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Water Quality Monitoring to Assess Pollutant Loadings in Brownsville Ship Channel Watershed

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WATER QUALITY MONITORING TO ASSESS POLLUTANT LOADINGS IN BROWNSVILLE SHIP CHANNEL WATERSHED

A Thesis
by
IVAN RENE SANTOS CHAVEZ

Submitted in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Civil Engineering

The University of Texas Rio Grande Valley
May 2022

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May 2022

ABSTRACT

Santos Chavez, Ivan R., Water Quality Monitoring to Assess Pollutant Loadings in Brownsville Ship Channel Watershed. Master of Science (MS), May, 2022, 121 pp, 31 tables, 68 figures, references, 85 titles.

The Brownsville Ship Channel (BSC) was listed as an impaired waterway from 2010 to 2018 due to screening levels of bacteria concentration. This study aims to address water quality at the three main tributary ditches draining into Brownsville Ship Channel to model present along with future pollutant loads within Brownsville Ship Channel Watershed. Load Duration Curves (LDCs) and Spatial Explicit Load Enrichment Calculation Tool (SELECT) models were developed to determine if current pollutant loads meet water quality standards stablished by the Texas Commission on Environmental Quality (TCEQ), and to estimate average daily potential E. Coli loading contribution from sub-watersheds within BSCW. Findings from this study indicate that E. Coli, Total Kjeldahl Nitrogen, Nitrate/Nitrite Nitrogen and Total Phosphorus daily loadings had been exceeding the maximum allowable loading criteria in most of the observations.

DEDICATION

Alicia and René, all this is for you. Thanks for giving all you had to make my dreams come true, reaching this moment in my life had been complicated but knowing that even in the distance you are always there, supporting me, makes life easier, I love you.

My birthday gift, Rebeca, I love you with all my heart sister. Thanks for all the happiness and love you provide to our family; you had always been my motivation to stay strong and keep working. I am extremely proud of the woman you became, cannot wait to see your new journeys.

Thanks Dr. Abdoul Oubeidillah and Dr. Andrew Ernest, for your guidance during my time at UTRGV, for giving me the opportunity get in involved in this project and for always trusting in me. Your help in this journey made me grow a lot professional and personally.

Dr. Chu-Lin Cheng, and Dr. Jungseok Ho, thanks for increasing my passion for environmental and water resources, thanks for your guidance to conclude this project.

Thanks to the field crew members; Linda Navarro, Binaya Poudel, Wendy Galvan, Carlos Reyes, and Abdulkabir Aduragba, your professionalism and good attitude were unvaluable to complete this study.

Thanks to the Texas Commission on Environmental Quality for funding this project.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Objective of the study

This study aims to address water quality at the three main tributary ditches draining into the Brownsville Ship Channel by developing Load Duration Curves (LDCs) and to model potential bacteriological loads at Brownsville Ship Channel Watershed by implementing the Spatial Explicit Load Enrichment Calculation Tool (SELECT) model.

Area of Study

This study focuses on Brownsville Ship Channel Watershed (BSCW), located at Cameron County in South Texas, where three sites were selected by a group of stakeholders in 2014 to measure water quality, flow, and bacteria along with nutrients concentration. The previously mentioned sites are within the three main tributary ditches that drain into Brownsville Ship Channel (BSC) that are: Ditch No. 1, Ditch No. 2, and Old Main Drain Ditch. 1 At each sampling location a Real-Time Hydrologic System (RTHS) station with a unique identification number was installed to measure some water quality parameters, the given IDs were utilized in this study to identify each of the sampling sites. Figure 1 shows sampling locations, main tributary ditches draining into BSC, the BSC, along with the boundaries of BSCW and Cameron County.

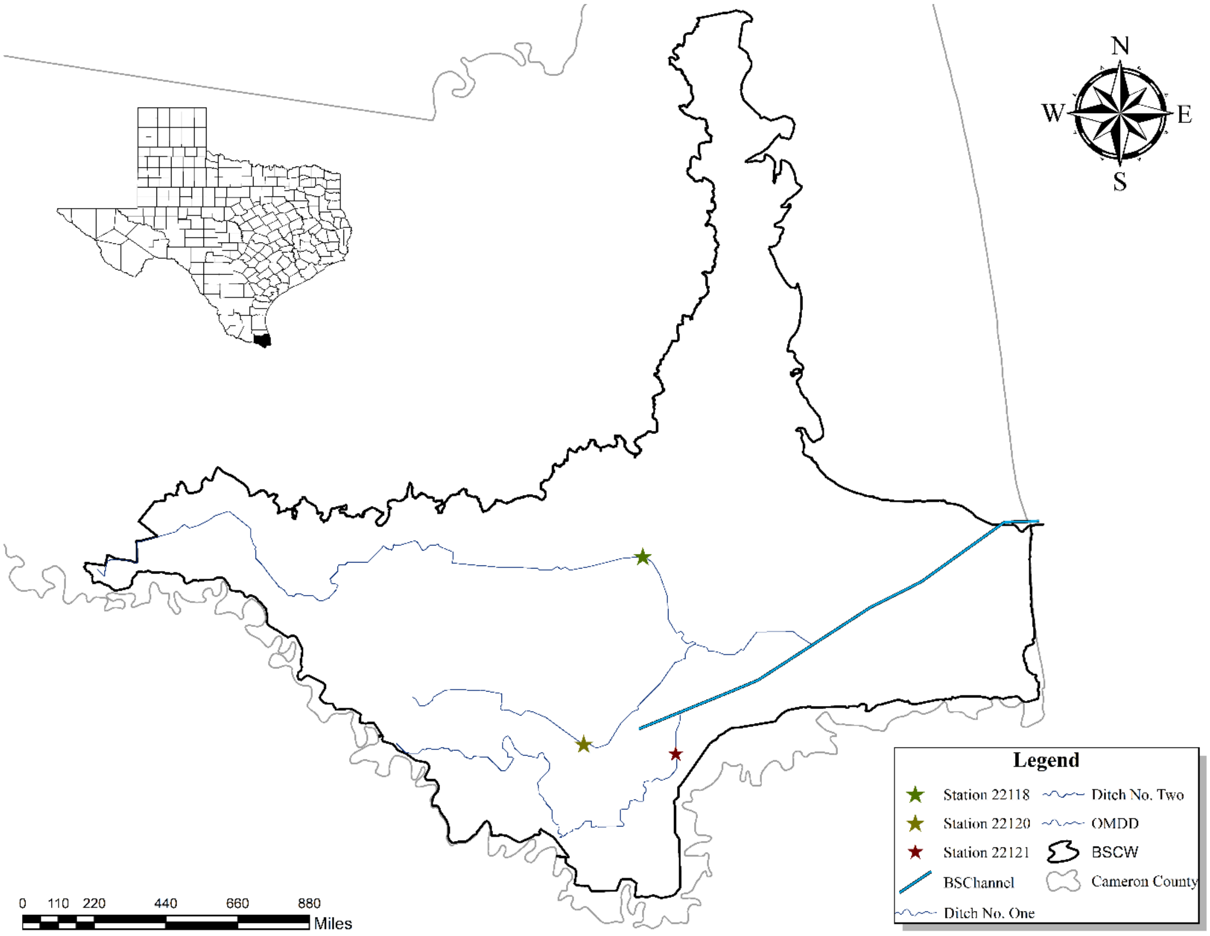


Figure 1. Area of study. BSCW boundaries in bold, Cameron County in gray, Station 22118 monitors Ditch No. 2, Station 22120 Ditch No. 1, and Station 22121, Old Main Drain Ditch (OMDD).

Load Duration Curves

The selected method to determine whether if pollutant loads measured on site met or not water quality criteria was the Load Duration Curve (LDC), cumulative frequency plot of mean daily flows, concentrations, or daily loads over a period of record, with values plotted from their highest value to lowest without regard to chronological order (Donald W. Meals et al., 2013).

LDCs are developed by multiplying stream flow with the numeric water quality target, usually a water quality criterion, and a conversion factor for the pollutant of concern (USEPA, 2007).

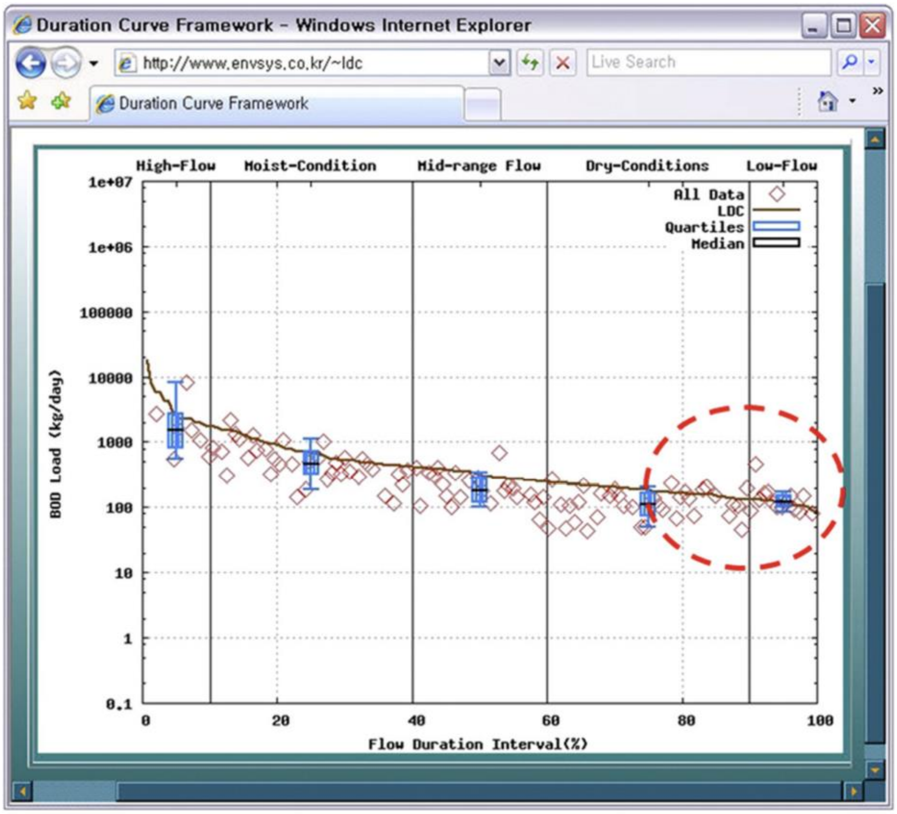


Figure 2. LDC of Biochemical Oxygen Demand (BOD) generated using Web-based system. Source: (Kim et al., 2012)

A study developed by (Kim et al., 2012) presents a Web-based LDC system that allows to generate LDCs by retrieving flow and concentration data from certified sources such as USGS or EPA, even data collected by the researcher can be input if necessary. Figure 2 presents a LDC showing Biochemical Oxygen Demand (BOD) loads observed at Nakbon watershed in Korea. Main advantages of using this Web-based system compared with the traditional development of LDCs, using spreadsheet software programs, are the ease of use, time saving, about 30 minutes less of work per LDC developed, and decrement of human error influencing. Waterways analyzed in this study had not been studied by any governmental or private entity (UTRGV et al., 2021) therefore, the necessity of collecting this type of data in situ. As the Web-based system does not allow to conduct any statistical analysis, this study opted to generate LDCs based on spreadsheet software program.

Spatially Explicit Load Enrichment Calculation Tool

The Spatially Explicit Load Enrichment Calculation Tool (SELECT) is an automated geographic information system (GIS) tool that can be applied to assess potential E. coli loads in a watershed based on spatial factors such as land use, population density, and soil type (A. , Teague et al., 2009). SELECT is able to calculate potential E. coli loads and highlight areas of concern for best management practices (BMPs) to be implemented. Visual outputs, as shown in Figure 3, allow a decision maker or stakeholder to easily identify areas of a watershed with the greatest potential for contamination contribution and enable them to formulate management strategies to include in the Watershed Protection Plan (WPP) implementation plan (Borel et al., 2012). Main requirements to develop SELECT model are, GIS software, a watershed delineation of the desired area of study along with the identification of non-point (NPS), point sources (PS) of pollution, population density, and wildlife identification (Karthikeyan et al., 2012).

(Borel et al., 2012; Karthikeyan et al., 2012; A. Teague et al., 2009), had implemented SELECT model in other regions at central area of Texas obtaining great results. No pollutant loading distribution studies had been conducted within BSCW before (UTRGV et al., 2021), therefore, SELECT model was developed for this watershed to understand the sources of pollution that threated the tree waterways analyzed in this study and offer scientific support for policymakers or stakeholders to implement Best Management Practices (BMPs) that increase water quality at BSCW.

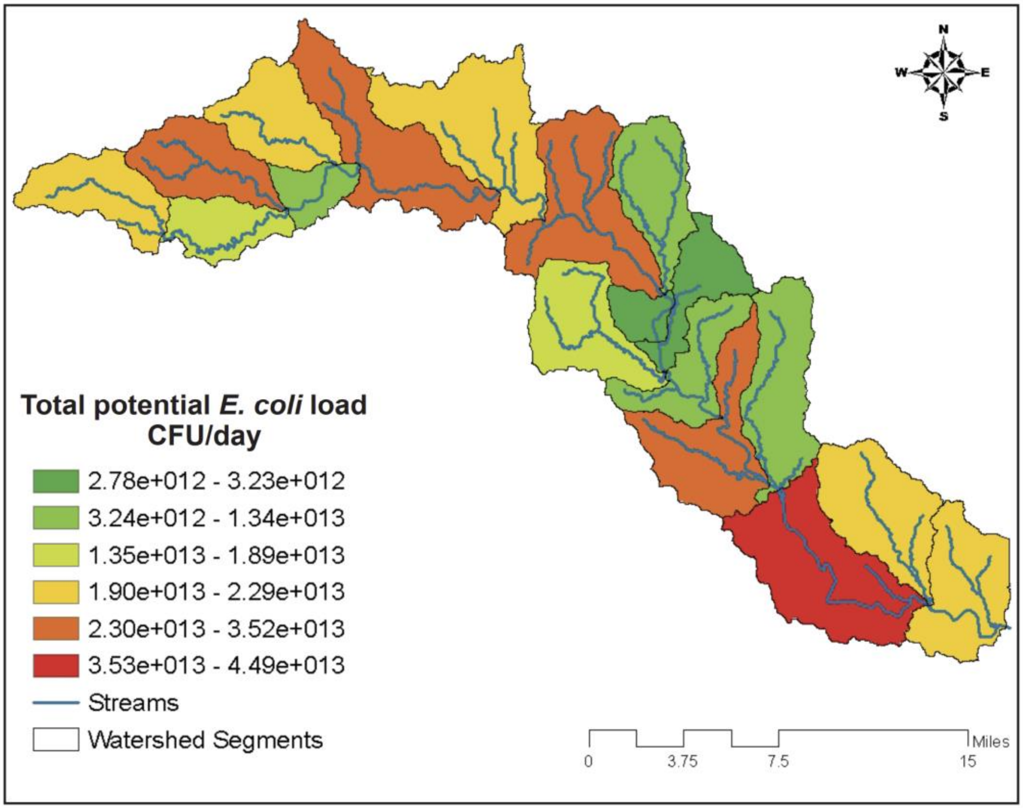


Figure 3. Total daily potential E. coli load from all considered sources in the Buck Creek watershed at Childress and Collingsworth Counties. Source: (Borel et al., 2012).

