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Characterization of Lower Rio Grande Valley Watershed

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CHARACTERIZATION OF LOWER RIO GRANDE VALLEY WATERSHED

A Thesis

by

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ABSTRACT

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The Lower Laguna Madre (LLM) is considered impaired because of the high concentration of bacteria and low level of dissolved oxygen (DO). LLM receives freshwater from the Lower Rio Grande Valley (LRGV) watershed. In other to understand the impairment, LRGV watershed is being studied by relying on water quality data of the contributing drainages and State resource geographic data to identify watershed boundary and pollutant sources.

The study on the North and Central LRGV watershed shows some correlation between the concentration of E. coli/Bacteria, Ammonia, Total Kjeldahl Nitrogen, Total Phosphorus, Nitrate and Nitrite, Chlorophyll-a and the sources of pollutant in the watershed.

The ongoing research into the LRGV watershed shows that the leading cause of impairment in LLM estuary is the agricultural activities, followed by industrial waste management, and the influence of urbanized area in the LRGV watershed.

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DEDICATION

I want to dedicate this project to my lovely family for their relentless and unconditional support,

Thank you!

ACKNOWLEDGMENT

I thank Allah for making me witness today in good health. Also, I would like to thank my supervisor Dr. Abdoul Oubeidillah, and the committee members, Dr. Jongmin Kim and Dr. Jungseok Ho Thank you.

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CHAPTER I

INTRODUCTION

The Lower Laguna Madre (LLM) is an estuarine wetland along the Gulf of Mexico that receives freshwater from the Lower Rio Grande Valley (LRGV) watersheds (Hernandez & Uddameri, 2013). Texas Commission on Environmental Quality (TCEQ) segmented the LLM bay into three different Assessment Unit (AU), namely: AU 2491_01, AU 2491_02, and AU 2491_03. The three AU of the LLM was declared impaired for drinking and recreational purposes according to Draft 2018 Texas Integrated Report. Generally, a watershed catches precipitation and sheds it as runoff to a lake, river, stream, wetland, estuary, or bay (USEPA, 2008). Similarly, LRGV watershed drains into the LLM estuary through five different waterways, namely: Raymondville Drain (RVD), Hidalgo/Willacy Main Drain (HWMD), International Boundary & Water Commission North Floodway (IBWCNF), Arroyo Colorado drain, and Brownsville Ship Channel (BSC). Consequently, a watershed protection plan (WPP) was initiated to address water quality in the LLM estuarine. The first and fundamental step in developing a WPP is to characterize the watershed. Watershed characterization is important to understand the physical, biological, and chemical properties of the watershed. Hydrology, geology, land use patterns, and water quality, is essential for identifying potential sources of pollution, determining the extent of pollution, and developing effective strategies to mitigate the impacts of pollution. Due to the large extent of the project area, the exercise is carried out in phases.

The first watershed characterization study on the LRGV watershed was carried out by a former student of the department. The study was centered around the North and Central LRGV watershed. The North and Central LRGV is located North of the Arroyo Colorado watershed in Hidalgo, Cameron, and Willacy counties. There are three significant waterways in the watershed, namely: Raymondville Drain (RVD), Hidalgo/Willacy Main Drain (HWMD), and International Boundary & Water Commission North Floodway (IBWCNF).

The RVD and HWMD drains into AU 2491_01 which is considered impaired because of the low level of dissolved oxygen (DO), and IBWCNF drains into AU 2491_02 which considered impaired because of the high concentration of bacteria and low level of DO. In addition, this report will discuss the on-going water quality monitoring exercise in Brownville Ship channel of the LRGV watershed.

The reliability of a watershed characterization depends on the accuracy of watershed delineation, determination of the existing/potential sources of pollutants, and analysis of the water quality in respective waterways.

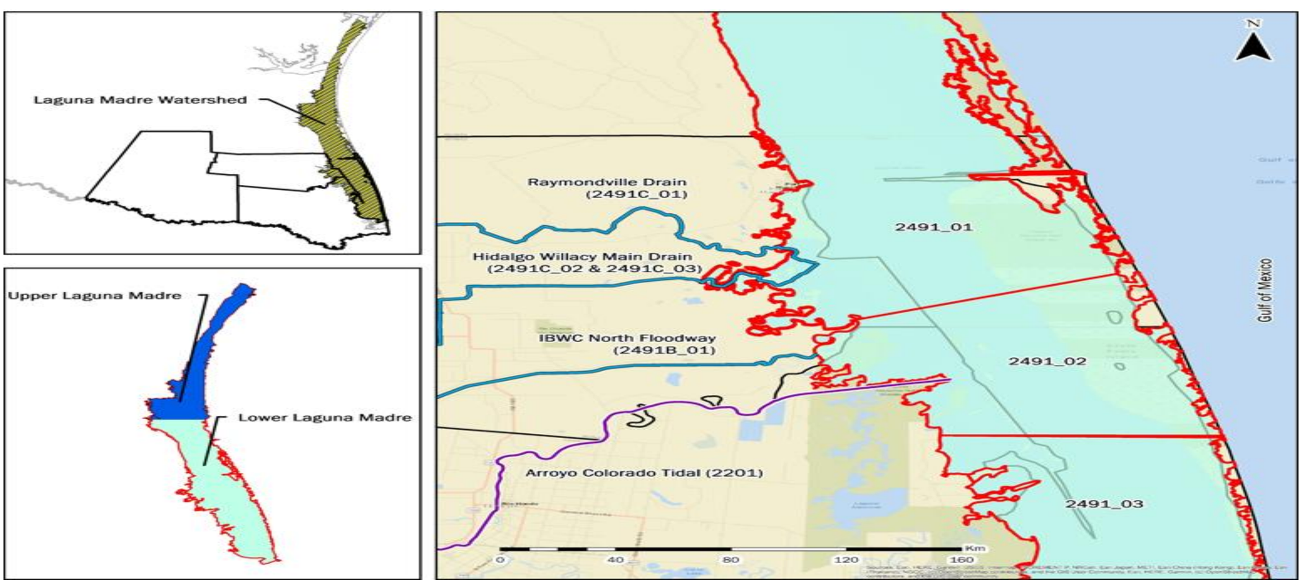

Figure 1: Map of LRGV waterways and Laguna Madre Bay (Navarro L. I., 2021)

CHAPTER II

LITERATURE REVIEW

In the work of Basnyat et al., 2000, basin characteristics such as land use/land cover, slope, and soil attributes affect water quality by regulating sediment and chemical concentration. Among these characteristics, land use/land cover can be manipulated to gain improvements in water quality. These land use/land cover types can serve as nutrient detention media or as nutrient transformers as dissolved or suspended nutrients move towards the stream. In this process, land use/land cover types were classified and basins and 'contributing zones' were delineated using geographic information system (GIS) and remote sensing (RS) analysis tools. A 'land use/land cover-nutrient-linkage-model' was developed to analyze the contributing zone contaminant levels downstream. Also, Xiao, H., & Ji, W., 2007, suggested that landscape characteristics of a watershed are important variables that influence surface water quality. Understanding the relationship between these variables and surface water quality is critical in predicting pollution potential and developing watershed management practices to eliminate or reduce pollution risk. To understand the impacts of landscape characteristics on water quality in mine waste-located watersheds, they conducted a case study in the Tri-State Mining District which is located in the conjunction of three states (Missouri, Kansas and Oklahoma). Severe heavy metal pollution exists in that area resulting from historical mining activities. They characterized land use/land cover over the last three decades by classifying historical multi-temporal Landsat imagery. Landscape metrics such as proportion, edge density and contagion were calculated based on the classified imagery. In-stream water quality data over three decades were collected, including lead, zinc, iron, cadmium, aluminum, and conductivity which were used as key water quality indicators. Statistical analyses were performed to quantify the relationship between landscape metrics and surface water quality. The results showed that landscape characteristics in mine waste-located watersheds could account for as much as 77% of the variation of water quality indicators. A single landscape metric alone, such as proportion of mine waste area, could be used to predict surface water quality; but its predicting power is limited, usually accounting for less than 60% of the variance of water quality indicators.

In the characterization of North and Central LRGV watershed, Navarro L. I., 2021 retrieved Geographic Information System (GIS) data of North and Central LRGV watershed and delineated the watershed to smaller drainage area/sub watershed pouring into unique waterways. In addition, water quality parameters such as E coli/Bacteria, Ammonia, Total Kjeldahl Nitrogen, Total Phosphorus, Nitrate and Nitrite, and Chlorophyll-a in each waterway were collected to analyze the relationship between the source of pollutants in each drainage area/sub watershed and the level of water quality in each waterway. The closeness of the studies of Basnyat et al., 2000 and Xiao, H., & Ji, W., 2007 on watershed characterization encourages the methodology for the characterization in the LRGV watershed.

CHAPTER III

WATERSHED DELINEATION

The first and the most fundamental step in a watershed characterization exercise is to identify the boundaries of watershed, area of land, that drains into a particular river, lake, or other body of water. The process of identifying the boundaries of the watershed is known as "Watershed delineation.” The most recent and accurate method of determining a unique drainage area is using the digital elevation model (DEM) of the area of interest for automated watershed and stream delineation. The North and Central LRGV watershed covers an area of 3,116.05 km^2, which is 37% of the total LRGV watershed (Navarro L. I., 2021), and it has three different waterways, RVD, HWMD, and IBWNF, flowing into the LLM bay.

The LRGV watershed has a peculiar challenge of flat slope. This unfavorable hydrological feature and low soil permeability are reasons for the hazardous flooding events experienced in the region. Its elevation gradually slopes from 102 to 0 m with a high range of precipitation between 50-70 cm per year (Navarro L. I., 2021). In general, the soil in the LRGV region consists of calcareous to neutral clays, clay loams and sandy loams. Clay soil is known for low permeability which causes poor drainage.

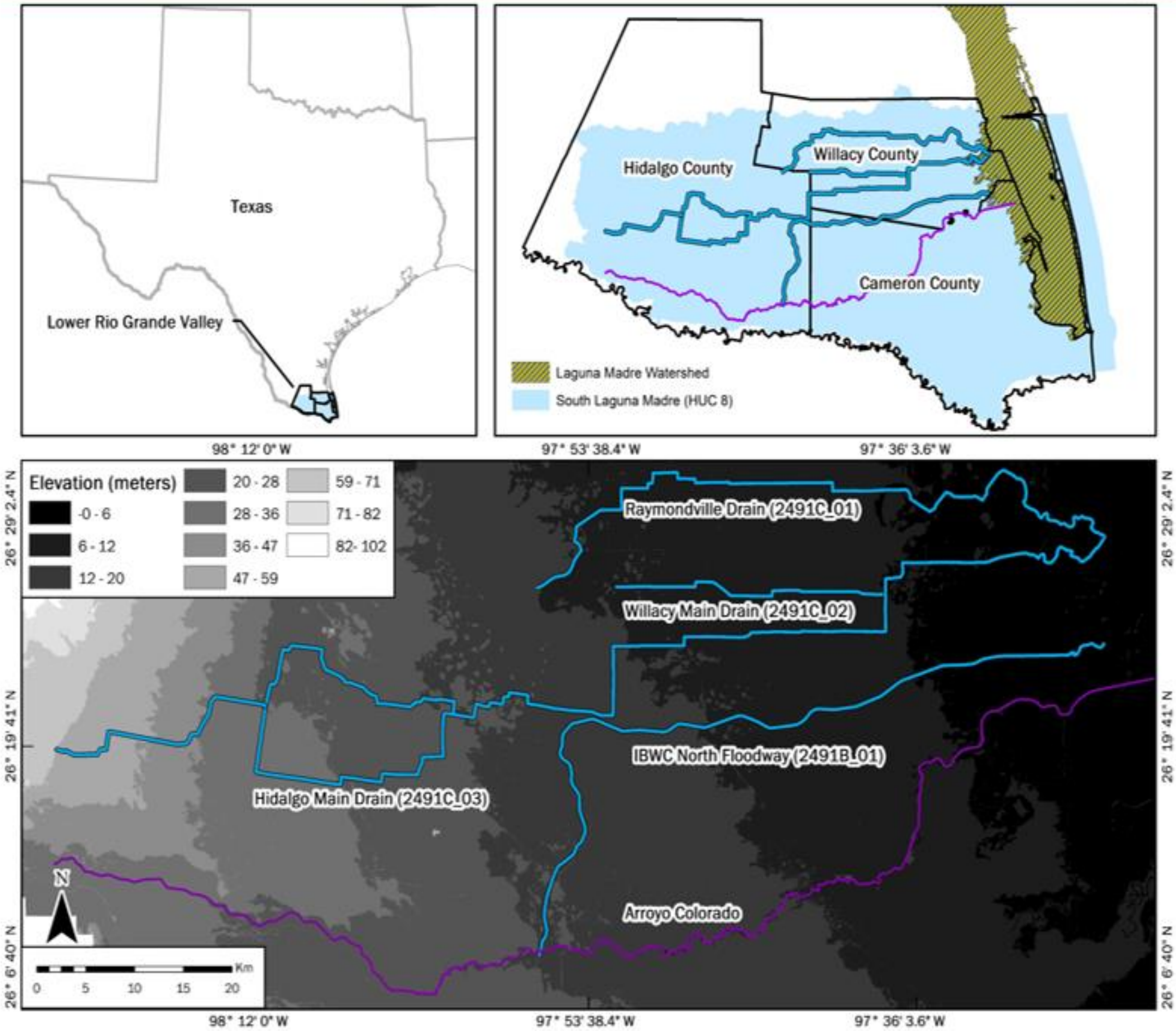

Figure 2: Location of the North and Central Watersheds and the elevation (Navarro L. I., 2021)

Delineation Process

Previous researcher used a DEM data retrieved from Texas Natural Resources Information System (TNRIS) as an input in the Arc-GIS Hydrology tool to carry out an automated watershed delineation. The hydrologic delineation process involved filling the elevation data to remove imperfect holes, setting the hydrologic flow direction towards the slope, and determining the flow accumulation in each cell before the watershed delineation.

