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The Rio Grande around Laredo, Texas/Nuevo Laredo, Mexico was designated for primary contact recreation by the EPA. However, monthly sampling over a ten-year period in this section of the river may show otherwise. Fecal contamination of the Rio Grande in this area may be a source of illness to the population. Four sites in the Laredo area were tested for fecal coliform density and rate of flow. Rainfall data from the USGS was used for comparisons. The rate of flow of the Rio Grande had an impact on fecal coliform density at one site measured. Rainfall in Laredo had an impact on fecal coliform density at two measured sites, and was a significant predictor of density at these sites as well. A review of the designation for this river segment is recommended. More research is needed to determine the exposed population, and effects of high coliform densities on downstream communities.

FECAL COLIFORMS IN THE RIO GRANDE:

A RISK TO HUMAN HEALTH

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A RISK TO HUMAN HEALTH

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Introduction

Research has been conducted in the past on the quality of waters in the Rio Grande. Many of the resulting publications have shown that human exposure to the river water would most likely result in unfavorable health outcomes. Numerous articles concluded that segments of these waters are not suitable for drinking, bathing, or, in many cases, for contact recreation (Texas Clean Rivers Program, 2003). Generalized research has been performed near cities and in rural areas around Laredo, TX; however, none so far has focused specifically on fecal coliform density in the river within the city limits, and outlying suburbs of Laredo. This research focused on determining the existence of harmful level of bacterial fecal coliforms for human exposure. Suggestions were made about the sources of the bacterial coliforms. The seasonality and timeliness of harmful fecal coliforms density was analyzed. The implications for human health were explained, based on results of the project.

Fecal Coliforms and Human Health

Bacterial monitoring of surface waters is done continuously to ensure public safety. The Environmental Protection Agency (EPA) recommends a geometric mean (GM) of no more than 126 colony-forming units (CFU) per 100 mL of water, and a sample maximum (SM) of 394 CFU/100 mL for freshwaters that will be used for "primary contact," such as recreation. For secondary contact, such as non-contact recreational use of freshwaters, the EPA recommends a GM of 605 CFU /100 mL (2000). Specifically, for bacterial fecal coliform testing, the criterion includes 200 CFU/100 mL of water for primary contact, and 2,000 CFU/100 mL of water for secondary contact (Texas Clean Rivers, 2003). Based on these criteria, segments of water are designated for contact recreation, including swimming, water skiing, or other activities involving prolonged contact with the water, with considerable risk of ingesting enough water to pose a significant health hazard (EPA, 2000; Iowa Department of Natural Resources, 2004). In the case of secondary contact, waters are designated for fishing, wading, and boating activities, which involve recreational or other water use, where contact with the water may occur, and there is a low probability of ingesting appreciable quantities of water (EPA, 2000).

These guidelines were set in 1986 by the document produced by the EPA called *Ambient Water Quality Criteria for Bacteria*. The goal behind the creation of this document was to develop a set of guidelines for states in order to preserve water quality, standardize procedures involving assessment of water quality, and to protect citizens from illness due to exposure to recreational waters (EPA, 2000). This document establishes *Escherichia coli* (*E. coli*) and enterococci as indicator organisms of fecal pollution, and recommends their use when testing surface waters for quality assessment (EPA, 2000). The testing of fecal coliforms in surface water can also give an indication of fecal pollution (EPA, 2000; Texas Clean Rivers, 2003). *E. coli*, a subset of fecal coliforms, is found in the gut of warm-blooded animals, and rarely exists in nature with no connection to fecal matter (Stuart, McFeters, Schillinger & Stuart, 1976). Indicators, such as fecal coliforms and *E. coli* give a measurement of the amount of fecal coliforms that are present in the water that could be associated with pathogens (Texas Clean Rivers Program, 2003).

After 2002, the EPA chose to focus on *E. coli* as an indicator species of fecal contamination because it has been shown to be a better predictor than fecal coliforms alone (Texas Clean Rivers, 2003). EPA (2000) studies indicate that *E. coli* and enterococci show the strongest relationships to gastrointestinal illness when primary contact with water has occurred. In the past, it has been found that gastrointestinal illness in swimmers is highly associated with swimming in fecally contaminated waters. Children are at a higher risk than adults of illness due to ingestion of water, because they frequently play in shallower waters where contamination is more likely to occur (EPA, 2000). Because they stand largely unchallenged, the 1986 guidelines for fecal contamination were used for comparison purposes throughout this project.

E. coli and fecal coliform data have been historically used to indicate potential risk of illness that may occur by using unfit waters for contact recreational activities. The presence of *E. coli*, and fecal coliforms, in a water sample, states the EPA, indicates fecal contamination (2001). Fecal coliforms often do not cause illness directly, but make good indicators of harmful pathogens in waterbodies (EPA, 2002). When fecal pollution exists in a water body used for primary contact, the main route of exposure to illness-causing organisms is through direct contact with polluted water while swimming, most commonly through accidental ingestion of contaminated water. This process of intake is termed the "fecal-oral route," and is used to describe the process by which fecally polluted water is taken into the body via the mouth. Swimmers in fecally polluted waters are at high risk for waterborne diseases frequently caused by ingestion. As a result, the EPA emphasizes that not only bacterial, but also viral and protozoan infections are a potential danger (2002). Bacterial infections from fecally polluted waters can include cholera, salmonellosis, shigellosis, and bacterially caused gastroenteritis. Gastroenteritis is a term for a variety of diseases that affect the gastrointestinal tract and are rarely life threatening (EPA, 2002). Viral infections, such as infectious hepatitis, virally induced gastroenteritis, and intestinal diseases caused by enteroviruses, and protozoan infections, such as cryptosporidiosis, amoebic dysentery, and giardiasis, pose a significant danger as well (2002). In particular, Hepatitis A as well as bacterially caused enteritis, are very common in the Laredo/Nuevo Laredo area (Weinberg et al., 2003).

The most common adverse effects of bathing in contaminated water are illnesses that affect the gastrointestinal tract (EPA, 2001; EPA, 2002). Other illnesses and conditions, however, affecting the eye, ear, and upper respiratory tract can be contracted as well from exposure to fecally contaminated waters. Frequently, infection occurs when pathogenic microorganisms come into contact with small breaks and tears in the skin or ruptures in delicate membranes in the ear or nose resulting from diving into the water (EPA, 2001; EPA, 2002). Persistent skin irritations have also been reported as a result of dermal contact of fecally contaminated waters (Downs, Cifuentes-Garcia & Suffet, 1999) and other illnesses due to water contact rather than ingestion (Fleisher, Kay, Salmon, Jones, Wyer & Godfree, 1996). Though these illnesses are not usually life-threatening for most people, they do represent a significant health burden on those who have been infected.

A vast number of species of microorganisms are present in the environment, but only a small subset are human pathogens, capable of causing varying degrees of illness (EPA, 2000; EPA, 2001). Some human pathogens are naturally occurring in the environment, but the source of most of these microorganisms is usually the feces or other wastes of humans and other warm-blooded animals. When infections by these means occur, the most frequent result is a gastrointestinal infection, called gastroenteritis (EPA, 2002). Symptoms of gastroenteritis can include vomiting, diarrhea, stomachache, nausea, headache, and fever (EPA, 2001; EPA, 2002). Symptoms of gastroenteritis are not often associated with swimming, because the onset of disease is generally several days after exposure to the pathogen, and are often not severe enough to cause individuals to go to the hospital or seek medical attention (EPA, 2002). Researchers have observed that approximately one-third of people reporting to have had gastroenteritis or similar symptoms have consulted a medical practitioner, or have been medically treated (Perez-Ciordia et al., 2002; Scallan et al., 2004). Most people afflicted by gastroenteritis have flu-like symptoms several days after exposure, and rarely suspect that ingestion of water during recreation could be the cause of their illness, and often assume that they have the flu or food poisoning (Perez-Ciordia et al., 2002; Theron, 2004). As a consequence, disease outbreaks are inconsistently detected and reported, which leads to difficulty in determining how many illnesses result from contact with recreational waters (Perez-Ciordia et al., 2002).