CHAPTER II

DATA COLLECTION

Objective

The objectives of this chapter were gathering metadata necessary to characterize BSCW, find existing studies developed in the area of study, and collect water quality data that allowed to develop LDCs to determine current status of monitored waterways.

Watershed Data Physical Data

Topography

The BSCW has several problems of flooding (Adam Cardona, 2021) due to the flat topography that decrease the incapacity of runoff to naturally reach the outlets. According to Light Detection and Ranging (LiDAR) topographic data obtained from (TNRIS, 2018), the highest elevation at BSCW was closer to 111 ft at the west side of the watershed, on the other hand, elevations at the central and east area are lower than 10 ft, the area is mostly compound of resacas, bays, and the Gulf of Mexico. Figure 4 shows a map built with GIS software and LiDAR data which is a remote sensing method that uses light in the form of a pulsed laser to measure ranges to the Earth to generate precise, three-dimensional information about the shape of the Earth and its surface characteristics (NOOA, 2021).

Stream Network

The stream network at BSCW was extracted from the topographic data previously mentioned using GIS software. Results from this procedure indicated that streams from south and central part of BSCW drain into BSC while the north part of the watershed drains into Lower Laguna Madre Bay, another finding was that the total length of the steam network was of 909 miles according to the analysis conducted with GIS software. According to (Rio Grande Valley Stormwater Management, 2021) BSCW and Lower Laguna Madre Watershed (LLMW) contribute approximately 25 percent of the freshwater flow that drains into the Lower Laguna Madre Bay. Figure 4 shows the stream network at BSCW.

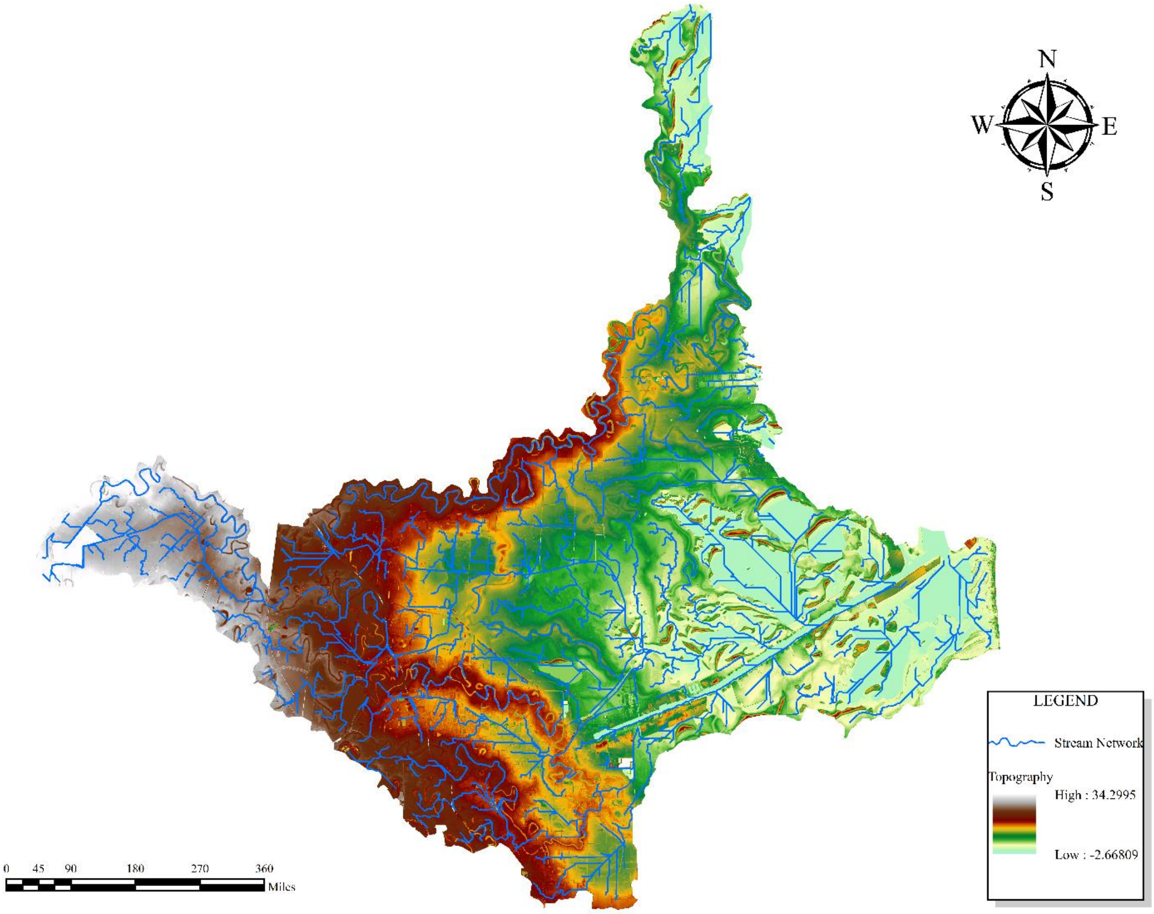


Figure 4. Topography data from LiDAR dataset and stream network created using GIS software.

Land Cover

Dataset obtained from (USGS, 2021), contains land cover information from 2019 for South Texas, this is the most recent dataset to be published, previous version is from 2016. Land Cover was utilized for modeling purposes, more details can be found in following chapters. According to Land Use dataset, BSCW is mainly compound by Emergent Herbaceous Wetlands (21.59%), Cultivated Crops (18.48%), Human settlements (18.04%), and Open Water (14.29%). A full description of Land Use categories at BSCW as well as their coverage percentage is shown at Table 1.

Table 1. Land Use percentages within BSCW

Land Use Category	BSCW (%)
Open Water	14.29
Developed, Open Space	4.24
Developed, Low Intensity	5.84
Developed, Medium Intensity	5.84
Developed, High Intensity	2.12
Barren Land (Rock/Sand/Clay)	4.77
Deciduous Forest	0.90
Evergreen Forest	0.19
Mixed Forest	0.96
Shrub/Scrub	9.38
Grassland/Herbaceous	6.18
Pasture/Hay	1.85
Cultivated Crops	18.48
Woody Wetlands	3.36
Emergent Herbaceous Wetland	21.59

Main Land Cover category is Emergent Herbaceous Wetlands that play a key role for BSCW as, they are essential for flat topography regions were runoff capacity is limited providing to the ecosystem services such as prevention from sediment, nutrients, harmful bacteria, pesticides, and metals from entering waterways and degrading water quality. Other benefits include groundwater recharge, flood water storage, wildlife habitat, recreational opportunities, among others (EPA, 2020). It was also observed that majority of human settlements are at the Southwest side of the watershed while the East side is where open water and wetlands are. Figure 5 is a map that represents spatial distribution of land use within BSCW.

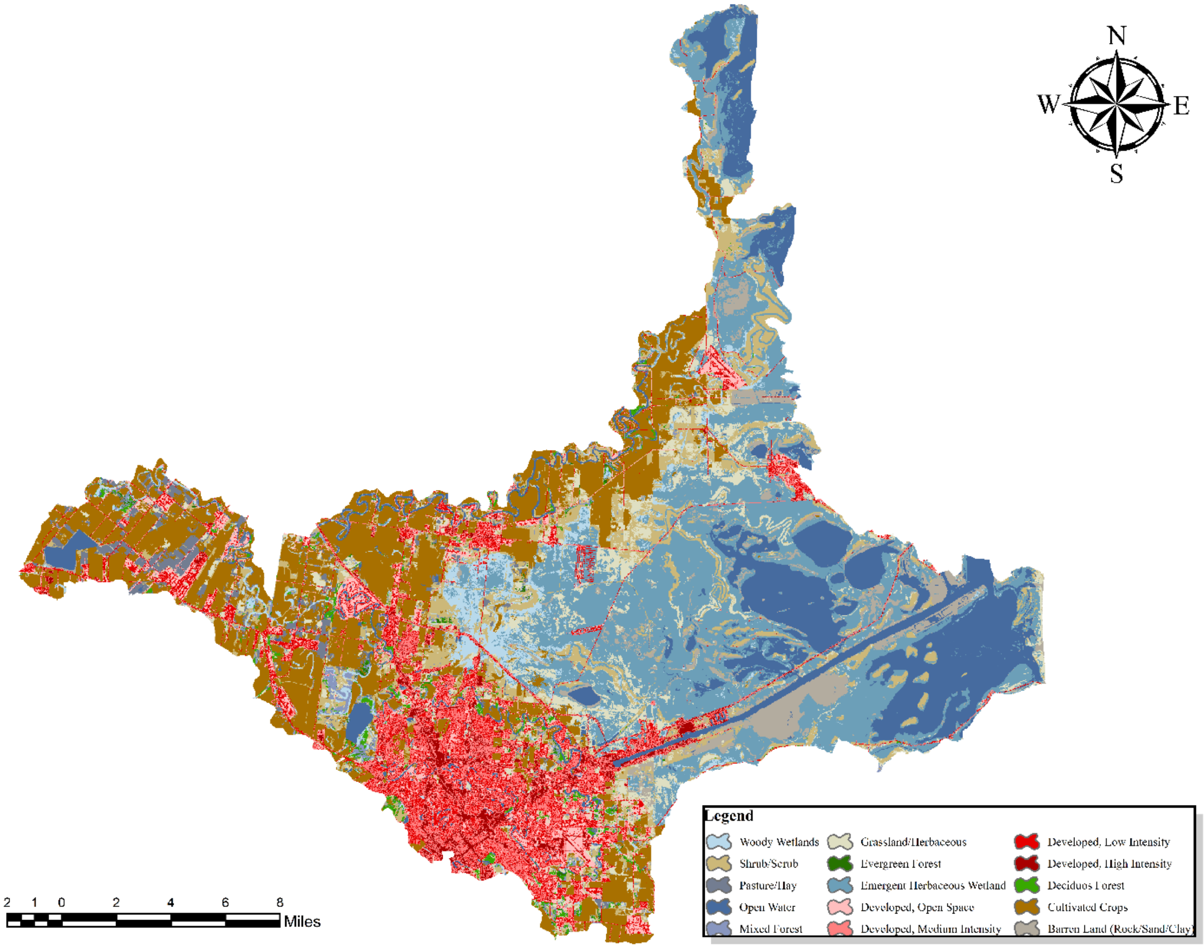


Figure 5. Land Use dataset from 2019 for BSCW.

Population And Economical Activities

According to (Texas Association of Counties, 2019), population at Cameron County, were BSCW is located is of 421,017 habitants. The City of Brownsville is the County Seat and had an approximate population of 186,738. In 2019 the population density at Cameron County was of 329.84 habitants per square mile. By comparing this information with the rest of the counties at Texas, Cameron County is the 13th most populated county and the City of Brownsville the 12th most populated city in Texas.

The BSCW is an important region for South Texas due to the diversity of services offered there. In terms of tourism, South Padre Island (SPI) is a resort community located at south LLMW where most of the businesses are related to the tourist trade-hotels, restaurants, condominiums, and souvenir shops (Texas State Historical Association, 2012). Cameron County also has The Port of Brownsville, the only deep-water port located on the US-Mexico Border that handles a wide variety of cargo including steel products, liquid, break bulk, dry bulk commodities, among others (Port of Brownsville, 2022). The report prepared by (Port of Brownsville & Martin Associates, 2019) indicates that The Port of Brownsville is responsible for more than 51,000 jobs and $3 billion annual state economic activity with more than 8,500 Rio Grande Valley workers employed by activities related to the port.

Existing Water Quality Data

Texas Integrated Report of Surface Water Quality for the Clean Water Act

The Texas Integrated Report of Surface Water Quality for the Clean Water Act is a report issued biannually by the Texas Commission on Environmental Quality (TCEQ) that evaluates the quality of surface waters in Texas based in continuous monitoring and historical data (TCEQ, 2021a). According to (TCEQ, 2011b, 2013b, 2015b, 2018, 2019c), the BSC had been listed as an impairment waterway due to screening levels of bacteria during five consecutive Texas Integrated Reports, from 2010 until 2018, a waterbody is declared as impaired if it does not attain the water quality criteria associated with its designated uses (USEPA, 2008). On the other hand, threatened waters are those that meet standards but exhibit a declining trend in water quality such that they will likely exceed standards in the near future (USEPA, 2008). The BSC fits in this category due to depressed levels of Dissolved Oxygen (DO), the amount of DO found by TCEQ meet their criteria but also showed a tendency to threat water quality and aquatic life soon. Other findings from (TCEQ, 2021a) determined that bacteria concentration decreased at BSC, reason why, for the first time in almost 10 years, BSC was not listed as an impairment waterway in 2020 but a warning was set due to depressed levels of DO.

Table 2. Summary of the last six Texas Integrated Reports from TCEQ, obtained from (TCEQ, 2011b, 2013b, 2015b, 2018, 2019c, 2020c)

Texas Integrated Report	Period of Record	Parameter	Data Assessed	Number of Exceedances	TCEQ Comments
2010	12/1/01-11/30/08	Dissolved Oxygen	69	10	Depressed Dissolved Oxygen[2]
	12/1/01-11/30/08	Enterococcus	61	19	Impaired due to Bacteria
2012	12/01/03-11/30/10	Dissolved Oxygen	75	10	Depressed Dissolved Oxygen[2]
	12/01/03-11/30/10	Enterococcus	50	1	Impaired due to Bacteria
2014	12/01/05-11/30/12	Dissolved Oxygen	77	12	Depressed Dissolved Oxygen[2]
	12/01/05-11/30/12	Enterococcus	30	1	Impaired due to Bacteria
2016	12/01/07-11/30/14	Dissolved Oxygen	78	13	Depressed Dissolved Oxygen[2]
	12/01/07-11/30/14	Enterococcus	9	1	Impaired due to Bacteria
2018	12/01/09-11/30/16	Dissolved Oxygen	81	15	Depressed Dissolved Oxygen[2]
	12/01/09-11/30/16	Enterococcus	N.M.[1]	N.M.[1]	Impaired due to Bacteria
2020	12/01/11-11/30/18	Dissolved Oxygen	104	17	Depressed Dissolved Oxygen in water[2]
	12/01/11-11/30/18	Enterococcus	24	0	Not Impaired

[1] N.M.: Not mentioned.

[2] Depressed Dissolved Oxygen is not a cause of Impairment.

Along with the Texas Integrated Report of Surface Water Quality for the Clean Water Act, TCEQ also publishes another report called Water Body Assessment by Basin that includes a detailed description of data gathered, methods, exceedances, among other information related to the waterbodies within the state (TCEQ, 2021b). Based on their last seven reports (TCEQ, 2011a, 2013a, 2015a, 2019a, 2019b, 2020b), depressed levels of DO had been detected since 2010. A summary with data gathered by TCEQ was built in Table 2, with a detailed description of data gathered, periods of data collection, data assessed, data exceedances, and TCEQ comments.