The delineation produced 3 sub watersheds, which are Raymondville, Hidalgo/Willacy, and International Boundary & Water Commission North (IBWCN) sub watersheds. Furthermore, the sub watersheds contained the flow accumulation lines, pour points, and waterways. In the IBWCN sub watershed, the flow accumulation lines synchronize well with the IBWCNF waterways. However, the delineation produced some inconsistencies in the flow accumulation lines and waterways in Raymondville and Hidalgo/Willacy sub watersheds. The inconsistencies observed are listed below:

1. The flow accumulation lines do not synchronize with RVD and HWMD.
2. The flow accumulation lines cut across the boundaries of Raymondville and Hidalgo/Willacy sub watersheds.
3. The flow accumulation lines are not continuous, that is, there are numerous pour points before the main outlet at the Laguna Madre estuary, see Figure 3 below.

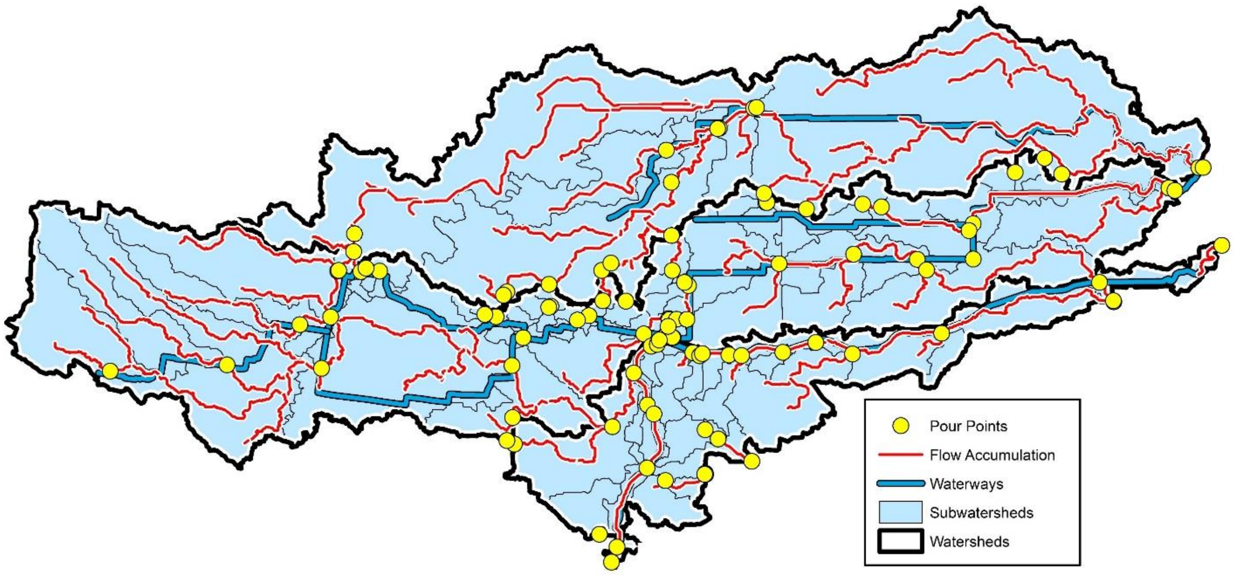

Figure 3: Result of the watershed delineation (Navarro L. I., 2021)

Watershed delineation accuracy is highly dependent on the map scale and nature of the DEM utilized; certain hydrologic features of a watershed may become obscured or oversimplified during the digital delineation process. The use of raster data sets for watershed and stream delineation can produce stream networks that are inconsistent with generally accepted vector representations. These inconsistencies are due to problems of map scale and the lack of adequate DEM vertical resolution in areas of low relief (Saunders *et al.,* 1995). In this case, the stream network inconsistency is related to the low-relief area. Generally, the watershed slopes from west to east through the heart of the LRGV, with an average slope of fewer than 0.3 m per kilometer (Flores *et al.,* 2017).

One difficulty that challenges all automated delineation methods is the establishment of channel networks in flat regions of DEMs (Zhang *et al.,* 2013). Figure 4 shows a cross-section of the RVD waterway resulting from an irregular topography. This irregularity is because of the insignificant elevation difference between the land surface and the stream point. According to Baker *et al.,* 2006, unenhanced coastal plain delineations had many errors due to the low relief of drainage divides and the extent of ditching. Therefore, the type of terrain in the area could affect the results of the watershed delineation (Navarro L. I., 2021).

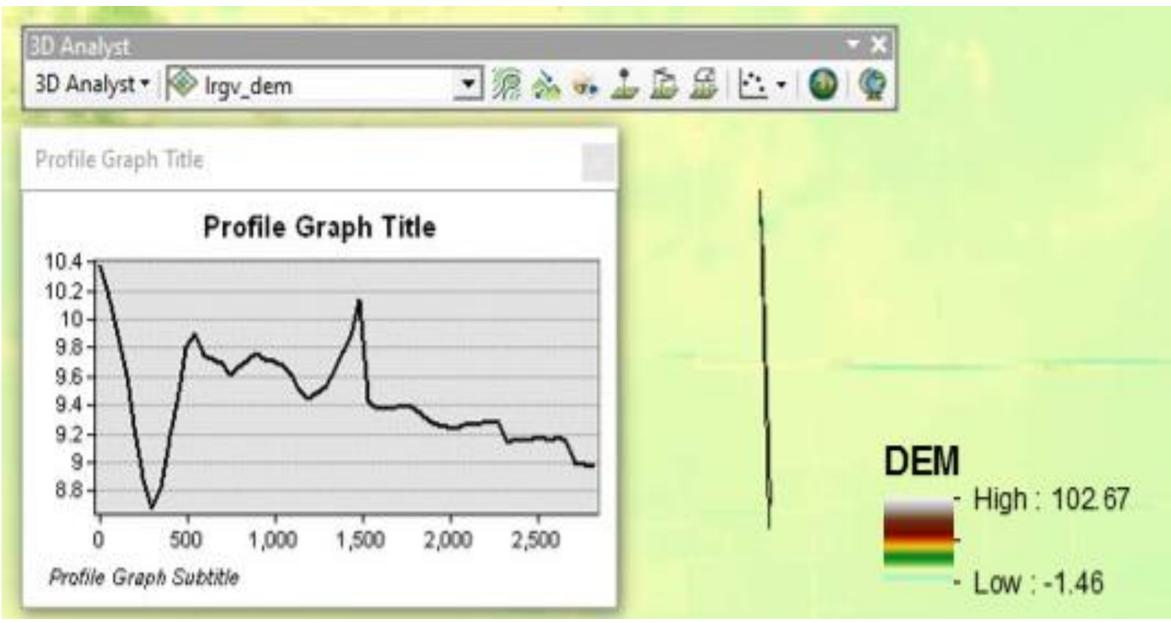

Figure 4: Cross–section of the stream by TNRIS DEM (Navarro L. I., 2021)

Enhanced Watershed Delineation

The inconsistency in the stream network was addressed by integrating a known vector data layer into the DEM prior to watershed delineation. This process is known as "stream burning" on the DEM or "DEM reconditioning." A practical method of eliminating pits or depressions is by stream burning algorithm. The algorithm often identifies river channels or lakes not recorded in the DEM, avoiding severe errors in the streaming (Li *et al.,* 2019; Chen *et al.,* 2012). According to Saunders, DEM reconditioning proved successful in previous studies of watershed delineations in flat terrains (Saunders W., 1999). DEM reconditioning is only suggested when the vector data of the stream is more reliable than the raster DEM information (Tarboton D., 2012).

The previous researcher edited the existing satellite data of the region to manually outline a dendric stream network of RVD, HWMD, and IBWCNF. The process involves creating a layer that represents the drainage network with a fully connected set of single lines which was achieved by:

- Removing all off-stream lakes (enclosed polygons),
- Lakes replaced with arcs that would otherwise bisect the lake as "centerlines,"
- Multiple coastlines removed and replaced by single arc layer representing the drainage path of the watershed,
- Braided streams are synchronized to follow a primary drainage path,
- The main stem of the drainage path must extend to the edge of the corresponding DEM,
- All stray arcs were deleted from the final layer.
- Hydrographic features adjacent to each sub watershed were captured.

These dendric stream networks were generated as vector data (Digitized dendric stream network). The vector data created was super imposed unto the DEM retrieved from TNRIS. Furthermore, elevation values were assigned to the grid cells containing the digitized dendric stream network in a descending order toward the outlet point(s). The elevation difference between the digitized stream network cells and the land surface cells at different point was constant. According to Navarro L. I., reconditioning the DEM was necessary to distinguish the change in elevation with respect to the waterway location (Navarro L. I., 2021). Then, the reconditioned DEM was used as input in the Arc-GIS Hydrology tool for the automated watershed delineation. The hydrologic delineation process involved filling the elevation data to remove imperfect holes, setting the hydrologic flow direction towards the slope, and determining the flow accumulation in each cell before the watershed delineation.

Output of Enhanced Watershed Delineation

The delineation of the reconditioned DEM avoided the inconsistency in the former watershed delineation. There is correlation/flow in the flow accumulation lines and the waterways of the North and Central LRGV watershed, see Figure 5 below. Also, a cut on the of RVD shows a well-defined elevation difference between the waterways and the land surface, see Figure 6. Thus, the result of the enhanced watershed delineation is more acceptable.

From the result, it can be observed that the Hidalgo/Willacy sub watershed has an area 1,357 km², the Raymondville sub watershed has an area 1,021 km², and the International Boundary & Water Commission North sub watershed has an area 737 km². The proportions of Hidalgo/ Willacy sub watershed found in Hidalgo County, Willacy County, and Cameron County are 68%, 30.6%, and 1.4%, respectively (Navarro L. I., 2021).

The Hidalgo/Willacy sub watershed has the most extensive area in the North and Central LRGV watershed. The Hidalgo/Willacy sub watershed extends across Alton, Palmhurst, Mission, McAllen, Edinburg, Elsa, Edcouch, La Villa, and Lyford. The Raymondville sub watershed is in the northern part of the LRGV watershed. The proportions of Raymondville sub watershed found in Hidalgo County, Willacy County, and Kennedy County are 30.7 %, 68.9%, and 0.4%, respectively. International Boundary & Water Commission North (IBWCN) sub watershed is the smallest watershed in the North and Central LRGV watershed. The proportions of IBWCN sub watershed found in Hidalgo County, Willacy County, Cameron County are 52.7 %, 23.6%, and 23.6%, respectively.

IBWCN sub watershed is in the southern part of the North and Central LRGV watershed and is adjacent to the Arroyo Colorado watershed. The cities of McAllen, Pharr, San Juan, Alamo, Dona, Weslaco, Mercedes, and Santa Rosa form parts of the IBWCN sub watershed. Table 1 summarizes each watershed area concerning LRGV Counties.