Tests conducted by the EPA for dissolved oxygen levels in the Laredo segment (2304) of the Rio Grande have historically shown acceptable dissolved oxygen content in this segment. As a result, segment 2304 has been designated for contact recreational use. Contact recreation use is assigned to all water bodies in the Rio Grande, except for special cases, according to the latest assessment of the Rio Grande by the Texas Clean Rivers Program (2003). The water body uses for the Laredo segment of the Rio Grande are high aquatic life use, contact recreation, general uses, fish consumption, and public water supply use (Texas Clean Rivers, 2003). In this document, the Texas Clean Rivers Programs states that the public water supply, fish consumption, and general uses are fully supported. The term "fully supported" was assigned because the tested segments of the river, sampled and assessed by the Texas Clean Rivers analysts, did not exceed established testing parameters. Measurements of dissolved oxygen at different sampling sites, in this case, are used to report river quality to the State of Texas, and then used to determine the designation of sampled river sites. The 2003 Texas Clean Rivers report also reminds readers that full support of the contact recreation use is not a guarantee that the water is completely safe from disease-causing organisms. The same study, however, indicated that the standard for fecal coliform was not met in different parts of the segment indicating a concern for contact recreation (Texas Clean Rivers, 2003). Measurements conducted by other groups, such as the Rio Grande International Study Center (RGISC) have found fecal coliform levels in surface water to exceed standards as well.

Processes by Which Fecal Coliforms Enter the Rio Grande

Fecal coliforms can enter a body of water by a number of different routes. The two most common ways fecal coliforms enter the Rio Grande are the release by humans in the form of untreated or poorly treated sewage (DeNapoli, Rutman, Robinson & Rhodes, 1996), and runoff as a result of precipitation in the area. Sources of pollution are generally divided into point, and nonpoint sources. According to the EPA (2001), pathogenic organisms, such as fecal coliforms, are one of many types of pollutants generated at a source (point or nonpoint) and then transported by stormwater runoff, groundwater, or other method, to a body of water. Additionally, the identification of sources and tracking the movement of the pathogens can be a difficult and costly task.

Waste Water Treatment Plants (WWTP) serve as one of the more apparent point-sources for fecal coliforms. The presence of high organic content is one reason why raw sewage is associated with high concentrations of pathogenic bacteria, viruses, and protozoans (EPA, 2001). If local WWTPs have inadequate or poorly designed treatment processes, which decrease the effectiveness of the facility, a resulting spike in the numbers of fecal coliforms in the body of water that receives the WWTP discharge can be expected. For this reason, any raw sewage runoff that is not treated by a WWTP directly contributes to the overall fecal coliform load of a body of water. Other point sources, such as concentrated animal feeding operations (CAFO's), slaughterhouses, meat processing facilities, tanning, textile, and pulp and paper factories, and fish and shellfish processing facilities can contribute substantial loads of pathogens and fecal indicators to waterbodies (EPA, 2001).

Nonpoint sources (not originating for a specific outfall location) contribute to fecal coliform levels as well. Nonpoint sources of pollution are differentiated by the EPA from point sources of pollution, because the former are typically wet-weather-dominated (2001). Nonpoint source pollutants are also diffuse in nature and do not enter waterbodies from any single point making these sources extremely difficult to identify and mitigate (EPA, 2001). In a document outlining Total Maximum Daily Load (TMDL) protocol for microorganisms in waterbodies, the EPA describes some of the sources of fecal coliforms in cities. Urban and suburban areas contain nonpoint sources of pathogens, such as urban litter, contaminated refuse, domestic pet and wildlife excrement, and failing sewer lines (EPA, 2001). Stormwater, after a major precipitation event, can also considerably increase the load carried by municipal sewers, adding organic matter as well as microorganisms. In addition, the EPA states that fecal bacteria densities are directly related to the density of housing, population, development, percent impervious area, and domestic animal density (2001). Due to economic and other conditions, parts of Laredo have some of these characteristics, such as areas of high density of housing, population development and locations of urban litter, and domestic animal density, making it a good candidate for the examination of nonpoint source runoff and the relationship to fecal coliform levels.

Because there is limited availability of data for point source contributors of fecal coliforms in Laredo, this project primarily focuses on nonpoint sources, specifically stormwater runoff, as a major contributor to the fecal coliform load of the Rio Grande. The EPA emphasizes that precipitation runoff contaminated with fecal coliforms is the source of considerable problems in the receiving body of water. Microorganisms, because of their small size, are easily carried by storm water runoff or other discharges into natural waterbodies (EPA, 2001). Once the pathogens enter a stream, lake, or estuary, they have the potential to infect humans through contaminated fish and shellfish, skin contact, or ingestion of water (EPA, 2001). Standards for testing exist for waters designated for recreation (primary and secondary contact); public water supplies; aquifer protection; and protection and propagation of fish, shellfish, and wildlife (EPA, 2001). Because protection from pathogenic contamination is one of the main goals of the EPA, as outlined in the Clean Water Act, identifying nonpoint source pollution plays an important role in this objective (2001).

The International Boundary and Water Commission (IBWC), which conducts a number of environmental studies on the Texas/Mexico border, believes that a source of concern within the Laredo/Nuevo Laredo city limits is illegal discharges and dumping (Texas Clean Rivers, 2003). As a result of a study of surface waters in the Rio Grande basin in 2000, the EPA confirmed that levels of fecal coliforms in the Laredo/Nuevo Laredo area at times exceeded water quality standards. The study results indicate that in the majority of the sampling locations the water quality standards for fecal coliform and dissolved oxygen are not met, typically because of partially treated or untreated wastewater discharges (EPA, 2001). A study done by the IBWC in 2003 also results in a report of fecal coliforms exceeding surface water requirements, and concern about the bacterial load in the Laredo area. The researchers report that the increases in fecal coliforms typically occur below return drains and tributaries, which indicates that the main source of contamination continues to be due to wastewater discharges (IBWC, 2000; Texas Clean Rivers, 2003). The study notes that the problem of high levels of fecal coliforms in the Laredo area is a concern for both the U.S. and Mexico, and that a wastewater treatment facility was built in Nuevo Laredo in 1996 to attempt to control bacterial levels from wastewater discharge (Texas Clean Rivers, 2003).

The IBWC advises that information concerning pathogen loading of a local waterway is important for communities to know especially for those concerned about using the Rio Grande as a drinking water supply as well as for eating the fish and coming into contact with the water (Texas Clean Rivers, 2003). Overall water quality is good, but more must be done to minimize the impacts of return flows, or leftover water returned to the river after irrigation, for example. This runoff flows into the river, and impacts the health of the system and compromises the benefits of the downstream users, remarks the IBWC. As communities experience growth, it becomes apparent that cities and counties have to play a more active role in preventing discharge practices that lead to increases of pathogens in local waterways (Texas Clean Rivers, 2003). Because the population on the Texas-Mexico border is expanding at such a rapid rate, controlling these activities often proves challenging for local governments.