Watershed Characterization Report

A watershed characterization is an activity that involves the gathering of information describing the bio-physical and socio-economic condition of a watershed to determine issues, vulnerability, and opportunities for development interventions in order to understand and control over the various biological and physical, and socio-economic processes in the watershed (Department of Environment and Natural Resources, 2016). A watershed characterization report was developed by (UTRGV et al., 2018) as a first attempt to assess the current situation at LLMW and BSCW. Main outcomes from this study are described in the following three sections.

Watershed delineation. LLM and BSC watersheds were delineated using LiDAR topographic data, local knowledge from the area, National Hydrography Dataset Plus Version 2 flowlines (NHD Plus v2), among others. Results obtained from this procedure divided BSCW into 14 new sub-watersheds from where LLM Sub-basin at the north side of the BSCW watershed drains into LLM Bay while the other 13 sub-watersheds drain into BSC. Figure 6 shows the results obtained in this delineation process conducted using GIS software.

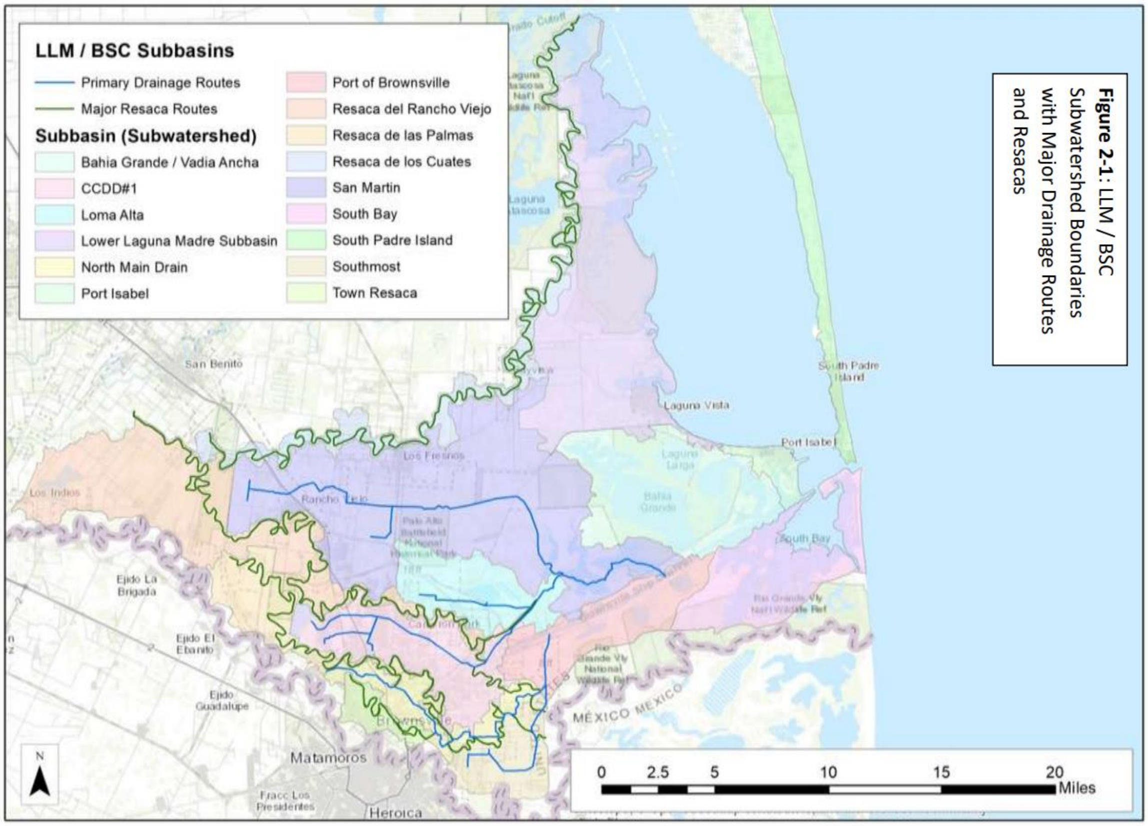
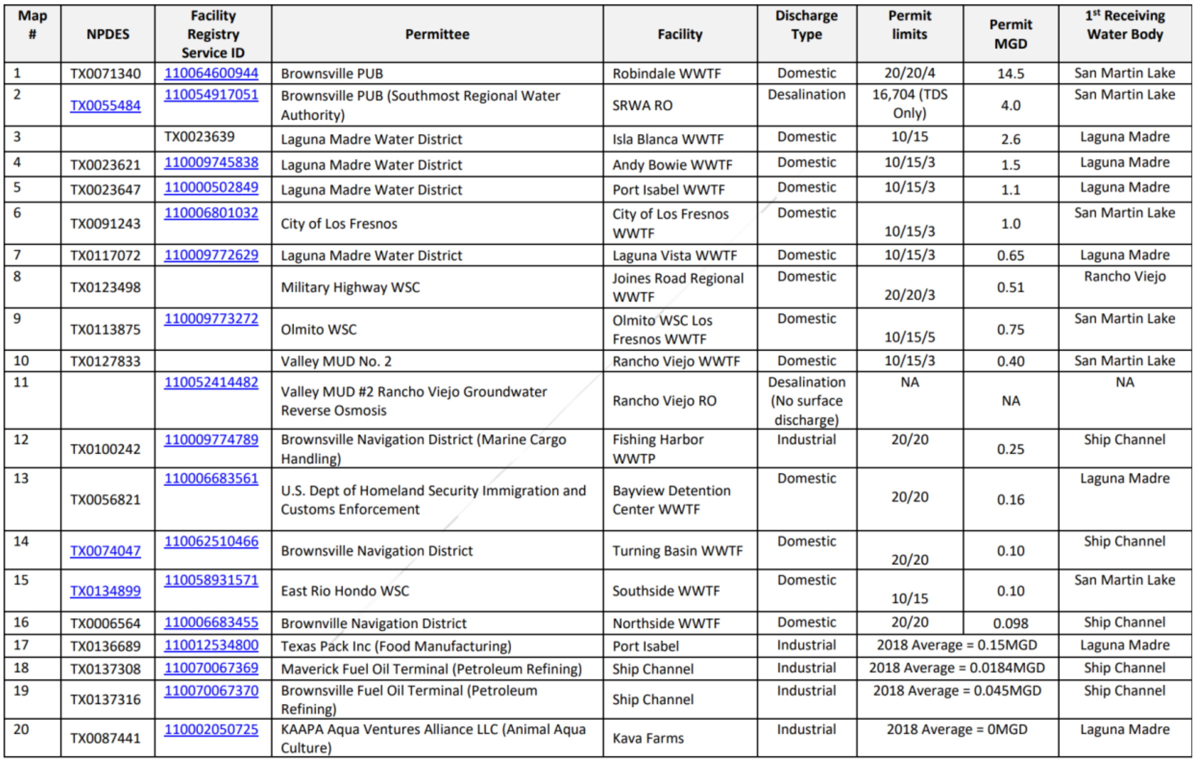


Figure 6. Watershed delineation results from Watershed Characterization Report. In total 14 new sub-basins were found. Source: (UTRGV et al., 2018).

Identification of Point Sources (PS). In this section a search was conducted to address regulated potential point sources of pollution such as, wastewater treatment facility (WWTF) outlets and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities. Twenty permitted domestic, industrial, and desalination wastewater facilities were identified at BSCW and LLMW. Table 3 presents main information of the PS found: name, discharge type, permitted million gallons per day (MGD) discharged, among others. Figure 7 is a spatial representation of the PS within BSCW and LLMW.

Table 3. Permitted domestic, industrial, and desalination wastewater facilities within Cameron County along with their information. Source: (UTRGV et al., 2018).



Map #	NPDES	Facility Registry Service ID	Permittee	Facility	Discharge Type	Permit limits	Permit MGD	1st Receiving Water Body
1	TX0071340	110064600944	Brownsville PUB	Robindale WWTF	Domestic	20/20/4	14.5	San Martin Lake
2	TX0055484	110054917051	Brownsville PUB (Southmost Regional Water Authority)	SRWA RO	Desalination	16,704 (TDS Only)	4.0	San Martin Lake
3		TX0023639	Laguna Madre Water District	Isla Blanca WWTF	Domestic	10/15	2.6	Laguna Madre
4	TX0023621	110009745838	Laguna Madre Water District	Andy Bowie WWTF	Domestic	10/15/3	1.5	Laguna Madre
5	TX0023647	110000502849	Laguna Madre Water District	Port Isabel WWTF	Domestic	10/15/3	1.1	Laguna Madre
6	TX0091243	110006801032	City of Los Fresnos	City of Los Fresnos WWTF	Domestic	10/15/3	1.0	San Martin Lake
7	TX0117072	110009772629	Laguna Madre Water District	Laguna Vista WWTF	Domestic	10/15/3	0.65	Laguna Madre
8	TX0123498		Military Highway WSC	Joines Road Regional WWTF	Domestic	20/20/3	0.51	Rancho Viejo
9	TX0113875	110009773272	Olmito WSC	Olmito WSC Los Fresnos WWTF	Domestic	10/15/5	0.75	San Martin Lake
10	TX0127833		Valley MUD No. 2	Rancho Viejo WWTF	Domestic	10/15/3	0.40	San Martin Lake
11		110052414482	Valley MUD #2 Rancho Viejo Groundwater Reverse Osmosis	Rancho Viejo RO	Desalination (No surface discharge)	NA	NA	NA
12	TX0100242	110009774789	Brownsville Navigation District (Marine Cargo Handling)	Fishing Harbor WWTP	Industrial	20/20	0.25	Ship Channel
13	TX0056821	110006683561	U.S. Dept of Homeland Security Immigration and Customs Enforcement	Bayview Detention Center WWTF	Domestic	20/20	0.16	Laguna Madre
14	TX0074047	110062510466	Brownsville Navigation District	Turning Basin WWTF	Domestic	20/20	0.10	Ship Channel
15	TX0134899	110058931571	East Rio Hondo WSC	Southside WWTF	Domestic	10/15	0.10	San Martin Lake
16	TX0006564	110006683455	Brownville Navigation District	Northside WWTF	Domestic	20/20	0.098	Ship Channel
17	TX0136689	110012534800	Texas Pack Inc (Food Manufacturing)	Port Isabel	Industrial	2018 Average = 0.15MGD		Laguna Madre
18	TX0137308	110070067369	Maverick Fuel Oil Terminal (Petroleum Refining)	Ship Channel	Industrial	2018 Average = 0.0184MGD		Ship Channel
19	TX0137316	110070067370	Brownsville Fuel Oil Terminal (Petroleum Refining)	Ship Channel	Industrial	2018 Average = 0.045MGD		Ship Channel
20	TX0087441	110002050725	KAAPA Aqua Ventures Alliance LLC (Animal Aqua Culture)	Kava Farms	Industrial	2018 Average = 0MGD		Laguna Madre

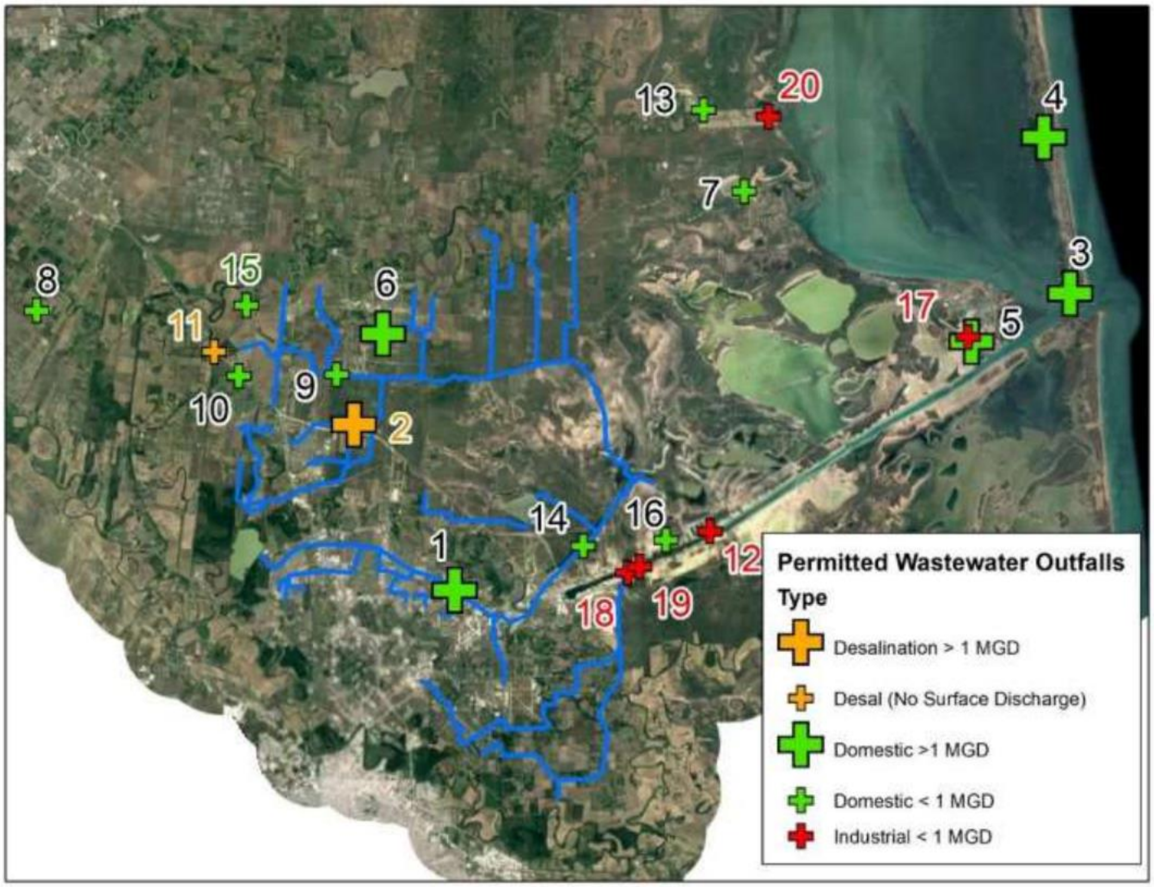


Figure 7. Wastewater treatment facilities and their permitted discharge in MGD within LLMW and BSCW. Source: (UTRGV et al., 2018).

Water Quality. Bi-monthly water quality monitoring was conducted by (UTRGV et al., 2018) at 5 locations, 3 of them along the BSC and the other 2 in the LLM area, the sampling locations are shown in Figure 8 . The study took place from November 2016 to August 2018. The primary focus of the study was to determine bacteria and nutrient concentrations along with conductivity, temperature, pH and DO levels. Findings from this study reveal that the BSC had no bacteria concentration exceedances, under same situation is Total Kjeldahl Nitrogen (TKN). In terms of Nitrate-Nitrite (NO_2+NO_3), between 1 and 4 exceedances were observed at each sampling location however, mean values reveal no screening level at any location. Finally, Total

Phosphorus (TP) observations revealed exceedances at one of the sampling sites at BSC and another one at South Bay site.