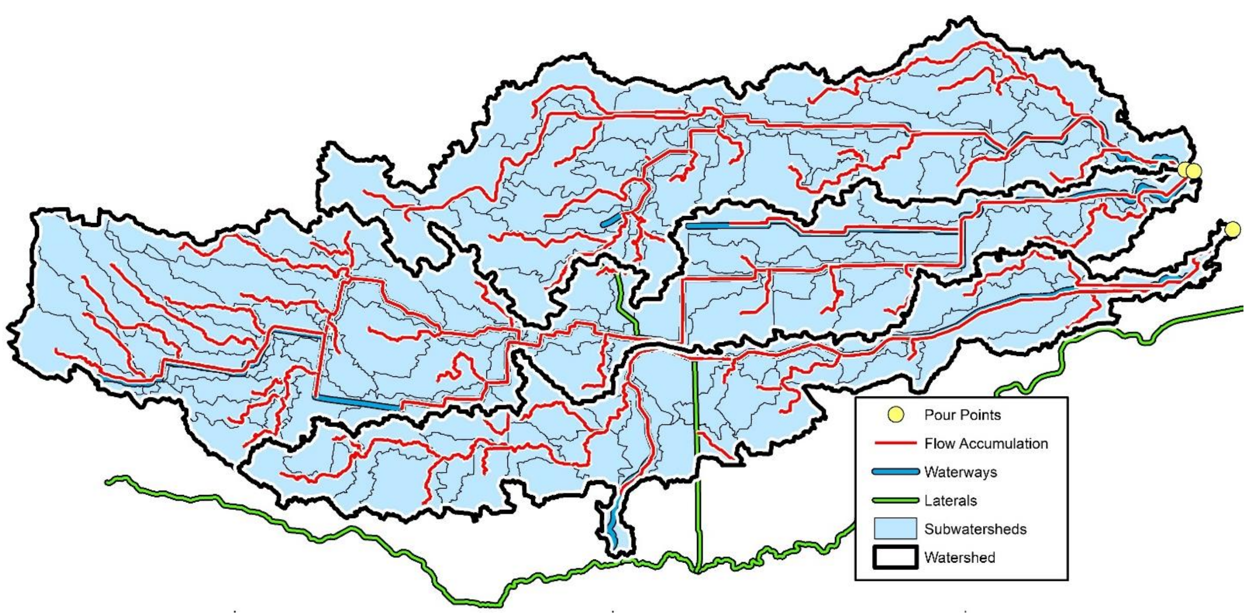

Figure 5: Enhanced watershed delineation (Navarro L. I., 2021)

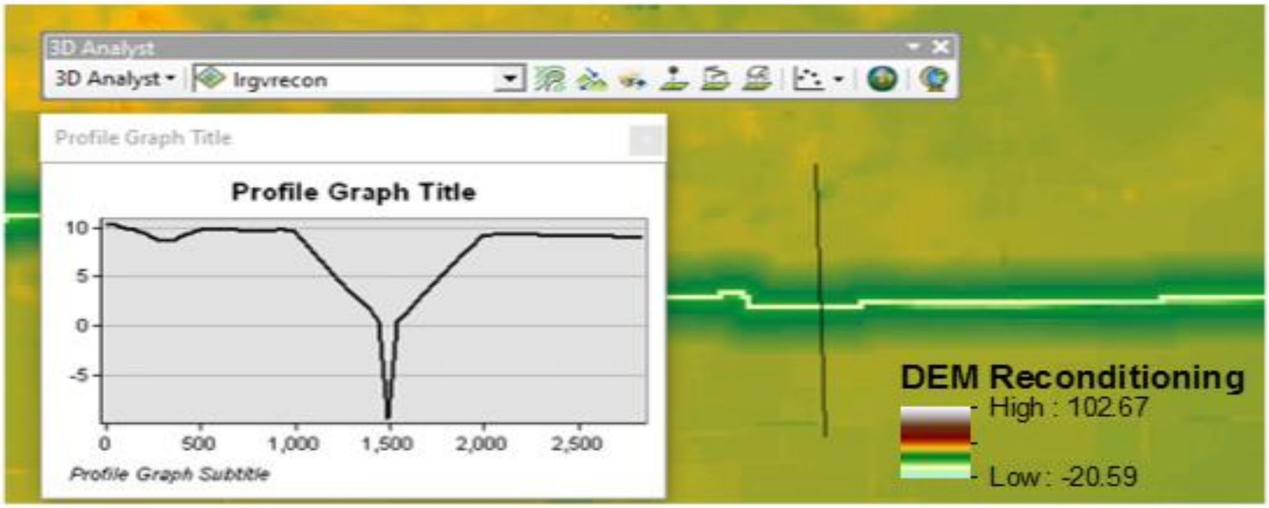

Figure 6: Cross–section of the stream after reconditioning TNRIS DEM (Navarro L. I., 2021)

Table 1: Delineated sub watershed spatial distribution (Navarro L. I., 2021)

	HWMD sub watershed	RVD sub watershed	IBWNF sub watershed
Watershed area (Km^2)	1,357	1,021	737
No. of Sub-watersheds	91	72	73
Hidalgo County	68%	30.7%	52.7%
Willacy County	30.6%	68.9%	23.6%
Cameron County	1.4%	0	23.6%

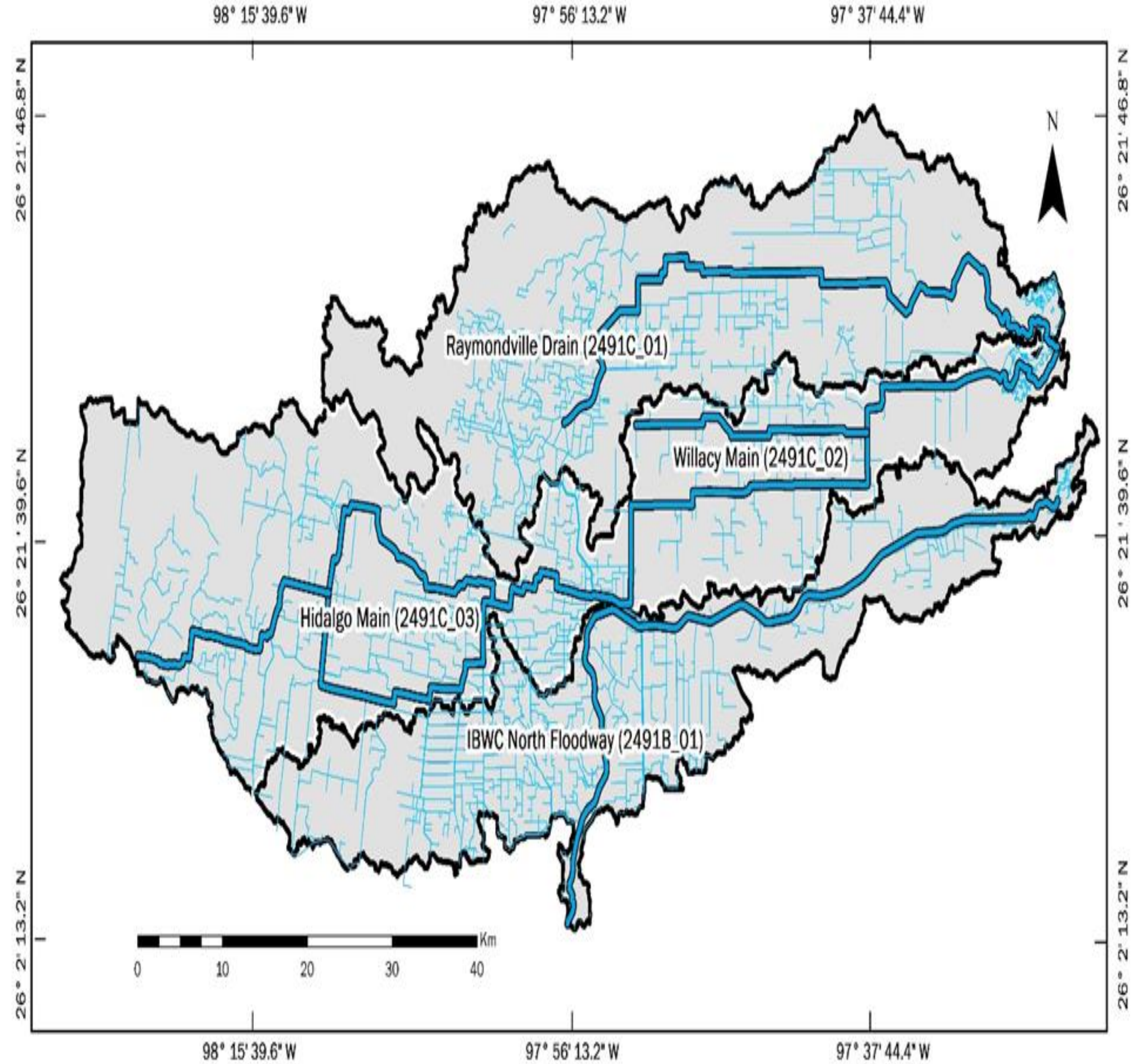

Figure 7: Sub watersheds in the North and Central LRGV (Navarro L. I., 2021)

CHAPTER IV

POLLUTANTS

After identifying the boundaries of each sub watershed, it was more feasible to track the existing and potential pollutant sources. A pollutant source is a concentration or amount that adversely alters the natural environment's physical, chemical, or biological properties (USEPA, 2008). It is cumbersome to identify a pollutant source due to its unpredictable generation and transportation route (Boano *et al.,* 2005). The typical way to identify a source of pollution is by gathering information on the source and their mode of transportation to the waterways (Guozhen *et al.,* 2016). The primary source pollutants are nonpoint sources (NPS) and point sources (PS). NPS of pollutants are difficult to identify since they usually come from several land uses and are scattered over the watershed. The primary mode of transportation of pollutants is stormwater runoff which ultimately discharges to lakes, canals, and coastal waters (Mahmoud *et al.,* 2020). Runoff carries significant pollutants such as fertilizers, oil, grease, sediments, bacteria, and nutrients (TCEQ, 2007). Stormwater runoff primarily comes from agricultural lands, residential areas, urban areas, construction sites, and livestock. NPS of pollutants contain significant amounts of nutrients such as total nitrogen (N) and total phosphorus (TP) (Shin *et al.,* 2016). An increasing effort has been made to reduce the pollution generated by agricultural activities because they contribute a significant amount of nutrients to water quality (Burt *et al.,* 2011). Though urbanization has led to decreased agricultural pollutants but an increase in urban waste (Hernandez & Uddameri, 2013; Rio Grande Regional Water Plan, 2015).

Also, urban runoff has shown negative results on water quality for high bacteria, and low levels of DO (Mahmoud *et al.,* 2020). Unlike NPS of pollutants, PS of pollutants are easily identified because they come from only one source. Although it is easier to identify these sources, it is difficult to address the issues causing PS pollution. The 2020 Texas Water Quality Inventory and 303(d) List indicated that nonpoint sources of pollutants are responsible for over 40% of all impaired water bodies, while only 10% of impairments were caused by point source discharges alone (USEPA, n.d.). These contaminants include but are not limited to E. coli/bacteria, ammonia, total Kjeldahl nitrogen (TKN), total phosphorus (TP), chlorophyll-a, nitrite and nitrate (Navarro L. I., 2021). E. coli in water is a strong indicator of sewage or animal waste contamination. Ammonia is commonly used in fertilizers and other industrial applications (Appl M., 1999). In the case of nitrogen, it is naturally abundant in the environment; it is also introduced through sewage and fertilizers. Chemical fertilizers or animal manure are commonly applied to crops to add nutrients. It may be difficult or expensive to retain on-site all nitrogen brought on to farms for feed or fertilizer and generated by animal manure (USGS, 2018b). Phosphorus is a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent. Though, it is an essential element for plant life, excess phosphorus can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by increased mineral and organic nutrients) of rivers and lakes (USGS, 2018c). According to USEPA, 2022, One of the symptoms of degraded water quality conditions is the increase of algae biomass, which is a measure of chlorophyll a concentration. Waters with high levels of nutrients from fertilizers, septic systems, sewage treatment plants and urban runoff may have high chlorophyll-a concentrations and excess amounts of algae.

Sources of Pollutants

Generally, the source of pollutants is classified into two: Nonpoint sources (NPS) and Point sources (PS) of pollutants. The NPS of pollutants identified within the North and Central LRGV watershed are cultivated crop areas, urban area, South Texas large ranches (STLR), species, wildlife management areas (WMA), Colonias or Onsite Sewage Facility (OSSF) (Navarro L. I., 2021). The term “Colonias” means settlement or neighborhood and is commonly used to refer to unincorporated rural and peri-urban subdivisions along Texas’ border with Mexico (Olmstead, 2004). Because of the level of organization, these colonias utilize OSSF as means of treating and disposing wastewater that is generated from the homes. Species, in biology, are related organisms that share common characteristics and are capable of interbreeding (Gittleman J. L., 2019). However, the definition of species is limited to shore birds, fishes, and terrestrial plants for purpose of characterization. Species and WMA were considered NPS of pollutants to assess their contaminant contribution to the water bodies. Jeong *et al.,* 2019, utilized a methodology to extract OSSF by combining the address points and colonias to estimate the number of OSSF within the watershed. It obtained 911 address points for Cameron, Willacy, and Hidalgo counties. The address point was used to identify each unit/house in a specific area, and the colonias are units/houses with OSSF as their wastewater collection facility.

The PS of pollutants identified in the North and Central LRGV watershed include permitted wastewater outfalls (WWO), Texas Land Application Permit (TLAP), Municipal Solid Waste (MSW), and Municipal Separate Storm Sewer System (MS4) (Navarro L. I., 2021), see Appendix A1-A6 for permittee.

The prevalent type of WWOs identified in the watershed are domestic and industrial wastewater discharge. A large proportion of wastewater from WWOs is from industrial wastewater treatment plant. These industrial treatment plant discharge more than 1 MGD of wastewater (TCEQ, 2010). It is considered that the wastewater treatment plants (WWTP) effluent also finds its way to the waterways. Fecal contamination usually results from the direct entry of wastewater from a municipal treatment plant into a water body (Jeong *et al.,* 2019). MS4s are identified to discharge significant levels of contaminants into the United States waterbodies (Abrams R., 2012).