Precipitation and Flow in the Rio Grande Basin

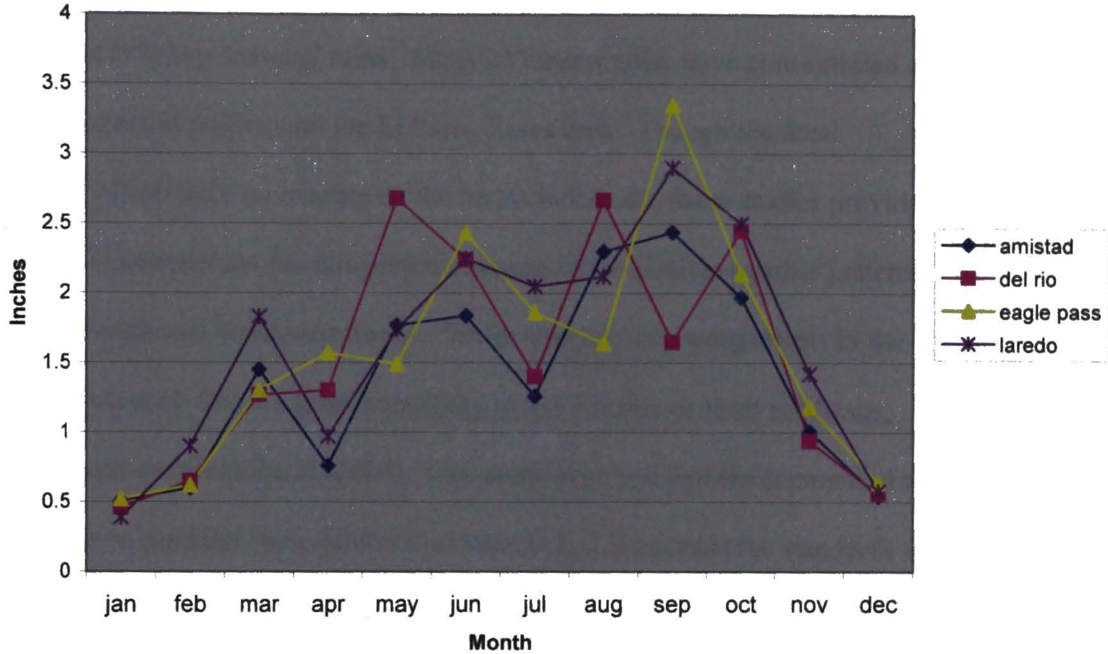
The South Texas region of the U.S. does not receive much precipitation on a regular basis, but many areas in and around Laredo are located on floodplains. The climate in this region is arid to semi-arid and annual rainfalls range from 9 inches per year in El Paso to 27 inches in Brownsville (Texas Clean Rivers, 2003). Laredo falls in an area called the Middle Rio Grande sub-basin, which begins below International Amistad Dam in Val Verde County, and ends at International Falcon Dam in Starr County. This stretch of the Rio Grande usually receives 25 inches of rainfall annually (Texas Clean Rivers, 2003). The topography in the Middle Rio Grande sub-basin forms rolling, irregular plains and continues until tuning into coastal plains as the river approaches the Gulf of Mexico in the Lower Rio Grande sub-basin (Texas Clean Rivers, 2003). The rolling hills and gently sloping plains in the Laredo area ensure that runoff from high precipitation events runs into a nearby tributary, which empties into the Rio Grande.

The nature of the precipitation and flow of the Rio Grande is due to its location in South Texas. The source for the segment of the Rio Grande that flows through the

Laredo area is water from the Amistad Reservoir, in Val Verde County. The Amistad Reservoir is fed by the Rio Conchos, a river with its origins in Mexico. The Rio Conchos is a completely different source of water than that which feeds the Rio Grande above El Paso, and is noted for its high-quality water. Much of the Rio Grande above Laredo is called the Forgotten River, named for its very low flow, which is generally composed of return flows from the United States and Mexico, from agricultural and municipal activities (Texas Clean Rivers, 2003). Due to seasonal variability of return flow, the Forgotten River frequently experiences intermittent flow on its way to Laredo, and is further decreased by use of the water by cities along the border, such as Del Rio, Texas, as a municipal source and for crop irrigation.

The rate of flow of a river and precipitation an area receives are connected. When the Laredo segment of the Rio Grande is experiencing high flow, it may be due to a high level of precipitation, which is sporadic, but not uncommon due to the city's location in a flood plain. Another potential reason for flow increase in this area could be from the release of water from Amistad Reservoir, approximately 180 miles upstream. Similarly, the South Texas Rio Grande Basin area experiences similar weather patterns. A traditionally arid region, intermittent, light precipitation is normal for the upper and middle Rio Grande Basin segments during winter months. Between the months of June and October, however, sharp and sporadic increases in rainfall are not uncommon.

Figure 1: Average Precipitation in the Middle Rio Grande Basin over 10 years



The IBWC comments that there are two other influences can affect the fecal coliform load of a river besides time, flow and season (Texas Clean Rivers, 2003). Typically, the rate of flow of a river and its fecal coliform levels are inversely correlated (Babinchak, Graikoski, Dudley & Nitkowski, 1977; Cho, Cho & Kim, 2000) so that the more rapidly the river is moving, the lower numbers of fecal coliforms will be observed. It is widely recognized that precipitation and level of fecal coliforms found in surface water of a nearby receiving stream are positively correlated, where higher levels of precipitation lead to an initial rise in the levels of fecal coliforms (Miller et al., 2004). Tunnicliff and Brickler confirm this phenomenon by noting that during rainfall cycles, fecal coliform densities are highly variable and often exceeded recreational contact standards (1984).

Though the Rio Grande basin does not receive much rainfall, compared to other portions of the United States, however studies on the Rio Grande have reported high fecal coliform counts due to heavy seasonal rains. Many of these studies have concentrated on the Rio Grande segment in and around the El Paso, Texas area. Though the fecal coliform levels in El Paso have no bearing on the levels in Laredo, these studies provide an important point of comparison for this project because of the similar weather patterns and topography of South and Southwest Texas. While studying microorganisms in the Rio Grande, Mendoza et al. found a great variability in the number of fecal coliforms, and *E. coli* on a month-to-month basis (2004). One study reported that the segment of the Rio Grande River from Sunland Park, NM to Fort Hancock, TX exceeds the standards for contact recreation water on a continuous basis, and that water quality is an area of concern for the bi-national region (Mendoza et al., 2004). The segment of the Rio Grande by El Paso in the study conducted by Mendoza et al., has many of the same features as the segment that passes through Laredo/Nuevo Laredo, including several international pedestrian and traffic bridges, and WWTPs on both the Mexico and the Texas side (2004). This segment of the Rio Grande is similarly impacted by street and agricultural runoff (Mendoza et al., 2004).

Life on the Rio Grande

The Rio Grande serves as an important water supply for the United States-Mexico border region. Laredo and Nuevo Laredo both rely on the Rio Grande for agriculture and as a drinking water supply (IBWC, 2000). The sources for drinking water in the Rio Grande Basin are a combination of a few groundwater sources and the Rio

Grande (Texas Clean Rivers, 2003). Fecal coliforms have been found in some shallow wells fed by groundwater in communities on the Rio Grande, making those sources unfit for human consumption (Mroz Jr. & Pillai, 1994). For communities south of the city of Del Rio, Texas, the groundwater is costly to treat and use for drinking water due to high salinity and mineralization. These communities depend entirely on surface waters (Texas Clean Rivers, 2003). One study estimates that a majority of groundwater sources in far West Texas will be depleted by 2025, and will force those communities to find alternate sources of potable water (Texas Clean Rivers, 2003).

Population growth on the border, primarily due to increasing trade between the U.S. and Mexico, is a growing concern (IBWC, 2000). It has been found that the population in the Rio Grande basin has doubled in the last 20 years, with the majority of the population along the Rio Grande in sister cities lying adjacent to each other, such as Laredo/Nuevo Laredo (Texas Clean Rivers, 2003). A study involving Rio Grande monitoring from Laredo as well as Nuevo Laredo reports that the Rio Grande is influenced in the Laredo area by treated wastewater effluents, untreated wastewater, and tributary flows (IBWC, 2000). With population growth on the border exceeding anticipated national average growth rates, in some cases higher than 40% for each country, the border population is expected to increase by 7.6 million people by 2020 if growth continues at the same rate (EPA, 2002). This rapid growth will place considerable strain, above what is now experienced, on the Rio Grande as the primary water source for the area.

Concerns about the improper disposal of wastewater are frequently mentioned in discussions about the Rio Grande. Many times dumping occurs because there are not many other options for citizens in low economic situations. Frequently, there is little understanding or concern about secondary contact with raw sewage. A significant portion of the population on the border lives in *colonias*. A *colonia* can be defined as the equivalent of a primarily low-income neighborhood or community. In Texas, a *colonia* refers to an unincorporated settlement that may lack basic water and sewer systems, paved roads, and safe and sanitary housing (Federal Reserve Bank of Dallas, n.d.; Texas Department of Health and Human Services, 1988). These communities exist on both sides of the border. *Colonias* were created when developers used land that had little agricultural value that lay in floodplains or other rural properties to create unincorporated subdivisions (Federal Reserve Bank of Dallas, n.d.). Developers divided the land into small lots without infrastructure or municipal connections, and then sold the lots to low-income individuals seeking affordable housing. Today, there is a shortage of affordable housing in many rural areas as well as cities on the Texas-Mexico border. This lack of housing, coupled with the rising need, has contributed to the development of new *colonias* and the expansion of existing ones. One report on the Texas-Mexico border region by the University of Texas estimates that by the year 2010, more than 700,000 additional people will need affordable housing on the Texas border if current trends continue (Federal Reserve Bank of Dallas, n.d.).