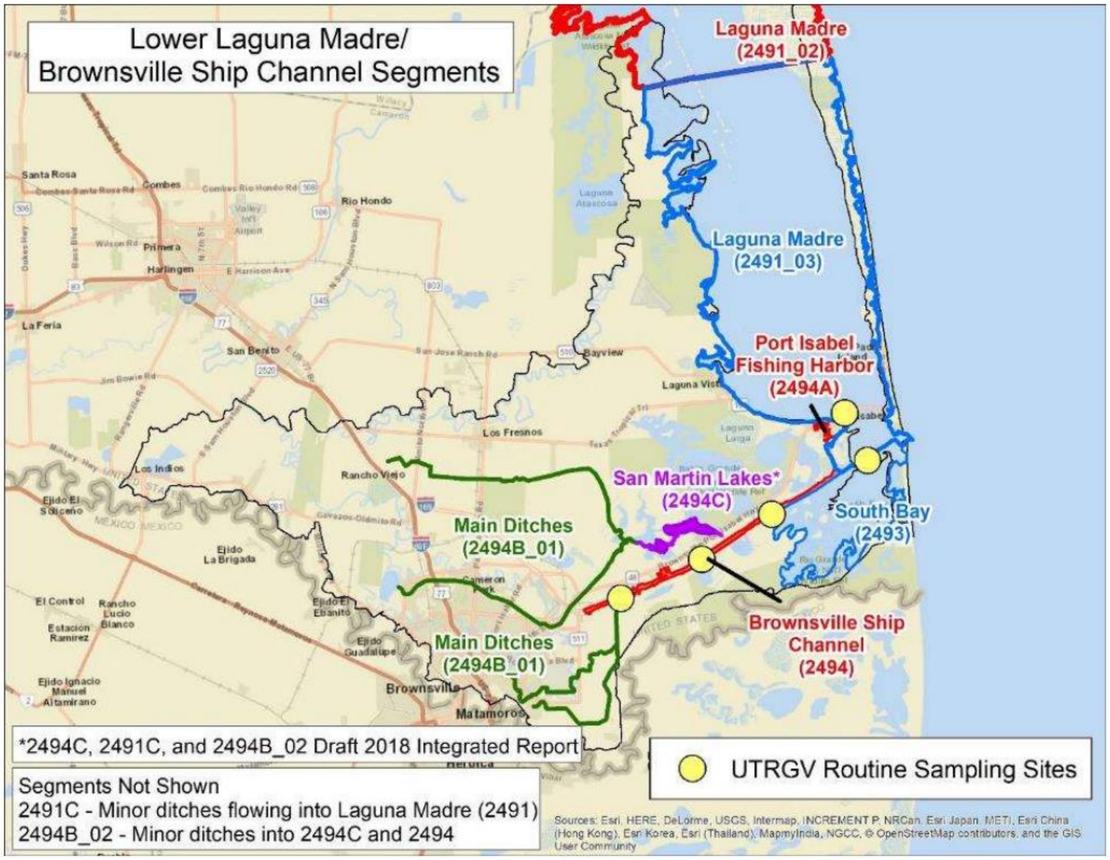


Figure 8. Sampling locations. Source: (UTRGV et al., 2018).

Real-Time Hydrological Stations (RTHS)

Three monitoring stations managed by the River and Estuary Observation Network (REON) were installed last February 2020 with the objective of monitoring water depths and other environmental factors at the three main tributary ditches draining into the BSC in real-time (Ernest, 2019). A new measurement is recorded and uploaded every five minutes to their website where data can be downloaded as a CSV file. As this study started at the same month that the stations were installed, all historical data was downloaded and processed to summarize monthly measurements and maximum heights observed. Findings from this analysis demonstrate that July and October were the months with the greatest average water height observed during the two years of analysis. While the months with lower water heights were December, January, and February. The following three figures show results obtained from RTHS stations.

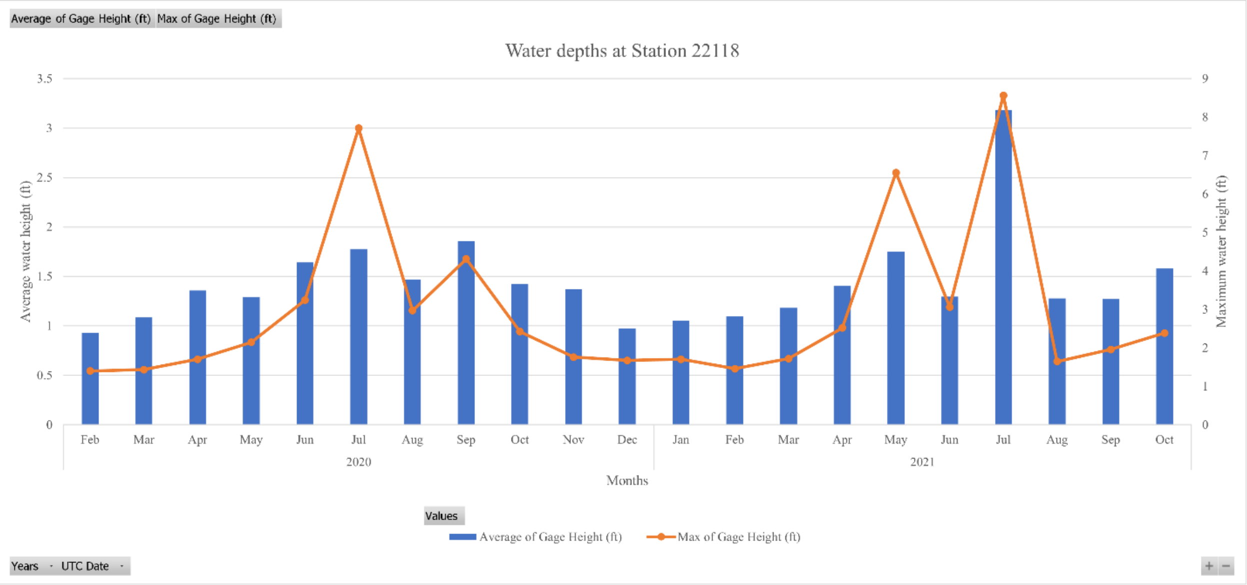


Figure 9. Historical data recorded from February 2020 to October 2021 by Station 22118 at City of Los Fresnos. In blue, average height observed each month. Orange dots are the maximum depths observed each month. Source: (REON, 2022c).

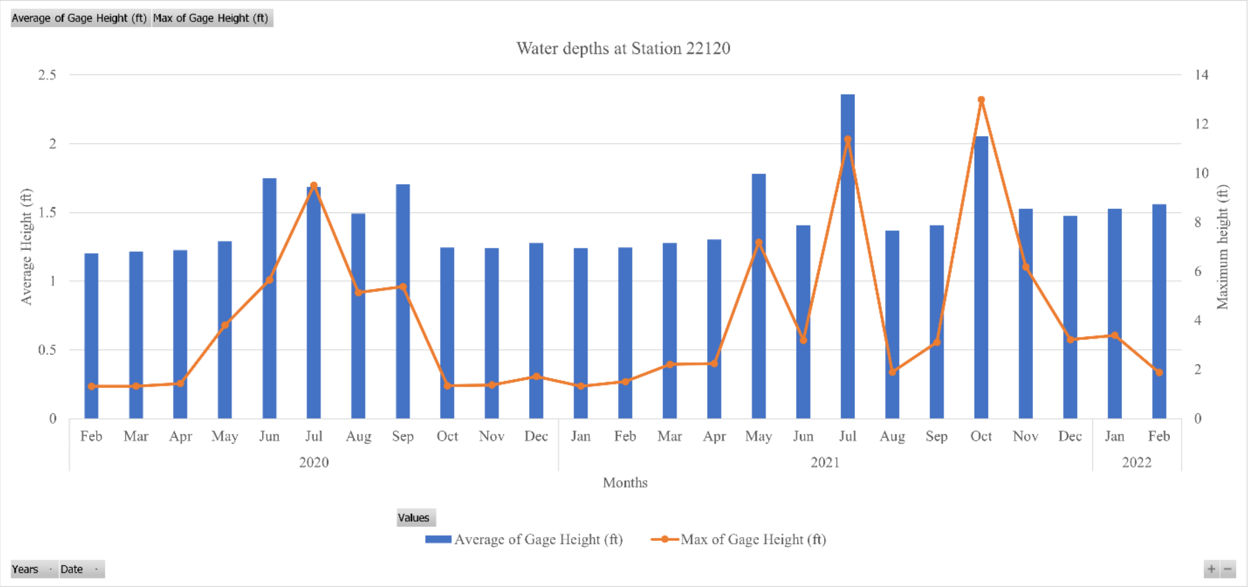


Figure 10. Historical data recorded from February 2020 to February 2020 by Station 22120 at Brownsville Public Works. In blue, average height observed each month. Orange dots are the maximum depths observed each month. Source: (REON, 2022b).

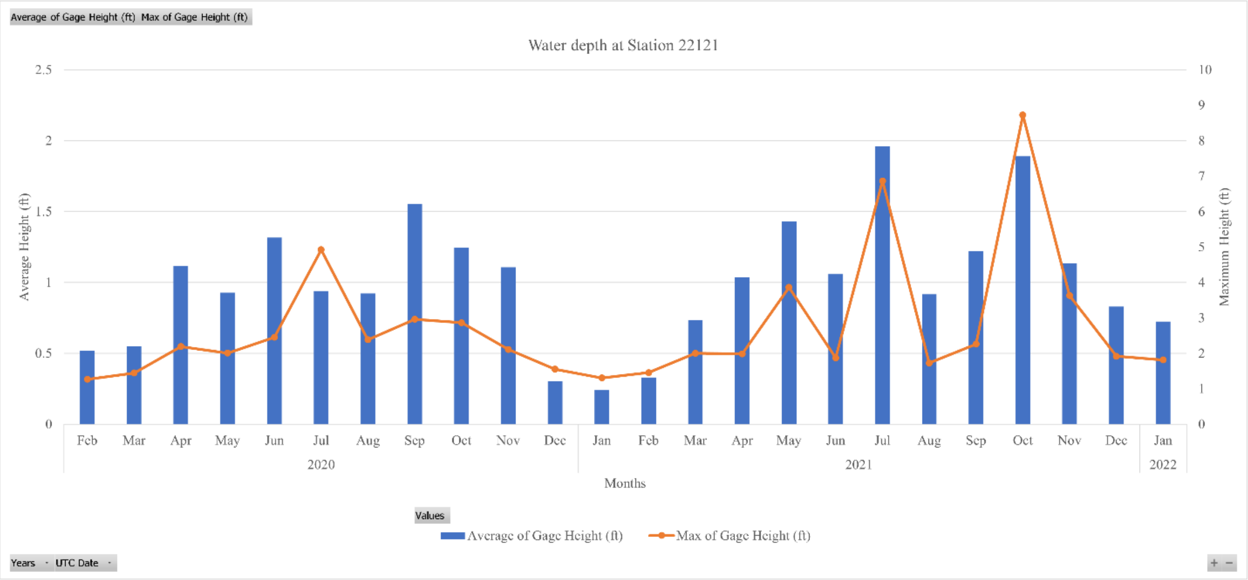


Figure 11. Historical data recorded from February 2020 to January 2021 by Station 22121 at Brownsville Landfill. In blue, average height observed each month. Orange dots are the maximum depths observed each month. Source: (REON, 2022a).

Direct Data Collection

Sampling Locations

In 2014 a watershed group of stakeholders was formed to address water quality in the BSC, in order to do it they selected three sites to measure water quality, flow conditions, and bacteria along with nutrients concentration at Ditch No. 1, Ditch No. 2, and Old Main Drain Ditch (UTRGV et al., 2021). Another decision made by the stakeholder group was to install Real-Time Hydrological System (RTHS) monitoring stations capable to measure water depths at each monitoring site to report data in real-time. Once installed, each station obtained a unique ID that was considered in this project to identify each stie where sampling took place. A detailed overview of the selected sites is shown in the following table.

Table 4. Detailed description of the three sites selected to measure water quality, flow conditions and bacteria and nutrients concentration

Station ID	Station Name	Ditch Measured	Longitude	Latitude	Description
22118	Los Fresnos	Ditch No. 2	26.0492	-97.39806	CCDD1 Ditch No. 2 at the intersection with Old Port Isabel Rd. downstream of Bayview East lateral.
22120	Brownsville Public Works	CCDD1 Ditch No. 1	25.942606	-97.43583	Ditch No. 1 at the Brownsville Public Works Offices
22121	Brownsville Landfill	CCDD Old Main Drain	25.936517	-97.37833	Old Main Drain at the Brownsville Landfill

Field Crew Members

Sites sampled in this study required a minimum of three people to coordinate field activities such as calibration, equipment installation, quality assurance, among others described at methodology section.

Sampling Frequency

Sampling campaigns should had been conducted quarterly to obtain a total of eight events from February 2020 until November 2021 according to the stablished by (UTRGV et al., 2021). Even though, the quantity of samples was reached, limitations explained during the next section impacted the frequency of data collection. The next table shows the dates when samples were collected.

Table 5. Sampling campaigns conducted for this study

Sampling campaign	Station ID	Date & Time (CST)
1st	22118	2/12/20 10:33
	22120	2/11/20 12:33
	22121	2/12/20 12:00
2nd	22118	9/28/20 14:22
	22120	9/28/20 13:46
	22121	9/29/20 11:39
3rd	22118	3/2/2021 10:23
	22120	3/2/2021 13:10
	22121	3/3/2021 10:43
4th	22118	4/13/2021 12:58
	22120	4/13/2021 16:19
	22121	4/14/2021 12:23
5th	22118	6/16/21 11:25
	22120	5/25/2021 13:34
	22121	5/27/2021 13:57
6th	22118	6/29/21 11:00
	22120	6/29/21 13:20
	22121	8/18/21 11:54
7th	22118	9/28/21 12:04
	22120	9/29/21 13:41
	22121	10/5/21 12:20
8th	22118	- [a]
	22120	11/16/2021 13:35
	22121	11/16/2021 11:39

[2] The 8th sampling campaign at station 22118 could not be performed due to lack of access to the monitoring site.

Limitations of direct data collection

Road Conditions. The main reason to cancel or delay data collection was the road conditions to access station 22118 at Los Fresnos City and station 22121 at Brownsville Landfill, both of them are farm roads with almost null traffic where rainfall flooded the road, making impossible to cross it, an example of road conditions after the rain is observed in Figure 12. In order to pass through these roads, the rental of a 4x4 truck was implemented to increase the probability to access to both stations without getting stuck. Even though this decision allowed to access to station 22121, the effort was not enough to access station 22118 as more than 1.4 miles of unpaved road resulted impossible to cross leading us to wait until the road got drier, which usually took between one and two months.

