Pollutant Mapping & Management Methods Along the San Pedro River

WPI

KINGUE adventure school

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Abstract (English)

Water Pollution is a problem throughout the world that needs addressing to preserve healthy habitats. Environmentalist groups worldwide have developed methods of cleaning certain polluted waterways, and each clean-up process requires a site-specific foundation to build off. For the San Pedro River, the clean-up process foundation was built by creating a map highlighting all the potential contamination sources. A collection of management methods supplements the map and shows the possible route to explore when treating confirmed pollutant sites. Through these methods, we found that there are four primary potential pollutant sources: industrial, agricultural/rural, residential, and commercial pollutants. Research also showed a large scale of nonpoint pollutant sources that can be carried into the San Pedro River by tributaries and stormwater runoff. With a collection of management methods, these identified potential pollutants can be treated. This offers an in-depth analysis of what each method combats, recommended use, potential issues, cost analysis, maintenance, and upkeep, what is needed, and how a method takes to affect the water.

Executive Summary (English)

Water is essential to all phases of life, and river pollution is dangerous and a nuisance. A contaminated river will not provide much to the surrounding communities other than a new discharge spot for waste (The World Bank, 2020). Efforts to mitigate water pollution prove to be a multi-faceted, long-term, but crucial project. Some of these efforts used maps to present their determined locations of pollution. All in all, changing the quality of water in riverways is necessary to develop better health, biodiversity, economy, and tourism of the riverbank communities.

The San Pedro River runs through Quito, Ecuador. There are multiple urban sectors, factories, agricultural farms, and commercial or tourist spots along the banks of it, all of which potentially pollute the river with their wastewater. Past efforts to improve San Pedro's water quality include the Kingue Adventure School's river cleanup for microplastics. In collaboration with the Kingue Adventure School, we, a team of student researchers from Worcester Polytechnic Institute, used categorical methods to develop a map and treatment plan for the individual pollutants.

Our goal, along with that of the Kingue Adventure School, is to map out the location and type of possible pollution sources along the San Pedro River. We aim to identify various methods to treat the contamination problem that, in time, will better the quality of the river and thus help the San Pedro River return to a healthy state. The Kingue IQP team determined that the first step to achieving the long-term goal was by promoting the clean-up and the conservation of the San Pedro River. This goal was reached by creating: a map with all potential pollution sources along and around the river, a list of contamination management methods, and an easy-to-read presentation of the collected data.

The first objective used Google Maps and internet research to determine the location of potential pollution sources. The second objective involved internet research of current waste management systems and procedures, and interviewing Dr. Camacho, an industrial pollution management consultant. The third objective used online investigation and the creation of descriptive infographics. The three objectives and their methodologies lead us to create a map of potential contamination sources and a list of waste management systems in the form of infographics.

Finding the right mapping programs was important for our group to relay data in a specific and understandable format. After completing a comparative analysis for various visualization systems, Google Maps was determined as the best fit for our project's scope. Google Maps provided a basic geographical map that could switch between various base maps. The easy-to-use tools and the ability to be shared amongst people to work on it simultaneously without undoing another person's work were the main reasons for selecting the map. We used the map to easily trace the river's span and drop pins at locations we defined as potential contamination sources.

After creating the map, we discovered two types of contamination sources. The first was non-point sources such as the San Pedro's tributaries. The second was point sources divided into four general pollution contamination source types: agricultural, commercial, industrial, and residential (Figure E.1). These four point source, contamination source types potentially contribute to the pollution of various organic matter levels, chemical waste, and heavy metals.

Figure E.1: Possible pollutant source locations along the San Pedro River.

We determined 29 pollution management systems that could aid in reducing water contamination from various sources. The management systems can be site-type specific and generic mitigation systems. These were ultimately presented in the form of one-page summaries, making the information easy-to-read for the public and easy-to-use in the field.

We determined that infographics were the best way to present our collected data. Researchers worldwide have found that using infographics improves education by involving visual stimuli to engage the audience with the presented information (Bicen, 2017). Our final infographics take many forms, and each type covers various aspects of our list of waste management systems (Figure E.3). To create the final versions of the infographics, there was lots of trial and error and back and forth between students, advisors, and sponsors, but ultimately presented the desired data in an easy-to-read manner.

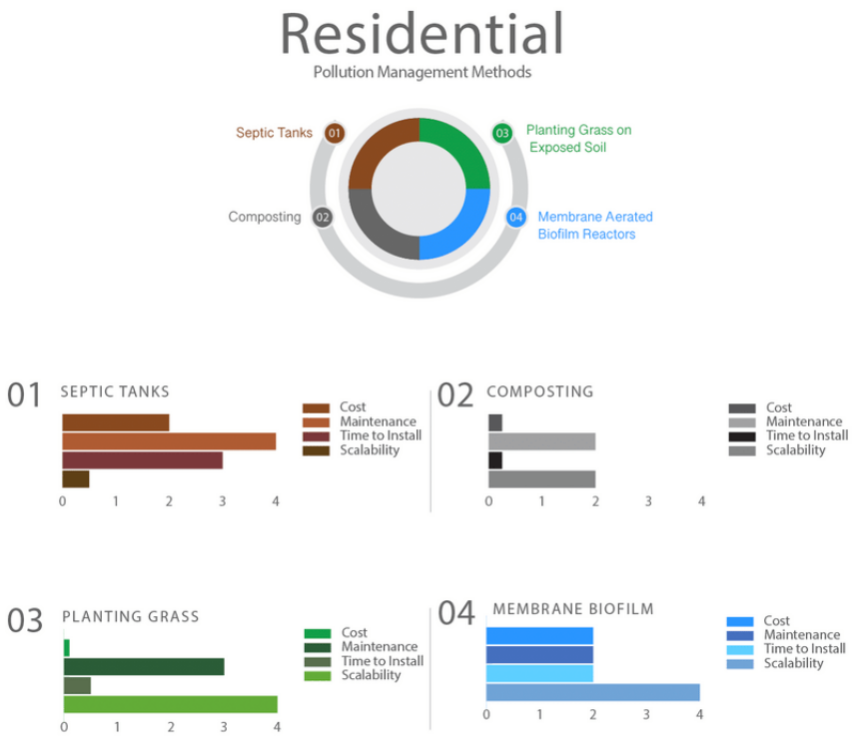

Figure E.2: Infographic of pollution management for residential contamination sources

Based on our research on river conservation strategies and the impact of water pollution on different life forms, we produced the following recommendations that we think will further our project's future progress. The map and wastewater management methods manual offer insight into the contamination in San Pedro and ideas on how to combat it. These may be useful for future community engagement and the spread of awareness, such as the Kingue Adventure School's collaboration with Patagonia®.

For future work, we recommend that Kingue expands on the current map. This can be done by determining point sources along the San Pedro's tributaries or confirming the potential contamination sources with water tests. Another future work is that Kingue Adventure School uses the map and list of management methods to create a waste management solution for the New Horizons Refuge, a climbing hut, and the San Pedro's first potential pollution source. Finally, we recommend that Kingue Adventure School uses infographics to teach and inform the local population about the San Pedro River and its pollution, starting at the World Water Day hike along the San Pedro river with Patagonia.

