a significant increase in the aquifer level, from 112 cm to 71 cm over a period of about two years. Even taking into account the cyclical effects of the seasons, the aquifer level increase during this time period is substantial. Once the beavers left the area, there was a drastic decrease in the aquifer level, from 68 cm to 144 cm below the tops of the wells over a period of approximately four months. This drastic drop can be attributed directly to the beaver presence, or lack thereof, leading to the conclusion that beaver ponds act to increase the aquifer level.

The SFGS took more measurements than just well depths. They also measured stream flow, water temperature, TDS, turbidity, pH, nitrates and phosphates. The stream flow measurement results can be seen in Figure 21. The methods for these tests stayed the same throughout the testing period, with the exception of the stream flow data. At the beginning, the stream flow measurements were conducted using a flow meter.

Around 2007, the flow meter broke and the method for taking stream flow changed. A ten foot section of the river was measured out and the depths were taken at three sections across the river. Once this was done, an object that floats mostly submerged, such as an orange, was used to measure the stream flow by tracking the time that it took the orange to travel the ten foot section. The stream flow could then be calculated based on the velocity and depth measurements that were taken. This was repeated three times and the average was calculated and recorded. Before the flow meter broke, this method was used as well as using the flow meter and the results were comparable, thus eliminating that as a factor that would greatly affect the measurements.

Figure 21, which shows the stream flow data, shows that there has been a steady increasing trend, again during the time period where the beavers were present in the area which is shown by the red line. There is a clear effect on the stream flow from the seasons passing, but even taking this into account, there is an increase in the stream flow for the river. Once the beavers leave the area, there is a significant drop in the rate of stream flow, from 30.20 cubic feet per second(cfs) to 1.0 cfs over a four month period This point is indicated by the star in Figure 21. This sudden drop correlates exactly to the time period when the dams fell into disrepair. This occurred for two different reasons. The first is the natural decay of the dams, since the beavers were no longer around to repair them. The second reason was that humans came and took apart the dams. The combination of the increase in stream flow when the beavers arrive, and the dramatic decrease in stream flow after the beavers leave creates a clear correlation indicating that beaver presence acts to increase the stream flow of the river. The reason for this could be that since the aquifer level is higher, there is more water available in the river area.

Water temperature was another measurement that the SFGS took. The temperature measurements were taken beginning in late 2007 and can be seen in Figure 22. The effect of the seasons can be clearly seen by the peaks and dips that occur during the summer and winter months. Apart from the effect that the changing seasons have on the water temperature, there appears to be no effect by beavers.

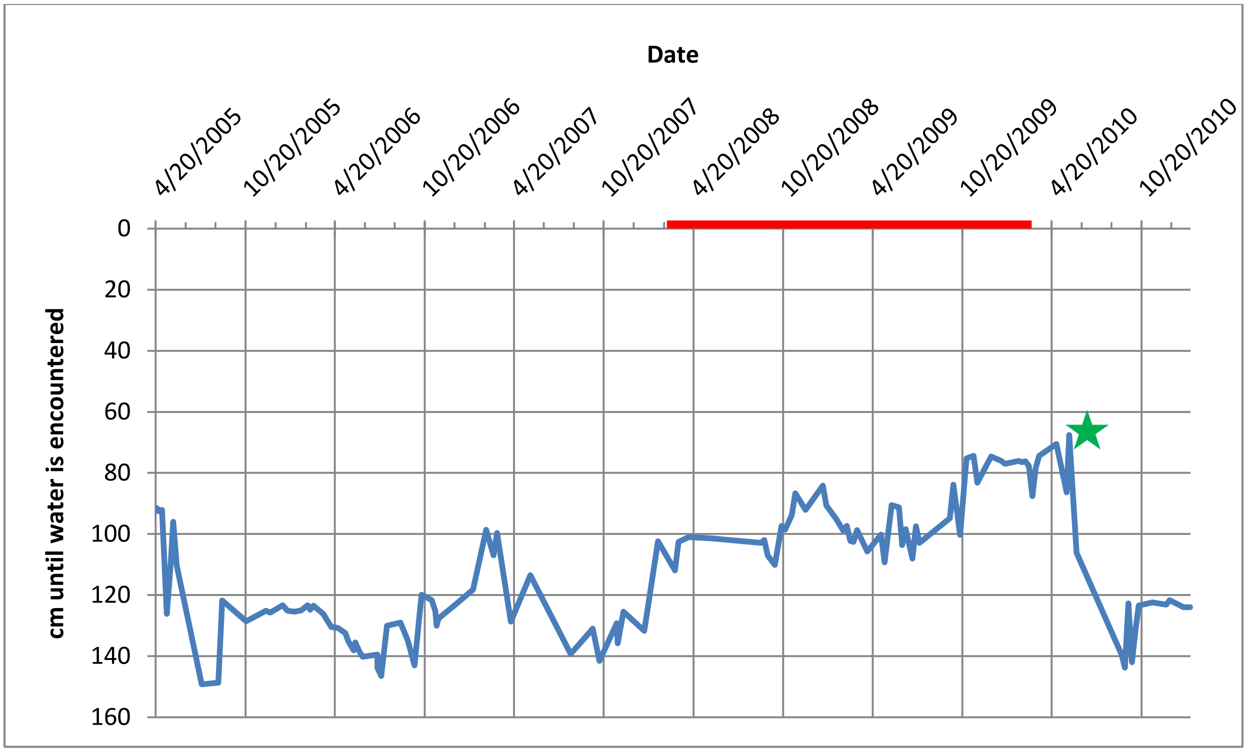


Figure 20: SFGS Well Depth Averages

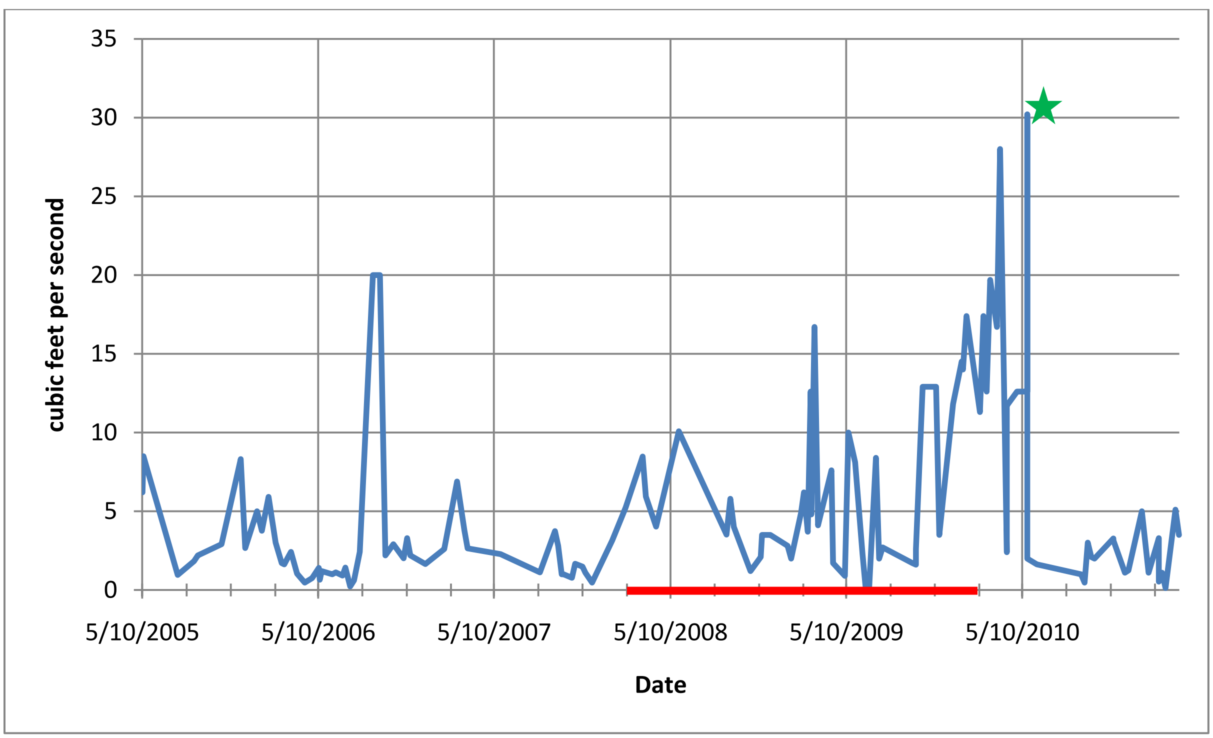


Figure 21: SFGS Stream Flow Averages

At the very left of Figure 22, the temperature value appears to still act in a cyclical manner, with the values being roughly at the level as the same month period during a year when the beavers are present. This leads to the conclusion that beavers do not affect the temperature of the water.

TDS was also another water quality measurement that was taken by the SFGS. The graph for this data can be found in Figure 23. The TDS data set was taken beginning mid-2009, thus there is no data from before the beavers were in the area. The end of the time period where the beavers were present is indicated by the red line. Based solely on this, it appears that the beaver presence may have acted to stabilize the TDS in the water at around 400ppm. After 3/24/2010, once the beavers vacate the area, the data becomes more erratic. Based on this data, the presence of beavers in the river does not act to increase or decrease the TDS level in the water, but simply acts to stabilize the TDS in the river. Further testing would need to be conducted to come to a solid conclusion.

The turbidity data acquired by the SFGS can be seen in Figure 24. The duration of the red line is when the beavers were present in the area. The cyclical effect on the turbidity of the water can be attributed to the cyclical trait of the changing seasons. The only alteration separate from the seasonal effects is the slight decrease of the peaks, though this change is statistically insignificant. The single high peak at 190NTU, which could simply be user of device error while taking the measurement, is an outlier point and is considered an error. There does not seem to be evidence to suggest that beavers have an effect on the turbidity of the water.

The pH, nitrate and phosphate measurements that were taken by the SFGS are the measurements with the least amount of data, thus these are the tests that will have the weakest conclusions. Figure 25 shows the pH readings during the testing period. The pH levels during the winter to early spring time, located at the star in the graph, appear to fluctuate more than normal.