Nonpoint Source of Pollutants

The relative contributions of NPS of pollutants were determined to identify the most significant source of pollution the watershed. According to NLCD, 61.1% of the North and Central LRGV watershed is represented as cultivated crops. Generally, cultivated crops practice is sited close to waterways. Also, 16.1% of the North and Central LRGV watershed is characterized as an urban area. Agricultural and urban areas are significant contributors to pollution. The STLR covers 10.2% of the North and Central LRGV watershed. These STLRs are found distributed along the coast of the watershed. The hazardous contaminants from livestock and livestock wastes (manure) are a source of surface and groundwater pollution. Contaminants from animal production systems discharge the waterways through surface runoff or seepage through groundwater (Schumacher, 2002).

OSSF is another NPS of pollutants, OSSF was initially designed to treat domestic wastewater using a septic tank for screening and pretreatment before it is distributed for soil infiltration and definitive treatment by naturally existing microorganisms (Jeong *et al.,* 2011). Species and WMA were found on the coast of each watershed. These NPS of pollutants from wildlife discharge high bacteria loadings to waterbodies. Wildlife is also considered a contributor of bacterial contaminant that affects the quality of runoff water and waterbodies (Jeong *et al.,* 2019). In Texas, non-avian wildlife, such as deer or feral hogs, are commonly found to significantly contribute bacteria to natural streams (Jeong *et al.,* 2019).

Generally, colonias often lack one or more sanitary systems, TCEQ has classified the colonias into smaller units to have a closer insight into which ones lack essential utilities. This classification is presented in Table 6 below. According to Jeong *et al.,* 2019, the priority classification by the Rural Community Assistance Partnership (RCAP), OSSF located in the colonias are assumed to have a greater failure rate (70%), and they are considered a high health hazard (red colonies).

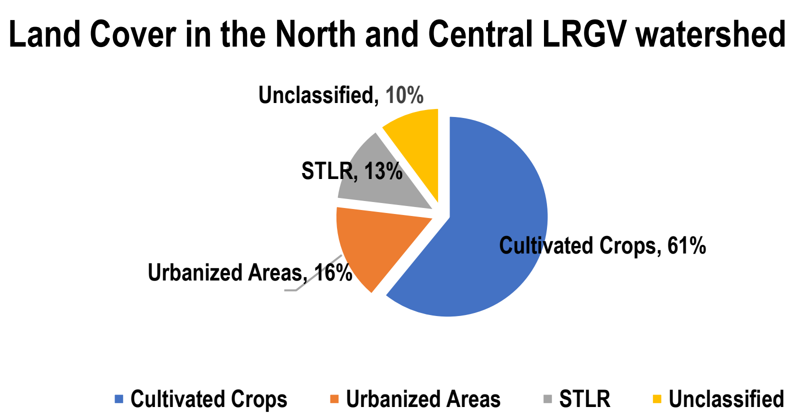

Figure 8: Ratio of Land cover in the North and Central LRGV from the National Land Cover Database.

Table 2: Percentage of nonpoint source of pollutants in each watershed (Navarro L. I., 2021).

	Hidalgo/Willacy watershed	**Raymondville watershed**	**IBWCN watershed**
Urbanized Areas	20.1%	4.5%	24.3%
Cultivated Crops	46.6%	52.3%	58.5%
STLR	6.4%	20.3%	3.8%
Totals	73.1%	77.1%	86.6%
Species*	42	106	151
OSSF	4591	56	4523
Wildlife Management Areas*	2	0	2

Source: Land Cover Data, 2016. TCEQ

Table 3: Percentage of nonpoint source of pollutants in the North and Central watershed (Navarro L. I., 2021).

	Hidalgo/Willacy watershed	**Raymondville watershed**	**IBWCN watershed**	**Total**
Urbanized Areas	8.8%	1.5%	5.8%	16.1%
Cultivated Crops	20.3%	17.1%	23.7%	61.1%
STLR	3.0%	6.5%	0.7%	10.2%
Totals	32.1%	25.0%	30.2%	87.4%

Source: Land Cover Data, 2016. TCEQ

Table 4: Area covered by nonpoint source of pollutants in the North and Central watershed.

	Hidalgo/Willacy sub watershed	**Raymondville sub watershed**	**IBWCN sub watershed**	**TOTAL**
Urbanized Areas	274 Km^2	46 Km^2	179 Km^2	499 Km^2
Cultivated Crops	632 Km^2	534 Km^2	738 Km^2	1904 Km^2
STLR	87 Km^2	202.5 Km^2	28 Km^2	317.5 Km^2

Table 5: Colonias Classification System (Navarro L. I., 2021)

	Green	**Yellow**	**Red**	**Grey**
Drinkable Water	Yes	Yes	No	-
Wastewater Disposal	Yes	Yes	No	-
Approved Subdivision Plats	Yes	Yes	No	-
Paved Roads	Yes	No	No	-
Adequate Drainage	Yes	No	No	-
Solid Waste	Yes	No	No	-

Source: TCEQ, August 2013

The study shows that 73.1% of Hidalgo/Willacy sub watershed is covered by NPS of pollutants. The proportions of cultivated crops, STLR, and urban areas are 46.6%, 604%, and 20.1%, respectively. According to Flores et al., 2017, urbanization in the watershed is imminent in cultivated areas, and this phenomenon will influence the region's water quality. In addition, the Hidalgo/Willacy sub watershed is identified with the highest percentage of urban areas in the North and Central LRGV watershed. Hidalgo/Willacy sub watershed is house to one STLR, El Suez ranch. The ranch spreads over 6.4% of the sub watershed. STLR is a livestock grazing area which is prone to high level of bacteria.

The Hidalgo/Willacy sub watershed houses 46 species and 2 WMA units. Out of the 9,170 OSSF found in the entire North and Central LRGV watershed, 4591 OSSF are in the Hidalgo/Willacy watershed. All OSSF have a potential adverse environmental impact if they are not functioning properly, but those closer to streams present an elevated risk (Flores *et al.,* 2017). There are 336 colonies in the watershed, and 113 are identified to have inadequate solid waste disposal.

Also, 77.1% of the Raymondville sub watershed is covered by NPS of pollutants. The proportions of cultivated crops, STLR, and urban areas are 52.3%, 20.3%, and 4.5%, respectively. King Ranch, East Foundation ranch, and a portion of El Suez ranch falls in the watershed. The droppings of the livestock are NPS pollutants transported through surface runoff and soil leaching; their origin can be the free grazing livestock droppings and manure in cultivated areas (Atwill *et al.,* 2002; Collins & Rutherford, 2004; Tyrrel & Quinton, 2003). There are 106 species and 56 OSSF identified in the Raymondville sub watershed.

Furthermore, 86.6 % of IBWCN sub watershed is covered by NPS of pollutants. The proportions of cultivated crops, STLR, and urban areas in the sub watershed are 58.5%, 3.8%, and 24.3%, respectively. El Suez ranch, STLR, covers 5% of the IBWCN watershed. Colonias in the IBWCN sub watershed are scattered over an approximate area of 23.4Km^2.

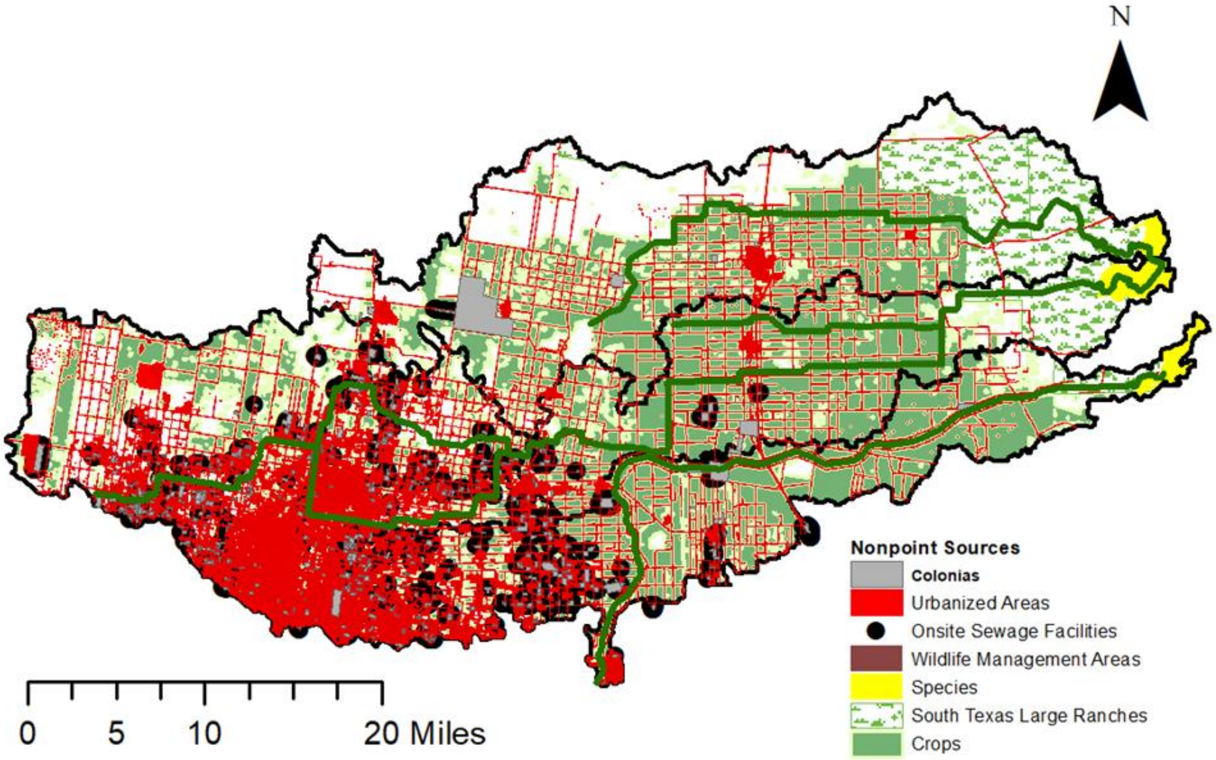

Figure 9: Nonpoint Source of pollutants in the North and Central Watershed (Navarro L. I., 2021).

Point Source of Pollutants

The point source of pollutants identified in the Hidalgo/Willacy sub watershed includes 11 WWOs, 8 TLAPs, and 17 MSW. Out of the WWOs in the sub watershed, it was recorded that only 5 facilities discharge less than 1 million gallons of wastewater daily (MGD), the remaining discharge more than 1 MGD. Two of the MSW are active, four are closed, four are inactive, two posts are closed, and the rest are not constructed. These facilities affect both the surface water and groundwater within the watershed.

The closed landfills, many of which are unlined and poorly capped, may be sources of many organic compounds known as emerging contaminants (ECs) to surrounding groundwater and surface water (Andrews et al., 2012). Record shows that 7 MS4s are permitted in the Hidalgo/Willacy sub watershed, the MS4s spread over 13% of the watershed. These MS4 are in Alton, Pharr, Palmhurst, Mission, McAllen, Edinburg, and Edcouch (Navarro L. I., 2021).

Although the Raymondville watershed has a greater area than the IBWCN sub watershed, it has the least PS of pollutants. There are five WWOs identified within the sub watershed; three are considered industrial, and two are domestic wastewater effluent. Also, four TLAPs and one active MSW was identified in the sub watershed. Raymondville sub watershed contributes an insignificant percentage of MS4 pollutants (Navarro L. I., 2021).

In the IBWCN sub watershed, 9 WWOs were identified, four of them are domestic and five are industrial wastewater effluent. Three active TLAPs, and three active MSWs were identified in the sub watershed. The MS4s are in the cities of McAllen, Edinburg, Pharr, San Juan, Alamo, Donna, Primera, Mercedes, Santa Rosa, Town of Combes, and Weslaco.

Table 6: Point Source of Pollutants in the North and Central Watersheds (Navarro L. I., 2021)

	Hidalgo/Willacy sub watershed	Raymondville sub watershed	IBWCN sub watershed	**Total**
Texas Land Application Permit	8	4	3	15
Wastewater Outfalls	11	5	9	25
Municipal Solid Waste	17*	1	3	21
MS4 Permit	7	0	12	19

* 2 of the MSW are active, 4 are closed, 4 are inactive, 2 posts are closed, and the rest are not constructed.