Abstract (Spanish)

La contaminación del agua es un problema en todo el mundo que hay que abordar para preservar los hábitats saludables. Los grupos ecologistas de todo el mundo han desarrollado métodos para limpiar determinadas vías fluviales contaminadas y cada proceso de limpieza requiere una base específica para el lugar en el que se va a realizar. En el caso del río San Pedro, la base del proceso de limpieza se construyó mediante la creación de un mapa que destaca todas las fuentes potenciales de contaminación. Para complementar el mapa, se utilizó una colección de métodos de gestión para mostrar la posible ruta que se puede explorar al tratar los lugares contaminantes confirmados. A través de estos métodos descubrimos que hay cuatro fuentes potenciales de contaminantes principales: contaminantes industriales, agrícolas/rurales, residenciales y comerciales. La investigación también mostró que puede haber una gran escala de fuentes contaminantes no puntuales que pueden ser llevadas al río San Pedro por los afluentes y la escorrentía de las aguas pluviales. Una vez identificados estos contaminantes potenciales, pueden tratarse mediante el uso de la colección de métodos de gestión que ofrecen un análisis en profundidad de lo que combate cada método, el uso recomendado, los posibles problemas, el análisis de costes, el mantenimiento y la conservación, lo que se necesita y el tiempo que tarda un método en afectar al agua.

Executive Summary (Spanish)

El agua es importante para todas las fases de la vida, y la contaminación de los ríos es peligrosa y molesta. Un río contaminado no aportará mucho a las comunidades circundantes, salvo un nuevo punto de vertido de residuos (Banco Mundial, 2020). Los esfuerzos para mitigar la contaminación del agua resultan ser un proyecto multifacético, a largo plazo, pero crucial. Algunos de estos esfuerzos utilizaron mapas para presentar sus lugares determinados de contaminación. En definitiva, cambiar la calidad del agua de los ríos es necesario para el desarrollo de una mejor salud, biodiversidad, economía y turismo de las comunidades ribereñas.

El río San Pedro atraviesa Quito, Ecuador. A lo largo de sus riberas hay múltiples sectores urbanos, fábricas, explotaciones agrícolas y puntos comerciales o turísticos, todos los cuales pueden contaminar el río con sus aguas residuales. Entre los esfuerzos anteriores para mejorar la calidad del agua del San Pedro se encuentra la limpieza del río por parte de la Escuela de Aventura Kingue en busca de microplásticos. En colaboración con la Escuela de Aventura Kingue, nosotros, un equipo de estudiantes investigadores del Instituto Politécnico de Worcester, utilizamos métodos categóricos para elaborar un mapa y un plan de tratamiento de los distintos contaminantes.

Nuestro objetivo, junto con el de la Kingue Adventure School, es trazar un mapa de la ubicación y el tipo de posibles fuentes de contaminación a lo largo del río San Pedro. Pretendemos identificar varios métodos para tratar el problema de la contaminación que, con el tiempo, mejorarán la calidad del río y, por tanto, ayudarán a que el río San Pedro vuelva a ser saludable. El equipo de Kingue IQP determinó que el primer paso para lograr el objetivo a largo plazo era promover la limpieza y la conservación del río San Pedro. Este objetivo se alcanzó mediante la creación de: un mapa con una lista de todas las fuentes potenciales de contaminación a lo largo del río y en sus alrededores, una lista de métodos de gestión de la contaminación y una presentación fácil de leer de los datos recopilados.

El primer objetivo se completó utilizando Google Maps e investigando en Internet para determinar la ubicación de las posibles fuentes de contaminación. El segundo objetivo consistió en una investigación en Internet sobre los sistemas y procedimientos actuales de gestión de

residuos y en una entrevista con el Dr. Camacho, consultor en gestión de la contaminación industrial. El tercer objetivo se completó mediante una investigación en línea y la creación de una infografía descriptiva. Los tres objetivos y sus metodologías nos llevaron a crear un mapa de fuentes potenciales de contaminación y una lista de sistemas de gestión de residuos en forma de infografía.

Encontrar los programas cartográficos adecuados era importante para que nuestro grupo transmitiera los datos en un formato específico y comprensible. Tras realizar un análisis comparativo de varios sistemas de visualización, se determinó que Google Maps era el más adecuado para el alcance de nuestro proyecto. Google Maps ofrecía un mapa geográfico básico que podía cambiar entre varios mapas base. La facilidad de uso de las herramientas y la posibilidad de compartirlo entre personas para trabajar en él simultáneamente sin deshacer el trabajo de otra persona fueron las principales razones para seleccionar el mapa. Utilizamos el mapa para trazar fácilmente el tramo del río y colocar chinchetas en los lugares que definimos como posibles fuentes de contaminación.

Una vez creado el mapa, descubrimos dos tipos de fuentes de contaminación. La primera eran las fuentes no puntuales, como los afluentes del San Pedro, y la segunda eran las fuentes puntuales, que a su vez podrían dividirse en cuatro tipos generales de fuentes de contaminación: agrícola, comercial, industrial y residencial (Figura 1). Estas cuatro fuentes de contaminación puntuales contribuyen potencialmente a la contaminación de varios niveles de materia orgánica, residuos químicos y metales pesados.

Figura E.3: Posibles localizaciones de fuentes contaminantes a lo largo del río San Pedro.

Hemos determinado 29 sistemas de gestión de la contaminación que podrían ayudar a reducir la contaminación del agua procedente de las distintas fuentes. Los sistemas de gestión pueden ser específicos de un sitio y/o sistemas genéricos de mitigación. En última instancia, se presentaron en forma de resúmenes de una página, lo que hace que la información sea fácil de leer para el público y de utilizar sobre el terreno (figura E.3).

Hemos decidido que la infografía es la mejor manera de presentar los datos recogidos. datos recogidos. Investigadores de todo el mundo han descubierto que el uso de infografías mejora la educación mediante la participación de estímulos visuales para involucrar profundamente a la audiencia con la información que se presenta (Bicen, 2017). Nuestra infografía final tiene muchas formas y cada tipo cubre varios aspectos de nuestra lista de sistemas de gestión de residuos (Figura E.4). Para crear las versiones finales de la infografía, hubo mucho ensayo y error, y un ir y venir entre los estudiantes, los asesores y los patrocinadores, pero finalmente se presentaron los datos deseados de una manera fácil de leer.

Figura E.4: Infografía de la gestión de la contaminación en los focos residenciales

Basándonos en nuestra investigación sobre las estrategias de conservación de los ríos y el impacto de la contaminación del agua en diferentes formas de vida, elaboramos las siguientes recomendaciones que creemos que harán avanzar nuestro proyecto en el futuro. El mapa y el manual de métodos de gestión de aguas residuales ofrecen información sobre la contaminación en San Pedro junto con ideas sobre cómo combatirla. Pueden ser útiles para el futuro compromiso de la comunidad y la difusión de la concienciación, como la colaboración de la Escuela de Aventura Kingue con Patagonia®.

Para el trabajo futuro, recomendamos que Kingue amplíe el mapa actual. Esto puede hacerse determinando las fuentes puntuales a lo largo de los afluentes del San Pedro o confirmando las potenciales fuentes de contaminación con análisis de agua. Otro trabajo futuro es que Kingue Adventure School utilice el mapa y la lista de métodos de gestión para crear una solución de

gestión de residuos para el Refugio Nuevos Horizontes, una cabaña de escalada y la primera fuente potencial de contaminación del San Pedro. Por último, recomendamos que la Escuela de Aventura Kingue utilice la infografía para enseñar e informar a la población local sobre el río San Pedro y su contaminación, empezando por la caminata del Día Mundial del Agua a lo largo del río San Pedro con la Patagonia.