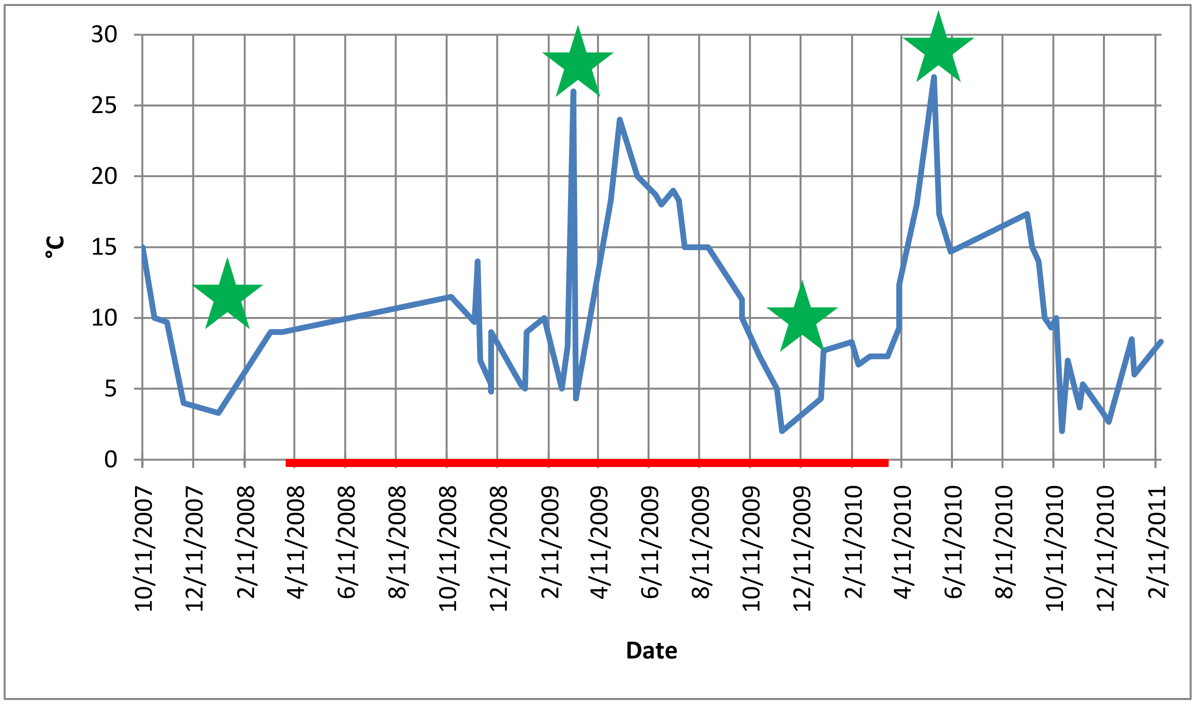


Figure 22: SFGS Water Temperature Averages

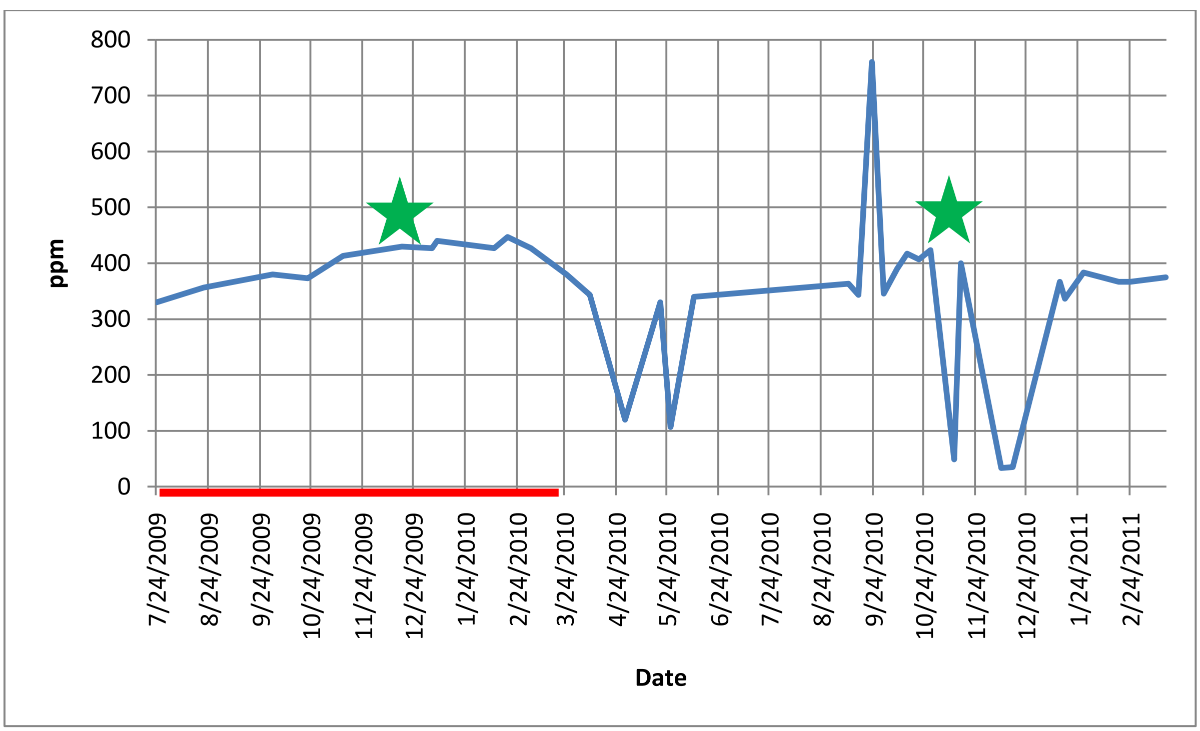


Figure 23: SFGS TDS Averages

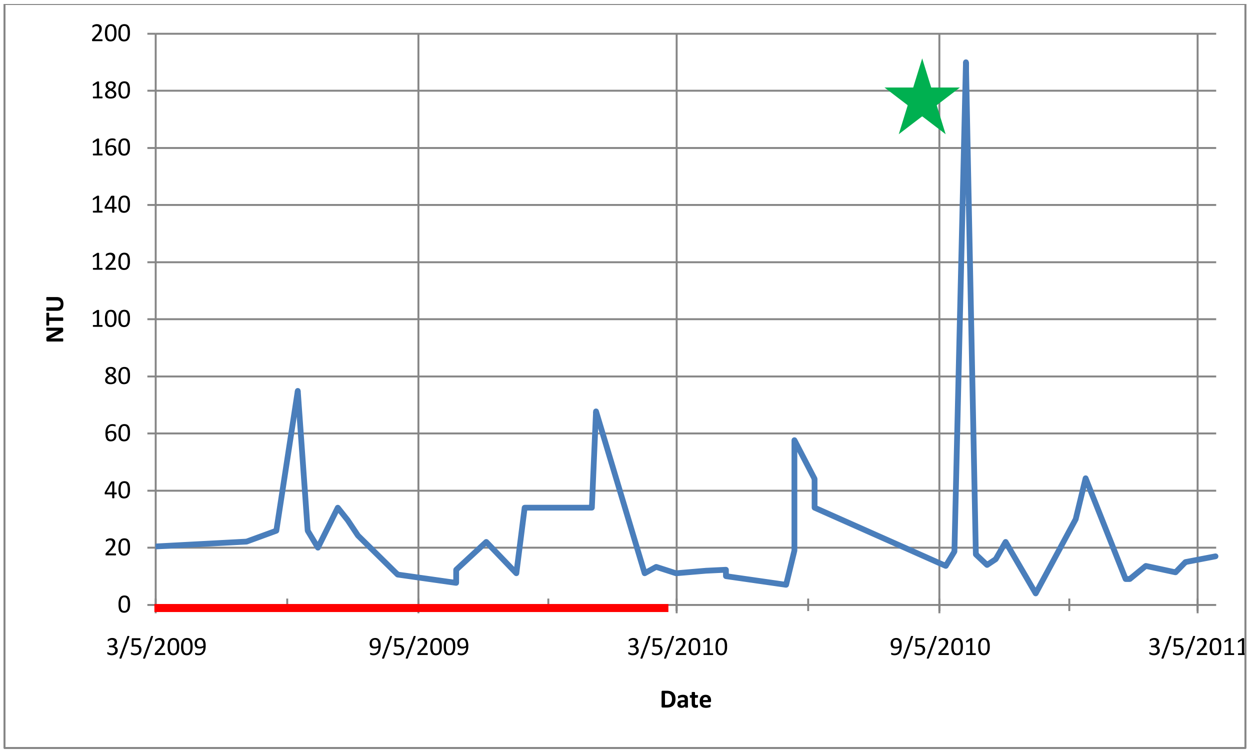


Figure 24: SFGS Turbidity Averages

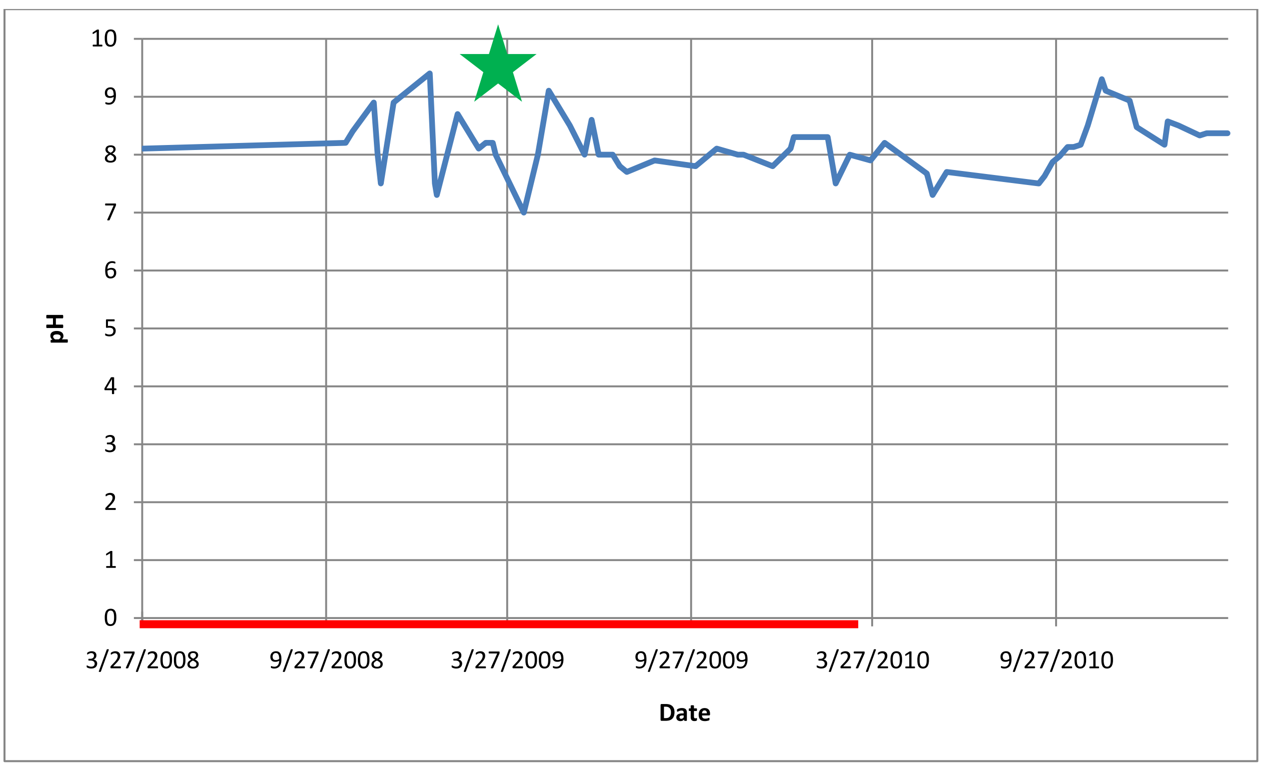


Figure 25: SFGS pH Averages

However, since this fluctuation does not repeat the following year, when the beavers are still present in the area, it can be considered merely the result of that particular year. This suggests that pH is unaffected by beaver presence. Further testing should be done to confirm this suspicion.

The graph of the nitrate levels in the Santa Fe River can be seen in Figure 26. The periodical spikes that are observed during the time when the beavers are present correlate with the changing of the seasons, being highest during the month of December at 8.60mg/L. During the summer, the level of nitrates in the water appears to decrease. Once the beavers leave, it appears that the cyclical pattern is somewhat altered, with December no longer being the highest nitrate value for the year. The nitrate values do seem to be increasing as the year progresses, suggesting that it were not affected by beavers. The beaver presence appears to possibly shift the cyclic behavior that the changing seasons cause, though more data would be needed to draw a concrete conclusion.

The phosphate level in the water is the test that has the least amount of data behind it. The data collection period for phosphates begins in early 2010 and is displayed in Figure 27. During the period that the beavers are present, the phosphate levels appear to have slightly higher values for that time of year, as compared to the values the following year when the beavers are gone, though this change is small enough to be statistically insignificant. This leads to the conclusion that beavers do not affect the phosphate levels in the water. This trend is over too short of a period of time for this to be a solid conclusion. Further data tests will be needed to solidify this conclusion.

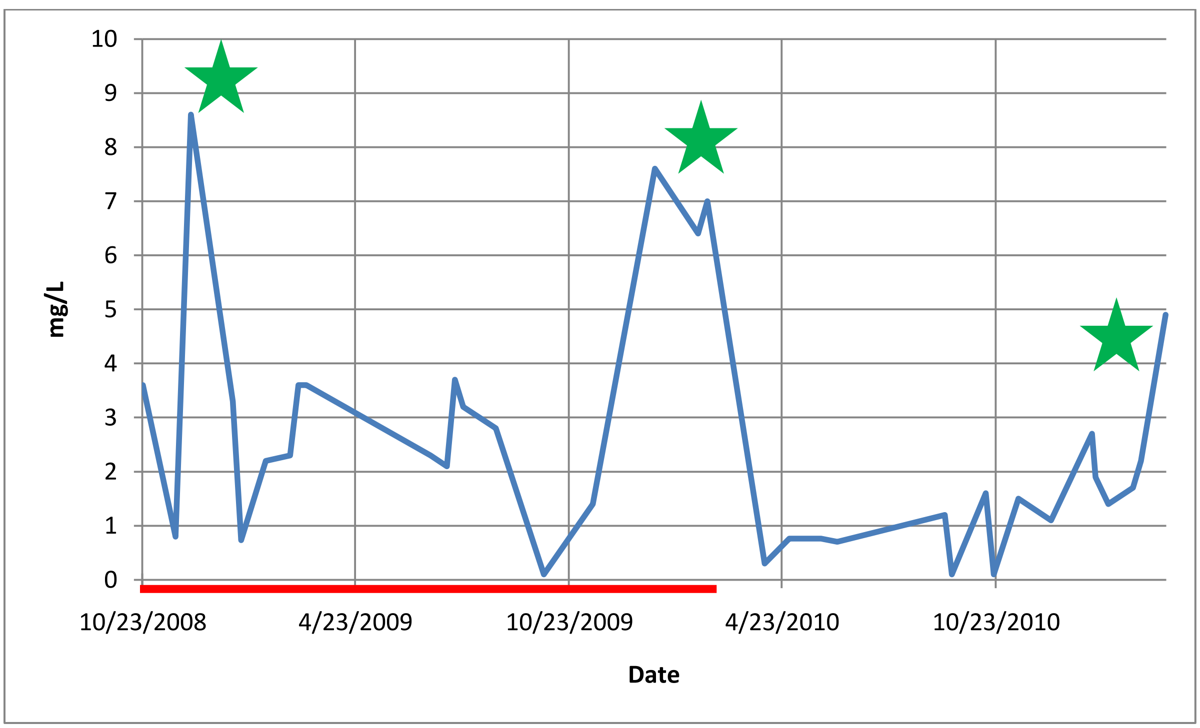


Figure 26: SFGS Nitrate Averages

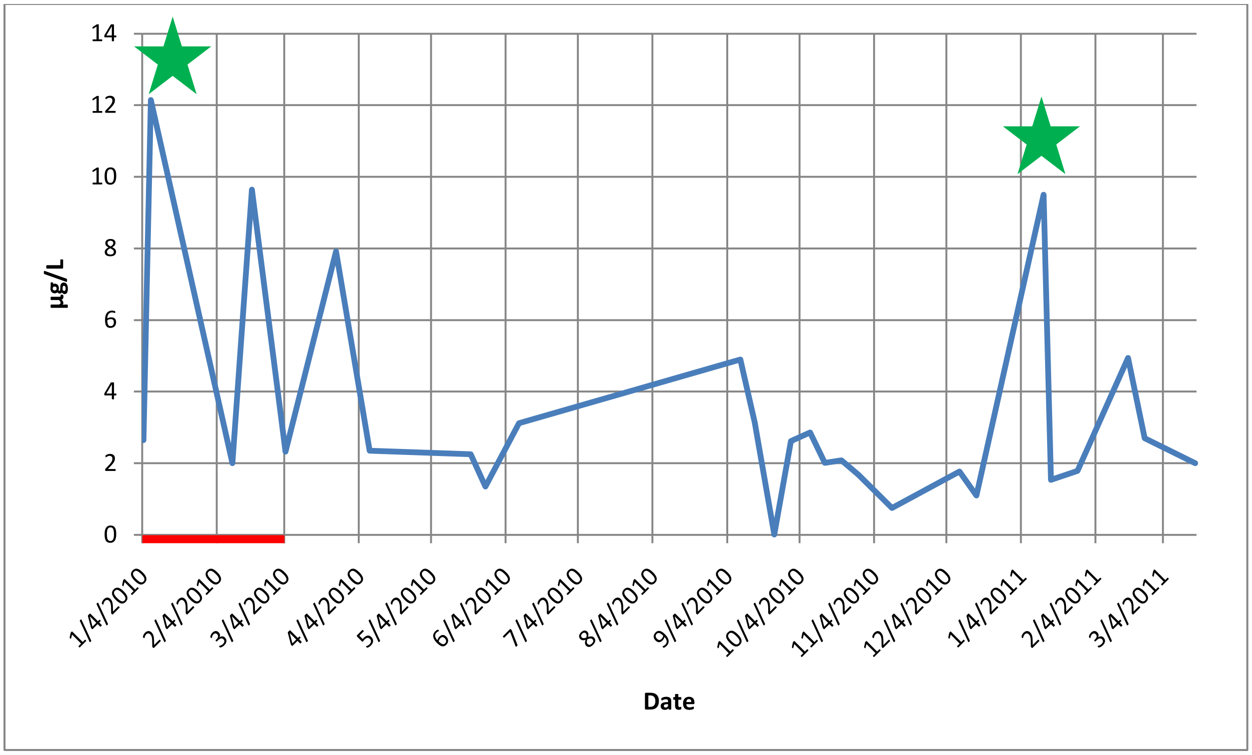


Figure 27: SFGS Phosphate Averages

4.1.2 WPI Team Data Analysis

The same water quality tests, with the exception of well depth, were done by our team at two different locations, one upstream and one downstream of the beaver dams as indicated by Figure 18. By conducting our tests at two different sites, we were able to see the impacts the beavers are having on the Santa Fe River. Our control test site, the site above the beaver habitat, told us about the qualities of the river before any beaver activity could affect it. Once the flow passed through the beaver habitat and arrived at the downstream test site, the measurements that we took there could be compared to the values gathered at the upstream site. Please see Appendix E for all of our data.