Figure 12. Old Port Isabel Rd after the rain, around 1.4 miles of unpaved road and unique access to station to 22118.

COVID-19. First sampling campaign was conducted one month before the lockdown imposed by the US government in March 2020, after that, and due to high health risk, only one more sampling campaign was executed seven months later in September. The last attempt to collect water samples at station 22118 for the 8th campaign was cancelled due to field crew members infected with COVID-19.

Equipment

Table 6, 7, and 8 list the equipment and tools required to accomplish the three main objectives of direct data collection: measure water quality, flow conditions, and bacteriological along with nutrient concentration. Heavy equipment: YSI EXO2 sonde and Acoustic Doppler Current Profiler (ADCP) were borrowed to UTRGV by Research Applied Technology Education Services, Inc (RATES) to collect data in situ, the rest of the equipment was purchased by UTRGV thanks to the grant awarded from TCEQ to develop this research project.

Table 6. List of equipment, calibration standards, and tools required to measure water quality.

Equipment for water quality sampling
YSI EXO2 Multiparameter Water Quality Sonde
YSI handheld multiprobe for field parameters measurements
Calibration standards (pH 4, pH 7, pH 10, and Conductivity 10,000)*
Distilled water*
Tap water*
Bucket*
Latex gloves
Hip and chest waders
Field logbook and indelible, waterproof ink pens*
Digital Camera*
4 extra D batteries

*Equipment needed to perform calibration that are not required while in the field.

Table 7. List of necessary equipment to measure flow.

Equipment for flow condition measurement
Fully charged laptop
WinRiver II software installed
Acoustic Doppler Current Profiler (ADCP)
Ropes
Extendable pole
8 extra AAA batteries
Hip and chest waders

Table 8. List of equipment and tools utilized to collect water samples to be analyzed for bacteria and nutrient concentration.

Equipment for bacteria and nutrient concentration
Plastic and glass containers of adequate volume size for water chemistry analytes provided by Ana-Lab
EXX sample-collection bottles – 290 ml. (Sterile sample bottles will be provided by Ana-Lab following NELAP requirements.)
Chain of custody forms (provided by Ana-Lab)
Latex gloves
Waterproof pen or markers
Ice chest with ice
Pole with plastic bottle to collect samples

Safety recommendations

Field personnel routinely come in direct and indirect contact with waterborne pathogens, chemicals, and potentially hazardous plants and animals, fieldwork requires an awareness of potential hazards and knowledge of basic safety procedures (TCEQ, 2012). For that reason, sampling campaigns followed safety recommendations provided in the Surface Water Quality Monitoring Procedures by (TCEQ, 2012), and Domestical Travel recommendations provided by (UTRGV, 2021) to minimize the risk of COVID-19 spreading.

Table 9. Safety recommendations provided by (TCEQ, 2012) and (UTRGV, 2021), followed by this study.

Safety equipment
Safety clothes : boots, hat, jeans, and long sleeve shirts
Carry a cell phone or other communication devices
Be aware of changing weather conditions and the potential consequences
Carry a first aid kit
Remain hydrated
Safety clothes: boots, hat, jeans, and long sleeve shirts
Use of gloves
Maintain social distance
Use of face mask and hand sanitizer

Inventory

First task to complete before scheduling a sampling campaign was to revise the inventory developed using productivity software called Notion, where status and remainders in regard to replacement and reparations of the equipment were described.

Transportation

Due to the large amount of equipment needed to sample and the long distance to reach the sampling sites, a truck was rented however, during rainy season the possibility of getting stuck in the road increased leading to delays in sampling campaigns. For this reason, the rental of 4x4 trucks was implemented to access even when road conditions were not favorable. Planning for sampling usually started by contacting the UTRGV travel department to request the rental of the transportation vehicle at least two weeks before going to the field since the rental company had a reduced availability of this type of trucks in the Edinburg/McAllen area.

Water Quality Measurement

Main findings from water quality measurement include pH, Conductivity, Dissolved Oxygen, Total Suspended Solids, and Water Temperature. The procedures to gather this data are described in the following sections.

YSI EXO2 Multiparameter Water Quality Sonde calibration. The YSI EXO2 Sonde is a multiparameter sonde for continuous water quality monitoring with six ports that measure water quality (YSI, 2022). Three of the six ports measure valuable parameters for this study such as pH, conductivity, and dissolved oxygen (DO). In order to ensure quality of the data measured in the field, the three sensors have to be calibrated in a maximum time frame of 24 hours before sampling to ensure that that EXO2 sensors are working correctly, increasing the fidelity of data recorded in the field. The procedures to calibrate the sonde are described during the next six sections and are based on the manual provided by the fabricant, (Xylem, 2020). Figure 8 presents the YSI sonde.

Figure 13. YSI EXO 2 sonde along with the handheld that stores data and their hard case.

Cleaning sensors. The cup that covers the sensor was dismounted to pour distilled water then, the cup was reinserted to rinse the sensors with distilled water, a small shake movement to the sonde allows to clean any residual in the sensors. Figure 14 shows the sensors contained in the sonde.

Figure 14. Sensors contained in the YSI EXO2 Sonde and the automatic wiper at the top

pH calibration. consists of comparing the output of the sensor against the value of a calibration standard of known accuracy (Morris & Langari, 2012). A three-point calibration was conducted using pH 4, 7, and 10, to evaluate the accuracy of the YSI Sonde sensors, increasing the accuracy of measurements out in the field. The process consisted of pouring the desired pH standard in the cup of the sonde, rinse the sensors with the calibration standard and finally, record the measurement using the KorEXO software. Once a calibration point is completed, the sensors have to be cleaned following the instructions described in previous section. pH standards expire after two years of being purchased or one year later after unsealed according to (Gaines, 2022), the vendor. Figure 15 shows all the calibration standards utilized to conduct calibration of pH, conductivity and DO.

Figure 15. Calibration standards: pH 7, pH 4, pH 10 (two 10L bottles), conductivity 10,000 uS/cm, and distilled water (from right to left).

Conductivity calibration. The YSI Sonde has a conductivity sensor that needs to be calibrated before using it, the procedure followed to calibrate is the same as the pH except that a conductivity standard needs to be poured in the sonde's cup. The objective is to reach a value of 10,000 uS/cm to accept the calibration as good, other values might suggest that calibration was not conducted properly or that the sensor needs to be replaced, maintenance of the sonde is described in following sections. Figure 16 shows a bottle of 1 liter of 10,000 uS/cm conductivity standard from Aqua Solutions vendor, this .

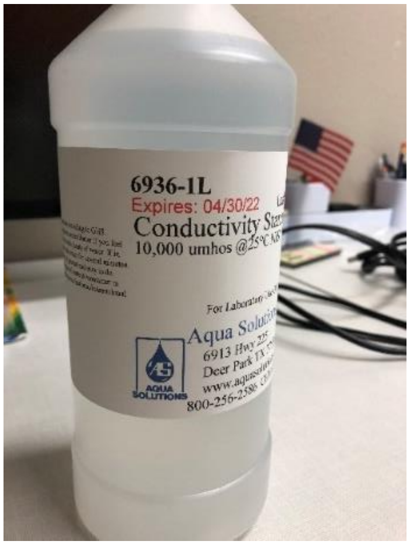


Figure 16. Conductivity standard of 10,000 uS/cm in a bottle of 1L.

DO calibration. Last sensor to calibrate before sampling in situ is the one for DO, the procedure was different to the one for pH and conductivity. The first step is to pour about one inch of tap water in the cup of the sonde making sure that the water did not touch the water then, place the sonde into the cup, seal it and finally, wait 10 minutes to record the calibration measurement using KorEXO software.

YSI EXO2 Sonde installation. Once in the field, the YSI EXO2 sonde was installed in the water to measure water quality. As shown in Figure 17 the sonde was secured using the staff gage installed at each sampling site and a rope, making sure that sensors were in contact with the water without immersing the entire sonde in the water to avoid water infiltrating into the batteries slot.

Figure 17. YSI EXO2 Sonde installed at station 22118.

Recording Water Quality Data. Once the sonde is correctly placed, two options are available to record data; stablish a Bluetooth connection between the sonde and a laptop using KorEXO software or connect the sonde using a cable to the Handheld as shown in Figure 18. During the first year, data was collected using the cable however, it stopped working and data was recorded directly to a laptop.

Figure 18. Handheld connected to YSI EXO2 sonde to store water quality data from Old Main Drain Ditch.

Discharge Measurement

The Acoustic Doppler Current Profiler (ADCP), shown in Figure 19, is a Teledyne instrument that had a transducer that allowed to measure flow and define the cross section of the waterways were the instrument is utilized. In order to store and process data a laptop with WinRiver II software is required.

Figure 19. Acoustic Doppler Current Profiler (ADCP).

ADCP Compass Calibration. The ADCP had integrated a compass that allows it to measure the transect direction, and the profiler course, this compass was calibrated once in the field and before placing the ADCP into the water. The process consisted of connecting the ADCP to the laptop via Bluetooth and follow the steps provided by WinRiver II software, it mainly consists of slowly rotating the ADCP on its own center to calibrate the compass, avoiding metals and other magnet objects that might affect the reading of the compass. For quality control, the maximum allowable error in the compass calibration cannot exceed 2°.

Measuring Discharge. With the compass calibrated, the ADCP was ready to measure discharge. Typically, the ADCP was attached to a pole with an extension that allowed to reach the other side of the stream as observed in Figure 20. Most of the times, a field member crew had to go inside of the water to reach the other side of the stream easily, for this task the use of a pair of waders was required to avoid getting in contact with the water.

Figure 20. Discharge measurement using the ADCP.

Water Depths Measurement

This task consisted of reporting the water depth observed from the staff gage while sampling. A staff gage as the one shown in Figure 21 was installed at each sampling site along with the RTHS monitoring stations described in previous sections.

Figure 21. Staff gage installed at Station 22120.

Nutrients and Bacteriological Concentration Measurement

Ana-Lab, a certified laboratory at Brownsville, TX, analyzed the samples collected in this study to determine their concentration of E. Coli, Total Phosphorus (TP), Nitrate-Nitrite (NO_2+NO_3) and Total Kjeldahl Nitrogen (TKN). Samples were collected using the sampling pole shown in Figure 22, the container had to be submerged three times into the water to rinse it, on the third time, the water collected was poured into the sterile collection bottles provided by Ana-Lab then, sampling details such as collection time, and site of collection were written with a permanent marker using the labels on each container. Finally, samples were preserved in an ice chest to remain fresh at a temperature not lower than 6°C. Samples were grabbed between 12:00 PM and 16:00 PM to accomplish the holding time restriction of 24 hours for E. Coli. In terms of nutrients, concentration results were reported in $\frac{\mathrm{mg}}{\mathrm{L}}$ while bacteria concentrations were reported as MPN that stands for most probable number, a statistical estimate of the number of bacteria present in the sample (Cho et al., 2010). Another common fecal indicator of bacteria is colony-forming unit (CFU), for purposes of this study, CFU and MPN indicators were assumed as equals as (Beckley et al., 2014).

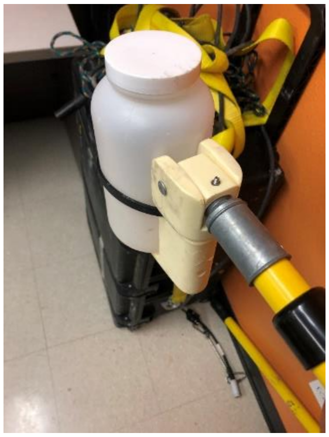


Figure 22. Plastic container utilized to grab water samples at the field.

The following table shows main characteristics of the containers utilized to collect water samples. Figure 23 shows the 250 mL plastic container provided by Ana-Lab to analyze them for bacteriological concentration.

Table 10. Measurements to collect Bacteriological and Nutrients concentration samples.

Parameter	Container	Preservation	Volume	Holding Time
E. Coli	Sterile container (provided by Ana-Lab)	Ice (cool to <6°C but not frozen)	250 mL	24 hours*
Total Phosphorus	Plastic	Ice (cool to <6°C but not frozen)	250 mL	28 days
Nitrate/Nitrite-Nitrogen	Plastic	Ice (cool to <6°C but not frozen)	150 mL	28 days
Total Kjeldahl Nitrogen	Plastic	Ice (cool to <6°C but not frozen)	100 mL	28 days

*Holding time could be extended up to 30 hours if the laboratory faced a delay in their chain of transportation process.

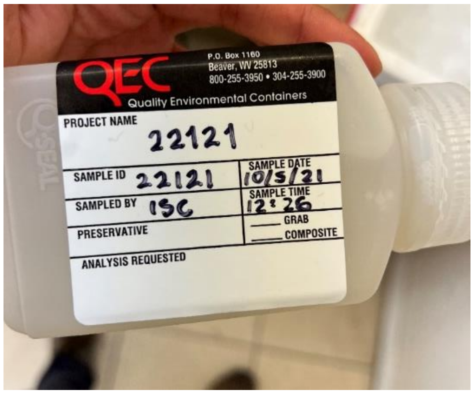


Figure 23. Sterile plastic container with a capacity of 250 ml provided by Ana-Lab to assess bacteria concentration.

Results

Results from the eight sampling campaigns are presented in Table 11, from its column 1 lists the number of sampling campaigns that took place to complete this study. In column 2 are the station IDs and their results in the same row. Column 3 indicates the day when the specific sampling campaign took place along with the time, in Central Standard Time (CST), when water quality sample was collected. Column 4 contains the staff gage height observed while sampling, all heights are in feet. Column 5 lists the average flow measured by the ADCP; flow was expressed in cubic meters per second $\left(\frac{m^3}{s}\right)$. Column 6 shows the average Specific Conductivity (SpC) expressed in microsiemens per centimeter $\left(\frac{uS}{cm}\right)$, values from column 6 to 8 were measured by the YSI EXO2 Sonde, column 7 is the average DO expressed in mg per liter $\left(\frac{mg}{L}\right)$ present in the water while pH, dimensionless, can be found in column 8.

Bacteriological concentration is displayed in column 9, the units utilized are Most Probable Number (MPN) per one hundred milliliters $(\frac{MPN}{100mL})$. Column 10, TKN concentration in $(\frac{mg}{L})$. Column 11, NO_2+NO_3 concentration in $(\frac{mg}{L})$. Column 12, TP concentration in $(\frac{mg}{L})$.

Column 9 to 11 show concentration values reported by Ana-Lab from the analysis conducted to the samples grabbed in this study. Column 9 presents the E. Coli concentration in Most Probable Number (MPN) over milliliters $\left(\frac{MPN}{mL}\right)$, MPN is the most commonly used technique to count E. Coli units (Erkmen, 2022). Column 10 to 12 list the concentration results of nutrients using milligrams per liter, $\left(\frac{mg}{L}\right)$, to express them., column 10 lists TKN concentration, column 11 the NO_2+NO_3 concentration while column 12 the concentration of TP.

All results obtained from the direct data collection were supervised and approved by project managers from UTRGV and the TCEQ.