Authorship

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Appendix	All	All

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Introduction

Rivers are polluted, and that is a problem. Waterways around the world are facing the problem of pollution daily. Potable water sources are finite; roughly one percent of the world's water is accessible for consumption without filtration (Denchak, 2020). The most significant water pollution source contributing to this small percentage is the poor treatment of wastewater and inadequate disposal of industrial and agricultural waste (UNESCO, 2008). A connection is made between the pollution in waterways and the biodiversity of an area through the change in a waterway's chemical balance, making it inhabitable (Verback et al., 2016). Polluted waterways also cause a decrease in tourism and agricultural income because of the lack of available activities involving the river (BEA, 2020; Kelsey, 2021). Due to these environmental and economic impacts, it is a focal point for conservationist groups worldwide to tackle the water pollution problem.

Involving communities in river clean-ups, using public science by asking and interviewing those in the surrounding communities as data collection, and partnerships with local government and businesses are approaches to tackle pollution issues worldwide. Unfortunately, these efforts have yet to make their way to every waterway. The San Pedro River in the Pichincha Province of Ecuador is one waterway that could benefit from these conservation efforts. One reason in particular that these efforts are needed is that despite the river running through various communities, many people fail to recognize it as the "San Pedro River", but rather describe it as the "smelly river by the mall" (J.Serrano, personal communication, 11 November 2020).

The collaboration with the Kingue Adventure School, a group dedicated to educating others about the natural environment, should aid in this process. With resources such as a map with potential pollution sources and a collection of wastewater management methods, the Kingue Adventure School is ready to begin a startup project against the San Pedro River's contamination. Striving for collaborations with the community and companies such as Patagonia, this long-term project sets foot to revitalize the river altogether.

2 Background

In this chapter, the Kingue IQP team presents background information on the research completed to understand the project's scope and how others in similar situations completed their work. To understand how the San Pedro's contamination should be addressed, the Kingue IQP team researched: how pollution affects rivers, the current attempts to clean the rivers, how maps aid in these attempts, and the current gaps in pollution management for the San Pedro River.

2.1 Rivers, their importance and their pollution

A clean waterway can support agricultural sites, biodiversity, and drinking water to a community (American Rivers, n.d.). Clean water helps grow crops that feed animals and ultimately produce a healthy food source for humans (EPA, 2020). Healthy farmland sustains a local ecosystem by providing a habitat for plants and animals (Kelsey, 2021). Clean rivers also provide a space for a variety of recreational activities. Popular activities such as fishing, rafting, and kayaking in clean rivers increase the touristic and economic value of an area. In 2019, outdoor recreational activities produced 459.8 billion in the current-dollar gross domestic product (GDP) in the United States (BEA, 2020). In addition to flourishing, outdoor recreational activities bring revenue into local hotels, restaurants, and other businesses from tourists traveling to the area. For these reasons and many more, the mitigation of water pollution will benefit people and ecosystems worldwide.

Around 80% of rivers worldwide face pollution problems, from the Nile to the Ganges (Bhuiyan et al., 2013). Approximately two million tons of sewage, industrial, and agricultural waste contaminate the world's waterways yearly (UN WWAP, 2003). Studies show that urbanization around a river lowers water quality, alters habitats, and decreases an area's biodiversity (Glińska-Lewczuk, 2016). Therefore, rivers are being drowned in pollutants from various sources when local, urbanized waterways do not have proper deterrent methods in place. These pollutants can be brought into an aquatic system as either nonpoint or point pollutants. A nonpoint pollutant would be a pollutant, or collection of pollutants, that indirectly gets washed into the affected stream as runoff. A point pollutant would be a direct source of pollution that is drained into the affected stream. Addressing these types of pollutant sources is vital to identify possible tactics to combat them easily.

The importance of clean rivers is undeniable; they are over polluted with little widespread assistance in cleaning them, posing problems for populations and biospheres dependent on the river. This is inspiring many environmental groups to take arms and attempt to clean and protect the waterways of the world.

2.2 Strategies Used in River Conservation

River conservation groups around the world use various strategies to complete their mission. The three explained later are the ones most often used. Their strategies are divisible into three main categories: public engagement, public science, and partnerships.

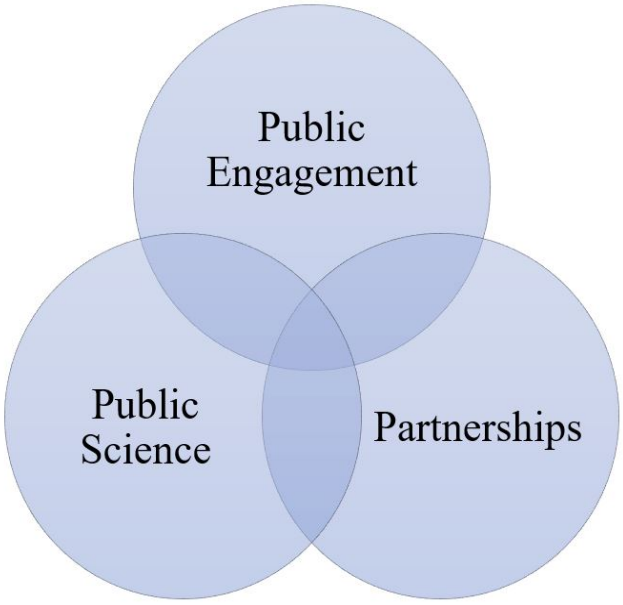

Figure 1: Venn diagram showing the relationship between strategies

Involving local communities gives the river conservation groups a better understanding of how the community is affected by water pollution. The River Network involves and engages the local communities by attending community meetings and events to understand how they can help the people (*River Voices*, 2015). They then hire community members to ensure that the affected population is always in the loop and create a multi-layer engagement system (*River Voices*, 2015). Involving the local population allows the river's cleanup to aid the local community by providing jobs and constant information. Another method to involve local communities is to enable them to join activities that raise water contamination awareness. For example, the American Rivers and River Cleanup, the community comes together to help remove litter on the banks of the river ("Volunteer with National River Cleanup®," n.d.; *River Cleanup World | River Cleanup*, n.d.).

Public science enables people to enhance their scientific literacy regarding fields that are relevant to them. This research is conducted amongst or includes the public, whether through

participatory research or science outreach (Mariconla, 2006). This allows citizens to gain a more significant say in and commitment to scientific research matters (Parthenos, 2020). Public science works in two parts: data collection and data presentation. Data collection in polluted waterways offers a specific understanding of the waterway's contamination issues. The International Rivers Group collects evidence of polluted waterways by organizing knowledge from the surrounding community, academics, NGOs, and policymakers (*Our Rivers, Our Water, Our Future: Strategic Plan 2018-2022*, 2018). For the River Alliance in the Delaware River Basin, water tests offer a specific understanding of the contaminants in a river and their locations (*Enhancing Policy and Engagement in the Delaware Basin - River Network*, n.d.). The other part of evidence collection involves presenting the collected data.

An efficient way to present data can be by creating maps that offer a customizable, accessible form of presenting the collected evidence to an audience. Maps provide a digestible and visual way to view researched data, whether collected through grouped knowledge, scientific data, or important locations. The easy accessibility of maps on a global scale creates a good first step for river conservation work. Maps are a good first step because they provide a basis for the community to understand where the problem is and what is being affected. For The Blackstone River Coalition, The Nature Conservancy and the Two Hearted Watershed use their maps to present areas with higher pollution levels than with others, as collected through water tests [*Blackstone River Coalition*, n.d. (*Two Hearted River Watershed Conservation Data Viewer 4.0*, n.d.)].