Figure 28 shows our stream flow data. It is a comparison of how the stream flow was changed by the beaver dams. The blue line indicates the readings taken at the upstream site, and the red line, the downstream site, do not have much difference. The only change between the two is a slight decrease in stream flow at the downstream site as compared to the upstream site. However, this change is so small that it is negligible and could easily be user or instrument error when taking the readings. The significantly higher reading at the starred date could also be attributed to user error, since it was the first time we took the readings. Such a small difference between the two test sites suggests that the beaver habitat has no significant effect on the stream flow of the Santa Fe River.

These results were unexpected. Since the SFGS data showed a clear increase in the stream flow as a result of beaver presence, it was expected that the stream flow would be different by a noticeable degree downstream of the beaver habitat. However, it is important to note that our tests included a control site above the dams and the SFGS did not. This introduces the possibility that the stream flow could simply have been higher during that time in general. This could explain the difference between our results and those of the Santa Fe Girls School. Another possible explanation is that since our data was taken over such a short period of time, it failed to encompass these changes. The time of year could have had an effect on the results, as well as the drought that Santa Fe is currently in.

The water temperature values, which are shown in Figure 29, show a noticeable difference between the upstream site and downstream site values. The water temperature at the upstream site was consistently several degrees higher than the temperature of the water at the downstream site. This difference stayed more or less consistent throughout the testing period, as seen in Figure 29. From the first reading, to the last reading, both lines follow the same pattern as well as maintaining the same degree of difference, such as at the starred point. One thing to also take note of is the more or less constant temperature at each site throughout the testing period. This constant difference in temperature could be explained by the fact that all of the water in this part of the river has been released by Wastewater Treatment Plant. The temperature of the water coming out of the plant could simply be higher. As the water travels down the river, it will naturally cool down to a normal level. This could explain why the water downstream was constantly lower than the water temperature upstream. Further data would need to be collected to come to a conclusion regarding this.

The TDS values in the water that we collected can be found in Figure 30. The TDS readings had slightly higher values downstream. The data lines also change at the same time periods, just like the temperature readings. The lower value at the starred date, since it is the only one at that lower level, can be considered an outlier point and has no statistical relevance. The fact that the next several readings are where they were originally further reinforces this conclusion. The beaver presence appears to have no effect on the TDS.

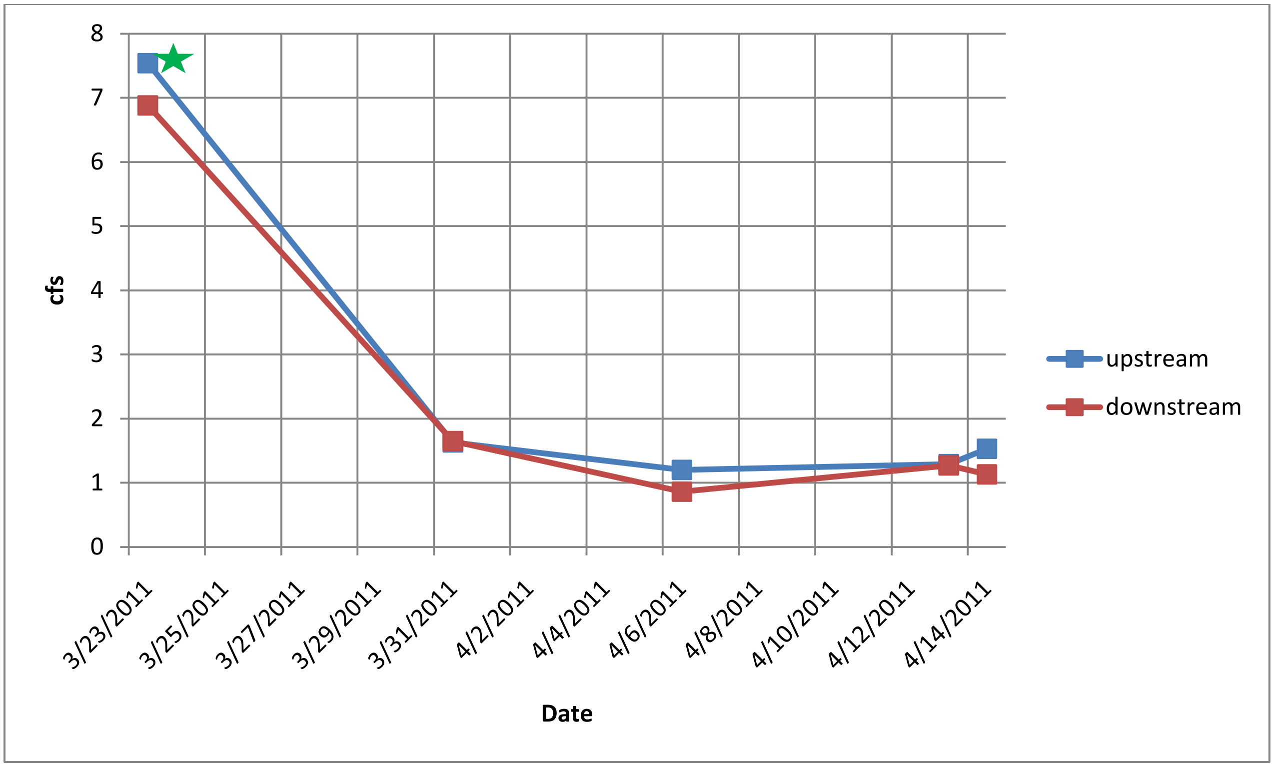


Figure 28: WPI Stream Flow Averages

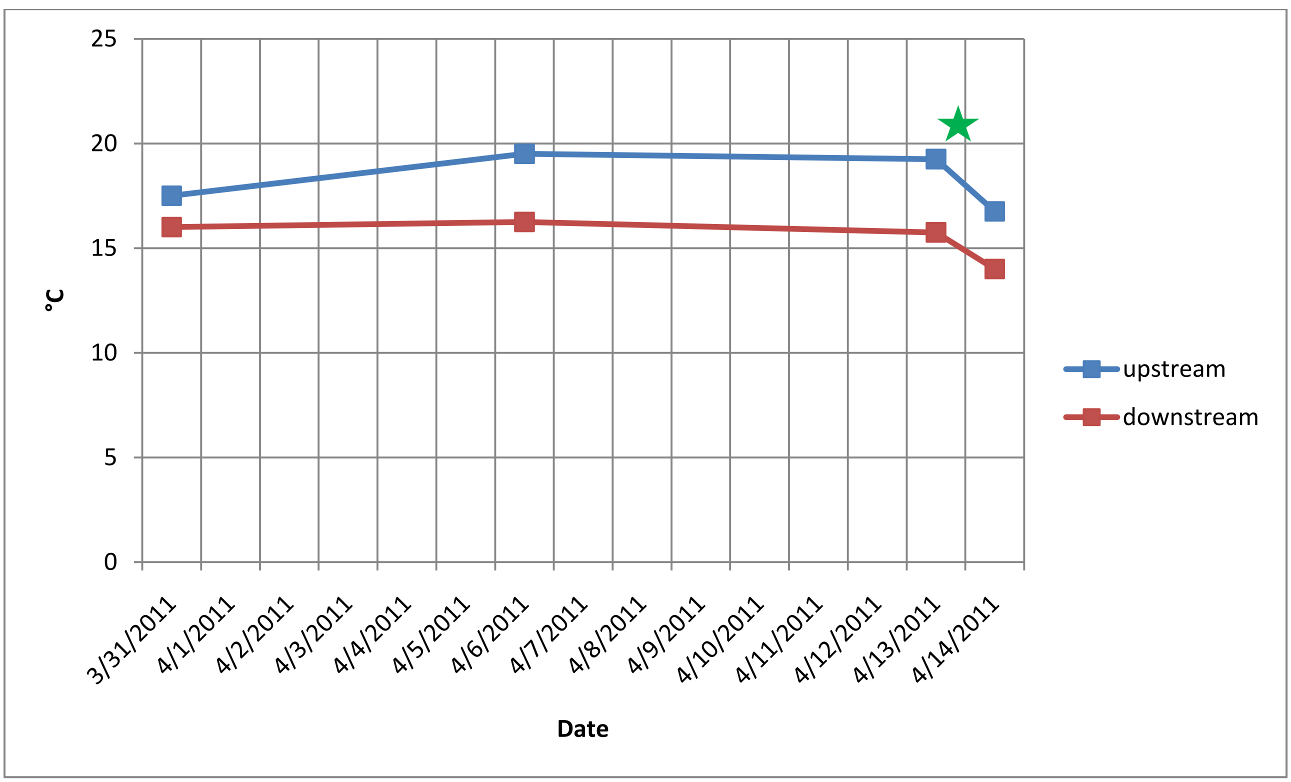


Figure 29: WPI Water Temperatures Averages

This conclusion matches the data from the SFGS. However, since the time period that we collected data for is so short, more testing would need to be done. In the SFGS data, the TDS values have a more stable trend while the beavers are in the area. Once the beavers leave the area, these readings become more erratic. This matches with the data that our group collected. Since our data is collected during a time when the beavers are present, it makes sense that our readings are more or less stable. Even though the upstream values are not erratic, this could be because our test period was over such a short period of time. The conclusion, based on these two data sets, is that the presence of beavers in an area acts to stabilize the TDS readings for the water.

A drastic difference between the turbidity levels of the water at the upstream and downstream site can be seen in Figure 31. Throughout the period of time when the tests occurred, there was a more or less consistent difference between the downstream site, which had a higher turbidity value, and the upstream site, which had a lower turbidity value. Near the end of the testing period, the turbidity values appear to be converging on each other, at the right side of the graph. Though there is not enough data to draw a conclusion from just this set of data. To obtain more conclusive evidence, further testing would have to be done.

The higher turbidity at the downstream site was unexpected. It is commonly believed that beaver habitats decrease the turbidity of the water by filtering out particulate material in the water. The data from the SFGS also suggests that beavers have no effect on the turbidity of the water. These two facts lead to the conclusion that the turbidity readings at the downstream site would be lower than the upstream site data. Again, one thing to keep in mind when comparing the SFGS site and our site is that the SFGS site only had one testing area, and our site had two that compared above and below beaver habitats. The results that we gathered were puzzling and merit further testing.

The pH testing results are shown in Figure 32. The upstream value for the pH was higher than the downstream value for the entire testing period, though this difference is small enough to be statistically insignificant. The second point, indicated by the star, is the only point that is different. This data, as well as the SFGS data, suggests that beavers do not have an effect on water pH. However, further tests would be needed to reinforce this conclusion.