Table 11. Summary of results obtained during the 8 sampling campaigns conducted from February 2020 to November 2021.

Sampling Campaign	Station ID	Date & Time (CST)	RTHS Gage (ft)	Average Q [m3/s]	SpC [µS/cm]	D.O. [mg/L]	pH	E coli [MPN/ 100mL]	TKN [mg/L]	Total NO_2+NO_3 [mg/L]	Total P [mg/L]
1st	22118	2/12/20 10:33	0.86	0.89	12128.00	7.72	8.20	1119.90	0.67	12	2.88
	22120	2/11/20 12:33	1.08	0.25	6808.00	5.68	7.50	648.80	2.19	5.82	1.8
	22121	2/12/20 12:00	0.21	0.16	6026.00	8.22	8.00	980.40	0.64	1.11	0.124
2nd	22118	9/28/20 14:22	1.67	0.36	15088.30	16.49	8.35	1046.20	1.66	<0.68	0.851
	22120	9/28/20 13:46	1.24	0.30	5637.29	9.41	7.96	1299.70	0.74	8.14	2.16
	22121	9/29/20 11:39	1.96	0.23	2235.84	7.44	8.06	>2419.60	1.05	<0.68	0.292
3rd	22118	3/2/2021 10:23	0.65	0.269	11522.1	7.265	8.33	547.5	1.62	1.43	1.16
	22120	3/2/2021 13:10	0.96	0.41	7253.00	13.57	8.52	1986.3	1.03	6.39	1.94
	22121	3/3/2021 10:43	1.1	0.13	6151.70	7.06	7.99	>2419.6	2.02	2.34	0.144
4th	22118	4/13/2021 12:58	0.9	0.1500	11521.91	8.74	8.40	727	1.6	0.77	0.844
	22120	4/13/2021 16:19	0.95	0.3096	3819.06	13.55	8.17	816.4	0.783	7.58	3.66
	22121	4/14/2021 12:23	1.3	0.55	9551.98	9.36	8.18	>2419.60	1.55	1.26	0.389
5th	22118	6/16/21 11:25	0.7	0.41	19431.14	6.55	8.12	613.1	2.45	7.11	0.805
	22120	5/25/2021 13:34	1.2	0.60	4164.50	8.76	8.45	866.4	1.35	4.43	2.44
	22121	5/27/2021 13:57	1.35	0.4	6802.10	10.12	8.4	1986.3	1.26	0.68	0.295
6th	22118	6/29/21 11:00	0.8	0.35	15156.10	6.35	8.15	1413.6	3.48	0.68	1.01
	22120	6/29/21 13:20	1.00	0.38	5888.40	7.63	7.93	>2419.6	1.45	6.86	2.20
	22121	8/18/21 11:54	1.06	0.41	18506.5	9.82	8.25	>2419.6	2.2	0.68	0.0265
7th	22118	9/28/21 12:04	1.04	0.181	13437.4	9.8	8.40	>2419.60	1.73	<0.68	0.904
	22120	9/29/21 13:41	0.98	0.313	6571.2	8.77	8.17	980.4	0.696	10.4	1.68
	22121	10/5/21 12:20	2.70	2.09	1620.66	7.53	7.87	1732.9	<0.68	0.369	0.123
8th	22118	*	*	*	*	*	*	*	*	*	*
	22120	11/16/2021 13:35	0.48	0.36	6556.40	8.80	7.85	816.4	0.876	7.57	2.86
	22121	11/16/2021 11:39	0.85	0.301	6949.74	9.13	7.89	1299.7	1.68	<0.68	0.196

*Data collection at station 22118 during 8th sampling campaign could not be completed due to road conditions preventing the access to the site.

Conclusions

From results obtained, Old Main Drain Ditch monitored by station 22121 is the waterway with higher flow discharging into BSC with an average of 0.53 $\frac{m^3}{s}$, while Ditch No. 2 monitored by station 22118 and Ditch No. 1 by station 22120 discharged almost the same flow, 0.37 $\frac{m^3}{s}$ and 0.36 $\frac{m^3}{s}$ respectively.

Specific Conductivity average value found at Ditch No. 1 was the greatest, 14,040 $\frac{uS}{cm}$ while values found at the other two monitoring sites were 7230 $\frac{uS}{cm}$ at Old Main Drain Ditch, and 5837 $\frac{uS}{cm}$ at Ditch No. 2.

Average DO values measured at the three monitoring sites did not present a significant difference as they varied in a range between 8.58 to 9.52.

pH values found were mostly uniform at the three sites, ranging between 7.50 and 8.52.

In terms of E. Coli concentration , the highest values found were observed at Old Main Drain Ditch 1871.24 $\frac{MPN}{100mL}$ while the lowest concentration was found at Ditch No. 2 where an average concentration of 996.82 $\frac{MPN}{100mL}$ was found.

TKN concentration at station 22118 was the highest of the three monitoring sites with an average of 1.89 $\frac{mg}{L}$, on the other hand, the smallest average concentration, 1.14 $\frac{mg}{L}$, was observed at station 22120.

Ditch No. 1 showed the highest concentration average of NO_2+NO_3, 7.15 $\frac{mg}{L}$, Ditch No. 2 presented 3.34 $\frac{mg}{L}$ concentration, and Old Main Drain Ditch, the lowest average, 0.97 $\frac{mg}{L}$.

Finally, concentration values of TP found at station 22120, 2.34 $\frac{mg}{L}$, were the highest of the three while the lowest, $\frac{mg}{L}$, was observed at station 22121.

CHAPTER III

DEVELOPMENT OF LOAD DURATION CURVES

Introduction

Load duration curve (LDC) is a technique that consist of graphs that show the percentage of time, or duration interval, for which a given value of pollutant load is equaled or exceeded within a particular waterway, such graphs can be generated using a spreadsheet computer program (Kim et al., 2012). LDCs play a key role not just because of its ease of development and ability to be understood (Cleland, 2003), they are also useful for the development of Total Maximum Daily Loads (TMDLs) that are utilized to guide pollutant reduction efforts needed to bring a waterway into compliance with standards (USEPA, 2007). Data required to build LDCs are flow measurements and concentration values of targeted pollutant, E. Coli, TKN, NO_2+NO_3, and TP for the purposes of this study.

Objective

Utilize water quality data collected from the three main waterways that drain into BSC to calculate daily discharge loads, determine maximum allowable load of nutrients, and develop LDCs that allow to visualize were water quality standards were exceeded in addition to address daily load reductions.

Flow Measurement

Flow refers to the quantity of water passing over a certain amount of time (Donald W. Meals et al., 2013). Flow data utilized to develop LDCs was retrieved from the ADCP while gathering direct data as explained in Chapter II. No flow data from any of the waterways studied had been collected by any other agency or particular entity (UTRGV et al., 2021).

E. Coli Concentration

Escherichia Coli abbreviated as E. Coli, is a type of fecal coliform bacteria that is commonly found in the gastrointestinal tract and feces of warm-blooded animals. Although usually harmless, E. Coli can cause illness such as meningitis, septicemia, urinary tract, and intestinal infections. E. Coli in water is a strong indicator of sewage or animal waste contamination. (U.S. Geological Survey, 2018). E. Coli concentration found in this study was determined by Ana-Lab from the samples collected as explained in Direct Data Collection chapter.

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN), measured by the use of Kjeldahl digestion of a whole-water sample, represents the sum of ammonia, dissolved-organic nitrogen, and particulate nitrogen (David L. Rus et al., 2012). Main sources of TKN in waterways include soil erosion, organic matter and debris, sewage, fertilizers, animal waste, and agricultural runoff, in high quantities, TKN can cause increased plant and algae growth, low dissolved oxygen (DO) levels, and increased water temperature. (Lake Pend Oreille Waterkeeper, 2021). TKN as well as TP and NO_2+NO_3 concentration utilized in this study was determined by Ana-Lab from the samples collected during sampling campaigns.

Total Phosphorus

Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication(USGS, 2018a), an excess of nutrients in the waterbody that leads to excess plant growth, such as, harmful algal blooms, resulting in deficiency of dissolved oxygen, a situation that threats aquatic life (USEPA, 2018). There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns, soil erosion, failing septic systems, runoff from animal manure, drained wetlands, and water treatment (USEPA, 2012).

Nitrite and Nitrate

Nitrite (NO_2) refers to an intermediate product when ammonium is transformed into nitrate (NO_3), this last is the main form of nitrogen (N) in groundwater and surface waters. Most commonly, laboratories test for a combination of nitrite plus nitrate (NO_2+NO_3) as nitrite is usually much higher than nitrite. Some sources of NO_2+NO_3 are agricultural fertilizers, urban runoff, the atmosphere, and human along with animal waste (Wall, 2013). Exceedances of NO_2+NO_3 in surface water provoke undesired threats to human and aquatics' life, for example, causing methemoglobinemia in humans (Minnesota Pollution Control Agency, 2013), a blood disorder that affects the oxygen in the body (NCI, n.d.), or eutrophication in waterways.

Methodology

Daily Load Calculation

Load refers the mass of substance that passes a specified point of a waterway in a specified amount of time. From a mathematically point of view, loads are the product of water discharge and the concentration of a substance in the water (Donald W. Meals et al., 2013). Mathematical procedure to determine bacteriological and nutrients loads differed as they have different units, the following two sections explain the procedures executed to determine daily loads and they are based on (USEPA, 2007, 2008).

Bacteriological daily load calculation. The following mathematical procedure was followed to convert flow and bacteriological concentrations into loads in this study. Data utilized for this example belongs to the results found at station 22118 during the second sampling campaign:

Variables:

Average flow [Q]: 0.362 $\frac{m^3}{s}$

Bacteria concentration [C]: 1,046.20 $\frac{MPN}{100mL}$

Equivalences and other factors:

1 day = 86,400 seg

1000 mL = 1 kg

Water density: 1,000 $\frac{kg}{m^3}$

Equation 1. Load determination:

$$Q_S = [Q] * [C] * [k]$$

Where:

Qs = Load in $\frac{MPN}{day}$

Q = Observed flow in $\frac{m^3}{s}$

C = Bacteria concentration in $\frac{MPN}{100mL}$

k = Equivalent factors

Plugin values in Equation 1:

$$Q_s = \left(0.362\ \frac{m^3}{seg}\right) * \left(1{,}046.20\ \frac{MPN}{100mL}\right) * \left(\frac{86{,}400\ seg}{1\ day}\right) * \left(1000\frac{kg}{m^3}\right) * \left(1000\frac{mL}{1kg}\right)$$

$$Q_s = 3.27E + 13\ \frac{MPN}{day}$$

Results:

A daily load of 3.27E+13 $\frac{MPN}{day}$ of E. Coli was found at station 22118 during the second sampling campaign.

Nutrients load calculation. The following mathematical procedure was followed to convert flow and nutrient concentrations into loads in this study. Data utilized for this example belongs to the results of TP found at station 22118 during the second sampling campaign:

Variables:

Average flow [Q]: 0.362 $\frac{m^3}{s}$

Total phosphorus concentration [C]: 0.851 $\frac{mg}{L}$

Equivalences and other factors:

1 L = 1E+6 mg

86,400 seg = 1 day

Water density: 1,000 $\frac{kg}{m^3}$

Equation 1. Load determination:

$$Q_s = [Q] * [C] * [k]$$

Where:

Qs = Load in $\frac{MPN}{day}$

Q = Observed flow in $\frac{m^3}{s}$

C = Total phosphorus concentration in $\frac{mg}{L}$

k = Equivalent factors

Plugin values in Equation 1:

$$Q_s = \left(0.362\ \frac{m^3}{seg}\right) * \left(0.851\ \frac{mg}{L}\right) * \left(\frac{86{,}400\ seg}{1\ day}\right) * \left(1000\,\frac{kg}{m^3}\right) * \left(\frac{1\ L}{1E + 6\ mg}\right)$$

$$Q_s = 26.62\ \frac{kg}{day}$$

Results:

A daily load of 26.62 $\frac{kg}{day}$ of TP was found at station 22118 during the second sampling campaign.

Numeric Water Quality Targets Calculation

The numeric water quality target represents the greatest amount of pollutant loading that a waterway can receive without violating water quality standards (USEPA, 2007). The methodology to calculate maximum allowable daily loads of pollutants in waterways is similar to the process described in previous section using flow observed at the area of study however, for pollutant concentration, governmental agencies determine the screening levels of concentration that can be found at the waterways without threating the environment. In terms of Texas, TCEQ stablished at (TCEQ, 2020a) the screening level of concentration of the pollutants targeted by this studied. Their values can be observed in Table 12.

Table 12. Maximum admissible concentration of bacteria and nutrients. Source:(TCEQ, 2020a).

Pollutant	Maximum allowable concentration
E. Coli	126 colonies/100ml
Nitrate and Nitrite (NO_2+NO_3)	1.95 mg/L
Total Phosphorus (TP)	0.69 mg/L
Total Kjeldahl Nitrogen (TKN)	0.33 mg/L

Maximum allowable daily load calculation. Mathematical approach to find maximum allowable daily load is similar to the one described in the daily load calculation section. To exemplify the process, flow value observed at station 22118 during the second sampling campaign and bacteriological screening levels previously described were utilized.

Variables:

Average flow [Q]: 0.362 $\frac{m^3}{s}$

Bacteria screening level [C]: 126 $\frac{MPN}{100mL}$

Equivalences and other factors:

1 day = 86,400 seg

1000 mL = 1 kg

Water density: 1,000 $\frac{kg}{m^3}$

Equation 2. Maximum allowable load determination:

$$Q_{allowable} = [Q] * [C] * [k]$$

Where:

$Q_{allowable}$ = Maximum allowable load in $\frac{MPN}{day}$

Q = Observed flow in $\frac{m^3}{s}$

C = Screening level of concentration in $\frac{MPN}{100mL}$

k = Equivalent factors

Plugin values in Equation 2:

$$Q_s = \left(0.362\ \frac{m^3}{seg}\right) * \left(126\ \frac{MPN}{100mL}\right) * \left(\frac{86{,}400\ seg}{1\ day}\right) * \left(1000\,\frac{kg}{m^3}\right) * \left(1000\,\frac{mL}{1kg}\right)$$

$$Q_s = 3.94E + 12\ \frac{MPN}{day}$$

Results:

A maximum allowable load of 3.94E+12 $\frac{MPN}{day}$ of E. Coli was found at station 22118 during the second sampling campaign. Same procedure applied to determine maximum allowable loads at all observations.

The same methodology was followed to obtain maximum allowable loads of the nutrients studied, TKN, NO_2+NO_3 and TP.

Development of Load Duration Curves

Twelve LDCs were created, each of them shows the maximum allowable load along with the loads observed of each pollutant, 4 by station, during the 8 monitoring campaigns. The following sections narrate the methodology followed to build LDCs.