Partnerships offer a shared database, development of conservation strategies, opportunities to resolve potential conflicts, and increased program support (Loesch, 1995). These collaborations have long existed among scientists, nonprofit organizations, and volunteers interested in freshwater ecosystems (Society for Freshwater Science, 2014). For example, The Nicoya Peninsula Waterkeepers, a water conservationist group, used Patagonia's International Grant to fund their research and "monitor, protect and restore water quality in the coastal watersheds and marine ecosystem" (*Nicoya Peninsula Waterkeeper - NGO in Costa Rica*, n.d.). The International grant has earned them a spot on Patagonia's website, giving them a larger audience, better finances, and more opportunities (*Nicoya Peninsula Waterkeeper - Patagonia Action Works*, n.d.; *International Grants Program - Patagonia*, n.d.). The partnership with a major company such as Patagonia makes the issue more present globally and harder for the local government and

community to ignore. This same approach can be applied to Kingue to gain the necessary databases and support to target the San Pedro River's contamination.

2.3 Maps

Maps play an essential role in the strategies explained in the previous section for river protection since they provide an in-depth understanding of the polluted area's issues. A measurable step to manage contamination is to know where the pollution concentration is located (Air Quality, n.d.). Using a map, the creator provides a visual representation of current pollution levels in an area. To truly understand the importance of maps to conservation groups, one must: understand their significance to pollution tracking, how mapping systems differ and how maps can aid future work.

With a visual representation of pollution data, maps help advance the river conservation efforts. Maps allow us to determine how and where contaminants appear in a river (Where Are PFAS Chemicals Found? | EWG, n.d.). Subsequently, by determining the pollution sources, one can determine the potential solutions to reverse the damage caused by the contaminants and implement the correct procedure to treat it (Rutkowski and Prokpiuk, 2018). There are various ways to complete the mapping process. Despite being used for different reasons, the map's accessibility and future implications make it the perfect tool for river conservation groups, no matter the size.

Different mapping tools offer different analysis options for both the reader and the researcher. The two principal methods of creating maps use Geographical Information Systems (GIS)/geo-analytic or visualization maps. GIS offers more variety and precise analysis of locations by combining topographical and selected datasets (ex: pollution levels) on a map (What Is GIS? | Geographic Information System Mapping Technology, n.d.). It's a map that stores, manages, and manipulates data to present an in-depth virtual view of a specific geographical area (Stephen, 2019). This allows for a precise analysis of the desired topic. Most GIS are costly and time-consuming to produce but offer better data analysis programs.

Visualization mapping systems, such as Google Maps, are less complex but more accessible to the general population. Although Google Maps can be considered a GIS map, it dissects geographic system data and can map out various landmarks and topographic features. It must be specified that it does lack the connection of topography to a database with detailed information by not noting other geographic features that intersect another set of features (Stephen, 2019). These types still allow for the importation of data sets represented by pins but do not qualify as complex data visualization (Google Earth and Google Maps - Geographic Information System

and Data Visualization Applications - Brooklyn College Library LibGuides Home at Brooklyn College Library, n.d.).

River Conservation groups have been using maps to better understand the pollution regarding an area. However, this approach has not been applied to every river despite the good it can do. One of those lacking rivers is the San Pedro River in Ecuador.

2.4 Pollution in the San Pedro River

Due to a lack of research on the San Pedro River, the team faced some obstacles when reaching a final set of possible solutions. The virtual setting also influenced getting less information about the area and ecosystem. Because of this, gaps in the approach of this project have been addressed and evaluated.

2.4.1 The San Pedro River and its Wasted Potential

The San Pedro River originates at the Illiniza Sur Volcano and runs through Quito, Ecuador. It flows along with various urban and agricultural areas, exposing it to contaminated water and waste being released not only into the river itself but the streams and tributaries that connect to it (Voloshenko-Rossin, 2015). The rapid growth of the population and further development of industry and agriculture has only caused this problem to progressively worsen (Tamim et al. 2016). Being in the location that it is, the river can do lots of good for the area (Pecl et al., 2019). Unfortunately, due to the contamination, that potential is wasted, and the river has more negative impacts than positive.

2.4.2 The Problem

The San Pedro River plays a significant role in the lives of people who surround it, whether they know it or not. Factories, homes, businesses, and farms line the banks of it, but many do not know its name. This makes it more difficult to bring awareness that the river is polluted if people do not care about it enough to learn about it (J. Anhalzer, personal communication. 2020). Ultimately, the lack of knowledge of the river and its state has led to minimal action from water conservation groups and the community (Pecl et al., 2019; Moore and Langner, 2012; Machangara water keepers). With no knowledge of the San Pedro River's issues, it is challenging to get people involved in clean-up efforts and create contaminant mitigation plans (Moore and Langner, 2012).

2.4.3 Kingue

Our sponsor, the Kingue Adventure School, is founded on a "leave good trace" principle meaning that they strive to leave the environment in better shape than they got to it. Being located at the San Pedro River banks, the Kingue Adventure School sees firsthand how this principle is

out of practice. The people of Quito see and interact with the river without understanding the underlying problems. Rather than being an eyesore, it can aid the lives of those around it (Harris and Heathwaite, 2012). Mapping the river and its possible contaminants creates a base resource and tool to help clean the river. The Kingue School must have a tangible resource and base plan for addressing the problem before bringing social and governmental attention to the issue.

In conclusion, we determined that pollution is detrimental to rivers and the surrounding communities. Minimal river conservation efforts have been focused on the San Pedro River, causing the waterway's quality to decrease and the Kingue Adventure School to worry if the river will ever be decontaminated. River conservation groups have created a strategy to combat river pollution, and more often than not, used mapping tools to do so. Ultimately, the Kingue IQP team's research and efforts will provide a base for a start-up project to decontaminate the San Pedro River.

3 Methodology

The project's goal was to promote the clean-up and conservation of the San Pedro River to the Quito community. To achieve this goal, we developed the following research objectives:

1. Create an interactive map that contains the locations of potential sources and types of contamination along the San Pedro river
2. Identify possible methods to manage the contaminations in the river
3. Find an easy-to-read format for data presentation

3.1 Objective 1: Create an interactive map that contains the locations of potential sources and types of contamination along the San Pedro river

This objective aimed to better identify the possible pollution sources along the San Pedro River and outline the possible contamination types due to the sources. The map intends to fill the knowledge gap regarding where the possible pollutant sources are, what they are, and what wastewater they produce. We mapped the potential contamination source using online mapping software. The Kingue Adventure School verified the sources, as they are more knowledgeable regarding the area. Once the contamination locations were confirmed, we determined the most common contaminants found in each category's wastewater with a semi-structured interview and internet research. All the gathered information regarding possible sources and their contaminants provided helpful information for finding potential solutions to the contaminants.

3.2 Objective 2: Identify possible methods to manage the contaminations in the river

While our group focused on identifying possible contaminants affecting the San Pedro River, it was crucial to identify possible steps used to treat contamination sources. Once contamination sources were identified, online research taught us about methods to treat each type of contamination source. The necessary steps, general timelines, and cost were continuously added to an excel sheet as we discovered different techniques. The collected information allowed us to present Kingue with many options to present to various organizations.