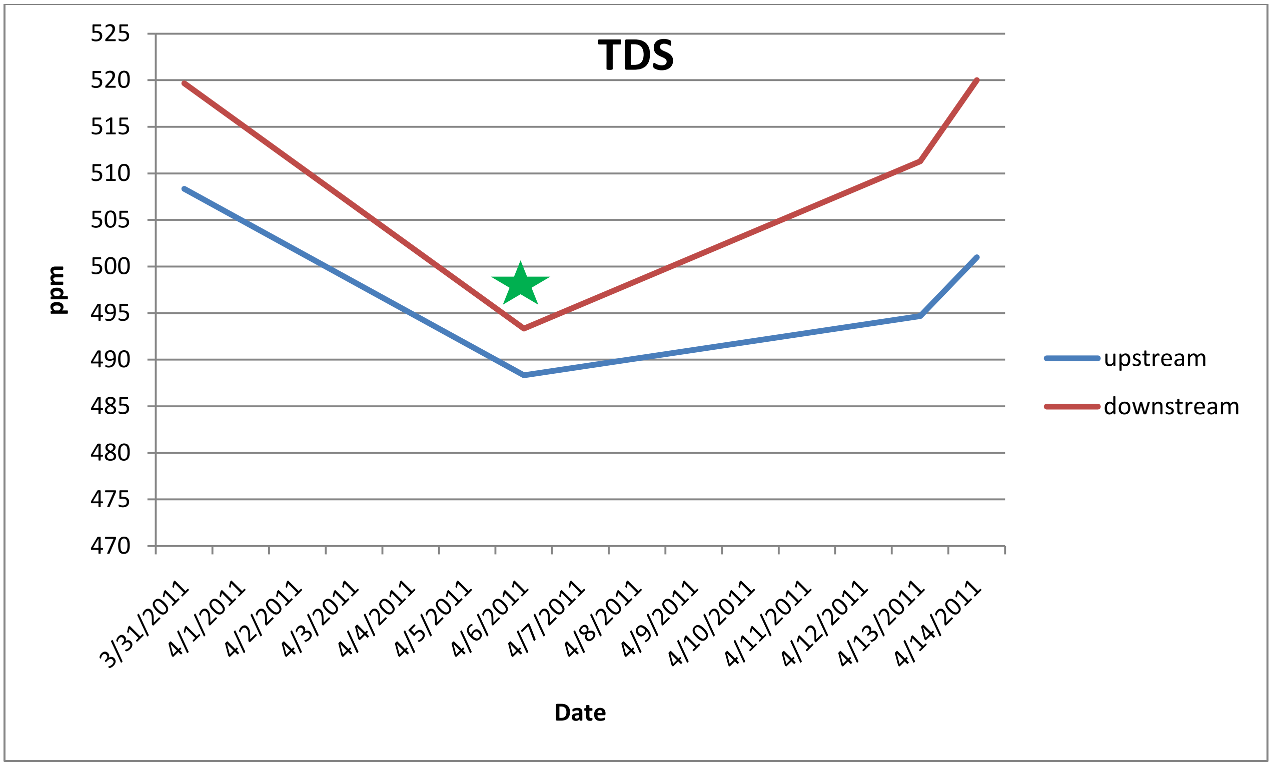


Figure 30: WPI TDS Averages

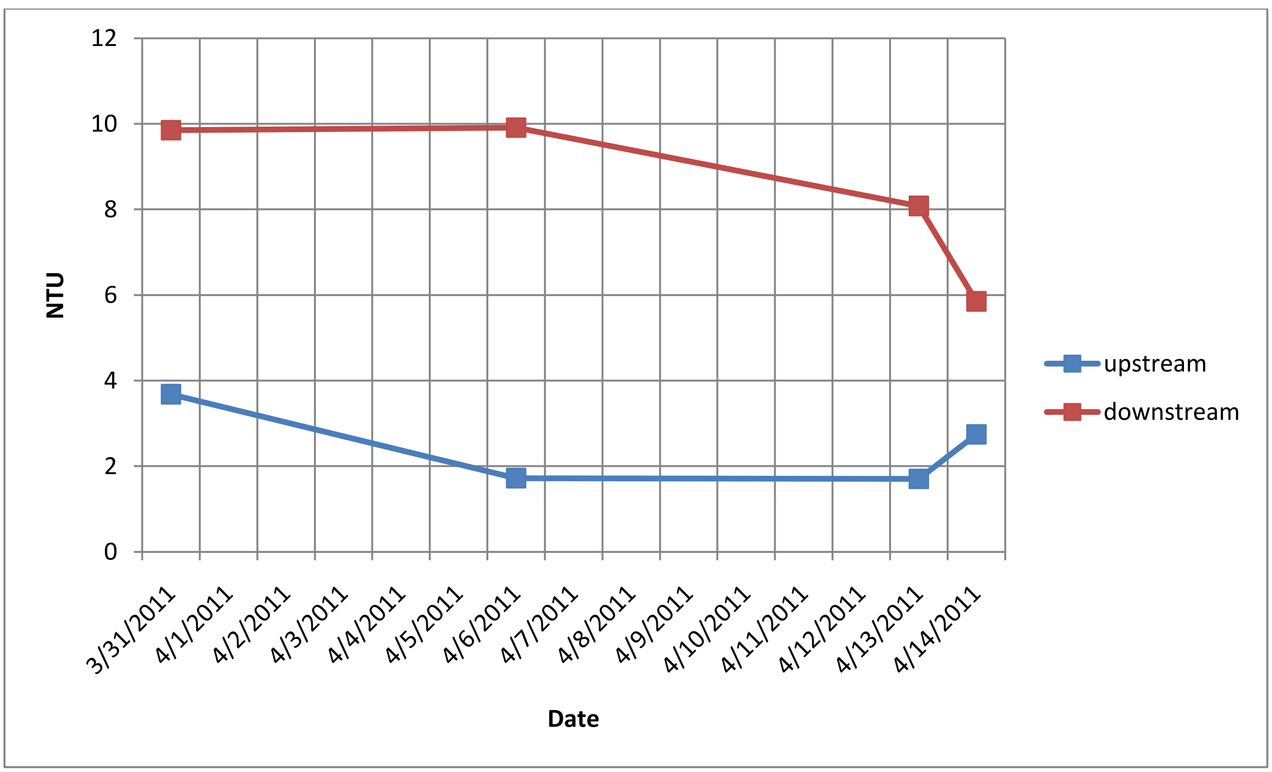


Figure 31: WPI Turbidity Averages

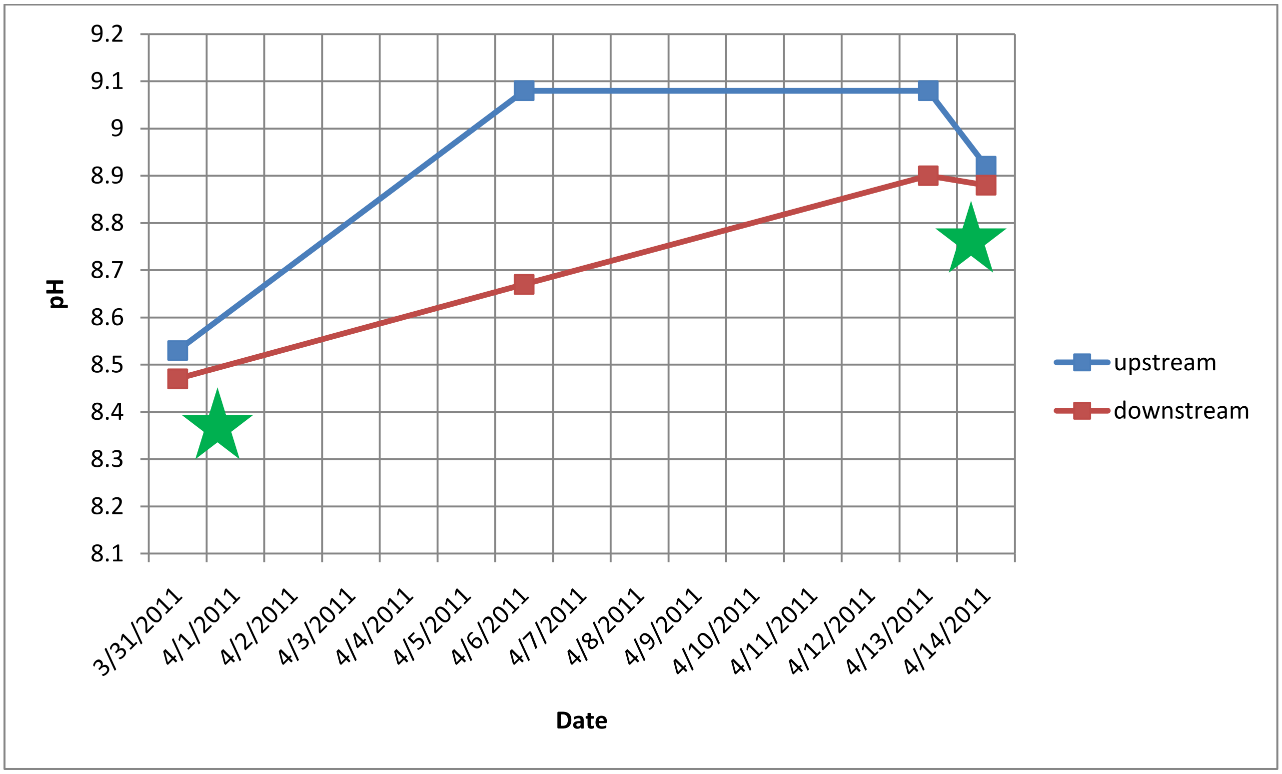


Figure 32: WPI pH Averages

The nitrates test results, shown in Figure 33, appear to have no significant difference between the two test sites. The difference between them is small enough that it can easily be explained as being caused by the instrumentation error. There is a slight increasing trend, though it is extremely small. This increase could be attributed to the progression of the seasons, or user or device error. However, in the SFGS data, the nitrate levels seem to be lower during the winter time as compared to the levels during the summer. Our data, taken with the SFGS data, leads to no concrete conclusions, but can possibly suggest that beaver presence does not affect the nitrate levels in the river.

Figure 34 shows the phosphate testing data. The very first point, indicated by a star, is the same at both sites. This is because the maximum reading for the device that we used was 2.75μg/L. The maximum result indicates that the level of phosphates on that day were higher than 2.75μg/L . Apart from this point, the differences between the two sites are not significant enough to lead to any statistical conclusions. This is further reinforced by the fact that the last couple points are very similar to each other, as indicated by the star to the right of the graph. This data, coupled with the SFGS data, possibly suggests that beavers have no effect on the phosphate levels, though this is by no means a solid conclusion. Since the time period for the tests is so short, further tests will need to be conducted to confirm this.

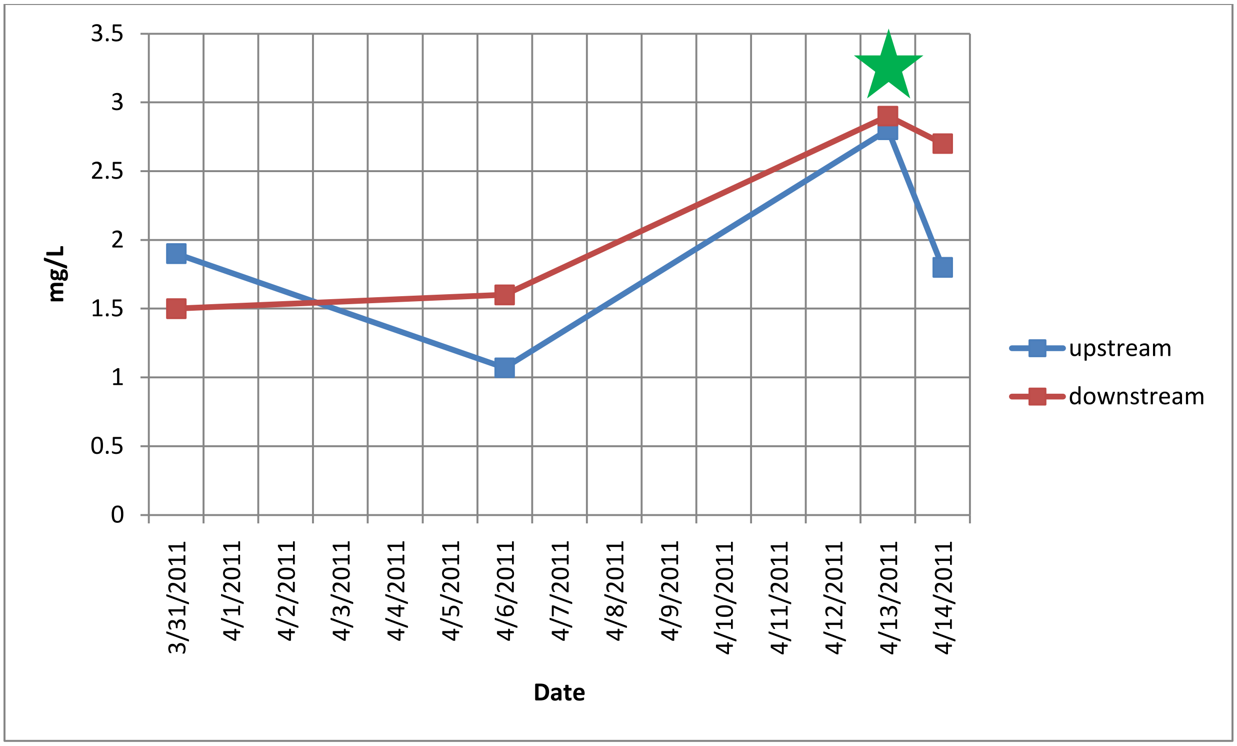


Figure 33: WPI Nitrate Averages

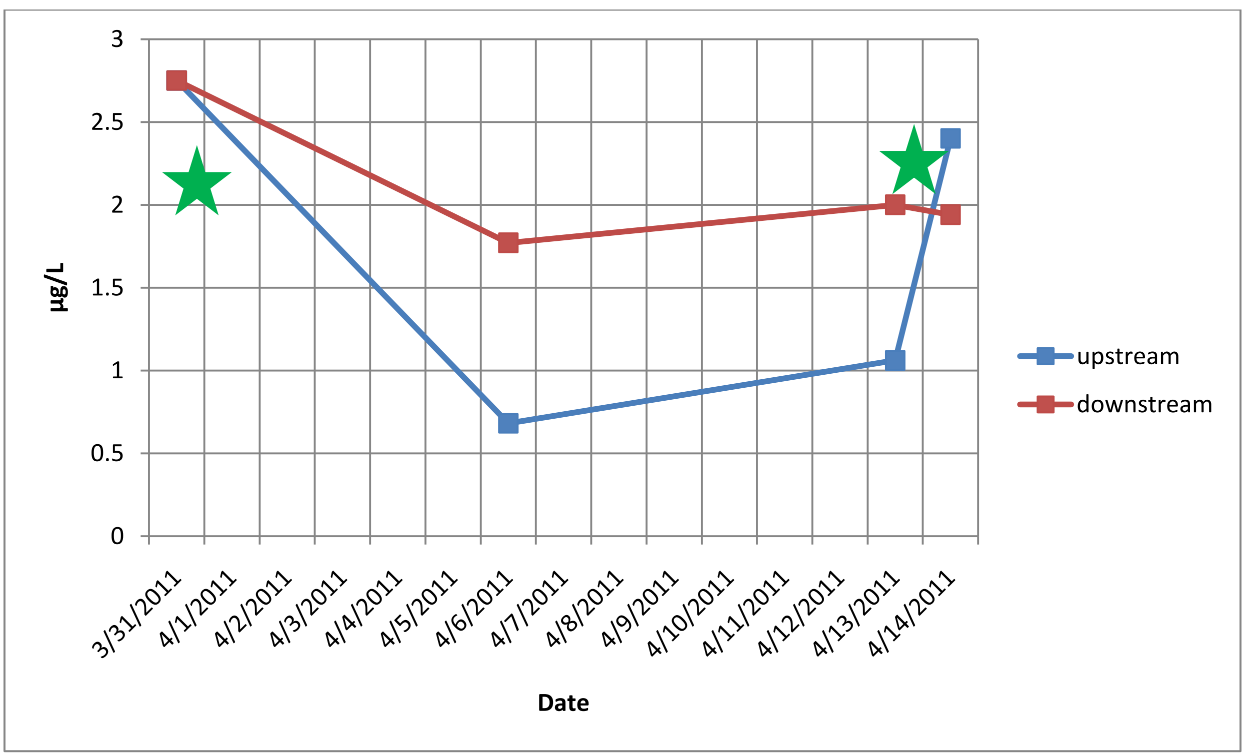


Figure 34: WPI Phosphate Averages

4.2 Resulting Impacts of Beaver Dams on the Santa Fe Airport

The Santa Fe Municipal Airport (SAF) is a regional airport located nine miles southwest of downtown Santa Fe. It is mostly a General Aviation airport with only two commercial flights arriving and departing daily operated by American Eagle Airline network[66]. During the last ten years the airport has reported an average of 75,000 flights annually, which includes commercial, military and private operation. In 2009, the airport reported 9767 boarding passengers which is 27 times the 355 passengers reported in 2008.[67] Figure 35 shows the annual number of flights reported by SAF from 2000-2010. Notice the slight decrease in the total number of flights as it approaches 2010.