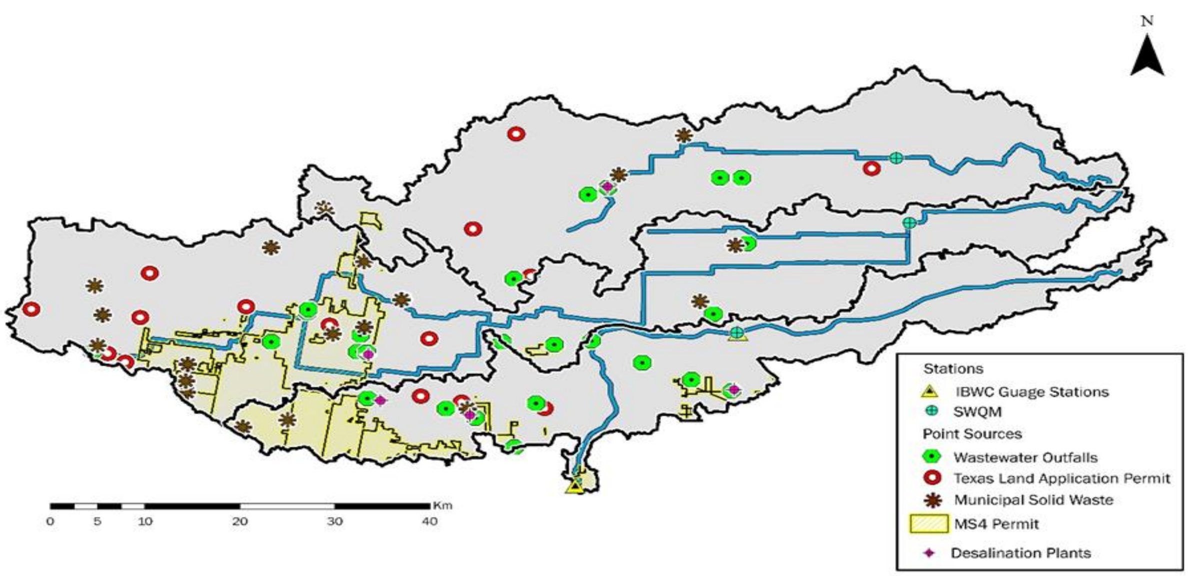

Figure 10: Point Sources of Pollutants in the North and Central LRGV watershed (Navarro L. I., 2021).

CHAPTER V

WATER QUALITY

Water quality refers to the chemical, physical, and biological properties of water. Pollutants deposited into the waterways affects water quality. According to Abrams R., 2012, pollutants deposited in recreational waters by runoff are dangerous, it has led to the closure of many beaches. Also, estuaries have faced eutrophication due to increased nutrient input deposits in waterways (Smith *et al.,* 1999; Percuoco *et al.,* 2015). For example, ammonia can enter the aquatic environment via direct means, such as municipal effluent discharges and the excretion of nitrogenous wastes from animals, and indirect means, such as nitrogen fixation, air deposition, and runoff from agricultural lands (USEPA, 2013). Improper wastewater management practices in this under-served region have caused severe water quality problems, and sections of the river have experienced poor water quality regarding dissolved oxygen, bacteria, and algae (TCEQ, 2006a). Chemical characteristic of water in the HWMD and RVD were retrieved from the Clean Rivers Program (CRP). CRP collected water samples from the HWMD and RVD quarterly between 2017 to 2019 (2 years). On the other hand, chemical characteristic of water in the IBWCNF was retrieved from Surface Water Quality Monitoring Information System (SWQMIS). SWQMIS collected water samples from the IBWCNF quarterly between 2012 to 2019 (7 years). See Appendix C1 – C3 for the available water quality data. However, the TCEQ approved screening levels and statistics of the data set are given in Table 9 and 10, respectively.

Table 7: Water Quality Screening Levels (Navarro L. I., 2021)

Water Quality Parameter	Screening Level
E. coli **	126 mpn/mL
Ammonia	0.33 mg/L
Total Kjelfahl Nitrogen (TKN)	1.0 mg/L
Total Phosphorus (TP)	0.7 mg/L
Nitrate and Nitrite (N+N)	1.95 mg/L
Chlorophyll-a	14.1 ug/L

Source: SWQM, 2020b, ** TCEQ, 2010.

Table 8: Summary of the water quality parameters (Navarro L. I., 2021)

		Bacteria MPN/100mL	**Ammonia mg/L AS N**	**TKN mg/L AS N**	**TKN-Ammonia mg/L AS N**	**TP mg/L AS P**	**Nitrite +Nitrate mg/L AS N**	**Chlorophyll-a ug/L**
HWMD 8 samples	Mean	559	0.1	2.0	1.8	0.6	3.5	43.8
	Max	2200	0.3	3.6	3.6	0.8	5.7	98.5
	Min	10	0.0	1.0	0.9	0.2	0.0	13.5
	Median	100	0.2	1.8	1.6	0.7	3.9	25.5
	SD	819	0.10	0.9	0.9	0.3	2.1	34.3
RVD 8 Samples	Mean	846	0.1	1.7	1.5	0.2	1.9	28.7
	Max	2400	0.2	3.1	3	0.4	5.7	67.0
	Min	74	0.0	0.4	0.3	0.1	0.6	3.8
	Media	185	0.1	1.5	1.3	0.2	1.5	26.6

Table 8, cont. Summary of the water quality parameters (Navarro L. I., 2021)

	SD	986.4	0.1	0.9	0.9	0.1	1.6	19.9
IBWCNF 25 Samples	Mean	505	0.1	1.3	1.4	0.3	3.2	39.9
	Max	7300	0.3	3.2	3	0.6	6.7	82.3
	Min	0.0	0.0	0.0	0.6	0.0	0.0	2.3
	Median	96.	0.1	1.4	1.4	0.3	3.0	36.3
	SD	1374	0.07	0.72	0.5	0.2	1.4	23.1
Geometric Screening Level		126	0.33	1.0		0.7	1.95	14.1

Source: Clean Rivers Program and SWQMs

Also, the physical characteristic of water in the IBWCNF was retrieved from the U.S. Section of the International Boundary and Water Commission (USIBWC). The USIBWC maintains two gage stations along the IBWCNF, namely; 08470100 North Floodway West of Mercedes (Mercedes) and 08470200 North Floodway Near Sebastian (Sebastian). The Mercedes station recorded a sample size of 140,261 observations between the period of 2015 to 2020. While the Sebastian station recorded a sample size of 304,982 observations between the period of 2012 to 2020. The flow data were collected at 15 minutes intervals in cubic meters per second (CMS); see Appendix B1 -B10. The physical characteristic of water in the HWMD and RVD is not available for the characterization exercise.

Analysis of the Chemical Properties

It was observed that the HWMD has E. coli levels higher than the screening level of 126 MPN/100 mL from 2017 to 2019. The E. coli levels rose above 2000 MPN/100mL in 2019. The existence of high levels of bacteria is caused by a variety of NPS and PS of pollutants such as urban runoff, agricultural lands, ranches, WWO, OSSF, MS4s, and colonias (Navarro L. I., 2021). The highest Ammonia level recorded in this waterway is 0.26 mg/L as N, which is below the USEPA screening level of 0.33 mg/L. In 2018, the concentration of TKN was recorded to be more than 3.0 mg/L as N. In 2017, the maximum TP concentration was recorded to be 0.8 mg/L; it exceeded the screening level of 0.7 mg/L. However, nitrite and nitrate levels in the waterway are higher than the screening level of 1.95 mg/L. The concentration of chlorophyll-a recorded is more than the USEPA screening level of 14.1 mg/L for the three years.

The RVD have the highest concentration of E. coli/bacteria relative to other sub watersheds in the North and Central LRGV. The high concentration of E. coli/bacteria can result from the high percentage of cultivated area and STLR. Furthermore, the small percentage of the urban area suggests that minimum sanitation protocols will be observed. Also, ammonia and TP concentrations were observed to be below the screening level in the RVD. TKN concentration was above the screening level of 1.0 mg/L after 2017. According to the USGS report, bank erosion during flooding events can be the primary source of total phosphorus in these waterways (Krempa et al., 2017). The highest Chlorophyll-a recorded in the RVD was 70 mg/L in 2019 (Navarro L. I., 2021).

In the IBWNF, E. coli was higher than the screening level of 126 MPN/100ml in 2013, 2014, 2015, and 2019. The highest level was around 7300 MPN/100 mL in 2013. However, the E. coli concentration was slightly below the screening level between 2016 and 2018. In all the sampled years, the ammonia level was identified to be less than the screening level of 0.33 mg/L. This finding indicates that the waterway received a significant portion of its ammonia from agricultural runoff. TKN concentration was relatively higher than the screening level of 1 mg/L and the highest value recorded was 2 mg/L as N in 2018. A high level of total nitrogen can be related to the decomposition of detritus and any anthropogenic loadings (Uddameri *et* al., 2018). TP level was lower than the screening level of 0.7 mg/L. The IBWNF was limited to algae growth since TP level was low. Nitrite and nitrate concentrations were consistently higher than the screening level except for the last two samples collected in 2017. Chlorophyll-a concentration was frequently higher than the SQWM's screening level, which is an indication of excess quantities of algae (USEPA, 2022).

Analysis of the Physical Properties

The IBWCNF has two gage stations: Mercedes and Sebastian. However, Sebastian station flow values were utilized for this analysis since the water quality samples were obtained near the station. Apart from 2017 and 2018, when the flow values were more than 10 CMS, flow values throughout 2012 to 2020 seem to have mean values below 5 CMS. Such a record suggests a consistent flow regime in this watershed (Navarro L. I., 2021). These data are not representative of the whole profile of the sub watersheds. More data should be quantified to better distinguish which sub watershed contributes the most to the water impairment in the LLM.

Water Quality Monitoring Exercise in the Brownsville Ship Channel

The characterization of the North and Central sub watersheds was carried out with secondary water quality data. On the other hand, the characterization of the Brownsville Ship Channel (BSC) will rely on primary water quality data for the overall watershed characterization. The BSC is in the southern part of the HUC8-12110208 and the most downstream portion of the Lower Rio Grande Valley (LRGV) Watershed. The BSC drains into Lower Laguna Madre Assessment Unit 2491_03.

There are 4 waterways draining into the Ship Channel: Ditch 1, Ditch 2, North Main Drain, and Old Main Drain 2. Ditches 1 and 2 merge and then flow through the Loma Alta and San Martin Lake system prior to discharging into the Ship Channel. North Main Drain receives much of the City of Brownsville water.

Old Main Drain 2 receives water from the rural area east of Brownsville, which is used for agriculture purposes. Consequently, the TCEQ established a stage height station on each of the drainage line. The stations are:

- TCEQ SWQM ID 22118 – Monitoring Ditches 1 and 2 after they merge at Old Port Isabel Road,
- TCEQ SWQM ID 22120 – Monitoring the North Main drains at Brownsville Public Works (BPW),
- TCEQ SWQM ID 22121 – Monitoring the Old Main Drain at City of Brownsville Landfill.

These stations also serve as point of periodic water quality sampling and field analysis (SFA). The sampling and field analysis is carried out to retrieve water quality data for the watershed characterization. The SFA exercise can be divided into 3 sections, which includes, deployment of YSI multi-parameter sondes, deployment of Acoustic Doppler Current Profiler (ADCP), and collection of water sample for further laboratory analysis.

Deployment of YSI Multi-Parameter Sondes

YSI multi-parameter sondes is used to measure water quality parameters such as pH, Specific Conductivity, Dissolved Oxygen, and temperature in the waterways. Prior to deploying the YSI sonde to field, a pre deployment calibration with known standards, approved by the National Institute of Standards and Technology (NIST), was carried out at the laboratory. The pre calibration was done within 24 hours of deployment to field. See appendix D1 for Table of data retrieved with YSI multi-parameter sonde.

Analysis of Data

The pH range of 7.60 to 8.30 in the drainage line indicates that the water is moderately alkaline. The pH range is within the acceptable range for aquatic life and human consumption. Temperature range of 26.60 to 33.40 ^{0}C can be considered adequate for aquatic organisms and recreational activities like swimming or fishing considering that the sampling was carried out at the start and peak of summer. The dissolved oxygen level of 81.5 to 153 % is high and this indicates excess nutrients or organic matter in the drainage line. It can cause an overgrowth of algae and other aquatic plants, which releases oxygen during photosynthesis. The specific conductivity of 12259-13182 µS/cm measured at station 22118 suggests high presence of pollutants or other contaminants in the water. On the other hand, in stations 22120 and 22121, the specific conductivity range between 4800 and 7400 µS/cm can be considered moderate level of specific conductivity. That indicates fair to good water quality. However, the water quality is highly dependent on the specific types of ions and minerals present, as some can be very harmful.

Observation

The sensors of the YSI multi-parameter sondes may get clogged when deployed in waterways and the equipment will continue producing the same value.

Deployment of Acoustic Doppler Current Profiler (ADCP)

The Acoustic Doppler Current Profiler (ADCP) was used to measure the average flow and the flow speed in the waterways. In the case of the ADCP, the calibration is done on site by registering the already acquired sound velocity profile of respective waterway onto the ADCP software and performing a self-test to verify the beam angles, configuration, and shape. The water discharge is measured by traversing the ADCP along the stream width. See appendix D2 for the Table of data retrieved with ADCP.

Analysis of Data

An average discharge of 0.4 m^3/s can be said to be a moderate flow which is necessary to dilute pollutants and other contaminants in the water. However, the discharge is 0.3 m^3/s or below was mostly recorded. The discharge of 0.3 m^3/s and flow of 0.1 m/s indicates a low flow in the stream which can lead to increase in water temperature, reduction of dissolved oxygen levels, and other factors that can make the water unfit for recreational activities. It can also result in decreased dilution of pollutants and other contaminants in the water, leading to degraded water quality and potential health risks for human and animal populations that rely on the water.

Observation

1. The high celerity caused by wind makes the velocity measurement rigorous.
2. It is necessary to update the profile periodically because sound velocity profile of water varies significantly over time.