3.3 Objective 3: Find an easy-to-read format for data presentation

Once information regarding potential pollutant locations and possible contamination management methods were identified, it became essential to display the information in a way that is easily readable by the general public. To do this, we used infographics since they straightforwardly display data (Bicen, 2017). The information provided in the excel sheet created during objective two was displayed on various types of infographics, both specific and general. All of the infographics get compiled in a singular document used by the Kingue Adventure School to present to different groups, ranging from farm owners to the average citizen. The infographics can also be printed and distributed to varying events that our sponsor may choose to hold.

3.4 Ethical Considerations

Due to this study's remoteness, our team relied on outside participation from human subjects. Research methods included ethically and professionally conducted interviews that helped with data gathering about the San Pedro River. We needed to respect all responses from interviews and understand the perspective of the people who partake in them. It was also vital that we understood and considered this project's effects on the San Pedro River and the surrounding community. We also obtained permission from every interviewee to record the said interview and use the information gathered. It was also essential to ensure that all personal information collected remained confidential and the participants' rights would be respected and lined out with a consent form. We followed the procedures approved by the WPI Institutional Review Board (Appendix 4).

4 Results & Analysis

The results and analysis highlight the information gathered from our group's previous three objectives set out to achieve. The discovered data is in four sections: Mapping the San Pedro River and its Contaminants, Contamination at Locations along the San Pedro River, Waste Management and Regulations, and Kingue's Collaborations.

4.1 Mapping The San Pedro River and its' Contaminants

When trying to learn about the specific contamination levels a waterway presents, it is essential to use a map plotting potential contamination source points to create a foundation of knowledge. A final map-making software is used to best fit the project by comparing and contrasting different programs.

Google Maps is the Best Visualization Mapping Tool for This Project

Finding the right mapping programs was important for our group to relay data in a specific and understandable format. There are two main types for creating thematic-styled maps; GIS/ Geo-Analytic and Visualization Systems. Visualization systems are more accessible and easier to use than essential GIS software (Park et al., 2011). Google Maps is an example of a visualization system that bases itself on GIS principles. It can map different topographic features similar to that of a GIS program but cannot connect those locations to a database with information on them and does not highlight all geographic features, specifically those intersecting with another (Wang et al., 2013).

Using the information gathered from the background and methods on various visualization mapping tools, our team discovered that Google Maps provided the best platform for mapping the San Pedro River and possible pollution locations. For example, the software Leaflet has significantly more tools to use but needs prior knowledge of JavaScript to properly use it (Brovelli et al. 2013). The table below outlines the various software programs researched for this project.

	Program	Pros	Cons
Visualization	Google Maps/Earth	free; very easy to use; visually clean and simple; can add data directly to it or upload file	has limited functionality in terms of direct source identification; very few features; can't hanle large data inputs
	Open HeatMap	free; relatively esay to use; can handle larger data input to show concentrations	organizing data is difficult; no auto save; need to use a spreadsheet to import data
	Leaflet	A good middle ground between a GIS program and something like google; has the ability to look really nice with the proper plugins	need to know JavaScript; might need to setup using a GIS program; paid-for features
	OpenLayers	can use different layers; much more comprehensive than other options; "mature"	Not free; relatively complex steps to setup a base map; tries to do/bemorethan it is capable of

Table 1: A comparison of various visualization software

Google Maps provided a basic geographical map that could switch between various base maps; we chose the satellite version. The various easy-to-use tools such as the “add line or shape tool” and “pin” tools are the main reasons this program worked (Figure 3). It also offered the ability to be shared amongst people to work on it simultaneously without undoing another person’s work, whereas other software could not. We could trace the span of the river easily and drop pins at locations we defined as potential pollution sources on this base map. Because of Google maps providing all of our needs, we chose the program for the San Pedro River.

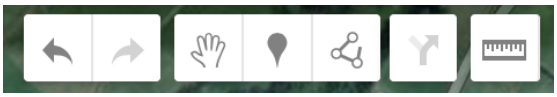

Figure 3: The basic tools available with Google Maps

4.2 Contamination Types at Locations Along The San Pedro River

To understand how to treat the contamination present, research was done on what types of pollutants could be present in the river and the locations of those pollutants. To understand the pollutant types, it was identified first that the pollutants are either coming from point or nonpoint-sources. From there, the potential location sites can be determined, and research is conducted on the contaminants most likely to be omitted from the specific sites. The following sections highlight the potential contaminants that are possibly found in the San Pedro River based on the previously identified locations.

Categorizing the Pollution Sources

Upon mapping the river using Google Maps, we determined contamination to the San Pedro River can come from four main pollution categories: industrial, residential, agricultural, and commercial (Figure 2). Each of these sources contributes to different pollution to the river, whether in the form of point-source or nonpoint source pollution. Point source pollution is any contaminant that enters the environment from an easily identified confined place (EPA). Industrial sites such as factories and wastewater treatment plants can contribute to point-source pollution; effluents from these can introduce nutrients and microbes into waterways (National Geographic, 2019). Nonpoint source pollution is the opposite; it includes sediments, plant nutrients, pesticides, and animal waste entering the surface and groundwater from a non-specific source (Geospatial World). For example, rainwater can wash away debris, chemicals, and waste found on farm sites, and this runoff will eventually funnel into a nearby river.

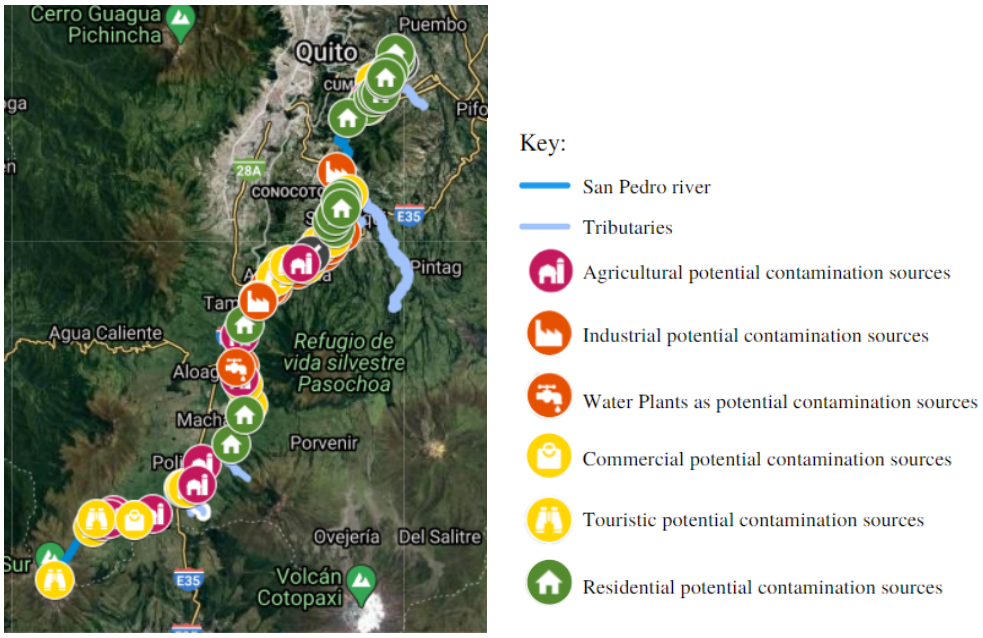

Figure 2: Possible pollutant source locations along the San Pedro River.