The existence of *colonias* does add to the runoff contributing to fecal coliform loading in the Rio Grande. The lack of a wastewater infrastructure and lack of available potable water are two of the greatest concerns in these unincorporated areas. *Colonias* are frequently without sewer systems, and instead, residents must rely on alternative, often-inadequate wastewater disposal methods (Federal Reserve Bank of Dallas, n.d.;

Texas Department of Health and Human Services, 1988). A survey from the Texas Department of Health and Human services reported that 50.7 percent of *colonia* households in El Paso and the Rio Grande Valley use septic tanks, 36.4 percent use cesspools, 7.4 percent use outhouses and 5.5 percent use other means to dispose of wastewater (1988). Septic systems are functional much of the time, but have the potential to overflow if not properly maintained, and still contain pathogenic organisms. Cesspools are seen as unhygienic because they contain untreated wastewater, and frequently contain pathogenic microorganisms (DeSerres et al., 1999), and frequently impede the soil's natural ability to filter out pathogenic organisms, due primarily to the solids found in these pools. The problem of runoff from *colonias* is exacerbated by the poor quality of *colonia* roads, which are often unpaved and covered with materials that prevent drainage or though drainage system installation (Federal Reserve Bank of Dallas, n.d.). Conditions such as these, combined with the frequent problem of inadequate septic systems, often result in sewage pooling on the ground in these neighborhoods.

Experts believe that even if sewer systems could be installed in the *colonias*, the border area lacks sufficient facilities to treat wastewater (Federal Reserve Bank of Dallas, n.d.). It is thought that wastewater treatment capacity on the border has been inadequate for the past 20 years, and in many places, there are no provisions for treatment at all. Consequently, border communities often discharge untreated or inadequately treated wastewater into rivers and canals, which then eventually flow into the Gulf of Mexico. Before the 1996 installation of the Nuevo Laredo WWTP, an approximate 27 million gallons of untreated wastewater a day was discharged into the Rio Grande (EPA, 1992). This discharge contributed to ecological and aesthetic degradation, economic loss and threats to public health in the Laredo/Nuevo Laredo area alone (EPA, 1992). After the plant completion, the amount of untreated wastewater discharged into the Rio Grande is approximated at eight million gallons a day.

Finding clean water to use on a daily basis is another difficult task for people living in *colonias*. The residents are faced with contaminated wells, lack of municipal connections, and a scarcity of water in general. The Federal Reserve Bank of Dallas states that in South and West Texas border counties, 23.7 percent of the households did not have treated water in the house (n.d.). Because of this, untreated water is used by 12.8 percent of households to wash dishes, 13.1 percent to wash clothes, 12.3 percent to bathe and 4.9 percent to cook (Federal Reserve Bank of Dallas, n.d.). The Texas Water Development Board estimates that 428 *colonias* with about 81,000 people are in need of potable water facilities, and 1,195 *colonias* with about 232,000 people need wastewater treatment facilities (Federal Reserve Bank of Dallas, n.d.). Other issues associated with *colonia* residents' inability to access potable water include homes that do not meet standard building codes. Though there are homes built on *colonia* land, many of them are considered substandard housing by the U.S. government, and do not meet the standards of the Federal Emergency Management Agency. Additionally, the cost of extending water lines to homes, especially ones located in floodplain areas, is high (Federal Reserve Bank of Dallas, n.d.). *Colonias* often lack a sponsoring entity to apply to for funds, such as a city or county, and in some cases, water is simply not available.

Because unsanitary water is routinely used in the *colonias*, many health issues, most specifically waterborne illnesses such as hepatitis and gastrointestinal diseases, frequently affect *colonia* residents (Texas Department of Health and Human Services, 1988). TDH in a report in 2000 asserts that at the time of the survey, *colonia* children one year to five years old were much more likely than non-*colonia* children to have had diarrhea in the past two weeks, and 11% of both *colonia* and non-*colonia* children under one year of age were reported to have had diarrhea in the past two weeks (2000). In several *colonias* without drinking water or wastewater services, health professionals found 20% of the children less than one year old had a 20% prevalence in a 2-week period. In these *colonias*, sewer service was only available to 54% of the *colonia* residents (TDH, 2000).

Materials and Methods

The data used for this project were collected by Dr. Thomas Vaughan of Texas A&M International University (TAMIU) in Laredo, Texas. Dr. Vaughan collected samples in each of four sampling sites once a month over a ten-year period of time. Site A is located approximately 14.8 river miles upstream from International Bridge I in Laredo (see figure 2). Dr. Vaughan states that Site A was chosen because it is upriver from Laredo and Nuevo Laredo, and therefore is relatively free of contaminants being produced by these cities (Vaughan, 1995). The property where Site A is located is privately owned, and access for sampling procedures has been given by the landowner.

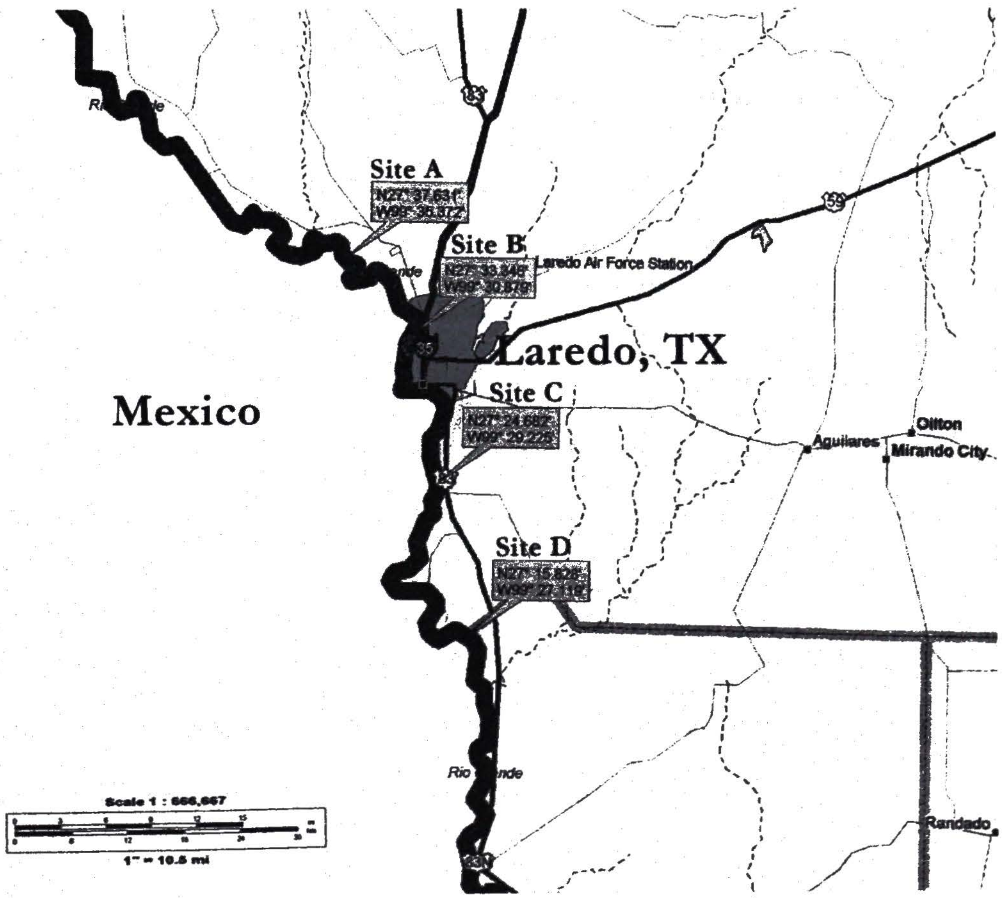
Samples for Site B are collected within the city limits of Laredo, at a location known as Bill Haynes Island (Vaughan, 1995). Site B is located approximately 9.3 river miles downstream from site A and 5.5 miles upstream from International Bridge I. The site is accessed through the City Ready Mix Plant at 1810 W. Mann Rd. Site B is approximately 0.9 miles downstream from the mouth of Manadas Creek, a known receiving stream for discharge containing high levels of Antimony. Site B is 0.7 miles from the Central Power and Light discharge as well as downstream from stormwater outfalls for the City of Laredo (Vaughan, 1995). Dr. Vaughan commented that Site B is sometimes a popular fishing spot for groups (2004).