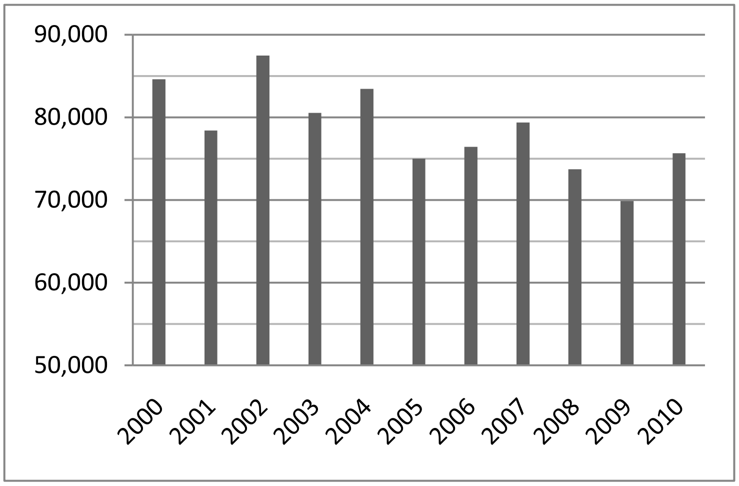


Figure 35: Number of flights per year for SAF. Source: FAA

The airport was built adjacent to the Santa Fe River, making it prone to wildlife hazards due to the river and the vegetation surrounding it. In compliance with the requirements of FAA Code of Federal Regulations 14 CFR 139.337 § (a) an "airport operator must be prepared to take immediate action to deal with unexpected incursions of hazardous wildlife" in the Air Operations Area (AOA)[68]. In this case, the unexpected incursions refer to the developing wetlands that can be found near the end of the airport's third runway. A Wildlife Hazard Assessment (WHA) began in September 2010. After the US Airways Flight 1549 Airbus 320 ingested several Canada geese into both of its engines, the FAA mandated WHAs at all commercial airports. Once completed, the airport's manager will work in collaboration with a biologist, and other qualified personnel to draft a Wildlife Hazard Management

66 (Anonymous)(Anonymous)
67 (Anonymous)
68 (Cleary and Richard Dolbeer July 2005))

Plan (WHMP) that will be presented to FAA officials.

Figure 36: Location of SAF, Santa Fe River, and Wastewater Treatment Plant

4.2.1 Wildlife Hazard Overview

Wildlife strikes are a serious concern because they threaten passenger and crew safety. Economic losses can result from damage to airport property and aircraft components as well as aircraft repairs. At least 122 aircraft have been destroyed and over 255 civilian lives have been lost worldwide due to wildlife strikes from 1960 to 2004. Wildlife costs the U.S. Civil Aviation Industry at least 500,000 hours of downtime a year and around 500 million USD in direct damage and associated costs[69].

The FAA has established a Wildlife Strike Database with records from 1990 to present. There have been approximately 72,000 reports entered since the creation of the database. In Figure 37, note the increase between 1997 to 2000 due to heightened awareness, number of flights, and population of hazardous wildlife. After 2000, the number of reported strikes is more constant most likely due to decreased number of flights following September 2001. Although these reports are extremely useful for researchers, the FAA estimates that only 20% of all strikes across the nation are reported. This is due to the fact that all strikes must be self-reported.

[69] (Cleary and Richard Dolbeer July 2005))

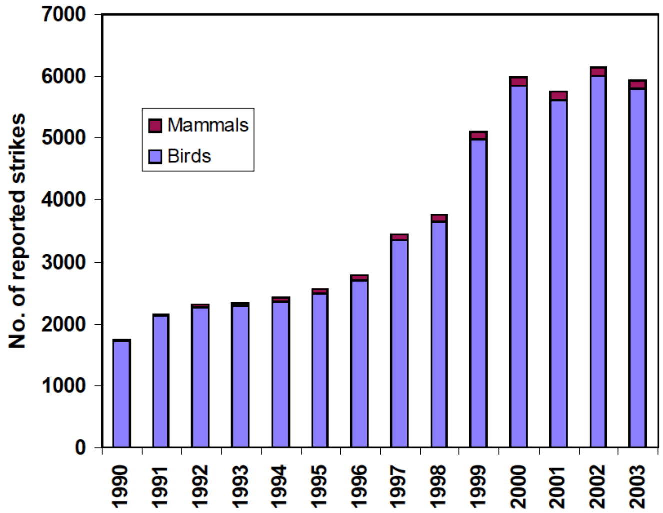


Figure 37: Number of Wildlife Strikes reported in the U.S. Source: Cleary, Edward

According to the FAA strike database, a total of 10 strikes have been reported at Santa Fe Airport from 2000-2007 (Figure 37). There have been a high of three strikes (in 2002 and 2006) and several years where no strikes were reported. Of these five species were unidentified birds (50%), nine of them have been birds, and one was a mammal. From previous visits to the wetlands, several waterfowl have been seen in several of the ponds. Waterfowl species are particularly hazardous according to the FAA, contributing to 10% of all bird strikes reported nationally. The Strike Rate, shown in Figure 38, is defined as the number of strikes per 10,000 operations (flights). For more information on these strikes see Appendix A.

Number of Aircraft Operations and Strikes at Santa Fe Municipal Airport (2000-2010)

Year	Number of Operations	Number of Strikes	Strike Rate
2000	84590	0	0.00
2001	78414	1	0.13
2002	87472	3	0.34
2003	80538	0	0.00
2004	83431	1	0.12
2005	74997	1	0.13
2006	76416	3	0.39
2007	79356	1	0.13
2008	73716	0	0.00
2009	69889	0	0.00
2010	75646	0	0.00

Figure 38: FAA Published Wildlife Data for Santa Fe Airport

Note that there has been a slight decrease in number of operations in this ten-year period while the rate of strikes has also decreased. Half of the reported strikes occurred during fall months (September to November). A third of the strikes have occurred during summer months (June to August), and 90% of all strikes took place during daytime. Figure 39 shows a comparison between SAF's strike rates and other airports for the last five years. Roswell International Air Center (ROW) handles a similar quantity of flights as SAF (an average of 70,000 flights per year). The other airports, despite their large number of flights, were chosen for comparison purposes. Notice that even though SAF averages a higher number of flights per year, it has a lower strike rate than ROW. Also note the very high rates that popular airports such as JFK and LAX have. These airports have to mitigate very serious wildlife attractants like oceans.

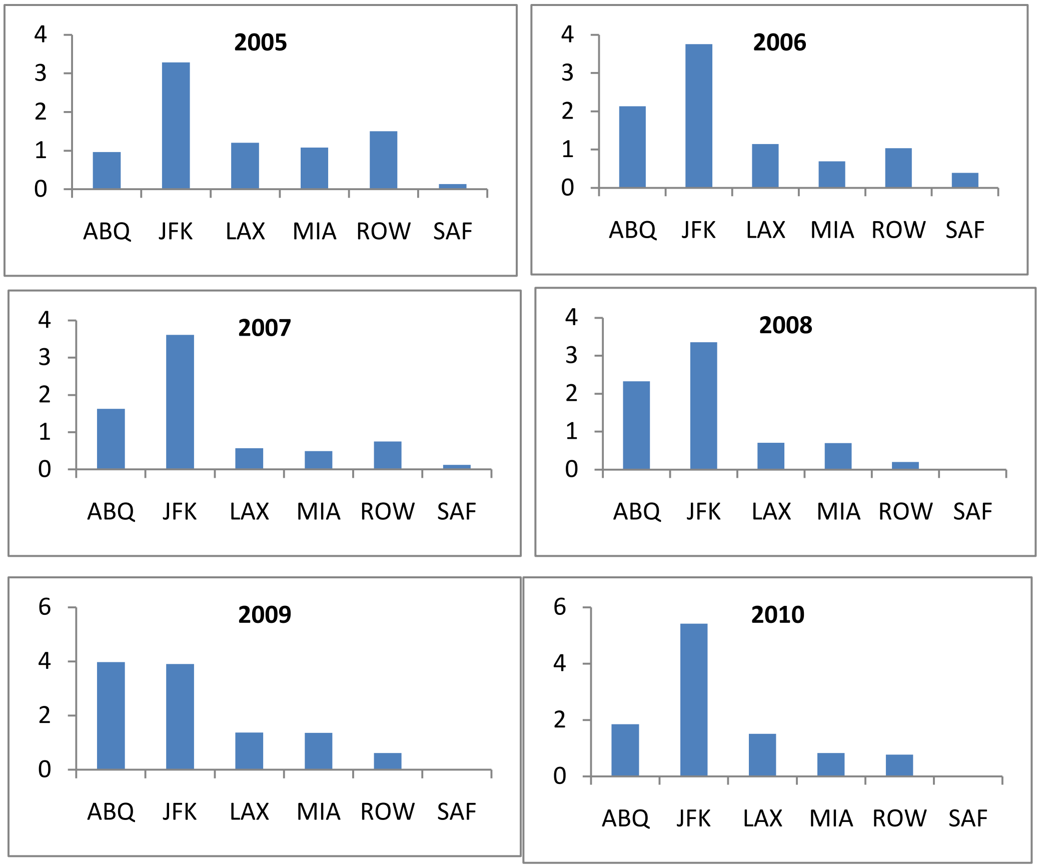


Figure 39: Strike Rate Comparison

4.2.2 Wildlife Control Techniques

There are several techniques airport officials and other certified personnel can follow once the WHA and the WHMP have been completed. It is important to understand, however, that there is not a defined method for dealing with hazardous wildlife. There are general types of mitigation procedures highlighted by the FAA:

1. Aircraft Flight Schedule Modification
2. Habitat Modification and Exclusion
3. Repellent and Harassment Techniques
4. Wildlife Removal

Modification to schedules will likely be impractical for most airports, but this will not be determined until further studies are made. If a particular time of the day when most strikes have occurred is noticed at SAF, commercial flight schedules could be modified to avoid these times.

After the completion of the WHA, it will be possible to understand the specific hazards associated with the wetlands of La Cieneguilla as well as other possible sources. The purpose of habitat modifications is to make it less attractive or inaccessible to the target wildlife. According to the FAA, this should "the foundation of every airport's Wildlife Hazard Management Plan." Possible modifications appropriate for SAF could be flow devices set up in all ponds caused by beaver damming. An example of a flow device can be seen in Figure 22. These devices can be inexpensive and relatively easy to assemble, and have proven efficient in avoiding the withholding of water, according to the Animal Protection of New Mexico agency. They direct water across the dams thus lowering the pond levels. Other modifications that could be made are vegetation and dam removal. Vegetation, however, could easily spread. Rarely used solutions approved by the FAA are floating devices such as floating balls to and permeable barriers that prevent birds from staying on the ponds. Exclusion techniques such as fencing of the airport's territory have already been followed.

Figure 40: Flow Device. Source: Animal Protection of New Mexico 2009

There are several FAA approved techniques that if combined with other strategies can be very efficient in repelling wildlife. It is important to keep in mind that wildlife can learn that these devices are harmless if they are used repeatedly without reinforcement. The FAA recommends using a variety of repellent techniques in an integrated fashion only when it is appropriate. Repellent techniques can be classified in several types: Auditory, such as propane cannons imitating shotguns; chemical like pesticides; and visual, taxidermy mounts of coyotes, for example.

Removing the hazardous wildlife will be not only difficult and time consuming, but it will have to be done following state and federal regulations regarding the particular wildlife. The removal can be non-lethal, relocation, or lethal, physically killing the wildlife or its nesting, and it would be done under the supervision of biologists and other qualified personnel. Please refer to Section 4 for more details on relocation of beavers.

There have been 10 wildlife strikes reported at the Santa Fe Airport to the FAA's Wildlife Hazard Mitigation Website since 2001. The last two incidents, in 2006 and 2007 respectively, involved the ingestion of birds. It is important to note that this was three years before the beavers arrived. There have been no more wildlife strikes reported since the beavers arrived. There was not a specific event that triggered the Wildlife Hazard Assessment. There was a nationwide mandate by the FAA that every commercial airport conduct a WHA. This was a result of the emergency Hudson River landing in January 2009. The assessment at the Santa Fe Airport, scheduled to complete during the last quarter of 2011, will include information on the species endangering aircraft, their numbers, locations, movements as well as wildlife attractants on or near the airport. After further analysis, the FAA will determine whether the airport is in such danger that a WHMP needs to be implemented to mitigate these hazards.

4.2.3 Hazardous Wildlife Attractants On or Near Airports

There are certain land uses that may attract hazardous wildlife on or near public-use airports. Facilities such as wetlands, agricultural crops and wastewater treatment facilities can increase the potential for wildlife strikes. The FAA established a minimum separation criterion to ensure the maximum possible margins between an airport's air operations area (AOA) and any hazardous wildlife attractant. These separation distances, also known as the critical zones, are based on flight patterns of both piston-powered and jet-powered aircraft, the altitude at which most strikes occur, 90 percent below 3000 feet Above Ground Level (AGL) and National Transportation Safety Board (NTSB) recommendations.

Airports serving piston-powered aircraft only are recommended to have at least a distance of 5,000 feet. Airports serving jet-powered aircraft are recommended to have at least a distance of 10,000 feet. Please refer to Figure 41 for an explanation of these distances. The 10,000 feet perimeter is where arriving and departing aircraft are usually operating at or below 2,000 feet AGL.

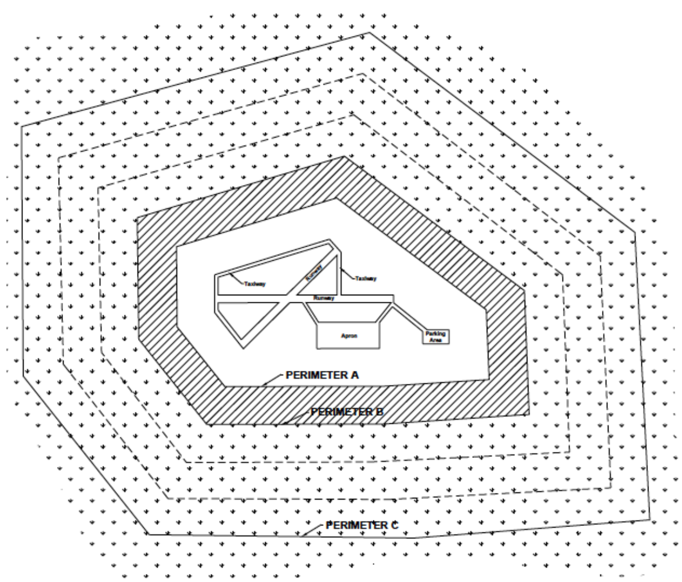


Figure 41: Critical Zones. Source: FAA

Perimeter A and B are the minimum recommended distances between an AOA and any source of wildlife for airports serving piston-powered and jet-powered aircraft respectively. Perimeter C (General Zone) is a five mile recommended distance between the farthest edge of an AOA and any hazardous wildlife attractant to protect approach, departure and circling space.