More research needs to take place before water tests at the various pollution sources determined on the map. We used scholarly articles and research to understand the types of contaminants present at every potential contamination source. Whether it is a point source or a nonpoint source, the types of contaminants would range depending on the types of locations along the river. Our research showed that industrial operations, residential sectors, agricultural, and commercial locations are possible contaminant contributors when identifying potential pollutant sources. The three pertinent types of contaminants found at these locations are chemical waste, organic matter, and heavy metals. The derived contaminant types found through online research represent the most common contaminants produced by each location type.

	Contaminant Type		
POLLUTANT SOURCES	ORGANIC MATTER	CHEMICAL WASTE	HEAVY METALS
Agricultural	✕	✕	
Residential	✕	✕	
Industrial		✕	✕
Commercial	✕	✕	

Table 2: Pollutant Source vs. Contaminant Type

Chemical Waste can be Found in Many Locations

Chemical waste is defined as any solid, liquid, or gaseous waste material improperly managed or disposed of, which may pose substantial hazards to human health and the environment (Speight, 2017). Chemical Oxygen Demand (COD) is generally due to waste from chemicals like cleaning products (degreasers or lubricants e.g.). COD demonstrates the amount of oxygen consumed through a chemical reaction. This type of chemical discharge to a river can produce adverse effects, affecting water's biodiversity and quality. Upon investigating each location, they can be responsible for this type of contamination (see Appendix 2).

Industrial operations, including factories, distribution centers, and water management plants, sometimes turn waterways into open sewers dumping oil, toxic chemicals, and effluents (Ohm, 2020). Also, residential sectors produce this type of contamination through chemicals such as house cleaners, car oil, and detergents that can make their way to the waterway after a storm. Farms and agriculture sites are liable for pesticides and fertilizers reaching nearby waterways due to runoff or irrigation. Lastly, specific commercial sites that supply products such as paints, solvents, and cleaners are liable for chemical contamination(Table 2).

Organic Matter as a contaminant type

This type of contamination is composed of organic compounds that include tissue from plants and animals, microbial indicators such as E. coli and helminth eggs, and nitrogen and phosphorus compounds (Jiménez, 2005; *Organic Contaminant - an Overview | ScienceDirect Topics*, n.d.).Generated Biochemical Oxygen Demand (BOD) appears when effluents contaminate water with high organic loads, such as slaughterhouses, dairy industries, or organic waste in general. In addition, it exposes the waterways to debris such as leaves and branches, along with bacteria and other organisms. These factors can alter the chemical balance of a waterway and influence the living ecosystem.

Organic matter presents itself differently for each potential contaminant source type. Farms and agriculture sites that produce livestock and food are responsible for this type of contamination due to proximity to waterways and runoff (Appendix 3). Commercial, tourist, and residential areas that lack adequate waste management systems are susceptible to contain organic matter in their wastewater (Table 2). Water plants mainly produce sludge in their wastewater; this is a combination of organic matter and chemical contaminants (Canziani & Spinosa, 2019).

Heavy Metals affect waterways

Heavy metals are naturally occurring elements that have a high atomic weight and density. Their wide use in industrial, domestic, agricultural, medical, and technological operations has led to their wide distribution in the environment (Tchnoinwou, 2014). Heavy metals such as arsenic, cadmium, lead, and nickel can originate in processing plants or chemical production processes. Heavy Metals harm a system's biodiversity due to them not naturally belonging to that ecosystem. This type of contamination should be removed from the water for purposes of domestic use or consumption.

By understanding the types of contaminants and where they are present, we can better understand how the different potential contaminant sites need addressing. Our research on heavy metals showed that they are present at water management facilities and Industrial/Distribution Centers (Appendix 3; Table 2). Although Industrial sites could be mainly responsible for heavy metal contamination due to inadequate wastewater treatment, Water Management Facilities usually see heavy metals due to insufficient treatment procedures.

4.3 Waste Management & Regulation

It was essential to provide a foundation of solutions that Kingue and future collaborators could reference in the project's future phases. A developed wastewater management methods manual provides future groups a list of methods that can be used to treat specific contamination areas such as residential, industrial, commercial, and agricultural sites.

A Breakdown Of The Wastewater Management Methods Manual

Along the banks of the San Pedro River, we found multiple pollution sources: agriculture sites, industrial sites, residential sectors, commercial establishments. These sites produce different kinds of contamination to the river by releasing chemical, organic, and metal waste. The wastewater management methods for the pollution sites explicitly combat the type of waste produced. In Appendix 2, we can find wastewater management methods that specify the type of treatment system applied to the pollutant source.

The management methods are broken down into sections to cover all necessary topics that need to be considered by a future group when choosing a cleaning method. The sections include: what the method combats, how it works, the time it takes to have a positive impact, cost, what is needed, recommended use, maintenance/upkeep, possible issues, examples of implementation, and links to where more information can be retrieved. These categories will provide a basis of knowledge towards understanding what methods are the best fit for each specific site.

There are a total of twenty-nine methods recorded as potential contaminant clean-up technologies and strategies. Within the twenty-nine methods, there are ten agricultural methods, nine commercial methods, five industrial methods, and five residential methods (Appendix 1). Through our research, we found that most agricultural methods under average conditions are relatively more feasible. This is without considering the resources available in individual agricultural lands (Figure 4). Compared to industrial, commercial, and residential methods, which require more time, money, and installation efforts. Agricultural sites offer simple solutions such as crop rotations and different irrigation strategies that don't require extensive systems to treat the pollutants. In contrast to agricultural sites, commercial, industrial, and residential sites require systems that are either large-scale projects, require professional assistance, need frequent maintenance and upkeep (Figure 4). Although the management methods highlight possible clean-

up routes that can be taken, the purpose of the list of methods is to provide a foundation for future groups to research site-specific clean-up methods.