Site C is located is South of Laredo and most of Nuevo Laredo city limits. This site is downstream of a creek called Arroyo El Coyote, the southernmost major sewer outfall from Nuevo Laredo (Vaughan, 1995). The site is 7.6 miles downstream from International Bridge I and approximately one-half mile south of the WWTP in Nuevo

Laredo. Site C requires access on to private property for sampling. Permission to sample the river in this location has been granted by the landowner.

Site D is located south of Laredo and Nuevo Laredo, at the Webb-Zapata County line. Samples for Site D are collected approximately 24 river miles downstream from International Bridge I and 16.4 miles from Site C. This site is also located on private property, and permission was given by the landowner for entry for sampling purposes (Vaughan, 1995).

Figure 2: Map of Sampled Sites



Once samples have been taken, they are packed in ice, and taken to the lab at TAMIU for processing. The analysis of coliform colonies involves two procedures. The Millipore method of analysis is used for culturing *E. coli.* To test for fecal coliforms, Dr. Vaughan uses 2, 5 and 10 mL filtered samples from each sampled location on the Rio Grande. Each sample is pumped through a filter, premixed medium is added for growth, and then the plates are incubated at 44.5 C° for 24 hours before counting. After incubation, the colonies are counted and recorded.

Dr. Vaughan has also collected the flow data used for this project. The flow of the river at each of the four sites is measured by a flow meter during the time of sampling, usually mid-day. The flow is measured in feet per second. The precipitation data used for this project is historical data that has been collected from rain gauges along the Rio Grande by the National Climactic Data Center. The sites used for this project are Amistad Reservoir, Del Rio, Eagle Pass, and Laredo. These sites were chosen because they represent locations upstream and within Laredo city limits.

The coliform, flow, and precipitation data were analyzed using SPSS® version 11.0. Dates within the database that contained the entries "no data" or "no growth" for fecal coliform density have been removed. Fecal coliform data was not collected most frequently, resulting in a "no data" entry, because the site locations were inaccessible due to heavy rainfall that had washed out the roads in the area. Each site was sampled once a month, usually on the third Thursday of the month. During the sampling time between 1993 and 2004, 75 months of coliform data was collected.

Analysis was then performed on the collected data using a Spearman Rank Order Correlation (Spearman Correlation), and linear regression analysis. A Spearman correlation ranks each data point, and calculates to show the degree of linear relationship between two variables. Because the dataset used in this study had a non-normal distribution, a non-parametric test, like the Spearman correlation, was used for analysis. Like parametric tests, results for the Spearman correlation are reported as values between 0 and 1. A correlation between two variables would indicate that a significant difference existed between them. A positive correlation between two variables indicates that the variables increase together, while a negative correlation indicates one variable increases, while the other decreases.

A correlation, however, does not indicate causality. In order to address this area, linear regression analysis was also used to identify predictors of fecal coliform levels at each site. Variables that are correlated can be added to a linear regression equation, or SPSS model, and designated as independent and dependent. Though the data was linear in nature, each site exhibited outliers that did not fit the overall trend of the data. These outliers were removed for linear regression analysis portion of this study only.

Coliform data was compared to Dr. Vaughan's collected flow data, and then each precipitation site individually for correlation. Coliform data from the four sites were compared using a Spearman correlation to discover any relationships that may exist. Because the flow is from A, to B, to C, to D, it was hypothesized that a relationship may exist between coliform density at one site, and an increased density at the site directly downstream. Precipitation data was also compared using a Spearman correlation. A Pearson correlation was used to show the relationship between precipitations in different areas of South Texas and fecal coliform densities at sites A-D in the Laredo area. Averages were calculated for coliform data and precipitation data, and graphed to identify any trends in the data. A linear regression analysis was also performed to find possible predictors for coliform levels at sites A-D. The regression analysis was used to identify any significant predictors at sites A-D for fecal coliform density.

Because the Nuevo Laredo WWTP was constructed just above site C on the Mexico side of the Rio Grande in 1996, fecal coliform counts from Sites C and D were divided into pre- and post- 1996 categories. Pre-1996 densities were matched by month to post-1996 densities, such as the recorded number of coliforms for Site C in January 1994 was tested against the recorded number of coliforms for Site C in January 1998. A Spearman correlation was then run on pre- and post- 1996 scores for both Site C and Site D. Matching by month was done to eliminate some seasonal bias, due to heavier rains in the summer and fall in South Texas as compared to the winter and spring months.

Flow data from the IBWC was also compared, using a Spearman correlation, to Dr. Vaughan's collected flow data. It was hypothesized that data from the IBWC might give a better overall picture of the river's behavior on the day sampled. The outliers were identified from each of the four sampled sites, and were compared with IBWC flow data measured on the same day for the City of Laredo. Outliers for these tests were identified as extremely high data points that lay outside the general trend of fecal coliform density, whether the density exceeded designation standards or not, on a regular basis. These comparisons were done using both a Spearman correlation as well as regression analysis. A five-day flow period was examined. The outliers were each compared to the five-day previous flow measurements to elucidate any relationships that may exist about precipitation upstream and its effect on fecal coliform density on Sites A-D.

Results

Coliform density was measured at each site once each month for 75 contiguous months. The average number and range of coliforms measured in the span of time between September 1993, and April 2004 are recorded in Table 1, as well as the number of times each site exceeded the designated value of 200 CFU/100 mL for contact recreation, and 2,000 CFU/100 mL for secondary contact.

Table 1: Fecal Coliform Counts By Site

Site	Mean of Fecal Coliform Numbers (CFU/100 mL)	Range of Fecal Coliform Numbers (CFU/100 mL)	Number of Times Counts Exceeded 200 CFU/100 mL	Number of Times Counts Exceeded 2,000 CFU/100 mL
A	170.41	0.00-3,333.00	14	1
B	138.43	0.00-2,200.00	12	1
C	2,228.54	0.00-38,000.00	59	18
D	4,367.01	0.00-88,000.00	70	22

Figure 3: Mean Fecal Coliform Density of Sites A-D Over a 10-Year Period of Time

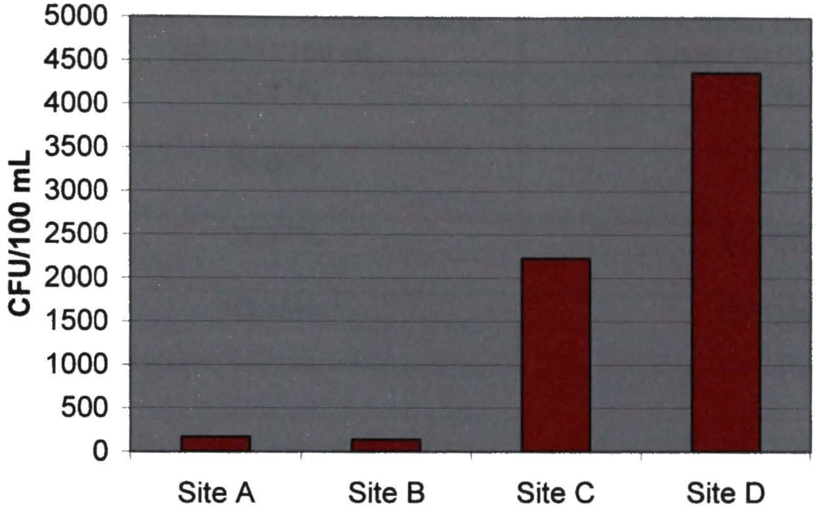


Figure 4: Fecal Coliform Density in Comparison to National Fecal Coliform Standards