Collection of Water Sample

Ana-Lab, a National Environmental Laboratory Accreditation Program (NELAP) certified laboratory provided a 250- and 100-ml sterile sampling bottles for the collection of water sample for each station. The 250 ml bottle has a preservative of H_2SO_4 (sulfuric acid), while the 100 ml has a preservative of Na_2SO_3 (sodium thiosulfate). The H_2SO_4 was used to prevent the growth of microorganisms in the sample and preserve the integrity of the sample's chemical composition such as Nitrate-Nitrate Nitrogen (N+N), Total Kjeldahl Nitrogen (TKN), and Phosphorus (P). Also, the Na_2SO_3 is often used as a dechlorinating agent to neutralize any free chlorine in water samples that could interfere with microbiological analyses. Water samples are collected at 0.3m below the top surface of water. The collected samples are secured in coolers with temperature less than 6 ^{0}C and are relinquished to Ana-Lab in less than 24 hours of collection. See appendix D3 for the results of water sample reported by Ana-Lab.

Analysis of Data

The MPN (Most Probable Number) is a statistical estimate of the number of bacteria in a sample, and a high MPN indicates a greater likelihood of fecal contamination. E. coli concentration greater than 2419 MPN/100mL in a stream indicates that the water quality is poor and unsafe for recreational use. This is an indication that the stream is receiving a high volume of contaminant, which can be from human, livestock, or wildlife. In general, it is recommended that E. coli concentration in surface water should not exceed 126 MPN/100 mL for primary contact recreation (such as swimming), and not exceed 1000 MPN/100 mL for secondary contact recreation (such as fishing or boating).

If the concentration of E. coli in a stream is found to be above these levels, it may be necessary to take corrective action to reduce the risk to human health and the ecosystem. Nitrate can come from various sources, including agricultural runoff. High levels of nitrate in streams can be an indicator of excess fertilizer use, which can lead to reduced crop yields and environmental damage. Elevated levels of nitrate in water bodies can lead to eutrophication, which is the excessive growth of algae and aquatic plants. This growth can deplete the oxygen in the water, making it difficult for other aquatic organisms to survive. The presence of TKN as Nitrogen and Phosphorus in water bodies can also lead to eutrophication, which is the excessive growth of algae and aquatic plants. This growth can deplete the oxygen in the water, making it difficult for other aquatic organisms to survive. TKN can come from various sources, including agricultural runoff. High levels of TKN in streams can be an indicator of excess fertilizer use, which can lead to reduced crop yields and environmental damage. However, the effect of N+N, TKN, and Phosphorus concentrations may vary depending on different characteristics of water in the drainage, such as flow rate and temperature.

CHAPTER VI

DISCUSSION AND CONCLUSION

The study shows that Raymondville sub watershed has an area of 1,021 Km^2. The dominant NPS of pollutants identified in the sub watershed includes urban areas, cultivated crops, and STLR. The sub watershed is house to 1.5% of the urban area, 17.1% of the cultivated crops, and 6.5% of the STLR in the North and Central LRGV watershed. Also, the PS of pollutants identified in the sub watershed includes 4 TLAP, 5 WWO, 4 MSW, and 1 MS4. The water quality maintains a safe level of TP and Ammonia. However, the E. coli/bacteria, TKN, N+N, and chlorophyll-a levels are above the screening level. The RVD have the highest concentration of E. coli/bacteria relative to other waterways in the North and Central LRGV watershed. These can be related to the high percentage of STLR, livestock activities, and species identified in the sub watershed. The cultivated crops, STLR, and the low sanitation practices can be related to the elevated TKN concentration in the sub watershed. Also, the concentration of chlorophyll is above the screening level. It is the lowest among the three sub watersheds. Therefore, it can be inferred that the excess nutrient is from cultivated crops.

Furthermore, the Hidalgo/Willacy sub watershed has an area of 1,357 Km^2. The dominant NPS of pollutants identified in the sub watershed includes urban areas, cultivated crops, STLR, and OSSF. The sub watershed is house to 8.8% of the urban area, 20.3% of the cultivated crops, 3% of the STLR, and 4591 OSSF in the North and Central LRGV watershed.

Also, the PS of pollutants identified in the sub watershed includes 8 TLAP, 11 WWO, 17 MSW, and 8 MS4. The water quality maintains a safe level for TP and Ammonia. The bacteria, chlorophyll, TKN, and N+N levels are above the EPA screening level. The high bacteria level can be related to the presence of urban area and STLR. Though it has the highest urban areas in the North and Central LRGV watershed, the relatively moderate bacteria concentration can be related to possible sanitation policy in the urban area. The HWMD has the highest concentration of TKN in the whole of North and Central LRGV watershed. It can be related to the presence of STLR and the high numbers of OSSF, WWO, MSW, and industrial activities discharging partially treated wastewater in the sub watershed. These wastewaters also increase the Nitrogen concentration in the HWMD. The high concentration of chlorophyll levels can be related to the presence of cultivated crops in the sub watershed.

The IBWCN sub watershed has an area of 737 Km^2. The NPS of pollutants identified in the sub watershed includes urban areas, cultivated crops, STLR, and OSSF. The sub watershed is house to 5.8% of the urban area, 23.7% of the cultivated crops, 0.7% of the STLR, and 4523 OSSF in the North and Central LRGV watershed. Also, the PS of pollutants identified in the sub watershed includes 3 TLAP, 9 WWO, 3 MSW, and 12 MS4. The water quality maintains a safe level for TP and Ammonia. The bacteria, TKN, N+N, and chlorophyll concentrations are above the screening level. The bacteria level can be related to the presence of urban area and STLR. The IBWCN sub watershed has higher urban areas and lowest STLR in the North and Central LRGV watershed, the relatively low bacteria concentration can be related to possible sanitation policy in the urban area and low STLR in the sub watershed.

The elevated TKN concentration can be related to the relatively medium numbers of OSSF, WWO, MSW, and industrial activities and the very low STLR. The higher Nitrogen concentration can be related to the numbers of OSSF, WWO, MSW, and industrial activities discharging partially treated wastewater to the waterways. Also, the high concentration of chlorophyll levels can be related to the presence of cultivated crops in the sub watershed.

Lastly, the correlation between the water quality in the waterways and the pollutants identified in respective sub watershed validates the result of the enhanced delineation for the terrain. Though the characterization effort is still ongoing, the available results identify agricultural activities as the dominant source of pollutant followed by industrial waste management, and the influence of urbanized area in the LRGV watershed.

REFERENCES

Abrams, R. (2012). Municipal Separate Storm Sewer Systems (MS4) -- Assigning Responsibility for Pollutants That Reach the Nation's Waters. Florida A&M University College of Law.

Andrews, W. J., Masoner, J. R., Cozzarelli, I. M. (2012). Emerging Contaminants at a Closed and an Operating Landfill in Oklahoma. *Ground Water Monitoring & Remediation*, Vol. *32*. Issue 1, pg., 120–130. https://doi.org/10.1111/j.1745-6592.2011.01373.x

Appl, M. (1999). Ammonia: Principles and Industrial Practice. Weinheim; New York; Chichester: Wiley-VCH.

Atwill, E. R., Hou, L., Karle, B. M., Harter, T., Tate, K. W., & Dahlgren, R. A. (2002). Transport of Cryptosporidium parvum Oocysts through Vegetated Buffer Strips and Estimated Filtration Efficiency. *Applied and Environmental Microbiology*, *68*(11), 5517–5527. https://doi.org/10.1128/AEM.68.11.5517-5527.2002

Baker, M. E., Weller, D. E., Jordan, T. E. (2006). Comparison of Automated Watershed Delineations. Photogrammetric Engineering & Remote Sensing, Number 2 / February 2006, pp., 159-168(10) https://doi.org/10.14358/PERS.72.2.159

Basnyat, P., Teeter, L. D., Lockaby, B. G., & Flynn, K. M. (2000). The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. *Forest Ecology and Management*, *128*(1-2), 65–73. https://doi.org/10.1016/s0378-1127(99)00273-x

Boano, F., Revelli, R., Ridolfi, L. (2005). Source identification in river pollution problems: A geostatistical approach. Water Resource Research, https://doi.org/10.1029/2004WR003754

Chen, Y., Wilson, J. P., Zhu, Q., & Zhou, Q. (2012). Comparison of drainage-constrained methods for DEM generalization. Computers & Geosciences, Vol. 48, 41–49. Comparison of drainage-constrained methods for DEM generalization - ScienceDirect

Collins, R. & Rutherford, K. (2004). Modelling bacterial water quality in streams draining pastoral land. *Water Research*, *38*(3), 700–712. https://doi.org/10.1016/j.watres.2003.10.045

Flores, J.; Wagner, K., Gregory, L., Benavides, J., Cawthon, T. (2017). Update to the Arroyo Colorado Watershed Protection Plan. Texas Water Resources Institute Technical Report – 504. arroyo-colorado-wppfinaloptimized 2017.pdf (lrgvdc.org) (accessed on 25, September 2021).

Gittleman, J. L. (2019). Species. Encyclopedia Britannica, 6 Nov. 2019, https://www.britannica.com/science/species-taxon. Accessed 11 August 2022.

Guozhen, W., Zhang, C., Li, Y., Haixing, L., Zhou, H. (2016). Source identification of sudden contamination based on the parameter uncertainty analysis. Journal of Hydroinformatics, Vol., 18. Issue 6, Pg. 919–927. https://doi.org/10.2166/hydro.2016.002

Hernandez, E. A., & Uddameri, V. (2013). An assessment of optimal waste load allocation and assimilation characteristics in the Arroyo Colorado River watershed, TX along the US– Mexico border. Clean Technologies and Environmental Policy, Vol., 15, Pg. 617–631. An assessment of optimal waste load allocation and assimilation characteristics in theArroyo Colorado River watershed, TX along the US–Mexico border | SpringerLink

Jeong, J., Wagner, K., Flores, J. J., Cawthon, T., Her, Y., Osorio, J. Yen, H. (2019). Linking watershed modeling and bacterial source tracking to better assess E. coli sources. ELSEVIER. Science of The Total Environment, Vol. 648, 15 January 2019, Pages 164-175. https://doi.org/10.1016/j.scitotenv.2018.08.097

Jeong, J., Santhi, C., Arnold, J.G., Srinivasan, R., Pradhan, S., Flynn, K. (2011). Development of Algorithms for Modeling Onsite wastewater Systems within SWAT. Trans. ASABE 2011, 54, 1693–1704. Development of Algorithms for Modeling Onsite wastewater Systems within SWAT (asabe.org).

Krempa, H.M., Flickinger, A.K. (2017). Temporal Changes in Nitrogen and Phosphorus Concentrations with Comparisons to Conservation Practices and Agricultural Activities in the Lower Grand River, Missouri and Iowa, and Selected Watersheds, 1969–2015

https://pubs.usgs.gov/sir/2017/5067/sir20175067.pdf. (Accessed on 19 July 2021).

Li, L., Yang, J., & Wu, J. (2019). A Method of Watershed Delineation for Flat Terrain Using Sentinel-2A Imagery and DEM: A Case Study of the Taihu Basin. *ISPRS International Journal of Geo-Information*, *8*(12), 528.

IJGI | Free Full-Text | A Method of Watershed Delineation for Flat Terrain Using Sentinel-2A Imagery and DEM: A Case Study of the Taihu Basin (mdpi.com).

Mahmoud, A., Alam, T., Sanchez, A., Guerrero, J., Oraby, T., Ibrahim, E., & Jones, K. D. (2020). Stormwater Runoff Quality and Quantity from Permeable and Traditional Pavements in Semiarid South Texas. Journal of Environmental Engineering, 146(6), 05020001. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001685

Navarro, L. I. (2021). Development of a cyberinfrastructure for assessment of the Lower Rio Grande Valley North and Central watersheds characteristics [Unpublished master's thesis]. University of Texas Rio Grande Valley

Olmstead, S. M., (2004). Thirsty Colonias: Rate Regulation and the Provision of Water Service. Land Economics., 2004, 80, 136–150.

Thirsty Colonias: Rate Regulation and the Provision of Water Service (uwpress.org)

Percuoco, V.P., Kalnejais, L.H., Officer, L.V. (2015). Nutrient release from the sediments of the Great Bay Estuary, N.H. USA. Estuarine, Coastal and Shelf Science, Vol., 161. 5 August 2015, Pages 76-87. https://doi.org/10.1016/j.ecss.2015.04.006

Saunders, W. (1999). Preparation of DEMs for Use in Environmental Modeling Analysis. Texas Natural Resource Conservation Commission Austin, Texas

Preparation of DEMs for Use in Environmental Modeling Analysis (esri.com)

Saunders, W.K. and D.R. Maidment (1995), Grid-Based Watershed and Stream Network Delineation for the San Antonio-Nueces Coastal Basin, In Proceedings: Texas Water '95: A Component Conference of the First International Conference of Water Resources Engineering, August 16-17, 1995, American Society of Civil Engineers, San Antonio,TX.

Schumacher, J. (2002). Surface Water Pollution from Livestock Production.

surface water pollution from livestock production.pdf (tamu.edu)

(Accessed on 27 January 2021.