Flow Duration Interval. The first step to develop them was to rank flow observations from higher to lower as in Table 13 following the next reasoning, (rank ÷ [number of data points - 1]). The observed flows are now in a rank that goes from 0% to 100%, observations in a range between 0% and 10% represent high flow conditions, those between 10% and 40% are in moist conditions, between 40% and 60% are mid-range flows, between 60% and 90% are dry conditions, and values in the range between 90% and 100 represent low flow conditions. This classification can be observed in Figure 24.

Table 13. Flow observed at station 22120 ranked from higher to lower

Average Q (m^3/s)	Rank	Percentage
0.60	1	0%
0.41	2	14%
0.38	3	29%
0.36	4	43%
0.31	5	57%
0.31	6	71%
0.30	7	86%
0.25	8	100%

Other studies, (Nevada Division of Environmental Protection, 2003), indicate that the methodology to classify flow consists of ranking flow using the following reasoning, (rank ÷

number of data points) however, due to the low number of samples grabbed in this study, any observation would be lower than 10% meaning that no daily load observations would be present on the high flows rank.

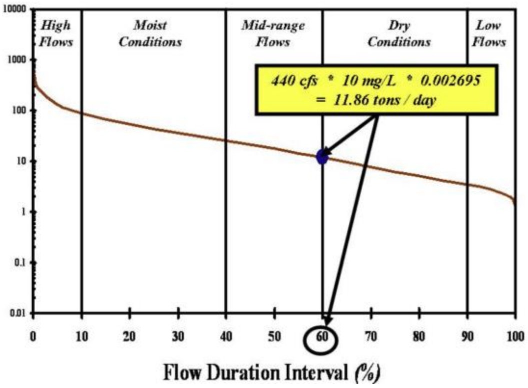


Figure 24. Flow intervals. Source: (USEPA, 2007)

Load Duration Curves. The LDCs were developed using spreadsheet software using flow, daily loads, and maximum allowable loads. Table 14 shows data utilized to develop LDC of bacteria daily loads at station 22120. Column 1 shows lists the flow measured in $\frac{m^3}{s}$, column 2 the rank developed in previous section, column 3 has the E. Coli maximum allowable daily load, and column 4 has the daily load observed during sampling campaigns.

Table 14. Data utilized to develop LDC of bacteria at station 22120.

Average Q [m^3/s]	Percentage	E Coli total maximum allowable daily load (MPN/day)	E coli daily load observed (MPN/day)
0.60	0%	6.53E+12	4.49E+13
0.41	14%	4.49E+12	7.08E+13
0.38	29%	4.12E+12	7.92E+13
0.36	43%	3.91E+12	2.53E+13
0.31	57%	3.40E+12	2.65E+13
0.31	71%	3.37E+12	2.18E+13
0.30	86%	3.24E+12	3.35E+13
0.25	100%	2.73E+12	1.41E+13

Figure 25 is an example of main components of the LDC where, the x-axis reflects the flow duration interval in percentage (0-100%), while the y-axis is for daily loads with daily loads units ($\frac{MPN}{day}$ or $\frac{kg}{day}$). The blue scatter smooth line represented the allowable daily discharge of TP, and the yellow squares indicate the daily load observed during sampling. With the LDCs developed, the frequency and magnitude of the water quality standards and allowable loads are easily presented, making the load duration reduction better understood for stakeholders and decision-making groups (Nevada Division of Environmental Protection, 2003).

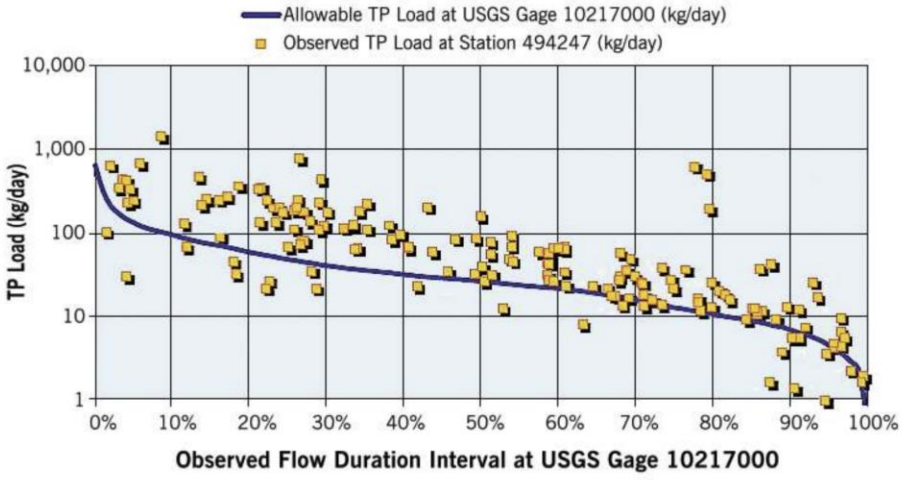


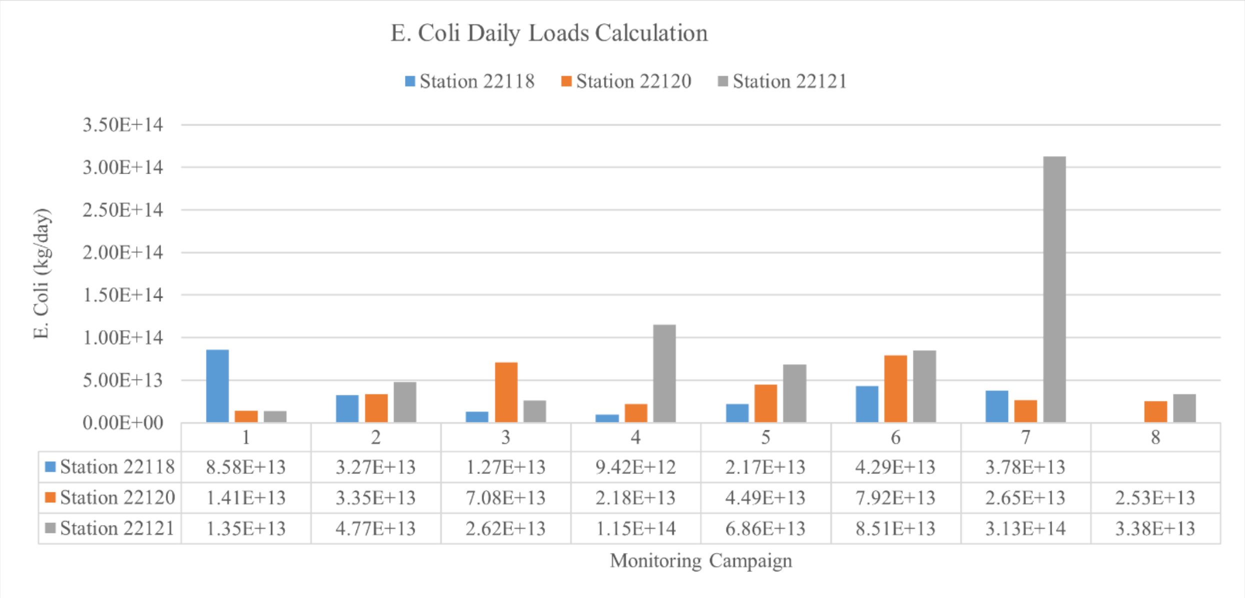
Figure 25. Example of LDC of Total phosphorus. Source: (Donald W. Meals et al., 2013).

Results

Daily Loads Observed

Guided by methodology described at daily load calculation section, the following daily load values were obtained.

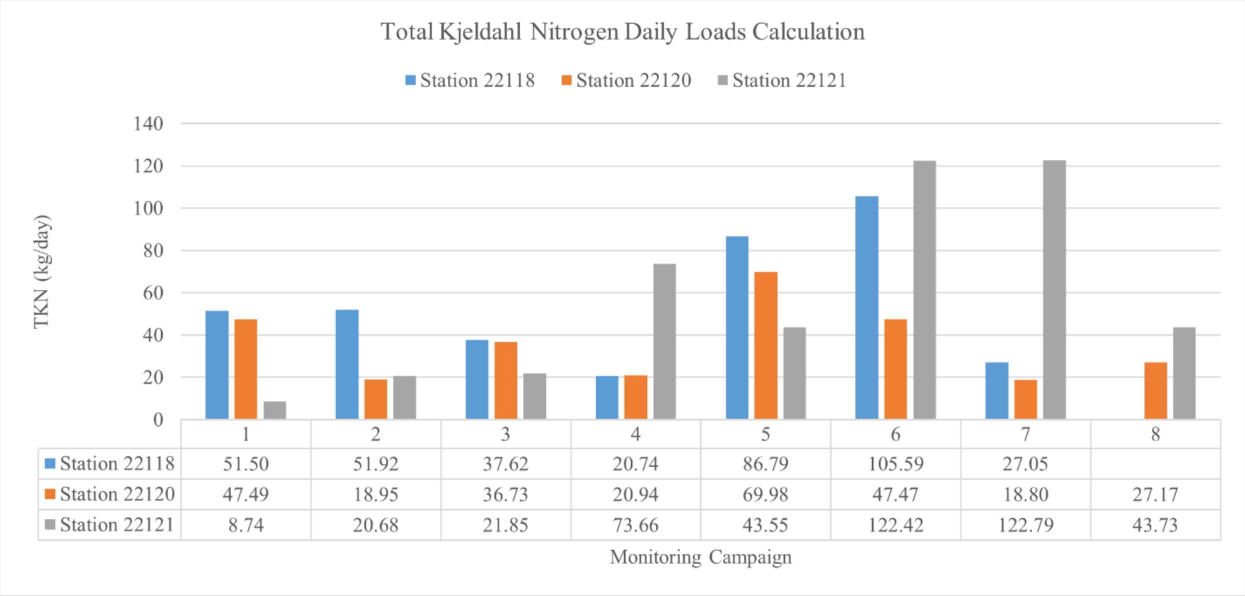
E. Coli Daily Load. From findings in this study, station 22121, monitoring Old Main Drain Ditch, was the waterway draining the largest amount of E. Coli into the BSC with an average of 5.75E+13 $\frac{MPN}{day}$. In second place was station 22120, at Ditch No. 1, with an average of 3.39E+13 $\frac{MPN}{day}$. Finally, Ditch No. 1, monitored by station 22118 showed an average bacteriological daily load of 2.75E+13 $\frac{MPN}{day}$. All E. Coli daily loads observed during sampling campaigns are shown in Figure 26.



	1	2	3	4	5	6	7	8
■ Station 22118	8.58E+13	3.27E+13	1.27E+13	9.42E+12	2.17E+13	4.29E+13	3.78E+13	
■ Station 22120	1.41E+13	3.35E+13	7.08E+13	2.18E+13	4.49E+13	7.92E+13	2.65E+13	2.53E+13
■ Station 22121	1.35E+13	4.77E+13	2.62E+13	1.15E+14	6.86E+13	8.51E+13	3.13E+14	3.38E+13

Figure 26. Daily E. Coli loads draining into BSC from Ditch No. 1 (in orange), Ditch No. 2 (in blue), and Old Main Drain Ditch (gray).

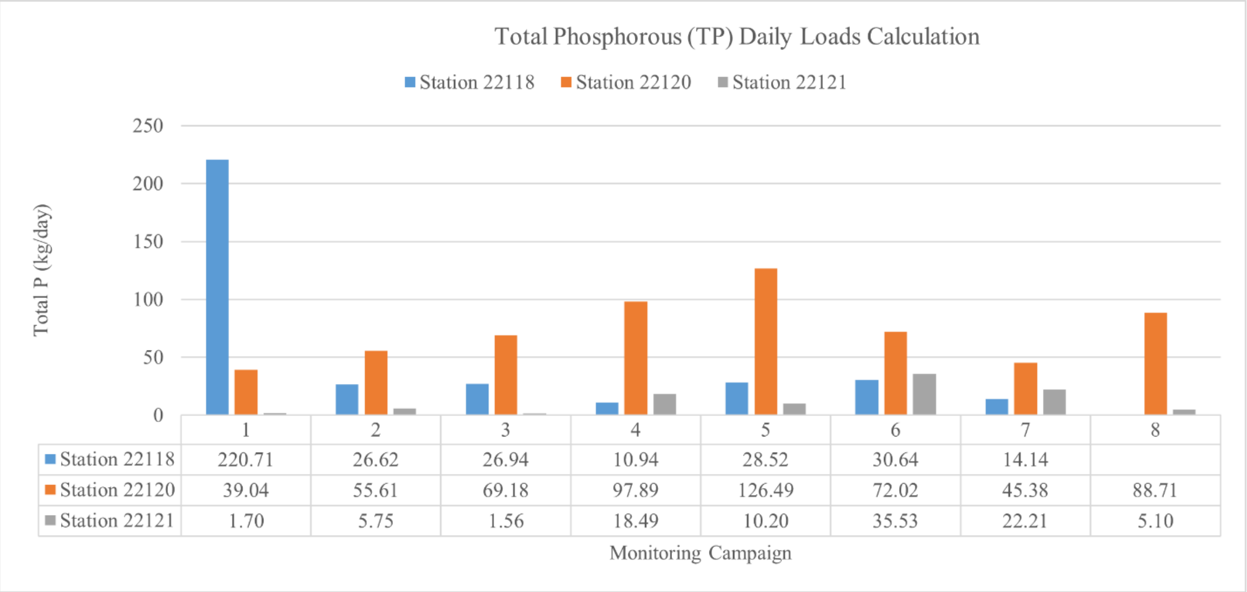
Total Kjeldahl Nitrogen Daily Load. Findings in this study revealed that station 22121 and 22118 discharge the largest amount of TKN to the BSC with an average of $57.17\,\frac{kg}{day}$ and $54.45\,\frac{kg}{day}$ respectively. Finally, station 22120 average discharge was of $35.95\,\frac{kg}{day}$ almost 40% less than station 22121. Results from observed during the eight sampling campaigns are shown at Figure 27.



	1	2	3	4	5	6	7	8
■ Station 22118	51.50	51.92	37.62	20.74	86.79	105.59	27.05	
■ Station 22120	47.49	18.95	36.73	20.94	69.98	47.47	18.80	27.17
■ Station 22121	8.74	20.68	21.85	73.66	43.55	122.42	122.79	43.73

Figure 27. Daily TKN loads draining into BSC from Ditch No. 1 (in orange), Ditch No. 2 (in blue), and Old Main Drain Ditch (gray).