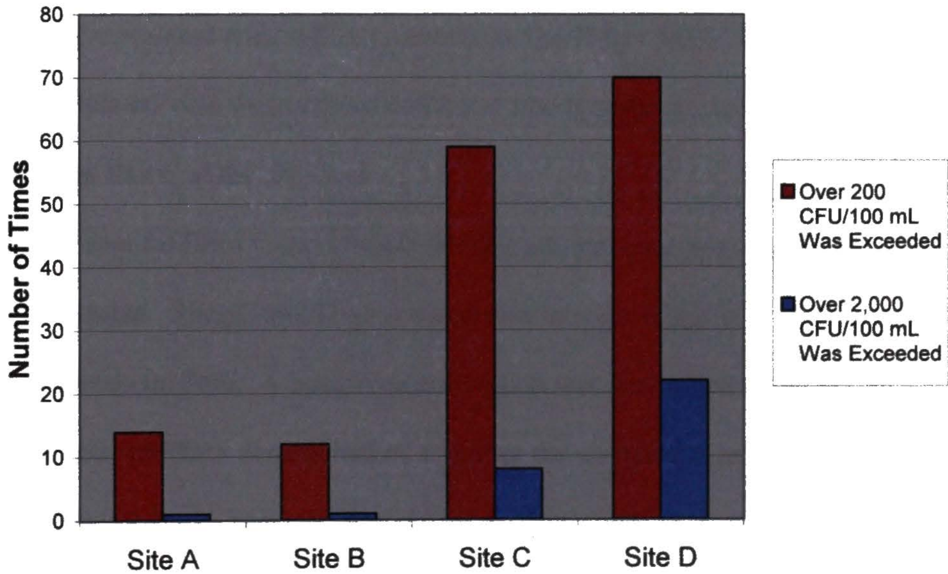


Table 2: Percentage Exceedance of Fecal Coliforms Over National Designation

Site	Percentage of the Time Fecal Coliform Counts Exceeded Above 200 CFU/100 mL	Percentage of the Time Fecal Coliform Counts Exceeded Above 2,000 CFU/100 mL
A	18.67%	1.33%
B	16.00%	1.33%
C	78.67%	24.00%
D	93.33%	29.33%

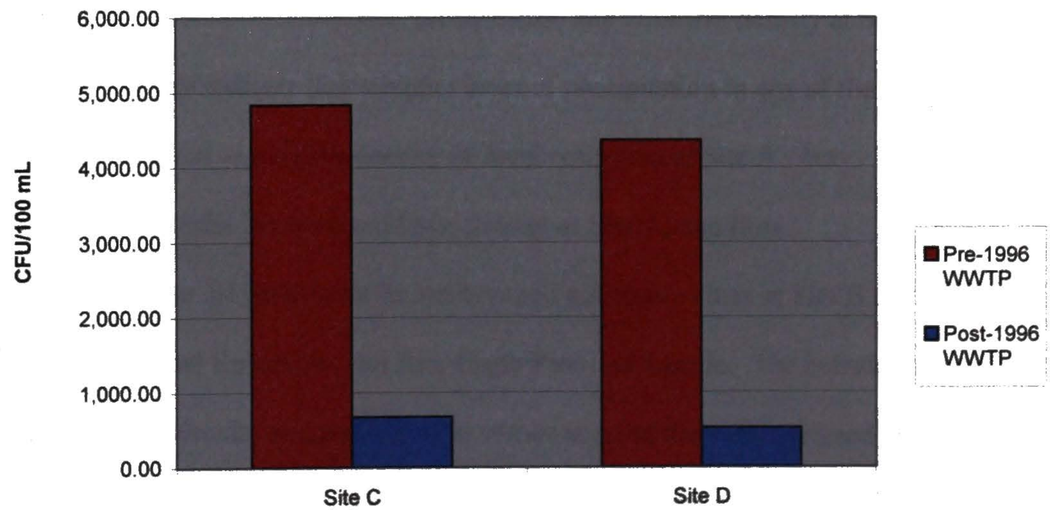
A Spearman correlation was used to determine a relationship between coliform densities in sites A, B, C and D. Coliform density at Site A exhibited no significant correlation to the other three sites. Coliform density at Site B was significantly correlated at the .05 level, with coliform density at Site D (p= .028). Coliform density at Site C was highly correlated with coliform density at Site D (p= .003). Coliform density at Site D was correlated with the coliform density at Site B at the .05 level, and with the coliform density at Site C at the .01 level.

Coliform data for Sites C and D were divided into pre- and post- 1996 values for coliform data collected. Sites C and D are located downstream of the WWTP that was built in Nuevo Laredo in 1996. A Spearman correlation was performed to determine a relationship between coliform density before and after the wastewater treatment plant installation in Nuevo Laredo, Mexico. Pre- and post-1996 coliform density at Site C did not show a significant difference (p=0.536) between fecal coliform densities, nor did pre- and post- 1996 coliform densities at Site D (p=.407). There is, however, a value difference in fecal coliform densities evident at both Sites C and D, pre- and post-1996 construction and implementation of the WWTP. Table 3 shows a comparison of averages and ranges for these two time periods.

Table 3: Fecal Coliform Density Pre- and Post-1996 Nuevo Laredo Wastewater Treatment Plant Construction

Site	Pre-1996 Coliform Mean (CFU/100 mL)	Post-1996 Coliform Mean (CFU/100 mL)	Pre-1996 Coliform Range (CFU/100 mL)	Post-1996 Coliform Range (CFU/100 mL)
C	4,837.16	673.40	0.00-38,000.00	5.00-4,500.00
D	4,367.01	523.89	0.00-88,000.00	0.00-7,100.00

Figure 5: Fecal Coliform Densities Downstream of Nuevo Laredo Pre- and Post-1996 Construction of Wastewater Treatment Plant



A Spearman correlation was computed on the precipitation values collected over a 10-year span of time. Precipitation values at each location were correlated with all other precipitation levels, significant at the .01 level. This test demonstrated a significant difference between precipitation levels in the Middle Rio Grande Sub-Basin. Over a ten-year span of time, Laredo received the most rain, followed by Eagle Pass, Del Rio, and Amistad Reservoir, in a decreasing pattern. Table 4 shows annual precipitation averages based on a ten-year period.

Table 4: Precipitation in the Middle Rio Grande Sub-Basin Over a 10-Year Period

	Amistad Reservoir	Del Rio	Eagle Pass	Laredo
Average Yearly Precipitation (inches)	16.45	18.27	18.74	19.65

Relationships between flow and precipitation to fecal coliform density were examined using a Spearman correlation. Correlations at the .01 level were found between coliform density at Site A and precipitation from Amistad Reservoir, Eagle Pass, Del Rio, and Laredo. Correlations between precipitation and coliform density at Site A were positive. The results indicate that a higher level of precipitation in any of the measured sites is correlated to a higher density of fecal coliforms at Site A. No correlation was found to exist between coliform density at Site A, and flow.

Correlations at the .01 level were found between coliform values at Site B and precipitation from Amistad Reservoir, Del Rio, Eagle Pass and Laredo. The correlations found between coliform density and precipitation values at all of the sites analyzed were positive. These results indicate that higher levels of precipitation are correlated to higher fecal coliform density at Site B. Additionally, fecal coliform density and flow at Site B were highly correlated at the .001 level. These results indicate that a correlation exists between the Rio Grande moving more rapidly, and higher fecal coliform density at Site B.

A correlation at the .05 level was found between coliform density at Site C and precipitation levels for Laredo (p=.019). Higher levels of precipitation in Laredo are correlated with higher fecal coliform density at Site C. No other precipitation site was correlated with fecal coliform density at Site C. Fecal coliform density was not correlated with flow at Site C.