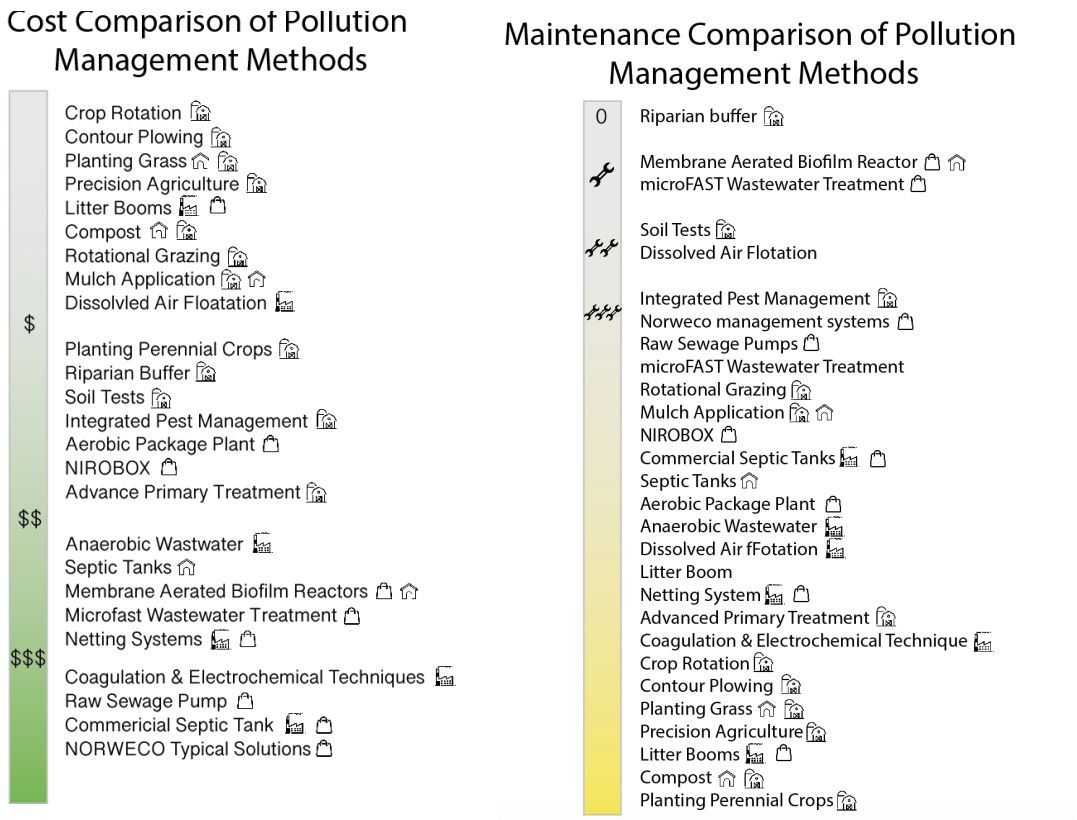

Figure 4: Infographics of cost & management comparison of all waste management solutions

Wastewater Management Methods Can Be Location Specific Or Applied To Multiple Locations

The wastewater treatment manual offers cleaning solutions that can work for contaminants from individual pollution sources. Since the same contaminants reappear at various potential contaminant sources of the same type, the same methods are available. For example, residential sectors, agricultural sectors, and livestock factories present organic matter as a pollution type. Thus the solutions targeting organic waste are versatile to differentiate the different potential contamination sites.

4.4 Kingue's Partnerships to Further the Clean-up Process

Kingue needs to have a wide range of collaborators that will have a hand in future clean-up processes. Kingue needed an easily presentable way to communicate information as they continue to raise awareness for the San Pedro River's clean-up. A major partner who helped choose to use infographics to present that information is Patagonia, who will work hand and hand with the Kingue Adventure School.

Figure 5: Summative Infographic of all determined methods

Data is presentable to Kingue's collaborators

A significant goal of most of our work was to make our researched information readable and accessible to the general population. One way to determine if it genuinely meets these marks is by debuting the information. Marcella Paloma, the manager of the newly opened Patagonia shop

in the Scala Shopping Mall in Quito, partnered with the Kingue Adventure School for a hike along the San Pedro River on March 20th, 2021 (M. Paloma, personal communications, February 11, 2021). They have invited an elite list of nature conservationists and social media influencers to this hike. During the event, they will be presenting our infographics and maps to the guests with the hope of sparking their interest to help clean the San Pedro river an example of the presented data can be seen in Figure 5 (J. Serrano, personal communications, March 1, 2021).

Kingue and Patagonia's partnership is the first of these collaborations, with the hopes of many more. The Kingue Adventure School hopes to use our presented research to entice people to get involved with the San Pedro River's decontamination. Hence our data must be presentable and understandable to those who are not initially interested in ecological projects.

Conclusion

Through the use of Google MyMaps, the Kingue IQP Team was able to create a map plotting the points of various possible pollution sites along the San Pedro River. The easy-to-use tools such as the colored pins with icons provided a simple way of displaying the different types of locations. After mapping the different sources (agricultural, industrial, residential, and commercial), the San Pedro River showed both point and nonpoint sources of pollution. Point sources are easily identifiable locations where the pollution directly pollutes the waterway. Nonpoint sources are the opposite; they are non-identifiable sources such as rainwater washing debris into a waterway or different waterways flowing into each other.

Three main types of contaminants can be identified based on the San Pedro River's location types: chemical waste, organic matter, and heavy metals. Chemical waste is considered to be any solid, liquid, or gaseous waste material that is improperly managed or disposed of, which may pose substantial hazards to human health and the environment. Organic matter is composed of organic compounds that include tissue from plants and animals, microbial indicators, and nitrogen and phosphorus compounds. Heavy metals are naturally occurring elements that have a high atomic weight and density. Chemical waste is a potential contamination type of agricultural, industrial, commercial, and residential areas; organic matter is a potential contamination type of agricultural, residential, and commercial locations; heavy metals are a potential contaminant of industrial locations.

It was determined that each location has different methods in which pollution could be addressed after gathering information on these various contaminant types; various types of management methods that are more general there could also be applied across. As a deliverable, a wastewater document highlighting these various types of pollution management methods was created. Various infographics were created from this manual, to display the gathered information in an easy-to-read format that is more comprehensible by the general population.

It was discovered that creating a more accurate map of potential pollutant sites involved water tests confirming locations of pollution. It is difficult to have a concrete idea about who and what is contributing to the San Pedro River's pollution without this knowledge. The more in-depth knowledge provided by water tests would also allow management methods to be tailored

specifically to the contamination site. ByDoings will offer the Kingue Adventure School more concrete information to present to those who will have a hand in physically cleaning the river. All of the gathered information from this project should serve as a base resource for further work between the Kingue Adventure School and future IQP groups and collaborators.

Recommendations

In this chapter, our team presents recommendations for the Kingue Adventure School to improve the San Pedro River's quality. Our results, research, and observations of the San Pedro River and its contamination has created a starting point for future work and conservation efforts of the San Pedro River. We hope our work is useful to support future work, and to ensure it does, our team to determine four recommendations that would help the Kingue Adventure School attain their long term plan of having a clean San Pedro River:

1. Completing water tests at each of the potential pollutant sites
2. Determining the point sources of pollution along the tributaries of the San Pedro River
3. Finding and cultivating new collaborations with the Kingue Adventure School
4. Helping the New Horizons Refuge improve its wastewater management

Water tests should be completed at each of the potential pollutant sites

Future steps of the project require knowledge of what contaminants are present in the water. Due to COVID-19, our group could not complete water tests; but, to consult a wastewater specialist in the future we recommend that these water tests are performed. Not only will water tests give information on the river as a whole, but they will allow future groups to gain site-specific details. A water test before and after the potential pollutant sources should then be performed. The water tests can then be compared to find the levels and presence of various contaminants. If there is a noticeable difference in contaminants between the two tests, conclusions can be made about the location being a pollutant source (Camacho, personal communication, February 25, 2021). This process will allow groups to create a course of action that focuses on sites with heavy contamination.

Determine the point sources of pollution along the tributaries of the San Pedro River

To understand the specifics regarding the various tributaries, it is essential to understand that a tributary is a stream or small river that joins a more extensive water body. Therefore, potential sources of pollution to the river are tributaries. Due to our group's inability to investigate tributaries entering the San Pedro River, given the time restraints, we did not investigate what commercial, residential, industrial, and agricultural locations fell along each tributary. We recommend that future groups examine the tributaries that feed into the San Pedro River and what

potential pollution sources fall along with them. This is done in a similar process to how maps were created or using citizen science methods.

Use further collaborations to promote the Clean-up Process

Our work included providing research such as a map of pollution sources and wastewater cleaning methods applied to the San Pedro River. One hope of future collaborations is environmentalists take an interest in this work and further investigate the sources of pollution. The river's story can be extended to a larger community by involving influencers and community members. Research has shown that through social media influence, projects will gain a larger following and increase the chances of reaching out to parties that specialize in river clean-up processes. Also, by creating a larger community and bringing awareness to the contamination, a larger pool of funds can be raised. This will open more doors to expanding future research and clean-up methods. Collaborators can achieve public engagement through their involvement in the community.