The purpose of the WHA, as previously discussed, is to identify all the possible hazardous wildlife attractants. It is necessary to wait for the completion of Santa Fe's WHA to consider all high-risk land uses on and around the airport. From a general survey to the region it is one may observe that the most hazardous wildlife attractant is the beaver created wetlands. This is because the long stretch of vegetation and flooded land along the river has attracted several species of birds. These wetlands are enhanced by the beaver activity in that stretch of land. A major controversy has developed between airport officials concerned about aircraft safety and ecologists concerned with watershed health. This has caused political debates across the city. It is also important to note that the municipal Wastewater Treatment Plant is located within the 10,000 foot boundary around airport property. Wastewater Treatment Plants can be attractants to hazardous wildlife according to FAA, and airport officials should work along the plant's personnel to ensure an environment as safe as possible and an assessment should be included in the WHA. Please note this is just a general survey of the area and this text is not intended to be a WHA.

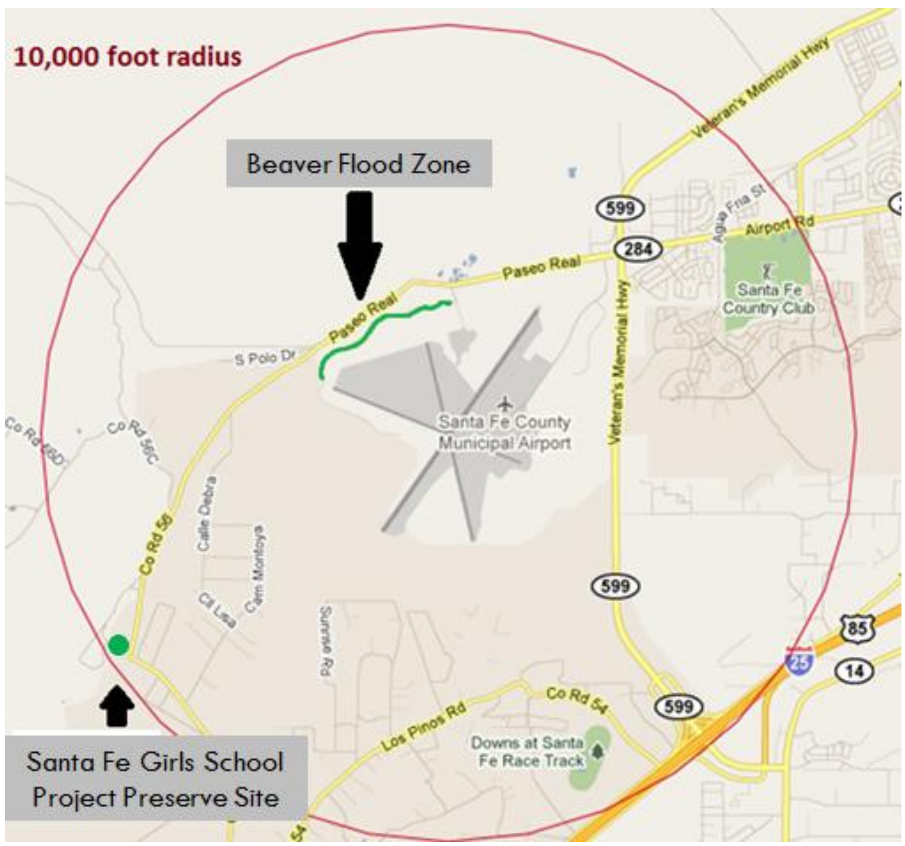


Figure 42: Santa Fe Airport Critical Zone. Source: Google

4.3 Analysis of New Potential Beaver Location

The land that the group visited in order to assess whether or not it would be a suitable potential location for beavers did not turn up favorable results. There were several key aspects of the land that would need to be improved in order for beavers to be introduced to the site. First, there is very weak water flow in the stream. Though there is a constant flow of water, the amount present in the stream is minimal. This is a concern, since spring is the time of year when there should be the most amount of water in the stream. It is possible that during the summer months all of the water might evaporate because there is so little water flowing. There is also another concern about the low water level in the stream. Should beavers dam the stream, the water flow will diminish downstream for a time, creating problems for the residents downstream.

The vegetation in the area is also a concern. It is unclear whether there are enough trees in the area to sustain beaver activities. There are numerous Russian Olive trees in the area, which beavers do not eat. An additional effect of the Russian Olives is that they use more water than trees such as cottonwoods and may be responsible for the weak water flow. Replacing these Russian Olives with trees such as cottonwoods could greatly aid in the creation of a suitable habitat for the beavers to live in. Doing this would make more resources available for the beavers to use for food and construction sources, as well as aid in raising the water level. This would be a crucial step to take before beavers were introduced to the area.

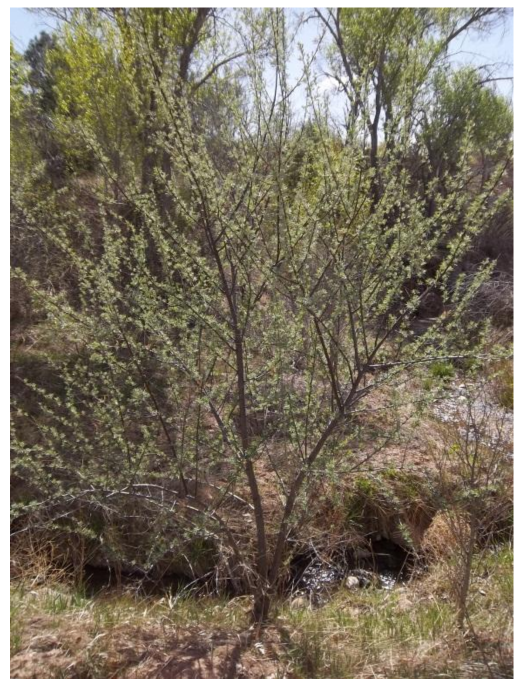


Figure 43: Russian Olive tree

Another issue that faces this particular land is the terrain surrounding the stream. Though the land right next to the stream has grass and trees on it, it quickly becomes very sandy and dry. This presents a limited environment for the beavers to live in, since the dry, sandy area is not suitable for them. If the beavers successfully dam the stream and raise the aquifer level, this might alter the sandy terrain surrounding the stream, although the effect of this would be limited. However, until then, the surrounding land will be a dry and sandy area with limited vegetation, not the most ideal location for beavers to make their home in.

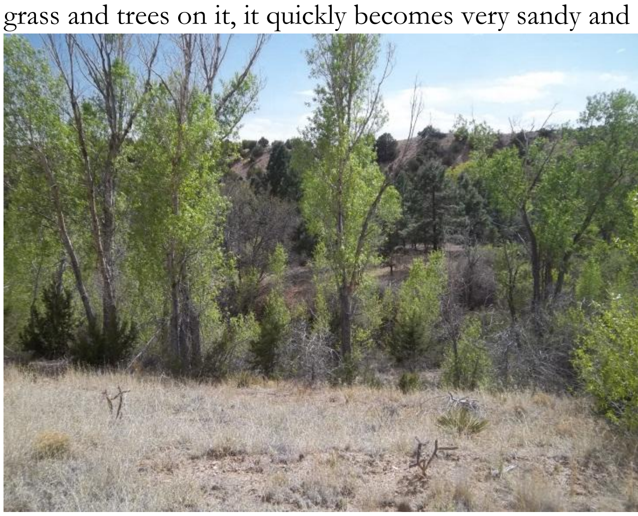


Figure 44: sandy land surrounding stream

Taking these factors into consideration, this particular plot of land does not seem to be an ideal location to introduce beavers. Removing the Russian Olives in the area as well as introducing trees such as cottonwoods and willows will help create a more suitable environment for beavers to live in. However, these actions will take time to affect the land to a degree that would create an ideal environment for beavers. If the beavers were introduced to the area now, they would most likely end up leaving, or worse, die because of lack of food. It would be best to begin removing the Russian Olives and begin planting cottonwoods, then several years from now, assess the land again for beaver introduction.

4.4 Educational Platform

After speaking with one of our sponsors, Mark Ericson, the group discovered that more than one school in the Santa Fe area uses the Santa Fe River as a basis for outdoor education programs. Each school collects water quality data and observes the environment at different spots along the river. The group decided that it would be beneficial to put all of this data in one place, so we gathered water quality data from each of these schools, as well the piezometer data from the Santa Fe Girls' School. After talking to each teacher the group realized that the schools were not communicating as well as they could be. Each teacher expressed that they wanted to be able to work with different schools and grade levels, but it never could be worked out. They are in different parts of the city and the distance between them makes it hard to work on projects together. In order to help the situation our group decided that an education platform in the form of a website would be the most useful for these teachers. The website is a place for information sharing, data input, and project collaboration. It designed with three objectives in mind:

1. To create a repository for data, lesson plans, and field forms collected and created by students and teachers of participating schools.
2. To facilitate the sharing of ideas between educators.
3. To enhance the education of students attending Santa Fe Area schools through the utilization of outdoor education programs.

4.4.1 Website User Interface

The Santa Fe River Teachers' Coalition (SFRTC) website was designed using Google Sites. The homepage consists of a small description of the goals of the site, as well as contact information for the site creator. The goal of the website was to make sharing as easy as possible for teachers in the Santa Fe area. In order to do this, every feature has its own tab at the top of the site. These features are the main shared spaces for all of the coalition to utilize. The left side of the site consists of a column links to each participating school's own page within the SFRTC website. The top tabs and left column are always visible for easy access to all features on the site.

4.4.2 Map of Data Collection Points and Project Sites

The main feature on the homepage of the SFRTC website is an interactive map displaying the location of the data collection points for each school. The map is linked to a spreadsheet containing all the information displayed in the descriptive text box. When a user clicks on a place marker the text box appears displaying information for that point. Each text box includes the name of the school, a short description of the project performed at that point, a link to the SFTRC website, and the grade level that performs the data collection. The image to the right is an example of this graph. Even if the map was not interactive, it would still be an important feature on the website. It is important that the website viewers understand where the project and data collection sites are located in relation to the Santa Fe River and each other. The fact that the map is interactive allows for users to further explore the SFRTC website and the projects that students are involved in.

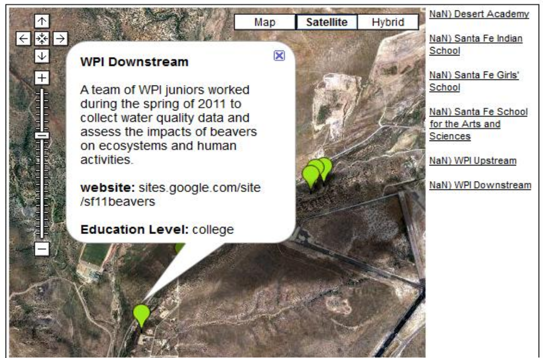


Figure 45: Example of Map

4.4.3 Shared Features

Each tab at the top of the SFRTC website links to a shared space which can be used by all schools and teachers in the coalition. The shared features consist of the following items:

- Calendar
- Student and Teacher Blogs
- Discussion Board

Each item can be utilized by teachers and students to distribute information about projects and resources that are available to them.

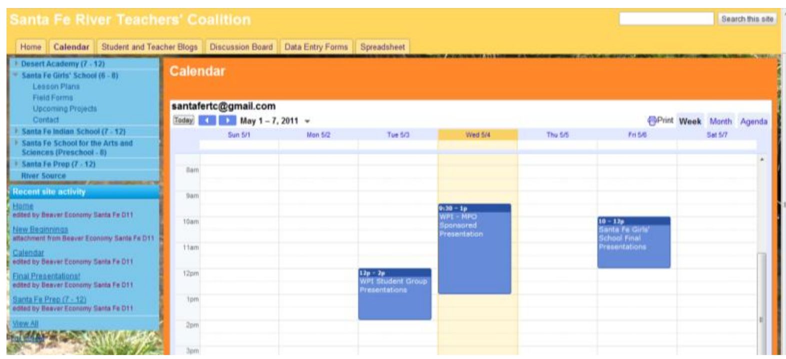


Figure 46: SFRTC Calendar

The calendar is a great feature because it allows participating schools to coordinate their schedules. After speaking to teachers from several different schools in Santa Fe, many expressed interest in completing projects in coordination with different schools and grade levels. However, they had never been able to do this because their only form of communication with each other was through email. A single calendar will allow teachers to better communicate project locations and dates, as well as view the project schedules for each participating school. Each school will create its own Gmail account and use Google Calendar to keep track of important event. The calendar on the SFRTC website will then act as a database, pulling in each individual school calendar and displaying all of the events in one place.

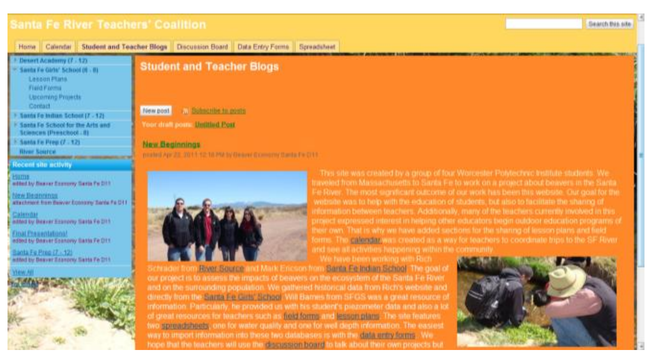


Figure 47: SFRTC Blogs

The student and teacher blog is a place

for reflection. Much of the exercises performed by students involved in outdoor education programs include observations. They could be observing plants, animals or even the general landscape of a project site. At the Santa Fe Indian School, students involved in this program keep journal entries of the different species they observe when in the field. The group felt that it would be useful if students from the Santa Fe Indian School could share some of these entries. Also, students from other schools will also be able to share observations and important findings with the entire coalition. Anytime a new blog is written a notification box on the homepage updates with the first few sentences and first picture from the blog. This allows students and teachers to see when the blog is updated without having to leave the homepage.

The discussion board was developed as a place to ask questions or request to borrow equipment. Each school has access to different materials, and in order to try new projects they may need to use equipment not available to them. The discussion board helps to create a network of equipment, as well as a network of people who can answer a broad spectrum of questions. The discussion board allows teachers to communicate with everyone in the coalition at one time, saving time and reducing communication errors.

4.4.4 Data Entry Forms and Spreadsheets

Also included in the tabs at the top of the SFRTC website is one of the most useful aspects, the data entry form and spreadsheet section. These sections are additional shared spaces and need to be covered in more detail. One of the objectives of the SFRTC website is to create a repository for data, lesson plans, and field forms. The entry forms and spreadsheets focus on the data portion of this objective. As the group discovered, each school produces their own set of data for their project site. Depending on the grade level and curriculum, some type of analysis is then performed by the students. However, this only pertains to their data and they are not aware of data that has been collected from other sections of the river. In order for students to view every school's data it needed to be in one place. The group created a database is Google Spreadsheets which holds information from every school. There are separate spreadsheets for water quality data and well depth data. The information can then be accessed through Google or downloaded into an Excel file for further analysis.