Fecal coliform density at Site D was correlated with precipitation at Amistad Reservoir at the .05 level (p=.212), and with precipitation at Del Rio (p=.005) and Laredo (p=.008) at the .01 level. In all three cases, a higher level of precipitation indicated higher fecal coliform density. No correlation between fecal coliform density and flow was found.

A regression analysis was performed to determine significant predictors for coliform density at Sites A, B, C and D. No significant predictors for fecal coliform density at sites A were found. Two variables were found to be good predictors of coliform density at Site B, flow and precipitation from Laredo. Flow was significant at the .002 level, while precipitation in Laredo was significant at the .000 level. These two variables were included in the predictor model, which produced and F-value of 8.266, and was significant at the .000 level. No significant predictors for fecal coliform density at Site C were found. The only significant predictor for coliform density at Site D was precipitation in Laredo (p= .005). The precipitation values for Laredo were found to be a highly significant predictor at the .000 level, with an F-value of 8.560.

Daily flow data from the IBWC was compared to the outliers for each sample site. It has been established that unusually heavy rainfall leads to an initial spike in the fecal coliform density of an affected body of water. Heavy rainfall is also generally coupled with increased flow of a river. Based on these assumptions, the outliers for each site were identified for further analysis. There were no outliers that fell below the general trend of the fecal coliform data, only unusually high ones. The high outliers for each site (usually approximately 6 data points) were compared with the IBWC flow data for the four days previous, and the day the sample was taken.

A Spearman correlation was conducted for each site as compared to each of the five days of flow data. No correlations were found to exist between the IBWC flow data and Sites A, C and D. The IBWC flow data for day five (same date as sample date) was found to be correlated with fecal coliform density at Site B (p= .023). The results indicate that if flow was high on the same day as sampling, fecal coliform density at Site B would be high on the day of sampling. A linear regression analysis was then performed on the two variables, and the IBWC flow measurement on the same sampling day also proved to be a good predictor of fecal coliform density for Site B. The analysis generated an F-value of 19.381, and was significant at the .007 level.

Conclusions/Recommendations

The segment of the Rio Grande that runs through Laredo, Texas has been designated as a "primary contact" segment (Texas Clean Rivers, 2003). Results from the data analysis show that over the past ten years, all sites (A-D) have exceeded the 200 CFU/100 mL of water restriction for surface waters designated for primary contact. Sites C and D exceed the secondary contact restriction of 2,000 CFU/100 mL of water multiple times as well. Though a number of groups, including the IBWC, and Dr. Vaughan have reported these exceedances, the designation for the segment of the Rio Grande through Laredo/Nuevo Laredo has not changed in the past ten years. River samples may pass the analysis for dissolved oxygen performed by the State of Texas at various times during the year. The State, however, does not test specifically for fecal coliform density on a regular basis. A good dissolved oxygen amount is enough to keep the current designation for contact recreation, and secondary contact in place.

River water with bacterial loads that surpass designated contact recreation limits pose a problem to people in the area who may come in contact with fecally polluted water. Many *colonia* citizens, because of lack of water resources, are forced to obtain water wherever they can. Many in Mexico buy their water from companies who circulate their services weekly among the *colonias*, and citizens of Laredo *colonias* generally obtain water from coin-operated stations. Not all residents, however, can afford to purchase water. There are currently no statistics on how many *colonia* residents use the Rio Grande as a source of household water. Based on the data used for this project, if the

Rio Grande becomes, or is already, a source of water for low-income families, there is a good possibility of fecal coliform exposure.

Correlations found between the densities of fecal coliforms in the various sites are to be expected. Because of their geographic locations, Sites A-D progress downstream, beginning approximately 14 river miles North of Laredo, and ending South of Laredo, at the Webb/Zapata county line. Generally, density of fecal coliforms increase as the Rio Grande moves through the Laredo/Nuevo Laredo area (such as the density at Site B are generally greater than density at Site A, density at Site C are generally greater than density at Site D). This phenomenon is could be related to several factors.

The coliforms multiply as they move downstream, fed by runoff from urban areas containing organic matter (Michaud, 1994). There is substantial runoff from urban and rural (*colonia*) areas in both Laredo and Nuevo Laredo. This runoff could both increase the bacterial load of the Rio Grande by contributing organic matter and fecal coliforms simultaneously. A greater volume of runoff exists as the area becomes more urban. Site A is located in a rural, relatively unpopulated area North of Laredo. A high volume of organic runoff is unlikely at this site. Site B is located in North Laredo, but downstream of two major tributaries, Sombrito and Manadas Creeks, on the U.S. side of the Rio Grande. Site C, downstream of Laredo, is much more likely to be affected by the high volume of runoff from industrial facilities and from dwellings in this area. Site D is located the furthest downstream, where it has the potential of being impacted the most by a combination of raw sewage, urban runoff, organic matter, as well as the time the fecal coliforms have had to multiply.

Before the construction of the Nuevo Laredo WWTP, density of fecal coliforms a Site C were expected to be extremely high due to the amount of raw sewage entering the river in this area. After 1996, the density of fecal coliforms were dramatically reduced due to the treatment of wastewater in Nuevo Laredo, however, Site C continued to exceed the EPA requirement of less than 200 CFU/100 mL of water on a regular basis. This exceedance may be exacerbated by the fact that factories (*maquiladoras*) in this area, and many *colonias* in Nuevo Laredo remain without wastewater treatment. Though the numbers of fecal coliforms have been reduced at Site C, the density remains too high to safely use this area for contact recreation. Statistics in this study indicate that a relationship exists between the four sites evaluated. The rate at which fecal coliforms increase and travel downstream, and impact the adjacent site, needs further research in order to fully develop reasoning behind their varying fecal coliform density.

The values for precipitation collected for Amistad Reservoir, Del Rio, Eagle Pass, and Laredo were all highly correlated. Significant differences existed for levels of precipitation at each site studied. Though each location analyzed had its own, unique level of annual precipitation, different from every other site, the weather patterns in the Middle Rio Grande Sub-Basin are very similar. Variable rainfall, punctuated by high precipitation events in this area of Texas may account for the results of fecal coliform densities seen at Sites A and B. These two sites were found to be correlated with all precipitation sites studied. Higher levels of precipitation are correlated with higher densities of fecal coliforms. The results showed that levels of precipitation at every site were significantly different from one another, yet they were all correlated with fecal coliform levels, even downstream of these two sites. The similarity in weather patterns in this region of Texas may account for the strong correlations exhibited for Sites A and B, in addition to the numbers of fecal coliforms measured at these sites. Fecal coliform densities at Sites A and B are considerably lower than densities found at Sites C and D. It is possible that, because fecal coliform densities at Site A and B are noticeably lower than the densities at the other two sites, that these lower levels influence the dataset in such a way that all every measured precipitation site appeared to be correlated.

Fecal coliform density at Site C was found to be correlated with precipitation levels in Laredo only. Higher levels of precipitation in Laredo were correlated with higher fecal coliform density at Site C. Coliform levels at Site C were considerably higher than levels found at Sites A and B. It can be surmised that runoff from a precipitation event in Laredo has a direct impact on the fecal coliform density at Site C. This site is located South of Laredo, and also South of the outfall of the Nuevo Laredo WWTP. Urban runoff from factories, warehouses, domesticated stray animals, and increased population density has had a chance to collect, and both add to the bacterial load, and encourage its growth.

Site D was correlated with precipitation data from Amistad Reservoir, Del Rio, and Laredo. Higher levels of precipitation in these three locations indicated a higher fecal coliform density at Site D. There is some uncertainty as to why rainfall data was so highly correlated with fecal coliform density for Site D, but not for Site C. It is possible that, due to the high variations in this dataset, that all sampled sites are in actuality correlated to precipitation in this area. Fecal coliform density, however, may not be statistically significantly related to precipitation, but could still, in fact, be influenced by it.

Site D has the unique placement as last in line of a chain of sites traveling downstream on the Rio Grande. Coliform levels at Site D regularly exceeded those collected at Site C. A conclusion cannot be made, based on the data used for this project, as to whether or not the coliform densities measured at Site C traveled downstream and have impacted the coliform densities measured at Site D. A similar situation to Site C exists at Site D, due to the regularly high density of fecal coliforms.