Starting research at the New Horizons Refuge

Since there is a baseline understanding of potential pollutant sites and various cleaning methods, groups can apply these methods to the Refugio Nuevos Horizontes or New Horizons Refuge. Without proper wastewater treatment, the New Horizons Refuge can send organic and chemical waste into the San Pedro River just as it begins to form. We recommend using the wastewater cleaning methods to create or improve the New Horizon Refuge's waste management to determine solutions to help treat and limit their waste before it has the opportunity to flow into the San Pedro River. Once the contaminants are determined, The best potential cleaning method is determined for the New Horizons Refuge group and its wastewater.

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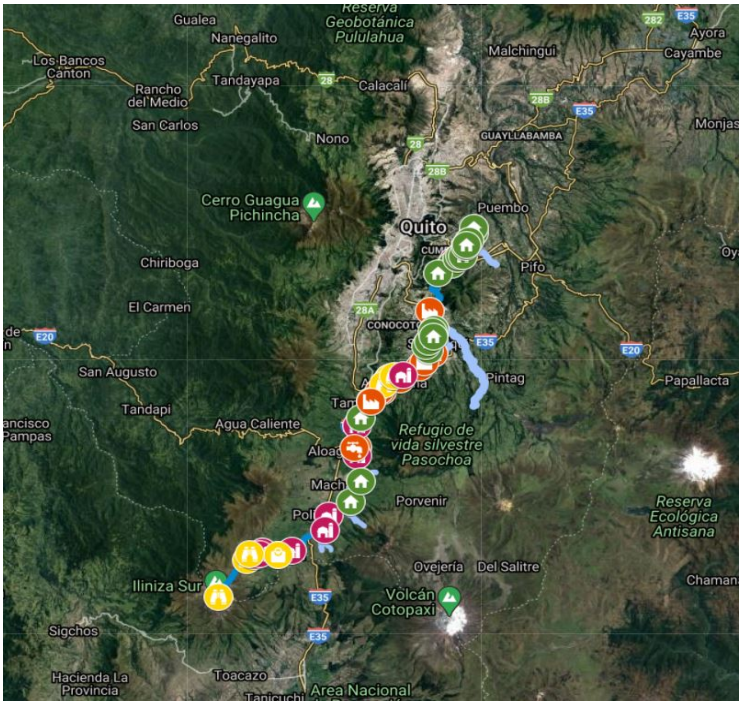
Appendices

Appendix 1: Map of the San Pedro River with pinned contamination sites:

1.a: The map



To view the map on Google Maps please click here:

https://www.google.com/maps/d/u/0/edit?mid=17nJrba_eIhwuPealuAH7Un0MlB8-p4dK&ll=-0.6420284905979982%2C-78.71480835356023&z=13

1.b: the key


Key:
San Pedro river
Tributaries
Agricultural potential contamination sources
Industrial potential contamination sources
Water Plants as potential contamination sources
Commercial potential contamination sources
Touristic potential contamination sources
Residential potential contamination sources

Appendix 2: Collection of Infographics to Explain and Analyze Waste Management Systems (in spanish)

Link:

https://drive.google.com/file/d/1X06G4eFcOmMPAsdX-qAqioAFJHZK6wsM/view?usp=sharing

Appendix 3: Transcript of Interview with Dr. Camacho

Dr. Camacho: I'm a doctor in biochemistry and pharmacy with a specialty in foods, history in quality, and productivity. I have 30 years of experience in the world of food, worked for 20 years in the food industry in Ecuador. I was in charge of quality, I would take charge of the analysis, quality, and productivity. I do certifications and therefore I have a microbiological laboratory.

For compliance with environmental regulations depends on the area where you are. Each municipality has its own ordinances and those ordinances in some areas are easier to enforce than in others.

When the river passes through Quito it has more complex ordinances, it passes through Sangolquí and it has more enforceable ordinances.

There are ordinances called TULAS unified text of environmental legislation, these regulations are the environmental regulations that have the parameters that the areas must comply with when the river passes through a rural area, you have to comply with specific ordinances the same as when it passes agricultural areas the microbiological requirement changes.

Plant the project in stages, obviously, at the source of the river in the volcano the level of contamination is shallow, it must be quiet pure water after it passes through the refuge where the mountaineers go to rest. I don't know how the shelter is made, but normally if the toilets have a manhole, which is a hole in the floor where all the excrement goes, if the manhole is not covered by a filtration system, there will be contamination. What you must do is plant an analysis prior to entering the river and leaving the refuge. When passing through different areas where there are pesticide livestock, another analysis should be done to see how the river water entered and how it left. When you enter through Sangolquí, you are going to enter through a very industrial area, there are mills, food industries, pharmaceutical plastics industries, hygienic services, the level of contamination in that area will pass through that area. I imagine that the river has already died from the bacterial load there may be.

For this project, you are going to have to do some COD analysis, which is the chemical demand, DOB biochemical demand, e.coli, analysis of fecal contamination, pesticides and heavy metals.

When you are going to pass through a cattle that will raise what is the DOB or the biochemical demand when you have a lot of Organic load in a river be it excrement, fat, blood, urine the biochemical demand increases that excess of Organic matter kills the river because it consumes the oxygen what fauna and flora need

When you go through an industrial zone that produces chemical products, paints, the chemical oxygen demand rises, which also consumes the oxygen from the river. The river dies.

And with e.coli it will come from farms due to fecal contamination as well as pesticides will be seen at high levels in agricultural areas

Heavy metals are there that are required that may be more chemical contamination by the soil

Depending on the environmental legislation, these are the parameters that you are going to analyze, established as I told you by sections of the river because the route is very long and you could evaluate and reach a point where you determine where the river died.

Nicole: What type of test do you perform?

Dr. Camacho: you can do all these tests in the field except for pesticides and heavy metals, you need a piece of spectrometer equipment. The rest as for him and tail and it would be presence or absence can be done there in the field.

Appendix 4: IRB

WORCESTER POLYTECHNIC INSTITUTE

100 INSTITUTE ROAD, WORCESTER MA 01609 USA

Institutional Review Board

FWA #00015024 - HHS #00007374

Notification of IRB Approval

Date:	11-Feb-2021
PI:	Elgert, Laureen
Protocol Number:	IRB-21-0296
Protocol Title:	Pollutant Source Mapping and Mitigation Assessment along the San Pedro River, Ecuador
Approved Study Personnel:	Elgert, Laureen~Miller, Fabienne~Bressner, Grete~Ballard, Braden~Garay, Nicole~Nicolas, Claire~
Effective Date:	11-Feb-2021
Exemption Category:	2
Sponsor*:	

The WPI Institutional Review Board (IRB) has reviewed the materials submitted with regard to the above-mentioned protocol.We have determined that this research is exempt from further IRB review under 45 CFR § 46.104 (d). For a detailed description of the categories of exempt research, please refer to the IRB website.

The study is approved indefinitely unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific approval must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue. You are also required to report any adverse events with regard to your study subjects or their data.

Changes to the research which might affect its exempt status must be submitted to the WPI IRB for review and approval before such changes are put into practice. A full IRB application may be required in order for the research to continue.

Please contact the IRB at irb@wpi.edu if you have any questions.

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*if blank, the IRB has not reviewed any funding proposal for this protocol