Shin, M., Jang, J., Lee, S., Park, Y., Lee, Y., Shin, Y., Won, C. (2016). Application of surface cover materials for reduction of NPS pollution on field-scale experimental plots: Effects of surface cover materials for reduction of NPS pollution. Irrigation and Drainage, Vol. 65, Issue 52. pg159–167. https://doi.org/10.1002/ird.2067

Smith, V.H., Tilman, G.D., Nekola, J.C. (1999). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution, Vol. 100. Issues 1–3, 1999, Pages 179-196. https://doi.org/10.1016/S0269 7491(99)00091-3

Tarboton, D. (2012). Exercise 4. Watershed and Stream Network Delineation. GIS in Water Resources. Utah State University https://www.caee.utexas.edu/prof/maidment/giswr2012/Ex4/Ex42012.htm (Accessed on July 6, 2022)

TCEQ. (2006a). Pollutant reduction plan for the Arroyo Colorado: Segments 2201 and 2202, Hidalgo, Cameron, and Willacy Counties. Texas Commission on Environmental Quality. https://arroyocolorado.org/media/zs1fkpzw/pollutantreductionplanseg2201-2202.pdf

TCEQ. (2007). Managing Nonpoint Source Pollution in Texas 2007 Annual Report; Texas State Soil and Water Conservation Board: Temple, TX, USA, 2007. https://texashistory.unt.edu/ark:/67531/metapth641115/

Tyrrel, S. F. & Quinton, J. N. (2003). Overland flow transport of pathogens from agricultural land receiving faecal wastes: PATHOGEN TRANSPORT IN OVERLAND FLOW. Journal of Applied Microbiology, https://doi.org/10.1046/j.1365 2672.94.s1.10.x

Uddameri, V., Singaraju, S., Hernandez, E. A. (2018). Detecting seasonal and cyclical trends in agricultural runoff water quality—hypothesis tests and block bootstrap power analysis. *Environmental Monitoring and Assessment*, *190*(3), 157. https://doi.org/10.1007/s10661-018-6476-y

USEPA. (n.d.). Section 319: Nonpoint Source Program. Introduction to the Clean Water Act. Introduction to the Clean Water Act | Watershed Academy Web | US EPA (Accessed on February 4th, 2021.)

USEPA. (2008). Handbook for Developing Watershed Plans to Restore and Protect Our Waters. Handbook for Developing Watershed Plans to Restore and Protect Our Waters, March 2008 (epa.gov)

USEPA. (2013). Aquatic Life Ambient Water Quality Criteria for Ammonia - Freshwater 2013. Regulations.gov

USEPA. (2022). Indicators: Chlorophyll-a. National Aquatic Resource Surveys. Indicators: Chlorophyll a | US EPA (Accessed on July 11th, 2022).

USGS (2018b). Nitrogen and Water. Water Science School (May 21, 2018). Nitrogen and Water | U.S. Geological Survey (usgs.gov)

USGS (2018c). Phosphorus and Water. Water Science School (June 5, 2018). Phosphorus and Water | U.S. Geological Survey (usgs.gov)

Xiao, H., & Ji, W. (2007). Relating landscape characteristics to non-point source pollution in mine waste-located watersheds using geospatial techniques. *Journal of Environmental Management*, *82*(1), 111–119. https://doi.org/10.1016/j.jenvman.2005.12.009

Zhang, H., Huang, G. H., & Wang, D. (2013). Establishment of channel networks in a digital elevation model of the prairie region through hydrological correction and geomorphological assessment. *Canadian Water Resources Journal*, Vol. *38*(1), 12–23. https://doi.org/10.1080/07011784.2013.773788.

Xiao, H., & Ji, W. (2007). Relating landscape characteristics to non-point source pollution in mine waste-located watersheds using geospatial techniques. *Journal of Environmental Management*, *82*(1), 111–119. https://doi.org/10.1016/j.jenvman.2005.12.009

Zhang, H., Huang, G. H., & Wang, D. (2013). Establishment of channel networks in a digital elevation model of the prairie region through hydrological correction and geomorphological assessment. *Canadian Water Resources Journal*, Vol. *38*(1), 12–23. https://doi.org/10.1080/07011784.2013.773788.

APPENDIX A

APPENDIX A

Appendix A1:

Hidalgo Willacy Main Drain Wastewater Outfalls

	PERMIT No.	PERMITTEE
1	13523-014	LA JOYA ISD
2	04040-000	CALPINE CONSTRUCTION FINANCE CO LP & CALPINE OPERATING SERVICES CO INC
3	10503-002	CITY OF EDINBURG
4	04138-000	CALPINE HIDALGO ENERGY CEN; CALPINE OP SERV CO; BROWNSVILLE PUB
5	10503-002	CITY OF EDINBURG
6	10633-004	CITY OF MCALLEN
7	13742-001	SEBASTIAN MUD
8	11510-002	CITY OF ELSA
9	04782-000	NORTH ALAMO WSC
10	14919-001	CITY OF EDCOUCH
11	00847719	CITY OF LYFORD

Appendix A2:

Raymondville Drain Wastewater Outfalls

Raymondville Drain		
	PERMIT No.	PERMITTEE
1	04480-000	NORTH ALAMO WSC
2	13747-001	NORTH ALAMO WSC
3	13747-004	NORTH ALAMO WSC
4	10365-001	CITY OF RAYMONDVILLE
5	05251-000	CITY OF RAYMONDVILLE

Appendix A3:

IBWC North Floodway Wastewater Outfalls

IBWC North Floodway		
	PERMIT No.	PERMITTEE
1	10619-001	CITY OF WESLACO
2	10619-003	CITY OF WESLACO
3	10330-001	CITY OF SANTA ROSA
4	15513-001	NORTH ALAMO WSC
5	14781-002	CITY OF LA VILLA
6	04758-000	PEN JOINT TENANTS AND NORTH CAMERON RWSC
7	01752-000	RIO GRANDE VALLEY SUGAR GROWERS INC

Appendix A4:

IBWC North Floodway Wastewater Landfills

IBWC North Floodway		
	NAME	FACILITY
1	CITY OF WESLACO LANDFILL	CLOSED

Appendix A5:

Hidalgo Willacy Main Drain Wastewater Landfills

Hidalgo Willacy Main Drain		
	NAME	FACILITY
1	CITY OF MCALLEN LANDFILL	POST CLOSED
2	HIDALGO COUNTY SHREDDER--GRINDER FACILITY	NOT CONSTRUCTED
3	HIDALGO COUNTY	CLOSED
4	CITY OF MISSION LANDFILL	CLOSED
5	CITY OF WESLACO LANDFILL	INACTIVE
6	WILLACY COUNTY LANDFILL	POST CLOSED
7	GREASE SPECIALIST LIQUID WASTE PROCESSING FACILITY	NOT CONSTRUCTED
8	CITY OF MCALLEN	NOT CONSTRUCTED
9	HIDALGO COUNTY LANDFILL	INACTIVE

10	**RUBENS VACUUM & HYDROJETTING LIQUID WASTE PROCESSING FACILITY**	**INACTIVE**
11	MLB EDINBURG LIQUID TRANSFER STATION	INACTIVE
12	CITY OF EDINBURG	CLOSED
13	CITY OF LYFORD LANDFILL	CLOSED

Appendix A6:

Raymondville Drain Wastewater Landfills

Raymondville Drain		
	NAME	FACILITY
1	HIDALGO COUNTY	NOT CONSTRUCTED
2	WILLACY COUNTY SOLID WASTE LANDFILL	NOT CONSTRUCTED
3	RECYCLING CONSULTANT SERCVICES	ACTIVE
4	UNION Y DIGNIDAD LANDFILL	CLOSED
5	CITY OF EDINBURG LANDFILL	NOT CONSTRUCTED
6	CITY OF MERCEDES TRANSFER STATION FACILITY	NOT CONSTRUCTED
7	CITY OF EDINBURG LANDFILL	ACTIVE
8	CITY OF RAYMONDVILLE LANDFILL	POST CLOSED

APPENDIX B

APPENDIX B

Appendix B1:

Monthly Flow Data

	West Mercedes				Near Sebastian			
Data Range	2012-2020				2012-2020			
Observations	135, 542				304, 977			
Month	Mean	Min	Max	Median	Mean	Min	Max	Median
January	2.27	0.00	6.26	2.35	2.41	0.46	16.74	1.83
February	0.70	0.00	6.01	0.21	2.67	0.47	10.15	1.99
March	0.86	0.00	89.49	0.10	2.85	0.41	235.52	1.49
April	2.28	0.00	44.25	0.22	3.23	0.44	17.23	2.63
May	1.17	0.00	8.23	0.39	4.03	0.59	135.42	2.93
June	21.86	0.00	1187.66	5.17	14.17	0.00	3852.96	2.47
July	3.30	0.00	15.21	1.67	28.32	0.00	8412.59	1.90
August	0.36	0.00	2.34	0.31	3.87	0.00	29.47	2.06
September	0.36	0.00	4.42	0.04	2.55	0.36	16.26	1.82
October	7.76	0.00	66.53	0.98	2.57	0.24	50.06	1.21
November	0.21	0.07	0.63	0.12	1.31	0.18	29.27	0.68
December	0.00	0.00	0.00	0.00	1.08	0.20	9.23	0.73

Source: USIBWC website

Appendix B2:

Annual Flow Data

	West Mercedes				Near Sebastian			
Year	Mean	Min	Max	Median	Mean	Min	Max	Median
2012	0	0	0	0	1.85	0.57	8.84	1.79
2013	0	0	0	0	1.64	0.58	11.96	1.33
2014	0	0	0	0	2.4	0.55	10.33	1.82
2015	10.72	0	66.53	0.96	4.07	0.3	135.42	2.2
2016	1.83	0	29.49	0.15	2.06	0.18	14.62	1.27
2017	19.29	0	1187.66	2.41	3.75	0.32	235.52	3.63
2018	4.16	0	424.28	0.77	10.51	0	3852.96	1.86
2019	3.3	0	15.21	1.67	2.85	0	164.63	1.13
2020	10.72	0	66.53	0.96	27.62	0	8412.59	2.89

Source: USIBWC website

Appendix B3:

Mercedes Annual Mean Flow Dataset

IBWNF Mercedes Annual Mean Flow Data	
Date	CMS
1/1/2015	0.379763321
1/1/2016	0
1/1/2017	0.277815597
1/1/2018	2.453020878
1/1/2019	1.221470144
1/1/2020	0.008724787

Appendix B4:

Mercedes Annual Max Flow Dataset

IBWNF Mercedes Annual Max Flow Data	
Date	CMS
1/1/2015	66.532
1/1/2016	0
1/1/2017	29.488
1/1/2018	1187.659
1/1/2019	424.28
1/1/2020	15.212

Appendix B5:

Mercedes Monthly Mean Flow Dataset

IBWNF Mercedes Monthly Mean Flow Data	
Date	CMS
4/1/2015	0.000003
8/1/2015	0.036335
10/1/2015	4.431523
11/1/2015	0.015832
9/1/2017	0.050864
10/1/2017	0.730040
3/1/2018	0.295422
4/1/2018	0.000121

5/1/2018	**0.000003**
6/1/2018	25.457163
9/1/2018	0.000606
10/1/2018	0.081366
1/1/2019	0.783847
2/1/2019	0.433344
3/1/2019	0.269581
4/1/2019	1.506642
5/1/2019	0.978656
6/1/2019	10.869474
8/1/2019	0.000786
9/1/2019	0.000305
7/1/2020	0.078638

Appendix B6:

Mercedes Monthly Max Flow Dataset

IBWNF Mercedes Monthly Max Flow Data	
Date	CMS
4/1/2015	0.001
8/1/2015	0.798
10/1/2015	66.532
11/1/2015	0.626

9/1/2017	**4.416**
10/1/2017	29.488
3/1/2018	89.488
4/1/2018	0.006
5/1/2018	0.005
6/1/2018	1187.659
9/1/2018	0.143
10/1/2018	9.03
1/1/2019	6.262
2/1/2019	6.01
3/1/2019	22.102
4/1/2019	44.249
5/1/2019	8.226
6/1/2019	424.28
8/1/2019	2.34
9/1/2019	0.878
7/1/2020	15.212

Appendix B7:

Sebastian Annual Mean Flow Dataset

IBWNF Sebastian Annual Mean Flow Data	
Date	CMS
1/1/2012	1.853545709
1/1/2013	1.64018472
1/1/2014	2.404222475
1/1/2015	4.071965205
1/1/2016	2.059347752
1/1/2017	3.749904318
1/1/2018	10.50905489
1/1/2019	2.853023695

Appendix B8:

Sebastian Annual Max Flow Dataset

IBWNF Sebastian Annual Max Flow Data	
Date	CMS
1/1/2012	8.841
1/1/2013	11.962
1/1/2014	10.33
1/1/2015	135.421
1/1/2016	14.623
1/1/2017	235.523

1/1/2018	**3852.955**
1/1/2019	164.628
	8412.59

Appendix B9:

Sebastian Monthly Max Flow Dataset

IBWNF Sebastian Monthly Max Flow Data	
Date	CMS
1/1/2012	4.093
2/1/2012	4.859
3/1/2012	8.841
4/1/2012	4.857
5/1/2012	4.979
6/1/2012	3.183
7/1/2012	3.692
8/1/2012	2.797
9/1/2012	2.806
10/1/2012	5.353
11/1/2012	1.003
12/1/2012	0.859
1/1/2013	1.541
2/1/2013	1.953