When regression analyses were performed on sites A-D and precipitation and flow variables were calculated, some sites proved to be good predictors for coliform density at other sites. Generally speaking, the downstream site, was a good predictor of coliform density at a given site. For example, fecal coliform density for Site C is a good predictor for fecal coliform density at Site D. This effect may be due to upstream fecal coliforms, or coliform growth between sites, impacting downstream sites. The only situation where this rule does not apply is with Site A. This site was not found to have any correlation to the fecal coliform densities at other sites. Site A maintained a low average of fecal coliforms, and was the first site measured on the Rio Grande. This site is upstream of major industrial and urban activities, though it probably does receive precipitation and runoff from upstream urban centers, as well as small towns.

The flow variable measured by Dr. Vaughan at Site B was determined to be a good predictor of fecal coliform density measured at Site B. Higher rate of flow indicated a higher fecal coliform density at this site. High flow is generally associated with a precipitation event, which usually correlates with an increase in fecal coliform density. Coincidentally, precipitation for Laredo was also found to be a significant predictor of fecal coliform density at Site B. The rainfall in Laredo increases the flow of the Rio Grande. It is logical that both of these factors predict an increase in fecal coliforms at this site.

Only one predictor, precipitation in Laredo, was found to be significant for Site D. Though Site D is miles downstream of Laredo, a major rainfall event can increase both the organic load of the river as well as the number of microorganisms, due to urban runoff at site C. The high correlation between Laredo precipitation and Site D can be potentially explained by the idea that runoff and a high upstream fecal coliform density can serve to significantly increase the bacterial load of a site downstream. Site C, just downstream of both Laredo as well as Nuevo Laredo, receives a bulk of the urban runoff from a major storm event in the area. Though fecal coliform density at Site D is not directly correlated with fecal coliform density at Site C, it is no doubt impacted by the bacterial load traveling downstream after a major precipitation event.

The IBWC flow data was examined in hopes that it would provide a more comprehensive idea of the Rio Grande's behavior. When Dr. Vaughan measured the rate of flow for each site, he took the measurement in the same place as he sampled for other water qualities. The IBWC, however, places their flow meters more in the middle of the river, in order to gain a more general idea of the river's behavior from day to day. It is important to note that when Dr. Vaughan's flow measurements were statistically tested against the IBWC's flow measurements, no statistically significant differences were found. The values were different, but did not, however, show a statistically significant difference.

The only IBWC data that was correlated with fecal coliform density was at Site B. The same day as the measurement was taken, day five, was statistically significant.

Fecal coliform levels at Site B were correlated with day five, such that a more rapid flow indicated a higher fecal coliform density. This variable also serves as a good predictor for fecal coliform density at Site B. These results are not surprising, considering Dr. Vaughan's flow variable also was statistically significant for Site B.

The development of a method for determining what rate of low flow, and what upstream fecal coliform density will produce a potentially harmful situation at a downstream site. The City of Laredo could use this information in order to stay abreast of seasonal locations on the river that may exceed the designated 200 CFU/100 mL of water. Once a value has been determined for the predictor of a site of interest by the city, authorities could warn residents of possible negative health effects from recreational contact of the water in that stretch of the river. Additionally, because Site B is a popular camping location, when levels at Site C or D increase over 200 CFU/100 mL of water, warning signs could be placed at Site B, for example, to alert the public of possible fecal contamination over deemed safe contact limit.

Though a ten-year body of data on fecal coliforms was available for use in this study, retrospective human data on exposures and illness was not available. It is often difficult to collect accurate health data in this region of Texas because so many residents seek health care across the border, in Mexico (Landek & Garza, 2002). Therefore, the accuracy of the predicted health implications in this project is limited to application of information published in academic works. In the future, a project including data from medical institutions in the Laredo, Texas area could be performed to more specifically indicate time of exposure, exact type of exposure, background health information for the patient that may complicate diagnosis, and rate of exposure per year. With this additional information, and the inclusion of accurate human data, a more accurate prediction of health implications resulting from exposure to bacterial coliforms in the Rio Grande could be generated.

Other limitations of this study included lack of information from the Mexico side of the Rio Grande. Working binationally can be a difficult and highly political endeavor. Before surveys done by the IBWC, which have been in recent years, very little information was available, in either the U.S. or Mexico, about water quality on the Mexican side of the Rio Grande (Cech & Essman, 1992). During the ten-year span of the data used for this project, some measurements were taken by Dr. Vaughan at various times by performing a grab sample, a sample representing a snapshot of that moment in time in the river, of the water on the other side of the Rio Grande by canoe. He states in one case that samples taken from the other side of the river from Site C, just downstream of the Nuevo Laredo WWTP, in March of 2001 produced an unexpectedly high coliform count resulting in the CFU being too numerous to count, but estimated at least 40,000 CFU/100 mL (Vaughan, 2001 a, b). It is evident that more data is needed from both sides of the river to accurately estimate the fecal coliform load in this segment of the Rio Grande.

Unsafe densities of fecal coliforms, for contact recreation in the Rio Grande, are not unique to Laredo. A study was performed on seven sites on the Rio Grande between El Paso, Texas and Fort Hancock, Texas. Though this segment, the portion of the Rio Grande from below the International Dam, South of El Paso, to the confluence of the Rio Conchos, in Presidio, is not designated for contact recreation, fecal coliform load is still a potential problem. Every site tested in this segment of the river between the years 2000-

2002 exceeded the standard regulation of 200 CFU/100 mL over 75% of the time they were tested (Mendoza et al., 2004; Sternes, 1999). Some of the same sources of fecal coliforms are suggested by this study, as are suspected in Laredo, such as municipal runoff from densely populated areas of El Paso, and WWTP effluent (Mendoza et al., 2004).

Unfortunately, water quality on the Rio Grande is not predicted to improve much in the future. The EPA indicates that public health problems along the border are worsened by the impact of cross-border travel and commerce (2001). Researchers believe that in this area of the U.S., waterborne diseases are created by unsanitary conditions and/or lack of treatment facilities (EPA, 2001). Significant progress is evident from the current bacterial load of the Rio Grande in the Laredo/Nuevo Laredo area with the installation of the Nuevo Laredo WWTP, though fecal coliform levels, at times, at Sites C and D continue to exceed the limits for that segment of the river. The real problem in this part of Texas is the population growth. The EPA's estimate of the water and wastewater funding needs for the people living on the Texas border, through the year 2020 totals $4.5 billion. More immediately, the need projected by the EPA is approximately $691 million; $342 million needed in the U.S. and $349 million needed in Mexico. Beyond this funding, long-term needs are estimated at $3.8 billion. Of these funds, $1.3 billion is needed for the U.S. and $2.5 billion for Mexico (EPA, 2001). Both the U.S. and Mexico must provide more funding to water and wastewater needs in order to reduce the fecal coliform densities in the Laredo/Nuevo Laredo area down to a safe level.

In addition to concerns about residents of Laredo who may come in contact with unsafe portions of the Rio Grande, questions exist about the safety of those living downstream in the primarily agricultural area of South Texas. Similar issues about fecal coliforms and health need to be addressed in areas South of Laredo as well. Though river water, as it flows, tends to dilute fecal coliforms (Kaunat, 1980), inquiries into potential health risks for downstream communities still need to be addressed. Aside from health risks associated with human contact with water from the Rio Grande, this South Texas agricultural area, commonly known as "The Valley," serves as a major fruit and vegetable provider for the U.S. and Mexico. The primary source of water for irrigation in this area is the Rio Grande. Potential for fecal contamination of produce should be thoroughly examined.

This study represents the first in a potential series of investigations based upon the ten-year body of data characterizing the Rio Grande in the Laredo, Texas area. Though it is the first formal examination of the data, this project has attempted to elucidate some of the health issues that result from the exposure of humans to water polluted with an unsafe level of fecal coliforms. The analysis and recommendations that have resulted from this project will hopefully serve as a helpful guide, and first step, to improving education about fecal coliforms in the Rio Grande and the safety of the population in the Laredo, Texas area.

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