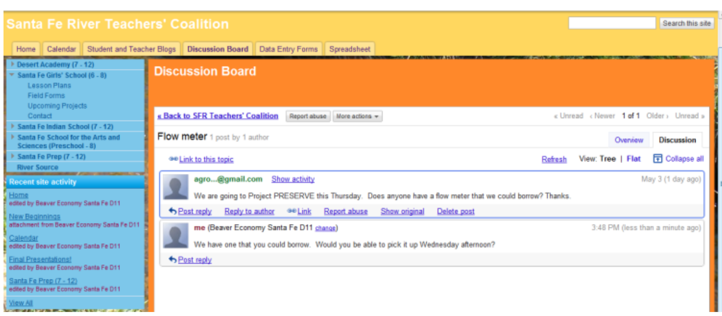
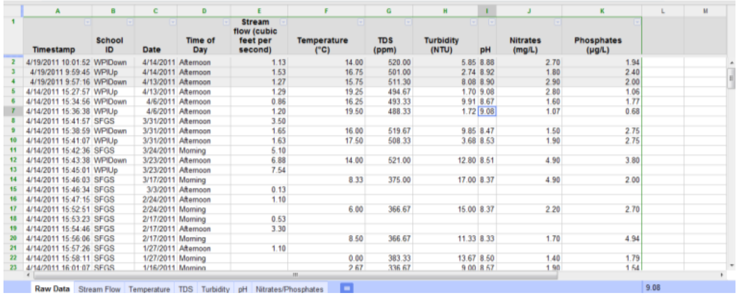


Figure 48: SFRTC Discussion Board

Since the spreadsheet is compiled of data from every school in the coalition there needed to be a way to identify the schools. Therefore, the team designated a unique ID to each school. These IDs refer to each school's project site, and if a school collected data from more than one site they received more than one ID. These unique identifiers were used in the spreadsheet and are a great tool for sorting and analyzing the data.



	Timestamp	School ID	Date	Time of Day	Stream flow (cubic feet per second)	Temperature (°C)	TDS (ppm)	Turbidity (NTU)	pH	Nitrates (mg/L)	Phosphates (µg/L)
2	4/19/2011 10:01:52	WPIDown	4/14/2011	Afternoon	1.13	14.00	520.00	5.85	8.88	2.70	1.94
3	4/19/2011 9:59:45	WPIUp	4/14/2011	Afternoon	1.53	16.75	501.00	2.74	8.92	1.80	2.40
4	4/19/2011 9:57:16	WPIDown	4/13/2011	Afternoon	1.27	15.75	511.30	8.08	8.90	2.90	2.00
5	4/14/2011 15:27:57	WPIUp	4/13/2011	Afternoon	1.29	19.25	494.67	1.70	9.08	2.80	1.06
6	4/14/2011 15:34:56	WPIDown	4/6/2011	Afternoon	0.86	16.25	493.33	9.91	8.67	1.60	1.77
7	4/14/2011 15:36:38	WPIUp	4/6/2011	Afternoon	1.20	19.50	488.33	1.72	9.08	1.07	0.68
8	4/14/2011 15:41:57	SFGS	3/31/2011	Afternoon	3.50						
9	4/14/2011 15:38:59	WPIDown	3/31/2011	Afternoon	1.65	16.00	519.67	9.85	8.47	1.50	2.75
10	4/14/2011 15:41:07	WPIUp	3/31/2011	Afternoon	1.63	17.50	508.33	3.68	8.53	1.90	2.75
11	4/14/2011 15:42:36	SFGS	3/24/2011	Morning	5.10						
12	4/14/2011 15:43:38	WPIDown	3/23/2011	Afternoon	6.88	14.00	521.00	12.80	8.51	4.90	3.80
13	4/14/2011 15:45:01	WPIUp	3/23/2011	Afternoon	7.54						
14	4/14/2011 15:46:03	SFGS	3/17/2011	Morning		8.33	375.00	17.00	8.37	4.90	2.00
15	4/14/2011 15:46:34	SFGS	3/3/2011	Afternoon	0.13						
16	4/14/2011 15:47:15	SFGS	2/24/2011	Afternoon	1.10						
17	4/14/2011 15:52:51	SFGS	2/24/2011	Morning		6.00	366.67	15.00	8.37	2.20	2.70
18	4/14/2011 15:53:23	SFGS	2/17/2011	Morning	0.53						
19	4/14/2011 15:54:46	SFGS	2/17/2011	Afternoon	3.30						
20	4/14/2011 15:56:06	SFGS	2/17/2011	Morning		8.50	366.67	11.33	8.33	1.70	4.94
21	4/14/2011 15:57:26	SFGS	1/27/2011	Afternoon	1.10						
22	4/14/2011 15:58:11	SFGS	1/27/2011	Morning		0.00	383.33	13.67	8.50	1.40	1.79
23	4/14/2011 16:01:07	SFGS	1/16/2011	Morning		2.67	336.67	9.00	8.57	1.90	1.54

Figure 49: Water Quality Data Spreadsheet

Although the spreadsheet is a great tool for a database, it is not ideal for students to be entering data directly into the spreadsheet. It is very risky to allow every student to access to the data. The group's way around this was to create forms linked to the spreadsheets. The forms allow you to enter all collected data from a project location without having to access the spreadsheet. The School ID, Date, and Time of Day columns must be completed in order to submit the form. However, the rest of the data does not need to be entirely completed. This is because of issues that may arise because of the weather or equipment. Once the form is submitted it automatically enters the information into the appropriate row and columns. If the wrong information is added through a form, the spreadsheet can be accessed and the information changed. There are separate forms for water quality data and well depth data.

Within the form are two different types of data entry. The first is a pull-down menu. The pull-down is used for the School ID and Time of Day columns. The menu for the School ID column consists of the unique identifiers for each school. The menu option does not allow the user to enter any text, so the spreadsheet will only contain the unique identifiers that are available in the form. The Time of Day menu consists of two options, morning and afternoon. It is not important for the students to know at exactly which time the data was collected, but it does help them to know if it was in the morning or after lunch for analysis purposes. The second type of data entry is text. For each column included in the form the user can enter any type of data, including numbers and text. This is ideal for the type of data that each school collects.

School ID *
Choose your school ID from the list below:
DA

Date *
Enter the data on which the data was collected in the form MM/DD/YY:

Time of Day *
Choose which time of day you took the data:
Morning

Stream flow (cubic feet per second)
Enter the average stream flow in cubic feet per second:

Temperature (°C)
Enter the average temperature in Celsius:

TDS (ppm)
Enter the average number of total dissolved solids in parts per million:

Turbidity (NTU)
Enter the average turbidity value in NTU:

pH
Enter the average value for pH:

Nitrates (mg/L)
Enter the average value of nitrates in milligrams per liter:

Phosphates (µg/L)
Enter the average value of phosphates in micrograms per liter:

Submit

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Figure 50: Water Quality Data Form

A great feature of using Google Spreadsheets as a database is being able to automatically update a series of charts for analysis. For both the water quality data and well depth data spreadsheets a series of tabs at the bottom of the page display trend charts for each data type. These trend charts allow the user to specify the amount of data they want to see by adjusting a timeline underneath the graph. The trend charts are a very useful tool for students working on projects along the Santa Fe River.

Figure 51: Example of Trend Chart

The picture above gives an example of a trend chart. The chart on the top has not been changed. The chart on the left has had its timeline manipulated in order to zoom in on information from 2008 to present.

As more outdoor education programs in the Santa Fe area develop, there will be a need to add more project sites to the interactive map on the homepage. Since the map is linked to a spreadsheet, a specific form is used to add more locations to the spreadsheet which will then update the map. Locations can also be removed from the map by accessing that spreadsheet and deleting the row.

4.4.5 Individual Pages

All of the shared spaces on the SFRTC website are very useful, but the group decided that it would also be beneficial for each school in the coalition to have their own page on the website. The left column of the website contains links to each school. There are also four subpages connected to each school:

- Lesson plans
- Field forms
- Upcoming projects

- Contact

These individual pages allow website users to learn about each school in the coalition, as well as download information regarding lesson plans and field forms specific to each school.

Figure 52: SFRTC Side Bar

The main page of each school contains a small description about the school, a link to the school's district website, and a notification box linking to the Upcoming Projects section. The Lesson Plans and Field Forms subpages are identical. Each one uses a file cabinet to which you can upload documents. This is a great place for teachers to display their plans. Also, if any other teachers in the coalition would like to borrow a field form there is easy access from the website. The Upcoming Projects subpage is in the same form as the Student and Teachers Blogs section on the main website. It is a place where either the students or teachers from the school can talk about upcoming field trips, or past trips they have taken. Finally, the Contact section is available for each teacher to provide their email and description about themselves, as well as contact information for the school.

4.4.6 Community Video

Included in the website, is a video aimed at dispelling the negative sentiments of locals about beavers by describing their positive impacts and providing ways of managing beaver flooding. We hope this video will be distributed amongst the community to help change people's opinions about beavers. Please see Appendix D for the video dialogue.

5. Conclusions and Recommendations

The results and analysis that we have compiled have led us to several conclusions. Along with these conclusions, we have developed recommendation for our objectives based on the data and analysis that we have performed.

5.1 Water Quality Conclusions

Throughout the analysis of the data that we have collected, only one set of data has stood out as being concrete evidence of the positive impacts of beavers. Based on the data collected by the Santa Fe Girls School, it is apparent that beaver presence acts to increase the level of the aquifer in the area. This conclusion is reinforced by data spanning a five year period. For two of those five years, beavers inhabited the area upstream of the SFGS site. During this time, there was a noticeable increase in the aquifer level. Several months after the beavers left the area, the aquifer level drastically plunges. The fact that the aquifer level increased to a significant amount when the beavers arrived, then decreased by a significant amount once they left, solidly supports the conclusion that the presence of beavers increases the aquifer level in an area.

We also came to the conclusion that stream flow increases when beavers are present in the area. However, there is less evidence to support this conclusion. The data from the SFGS shows a steady increase over the two year period when the beavers lived near the testing site. Like the aquifer level, once the beavers leave, the stream flow plummets. This combination of increasing and decreasing level supports the conclusion that one of the effects of beavers is to increase stream flow. However, the data that we collected shows no difference between the stream flow upstream and downstream of the beaver habitat that we studied. This goes against the SFGS data, thus taking away from the validity of the conclusion. Though the SFGS data strongly suggests that stream flow is increased by beavers, the data that we collected proves that further data collection is necessary to conclusively state anything.

It is important to note that one of the concerns of landowners downstream of the beavers is that the beaver dams trap the water upstream and prevent it from reaching their land. Our results show that there is no difference in stream flow above and below the dams. This would indicate the beavers have no impact on the water levels downstream. The same amount of water is present below the dams as above. This means that the beavers are having an overall positive impact because their ponds allow for aquifer recharge and do not stop water flow through the river. More testing would need to be done, but according to our results, the concern that beavers are slow down stream flow is unfounded.

Along with the aquifer level and stream flow, our data led us to the conclusion that the beavers themselves present no negative impacts. The rest of the data either showed no change in the water quality being studied, or failed to provide enough evidence of a conclusion. For most of these tests, there appeared to be a trend, but we did not have enough data to draw conclusions.

5.1.1 Water Quality Recommendations

The conclusions that we have come to, in relation to the quality of the water in the Santa Fe River, have led us to a recommendation. Since only limited conclusions were made about two of the tests, and only on with certainty, it is recommended that testing continue for all the water quality tests performed in this report. The main consequence we encountered when drawing our conclusions was the lack of data for the various water quality tests. Further testing would remedy this.

5.2 Beaver Introduction Assessment Conclusion

The assessment of the land on the Tesuque pueblo for the suitability of introducing beavers to the area brought us to a conclusion in regards to whether or not to introduce beavers to that area. We decided that, due to the low level of water flow present in the stream, the land may not be suitable to introduce beavers to. The reasoning behind our conclusion is that there is not enough water in the area for the beavers to construct a suitable habitat. Even if the beavers did dam the small river that flowed through the area, this activity would completely cut off the water downstream for a significant period of time. Most likely this also would not create a pond deep enough for them to make a shelter in. If the flow was stopped because of the beavers, it would infringe upon the right of landowners downstream.

5.2.1 Beaver Introduction Assessment Recommendations

Based on our conclusion, we are recommending that an expert in this field do an official assessment of this plot of land and make an official review. We believe that this land has the potential to be a suitable environment for beaver habitation. There are numerous cottonwoods and willows in the area, providing a food source and building material for beavers. There are however, lots of Russian Olives as well, which use up much more water than cottonwoods and willows. We recommend removing the Russian Olives, since this should help decrease the amount of water that is used by the vegetation. This could possibly increase the level of water in the area, even if it is only a small amount. Once the river has more flow in it, the beavers might be able to build their dams and lodges. The land around the area is also very dry, with only a small strip of vegetation near the river. The removal of the Russian Olives would increase the availability of resources for cottonwoods and willows, thus increasing the area that the beavers can make their home and making it a more suitable habitat for beavers.

5.3 Santa Fe River Teachers' Coalition Recommendation

The Santa Fe River Teachers' Coalition and its accompanying website can be a valuable resource for environmental and student education. In order for the Coalition to flourish and be effective, it has to be implemented to its full potential. In order to do this, it is recommended that constant communication be maintained between the teachers of the involved schools. Learning how to utilize the Coalition is also key to its success. The website itself has many tools to make use of, and full knowledge of how to apply these tools is essential. It is also recommended that data entry be kept up to date so that it can be truly helpful to the students and community in recognizing trends in water quality. The final recommendation for the Santa Fe River Teachers' Coalition is to involve as many organizations as possible, since this will increase education regarding the environment, as well as educating future generations.

5.4 Assessment of Wetlands Conclusions

As mentioned earlier, Santa Fe Airport officials and biologists are conducting a Wildlife Hazard Assessment at the time of the conclusion of this project. After the assessment is completed and a management plan is put together, biologists and other qualified people from the different organizations involved in the management plan will take the necessary measures to mitigate the hazardous wildlife. Because of the political tensions associated with the future of the wetlands, and consequently the beavers, we were advised to refrain from making any recommendations to the airport, the city, or any other affiliated parties. After further discussions with our sponsors and advisors we concluded that the only thing organizations such as River Source and other non-governmental organizations could do as an attempt to protect the future of the beavers is to try to get involved in the Wildlife Management Plan process by becoming part of the Wildlife Hazard Working Group (WHWG). The WHWG is a group created by the airport management with the goal of providing assistance with the wildlife mitigation process. Membership to this group is controlled by the airport's manager, thus activists such as Rich Schrader and members of the Santa Fe Watershed Association, WildEarth Guardians or even teachers from local schools need to get in touch with airport officials and ask to be included in this process. This will allow them to be a part of the overview of the management process and hopefully provide a different perspective and suggestions to the steps that the Wildlife Hazard Assessment will lead to in the future.