3/1/2013	**1.216**
4/1/2013	5.16
5/1/2013	7.988
6/1/2013	3.614
7/1/2013	2.979
8/1/2013	3.635
9/1/2013	7.617
10/1/2013	2.462
11/1/2013	11.962
12/1/2013	6.541
1/1/2014	6.541
2/1/2014	2.026
3/1/2014	2.5
4/1/2014	3
5/1/2014	4.445
6/1/2014	3.453
7/1/2014	3.299
8/1/2014	5.102
9/1/2014	10.33
10/1/2014	6.541
11/1/2014	9.956

12/1/2014	**9.228**
1/1/2015	16.741
2/1/2015	4.027
3/1/2015	16.855
4/1/2015	17.228
5/1/2015	135.421
6/1/2015	18.09
7/1/2015	6.112
8/1/2015	27.069
9/1/2015	16.259
10/1/2015	50.058
11/1/2015	29.267
12/1/2015	1.971
1/1/2016	4.034
2/1/2016	4.29
3/1/2016	12.807
4/1/2016	6.515
5/1/2016	13.217
6/1/2016	11.712
7/1/2016	4.686
8/1/2016	14.623

9/1/2016	**9.532**
10/1/2016	0.6
11/1/2016	4.368
12/1/2016	2.626
1/1/2017	10.762
2/1/2017	7.562
3/1/2017	235.523
4/1/2017	8.733
5/1/2017	16.443
6/1/2017	8.99
7/1/2017	8.558
8/1/2017	7.266
9/1/2017	6.902
10/1/2017	8.25
11/1/2017	4.489
12/1/2017	3.309
1/1/2018	5.688
2/1/2018	10.149
3/1/2018	5.963
4/1/2018	7.78
5/1/2018	6.463

6/1/2018	**3852.955**
7/1/2018	4.167
8/1/2018	3.714
9/1/2018	15.017
10/1/2018	3.115
11/1/2018	0.824
12/1/2018	1.56
1/1/2019	6.512
2/1/2019	6.54
3/1/2019	5.504
4/1/2019	7.953
5/1/2019	4.164
6/1/2019	164.628
7/1/2019	33.66
8/1/2019	10.458
9/1/2019	7.996
10/1/2019	4.408
11/1/2019	6.242
12/1/2019	3.502
1/1/2020	3.782
2/1/2020	4.545

3/1/2020	**5.912**
4/1/2020	5.584
5/1/2020	7.92
6/1/2020	19.576
7/1/2020	8412.59
8/1/2020	29.472
9/1/2020	2.894
10/1/2020	2.894
11/1/2020	2.894

Appendix B10:

Sebastian Monthly Mean Flow Dataset

IBWNF Sebastian Monthly Mean Flow Data	
Date	CMS
1/1/2012	2.02740289
2/1/2012	3.020897731
3/1/2012	1.76131588
4/1/2012	1.961717976
5/1/2012	2.689133108
6/1/2012	2.556851513
7/1/2012	2.275675237

8/1/2012	**2.084891574**
9/1/2012	1.50170625
10/1/2012	1.033675101
11/1/2012	0.736692254
12/1/2012	0.663114353
1/1/2013	0.839900571
2/1/2013	1.483316865
3/1/2013	0.893158532
4/1/2013	1.683935664
5/1/2013	1.885742945
6/1/2013	1.461047454
7/1/2013	1.343491743
8/1/2013	1.441226178
9/1/2013	3.018519834
10/1/2013	1.837949849
11/1/2013	2.196181252
12/1/2013	1.630258517
1/1/2014	2.420097301
2/1/2014	1.568461027
3/1/2014	1.412319533
4/1/2014	1.853850312

5/1/2014	**2.589646309**
6/1/2014	2.135571776
7/1/2014	1.904715729
8/1/2014	1.750061348
9/1/2014	5.046942957
10/1/2014	3.63469886
11/1/2014	2.474148907
12/1/2014	2.05501914
1/1/2015	2.34797379
2/1/2015	2.352173363
3/1/2015	5.550554772
4/1/2015	3.915702224
5/1/2015	10.12663138
6/1/2015	3.805440319
7/1/2015	2.352503024
8/1/2015	3.87776967
9/1/2015	2.4554125
10/1/2015	8.663968425
11/1/2015	2.075866435
12/1/2015	1.038026546
1/1/2016	0.988954637

2/1/2016	**1.767099497**
3/1/2016	1.687740255
4/1/2016	3.444958333
5/1/2016	4.20462836
6/1/2016	3.186446181
7/1/2016	2.82556922
8/1/2016	3.366549059
9/1/2016	1.769836572
10/1/2016	0.390949933
11/1/2016	0.444636364
12/1/2016	0.636858199
1/1/2017	2.767975806
2/1/2017	3.153190458
3/1/2017	7.860833725
4/1/2017	5.761921181
5/1/2017	5.754701826
6/1/2017	4.447475694
7/1/2017	5.371573554
8/1/2017	4.300611523
9/1/2017	1.868826761
10/1/2017	2.07687727

11/1/2017	**0.686013889**
12/1/2017	0.814162634
1/1/2018	3.921058468
2/1/2018	5.630433218
3/1/2018	2.495565736
4/1/2018	4.85872255
5/1/2018	3.864083659
6/1/2018	144.0308541
7/1/2018	1.270146268
8/1/2018	1.906449933
9/1/2018	2.99749606
10/1/2018	0.780062555
11/1/2018	0.584860353
12/1/2018	0.661415659
1/1/2019	4.258639543
2/1/2019	3.008759673
3/1/2019	1.058281629
4/1/2019	1.910559722
5/1/2019	2.007825269
6/1/2019	14.83705799
7/1/2019	0.705749832

8/1/2019	**1.68481754**
9/1/2019	1.450426736
10/1/2019	1.390422043
11/1/2019	1.041092014
12/1/2019	1.144411962
1/1/2020	2.124138777
2/1/2020	3.389125718
3/1/2020	2.911936156
4/1/2020	3.782814236
5/1/2020	3.102975437
6/1/2020	3.5954125
7/1/2020	236.7467189
8/1/2020	14.41914487
9/1/2020	2.894
10/1/2020	2.894
11/1/2020	2.894

APPENDIX C

APPENDIX C

Appendix C1:

HWMD Water Quality Dataset

Hidalgo Willacy Main Drain Water Quality							
Date	Bacteria MPN/100ML	Ammonia MG/L AS N	TKN (Total Nitrogen) MG/L AS N	TP (Total Phosphorus) MG/L AS P	Nitrite MG/L AS N	Nitrate MG/L AS N	Chlorophyll-a UG/L
10/4/2017	610	0.02	1	0.733	3.02	0	57
12/3/2017	10	0.26	2.85	0.847	3.87	0	13.5
5/1/2018	120	0.002	3.63	0.755	4.71	0	91.5
7/18/2018	20	0.2	2.1	0.2	1.2	0.099	98.5
10/31/2018	80	0.1	1.5	0.67	5.6	0.09	23.9
1/29/2019	31	0.1	1.21	0.7	5.6	0.06	19.3
4/2/2019	1400	0.2	1.4	0.78	4.02	0.06	27
7/16/2019	2200	0.26	2.1	0.23	0.03	0.02	19.3

Appendix C2:

RVD Water Quality Dataset

Raymondville Drain Water Quality							
Date	Bacteria MPN/100ML	Ammonia MG/L AS N	TKN (Total Nitrogen) MG/L AS N	TP (Total Phosphorus) MG/L AS P	Nitrite MG/L AS N	Nitrate MG/L AS N	Chlorophyll-a UG/L
10/4/2017	1940	0.02	1	0.28	1.17	0	36.3
12/3/2017	150	0.1	0.42	0.2	1.52	0	18
5/1/2018	220	0.02	2.75	0.12	2.34	0	33.3
7/18/2018	150	0.1	3.1	0.2	0.8	0.05	39.8
10/31/2018	1700	0.2	1.3	0.2	1.5	0.05	11.7
1/29/2019	74	0.17	1.43	0.2	5.6	0.06	3.8
4/2/2019	2400	0.04	1.7	0.44	1.34	0.08	67
7/16/2019	130	0.2	1.6	0.19	0.64	0.11	19.8

8/27/2015	**0**	**0.07**	**1.53**	**0.26**	**3.02**	**76.20**
11/30/2015	610	0.19	3.19	0.25	4.98	23.40
5/4/2016	360	0.21	2.01	0.31	4.37	68.30
8/4/2016	0	0.00	0.00	0.27	2.08	20.10
11/2/2016	95	0.05	0.74	0.42	2.98	52.80
2/8/2017	0	0.08	1.72	0.39	4.29	11.00
5/3/2017	75	0.08	1.55	0.27	4.37	2.31
7/25/2017	120	0.05	0.00	0.25	1.07	19.60
11/29/2017	160	0.00	0.00	0.00	0.00	9.94
1/30/2018	20	0.16	0.00	0.29	3.80	6.91
4/18/2018	340	0.05	1.29	0.50	4.43	66.90
7/18/2018	96	0.05	2.30	0.39	2.36	78.10
10/16/2018	300	0.29	1.51	0.57	1.79	72.30
1/23/2019	200	0.10	1.03	0.35	4.67	28.60
4/16/2019	1600	0.05	1.03	0.24	2.65	36.30
11/7/2019	0	0.21	1.20	0.15	2.35	32.60

Appendix C3:

IBWNF Water Quality Dataset

IBWC North Floodway Water Quality						
Date	Bacteria MPN/100ML	Ammonia MG/L AS N	TKN (Total Nitrogen) MG/L AS N	TP (Total Phosphorus) MG/L AS P	Nitrate+Nitrite MG/L AS N	Chlorophyll-a UG/L
11/3/2011	0	0.16	2.03	0.00	2.42	29.70
2/23/2012	0	0.09	0.95	0.21	5.28	35.00
5/3/2012	0	0.13	1.49	0.29	4.47	40.20
8/23/2012	0	0.12	1.04	0.23	2.26	55.70
11/19/2012	0	0.06	1.50	0.59	2.75	42.60
3/12/2013	110	0.16	1.08	0.00	2.68	40.50
8/21/2013	640	0.23	0.89	0.23	2.01	51.40
11/25/2013	7300	0.12	0.68	0.41	3.96	9.50
8/14/2014	0	0.06	1.70	0.00	2.03	82.30
11/24/2014	1100	0.11	1.36	0.34	3.82	44.40
2/25/2015	110	0.13	1.57	0.27	3.08	35.40
3/26/2015	0	0.25	1.66	0.35	6.71	26.00
8/26/2015	1400	0.12	1.84	0.32	3.10	60.20

APPENDIX D

APPENDIX D

Appendix D1:

Water Quality Data retrieved with YSI SONDE

SFA	Date	Time	Station No.	pH	Temp. (^{0}C)	D.O. %	SpC (µS/cm)
9	5/4/22	10:23	22118	8.05	26.932	81.6	12259.5
	5/3/22	12:51	22120	7.62	27.335	90.7	7372.7
	5/3/22	10:34	22121	7.82	26.607	85.6	4917.9
SFA	Date	Time	Station No.	pH	Temp. (0C)	D.O. %	SpC (µS/cm)
10	7/13/22	15:00	22118	8.30	33.37	152.6	13182.8
	7/27/22	14:15	22120	7.98	33.18	141.4	6471.8
	7/27/22	12:05	22121	8.11	31.02	110	4824.9

Appendix D2:

Water Quality Data retrieved with ADCP

SFA	Date	Time	Station No.	Ave. Discharge (m^3/s)	Ave. Flow speed (m/s)	Flow Direction Towards (^0N)
9	5/4/22	10:23	22118	0.063	0.019	103.5
	5/3/22	12:51	22120	0.438	0.12	95.5
	5/3/22	10:34	22121	0.209	0.16	239.69
10	7/13/22	15:00	22118	0.269	0.046	103.99
	7/27/22	14:15	22120	0.32	0.105	86.64
	7/27/22	12:05	22121	0.302	0.182	352.51

Appendix D3:

Water Quality Data reported by Ana-Lab

SFA	Date of sample collection	Station No.	E Coli (MPN/ 100mL)	N+N (mg/L as N)	TKN (mg/L as N)	Phosphorus (mg/L as P)
9	5/4/22	22118	>2419.60	1.34	1.59	1.06
	5/3/22	22120	1413.6	0.969	7.37	6.09
	5/3/22	22121	1732.9	2.62	<0.68	0.379
10	7/13/22	22118	1119.9	2.34	<0.68	1.86
	7/27/22	22120	1986.3	0.372	11.00	3.58
	7/27/22	22121	>2419.6	1.50	<0.680	0.772

BIOGRAPHICAL SKETCH

Abdulkabir Aduragba is a citizen of Nigeria. He obtained is bachelor's degree in civil engineering from University of Ilorin, Nigerian, in 2007. He worked on Dams, Structures and Highways before he decided to pursue a master's degree in civil engineering at the University of Texas Rio Grande Valley and he earned master's degree of Civil Engineering on May 15th, 2023.

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