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Appendix A: FAA Recorded Strike Data

TIME OF DAY	INCIDENT DATE	PHASE OF FLIGHT	SPECIES	BIRDS STRUCK	BIRDS SEEN	INGESTED
Day	8/21/01	Take-off run	Burrowing owl	1	1	False
Day	2/24/02	Climb	Unknown bird - medium	1		False
Day	6/14/02		Unknown bird - medium	1		False
Day	11/4/02	Climb	Unknown bird - small	1	2 to 10	False
Day	6/27/04	Take-off run	Prairie dog	1		False
Night	10/7/05		Blue-headed vireo			False
Day	10/13/06	Take-off run	Perching birds			False
Day	11/24/06	Take-off run	Unknown bird or bat			False
Day	12/5/06	Landing Roll	Horned lark	1	2 to 10	True
Day	9/19/07	Take-off run	Unknown bird - small	1	11 to 100	True

Appendix B: Pueblo Information

There are eight pueblos located near the city of Santa Fe. They include: Tesuque, Pojaque, Nambé, San Ildefonso, Santa Clara, Ohkay Ohwingeh, Picurís, Taos. Mark Erikson has indicated that some of these pueblos might have a spiritual connection with beavers and therefore would be interested in attempting to reintroduce them to the pueblos. It is not clear which of the pueblos would be interested in the beavers. Below is some preliminary information on the eight northern pueblos.

The Tesuque pueblo is located on a stream that is most often dry. The translation of the name means "spotted dry place." This name refers to the creek which is sometimes spotted with water. If there were cottonwood trees in the area it is possible that a beaver colony would be beneficial to the area to help create ground water that could be used for the organic farms located there.

Pojoaque pueblo has been undergoing an economic overhaul including an extensive casino, golf course, and a new luxury resort.

Nambé pueblo is located north of Santa Fe and is a fairly small pueblo. It is situated in a flat valley with much vegetation. Most of the activities here are recreational outdoor activities such as fishing and hiking. There is a lake there as well which could be one of the best sites for beaver relocation because of the ample vegetation as well as the presence of water. Much of the tourism to this area is nature related and would be a good match for the beaver presence.

San Ildefonso pueblo is best known for its pottery but the name translates to "where the water cuts through."[70] The people there place a high value on education. Many of them speak English as a second language and go on to complete high school and college educations. This would make them a good fit for the beavers because they might be more open to understanding how they could live together and gain from the ecosystem services offered by the beavers.

Santa Clara pueblo translates to "spring water." This pueblo would also be a great candidate for beaver relocation because it features four lakes, a stream, and a forest with pine, spruce, and aspen trees. These areas are currently suffering due to a wildfire that swept through the area in 2000. We could evaluate how beaver ecosystem services could help the area recover from the fire.

Ohkay Ohwingeh pueblo was the most welcoming to the Spanish when they first arrived. Much of their tourism today relies on pottery and other crafts.

Picurís pueblo is also known for their pottery but is one of the smallest pueblos consisting of only 300 residents.

Taos pueblo is translated to "red willow place." This pueblo is best known for the unique ancestral living spaces that resemble modern-day apartments. There is no electricity or running water in these

[70] (Anonymous2007)

structures, so many of the residents live in modern homes outside of the main village. Some of the older structures have been converted into shops and storefronts.[71]

[71] Cheek, 143-55

Appendix C: Testing Methods

The following are descriptions of the proper methods for data collection. All of these methods were used while gathering measurements of stream flow, temperature, pH, turbidity, total dissolved solids, nitrates, and phosphates.

Stream Flow Testing Method

Figure 53. Plastic Probe Propeller

There are many different methods for calculating stream flow. We chose to use a flow meter. This piece of equipment uses a propeller with a magnet to digitally measure the instantaneous velocity of water flows. This probe was first introduced in 1990 by Global Water to measure flows in open channels and partially filled pipes. The model used for data collection here, FP101-FP201 Flow Probe, consists of a plastic Turbo-Prop propeller encased by a plastic housing. See Figure 53. The propeller and housing are connected to a telescoping metal rod that is attached to digital readout display. The procedure for calculating stream flow is as follows:

1. Prior to using this device, check that the display is properly calibrated to zero. To do this, press both buttons simultaneously.
2. Check that the propeller turns freely by blowing strongly on the propeller.
3. Use the right button to select the mode for velocity. The top number on the screen is the instantaneous velocity. You can alternate the bottom number between maximum and average velocities using the left button.
4. Place the propeller at the desired location, being sure to stand downstream of the device, submerge the propeller to approximately forty percent of the stream's depth for 30 seconds. See Figure 54.
5. Record the reading from the digital display for the average velocity.
6. Calculate the cross-sectional area of the flow stream.
7. To obtain stream volume flow, multiply the average velocity by the cross-sectional area.

Figure 54: Proper Positioning of Probe

Surface Water Temperature Testing Method

Temperature is an inherent property of water. Even though it doesn't directly tell us about the influence of beavers on the Santa Fe River, it can give us insight into the health of the river and what types of organisms are living in it. We took a very simple approach to taking water temperature. We used a simple glass thermometer and followed these guidelines:

1. Find a section of the river that is shaded
2. Hold the entire thermometer under water for at least one minute
3. Take the thermometer out of the water and read immediately

We then repeated these steps for another shaded section of the river for a total of two readings per data collection site. Average those values to get the average temperature of the stream. After all measurements have been collected, rinse off thermometer with deionized water and dry it.

Total Dissolved Solids and pH Testing Method

Total dissolved solids, or TDS, is the combination of all inorganic and organic substances contained in a liquid that are present in a molecular or suspended form.[72] These substances can include any salt, metal or mineral. The lower the TDS level of water, the more pure it is. We used TDS because it is a quick and inexpensive way to determine water purity. The only true way to measure TDS is to evaporate a water sample and weigh any remaining substances. This is very reliable, yet expensive, and not in the realm of our capability for this project. Companies have developed inexpensive tools to help measure TDS, including the Multi-Parameter Tester 35 produced by Oakton. We used this tool to take measurements of TDS and pH.

pH is a primary factor in the chemistry of water systems, and can also be determined using the Multi-Parameter Tester 35. It is measured routinely by organizations such as the Environmental Protection Agency and the U.S. Geological Survey. pH directly affects physiological functions of plants and animals and is an indicator of the health of a water system, in this case the Santa Fe River.[73] The measured pH for water needs to be between 6.5 and 8.5.[74] We followed these guidelines when taking measurements:

1. Put the instrument in the correct mode (pH or TDS).
2. Fully place the tip into the river and hold there until reading stabilizes.
3. Record either the pH or TDS measurement.
4. Repeat these steps in different sections of the river for a total of three readings.
5. Be sure to rinse off the tip when finished.

Turbidity Testing

Turbidity is caused by the presence of suspended and dissolved matter in water, which can make it appear cloudy or muddy. The most common matter found in water is clay, silt, plankton, organic acids, and dyes. Turbidity is not an inherent property of water, however it is a good indicator of the health of water bodies. The following are examples of incongruent uses for turbidity data[75]:

- Regulating and maintaining drinking water clarity

[72] (Samborn January 2008)
[73] (USGS 2008, pH 3)
[74] (United States Environmental Protection Agency 2011)
[75] (USGS 2005, Turbidity 1-55)(U.S. Geological Survery 2011)

- Determining water clarity for aquatic organisms
- Real-time monitoring that indicates watershed conditions
- Determining transport of contaminants associated with suspended materials

For the purposes of our project, turbidity will be analyzed both upstream and downstream of beaver dams in order to conclude how dams affect the amount of suspended and dissolved matter in water.

The accepted turbidity of water is less than 5 NTU (nephelometric turbidity unit).[76] The equipment used to measure turbidity at each of the sites is the Hach Model 2100P Portable Turbidimeter. It measures turbidity from 0.01 to 1000 NTU in automatic range mode with automatic decimal point placement. The turbidimeter operates on the nephelometric principle of turbidity measurement, using a 90° detector to monitor scattered light and a transmitted light detector. The instrument calculates the ratio of signals from these two detectors in order to determine the turbidity. The procedure that we followed is listed below:

1. Collect a sample of water from the river in a clean container. Hold sample cell by top and cap the cell.
2. Wipe the cell with a soft, lint-free cloth to remove water spots and fingerprints.
3. Press the power button to turn the instrument on.
4. Insert the sample cell in the instrument cell compartment so that the diamond mark aligns with the orientation mark in the cell compartment. Close the lid.
5. Select the manual or automatic range by pressing the **RANGE** key. In our case we used the automatic range.
6. Press **READ**. The display shows turbidity in units NTU.[77]

Nitrate and Phosphate Testing Method

We used the Cadmium Reduction Method for determining the level of nitrates in the water samples collected at both the upstream and downstream sites. For collecting phosphate data we used the Orthophosphate (Ascorbic Acid) Method. Both of these methods are viable for water, wastewater, and seawater. For our measurements we will be using a Hach DR/890 Colorimeter for all measurements of nitrates and phosphates. The procedure for Nitrate testing is as follows:

1. Load the program for nitrates on the colorimeter
2. Rinse out glass tube three times before filling with 25mL of water
3. Add contents of NitraVer 5 Nitrate reagent powder pillow to the sample
4. Screw on cap and shake vigorously for one minute (use timer in colorimeter)
5. 5 minute reaction period begins (use timer in colorimeter)
6. While reaction is occurring rinse and fill another glass tube with 25 mL of water.

[76] (Health Canada 1995)
[77](Hach Company 2008, 13-22)

7. Wipe off surface of the glass and place in colorimeter
8. Use this untreated sample to zero the colorimeter, press **ZERO.**
9. Clean the prepared sample and place it in the colorimeter to read the sample, press **READ.**
10. Record reading from colorimeter.

The procedure for testing phosphates is as follows:

1. Load the program for phosphates on the colorimeter.
2. Rinse out glass tube three times before filling with 25mL of water.
3. Add contents of PhosVer 3 Phosphate powder pillow to the sample.
4. Screw on cap and shake vigorously for 15 seconds.
5. 2 minute reaction period begins (use timer in colorimeter).
6. While reaction is occurring rinse and fill another glass tube with 25 mL of water.
7. Wipe off surface of the glass and place in colorimeter.
8. Use this untreated sample to zero the colorimeter, press **ZERO.**
9. Clean the glass of the prepared sample and place in the colorimeter to read the sample, press **READ.**
10. Record reading from colorimeter.

The limit for nitrates in safe drinking water is 10 mg/L of nitrate-nitrogen (NO_3-N). This standard was set in 1974 in the Safe Drinking Water Act. Infants younger than six months are particularly susceptible to the dangers of high levels of nitrates. Some of these dangers include shortness of breath and methemoglobinemia.[78] Similarly for phosphates the safe level for drinking water it 10 mg/L.

[78] (Environmental Protection Agency 2010)

Appendix D: Video Dialogue

Santa Fe, the oldest state capital in the U.S., is located in the northern part of New Mexico. As the population of the capital city grew, so did the demand for water. As a result, within the past 50 years, water in the Santa Fe River area has become a scarce resource.

Two large dams upstream of the river provide water to the city of Santa Fe, but trap almost all of the water, limiting the amount allowed to flow through the city.

Consequently, there is no regular flow in the Santa Fe River.

Organizations like the WildEarth Guardians have initiated projects aimed to improve the river's health. In 1996, WildEarth decided to start a re-vegetation campaign in the La Cieneguilla Land Grant area. The goal of the project was to remove non-native trees such as Russian Olives and reintroduce native species such as willows and cottonwoods.

Within the first few years, the new plantings took root, populating the land along the river with more trees and shrubs, creating a suitable environment for numerous species of birds, such as kingfishers and sparrows.

The new vegetation also attracted beavers. Historically, beavers have been present in New Mexico and most of North America. The beavers in the Santa Fe River began damming and building their lodges, which in turn created wetlands that attracted ducks and other waterfowl, as well as fish and frogs. These wetlands help raise groundwater levels by allowing more water to be absorbed into the ground, creating a welcoming environment for plants.

School teachers in the Santa Fe area are taking advantage of this thriving ecosystem, offering their students hands-on exercises near the river, including tree wrapping. These experiences help them to understand the benefits of biodiversity and its importance to the local ecosystem.

Tree wrapping is a very simple and inexpensive technique used to control damming caused by beavers. The wire acts as a barrier, preventing beavers from chewing on the trees.

Other options for limiting beaver behavior include flow devices, used to control the number and size of ponds. They allow water to flow through the dams, avoiding excessive water retention. Flow devices can be made with PVC pipes and other readily available materials.

Trapping and killing the beavers is not a permanent solution. If you are being affected by these animals, please wrap your trees. It is the only way to keep them from returning and flooding the land again.

For assistance in building these devices please contact Steve Carson from Rangeland Hands. To view instructions on how to build these devices please visit the Animal Protection of New Mexico website at www.apnm.org.

Appendix E: WPI Collected Water Quality Data

School ID	Date	Time of Day	Stream flow (cubic feet per second)	Temp (°C)	TDS (ppm)	Turbidity (NTU)	pH	Nitrates (mg/L)	Phosphates (µg/L)
WPIDown	4/14/2011	PM	1.13	14.00	520.00	5.85	8.88	2.70	1.94
WPIUp	4/14/2011	PM	1.53	16.75	501.00	2.74	8.92	1.80	2.40
WPIDown	4/13/2011	PM	1.27	15.75	511.30	8.08	8.90	2.90	2.00
WPIUp	4/13/2011	PM	1.29	19.25	494.67	1.70	9.08	2.80	1.06
WPIDown	4/6/2011	PM	0.86	16.25	493.33	9.91	8.67	1.60	1.77
WPIUp	4/6/2011	PM	1.20	19.50	488.33	1.72	9.08	1.07	0.68
WPIDown	3/31/2011	PM	1.65	16.00	519.67	9.85	8.47	1.50	2.75
WPIUp	3/31/2011	PM	1.63	17.50	508.33	3.68	8.53	1.90	2.75
WPIDown	3/23/2011	PM	6.88	14.00	521.00	12.80	8.51	4.90	3.80
WPIUp	3/23/2011	PM	7.54						