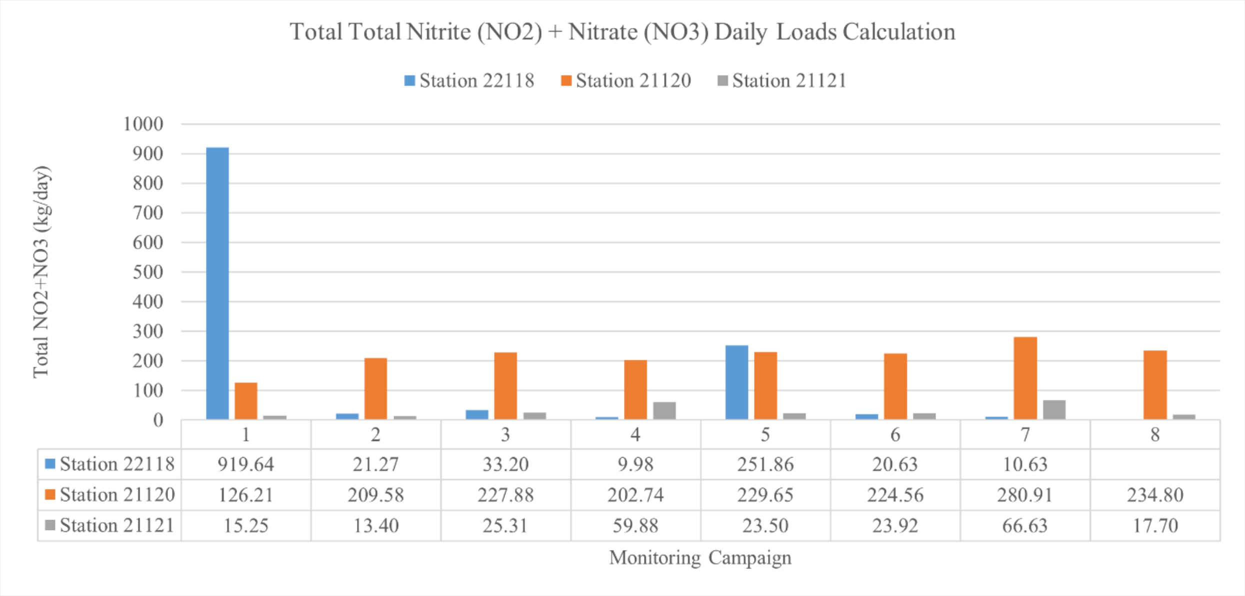
Daily Total Phosphorus Load. Findings in this study indicate that Ditch No. 1 discharges the largest amount of TP into the BSC with an average of $74.29\,\frac{kg}{day}$. Ditch No. 2 drains an average of $51.22\,\frac{kg}{day}$ of TP while the Old Main Drain Ditch drains the lowest amount of this nutrient with an average of $12.57\,\frac{kg}{day}$, a difference of 83% compared with Ditch No. 1. Daily TP loads observed during the eight sampling campaigns are shown in Figure 28.



	1	2	3	4	5	6	7	8
Station 22118	220.71	26.62	26.94	10.94	28.52	30.64	14.14	
Station 22120	39.04	55.61	69.18	97.89	126.49	72.02	45.38	88.71
Station 22121	1.70	5.75	1.56	18.49	10.20	35.53	22.21	5.10

Figure 28. Daily TP loads draining into BSC from Ditch No. 1 (in orange), Ditch No. 2 (in blue), and Old Main Drain Ditch (gray).

Daily Nitrate and Nitrite Load. Findings from this study indicate that station 22120 monitoring Ditch No. 1 has the largest NO_2+NO_3 daily load with an average of 217.04 $\frac{kg}{day}$, followed by Ditch No. 2 with an average of 181.03 $\frac{kg}{day}$. Old Main Drain Ditch drains a drastically lower amount of NO_2+NO_3 compared with the other two waterways. an average of 30.69 $\frac{kg}{day}$. Results of NO2+NO3 daily load observed during the eight sampling campaigns are shown in Figure 29.



	1	2	3	4	5	6	7	8
■ Station 22118	919.64	21.27	33.20	9.98	251.86	20.63	10.63	
■ Station 21120	126.21	209.58	227.88	202.74	229.65	224.56	280.91	234.80
■ Station 21121	15.25	13.40	25.31	59.88	23.50	23.92	66.63	17.70

Figure 29. Daily NO_2+NO_3 loads draining into BSC from Ditch No. 1 (in orange), Ditch No. 2 (in blue), and Old Main Drain Ditch (gray).

Load Duration Curves

LDCs for this study were developed following the methodology described at Development of Load Duration Curves section, the results are shown in the following 12 figures.

LDCs for Station 22118 monitoring Ditch No. 2. From LDCs in Figure 30, Figure 31, Figure 32, and Figure 33 can be observed that any of the E. Coli, TKN, and TP loads met water quality criteria. On the other hand, for NO_2+NO_3 only two out of seven observations did not met water quality standards, those two values were found during high flows and moist conditions.

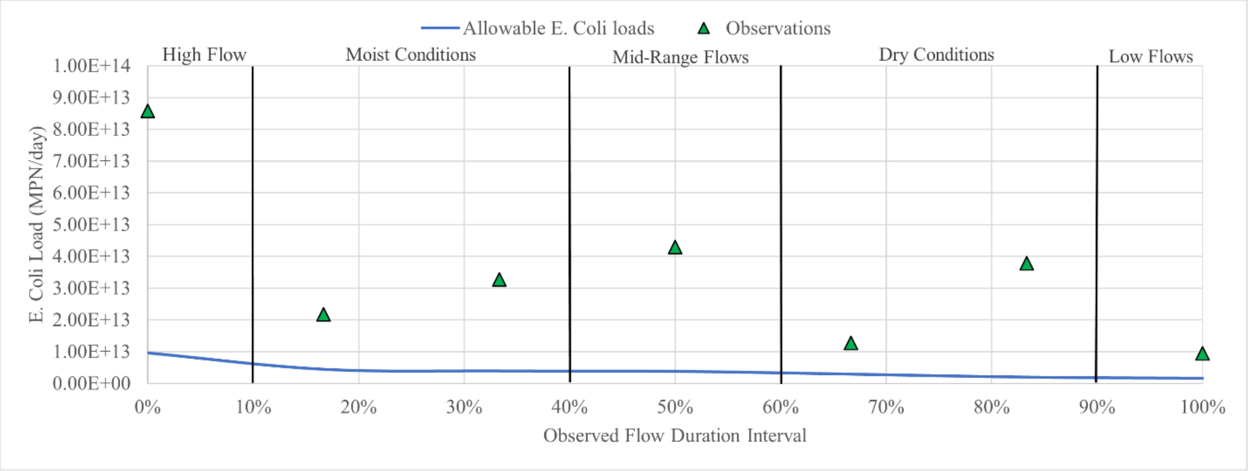


Figure 30. Load duration curve for Ditch No. 2 near City of Los Fresnos, South Texas, February 2020 through September 2021. Blue line represents calculated maximum allowable E. Coli loads. Green triangles represent observed E. Coli loads at the same flow duration intervals.

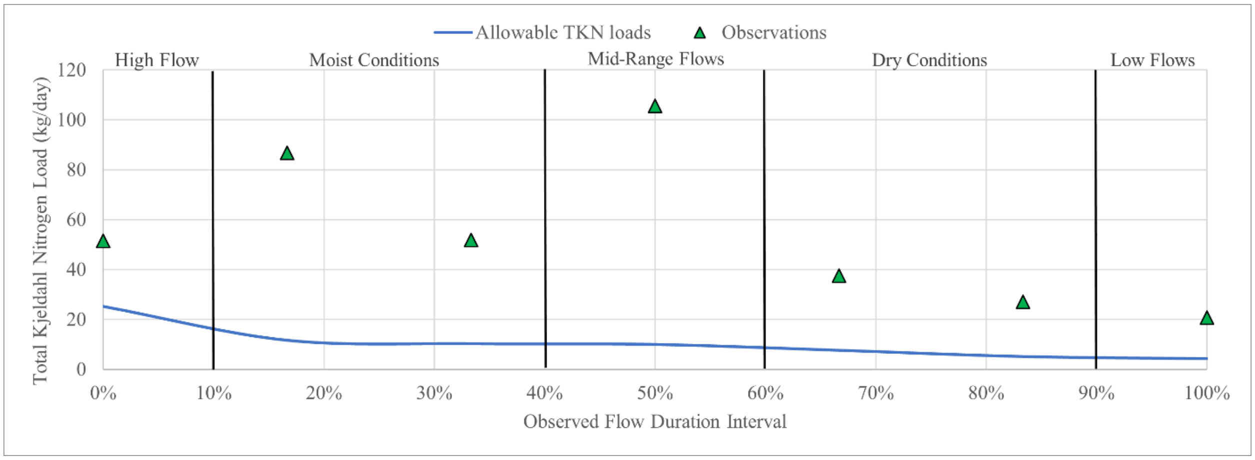


Figure 31. Load duration curve for Ditch No. 2 near City of Los Fresnos, South Texas, February 2020 through September 2021. Blue line represents calculated maximum allowable TKN loads. Green triangles represent observed TKN loads at the same flow duration intervals.

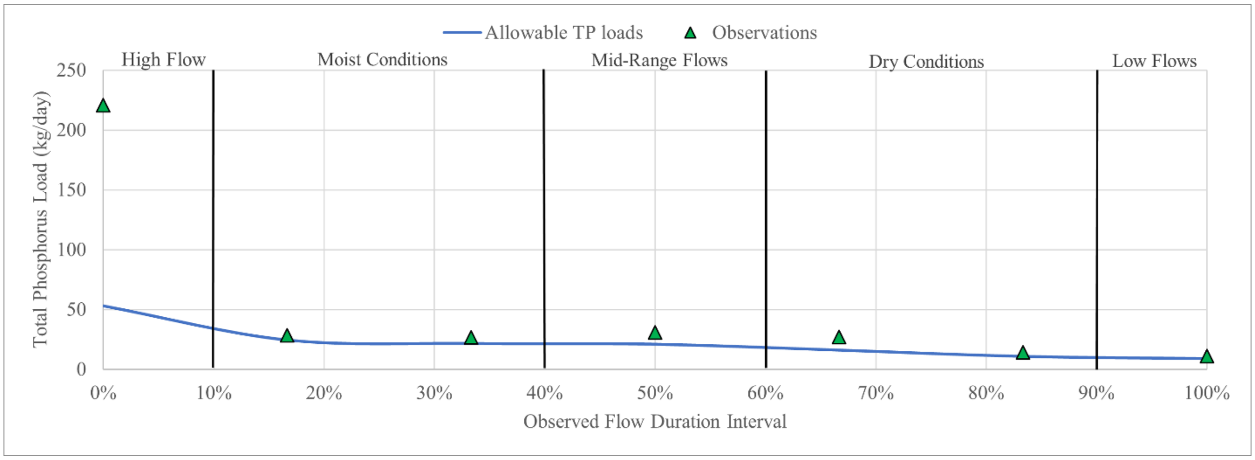


Figure 32. Load duration curve for Ditch No. 2 near City of Los Fresnos, South Texas, February 2020 through September 2021. Blue line represents calculated maximum allowable TP loads. Green triangles represent observed TP loads at the same flow duration intervals.

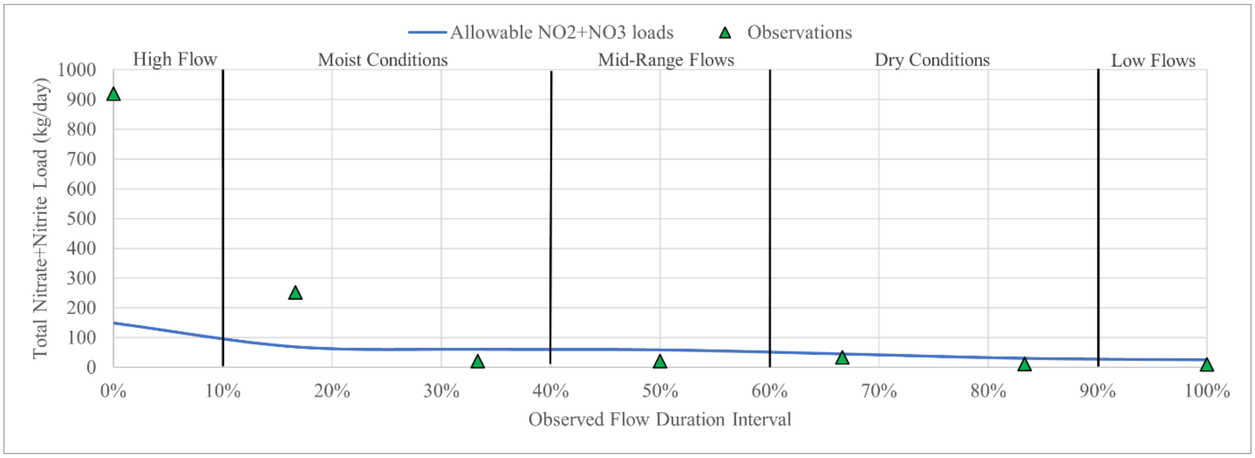


Figure 33. Load duration curve for Ditch No. 2 near City of Los Fresnos, South Texas, February 2020 through September 2021. Blue line represents calculated maximum allowable NO_2+NO_3 loads. Green triangles represent observed NO_2+NO_3 loads at the same flow duration intervals.

LDCs for Station 22120 monitoring Ditch No. 2. From LDCs developed for this waterway revealed that all nutrients and bacteria loads exceed the water quality standards.

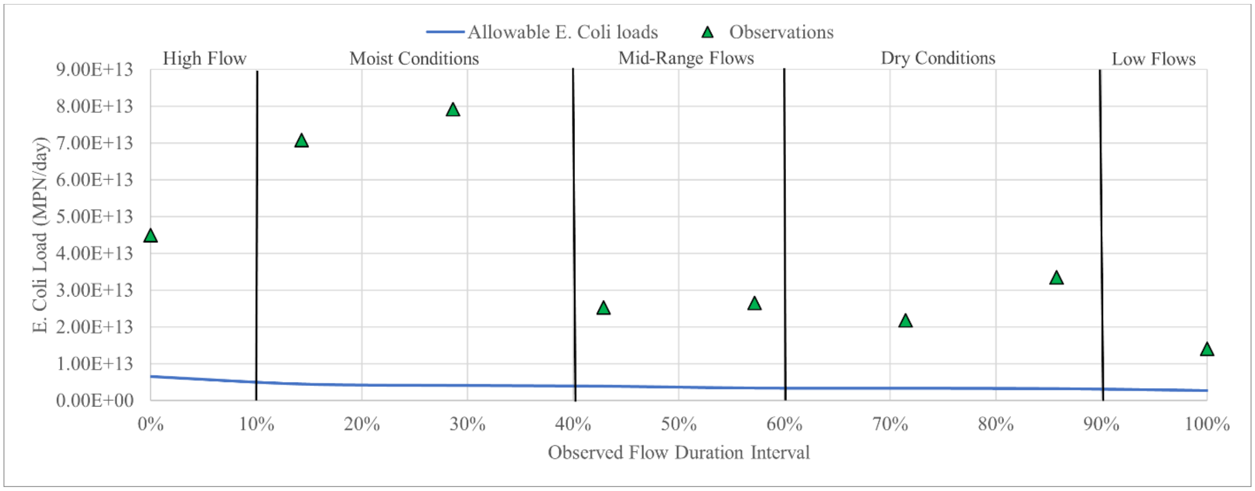


Figure 34. Load duration curve for Ditch No. 1 at Brownsville Public Works, February 2020 through November 2021. Blue line represents calculated maximum allowable E. Coli loads. Green triangles represent observed E. Coli loads at the same flow duration intervals.

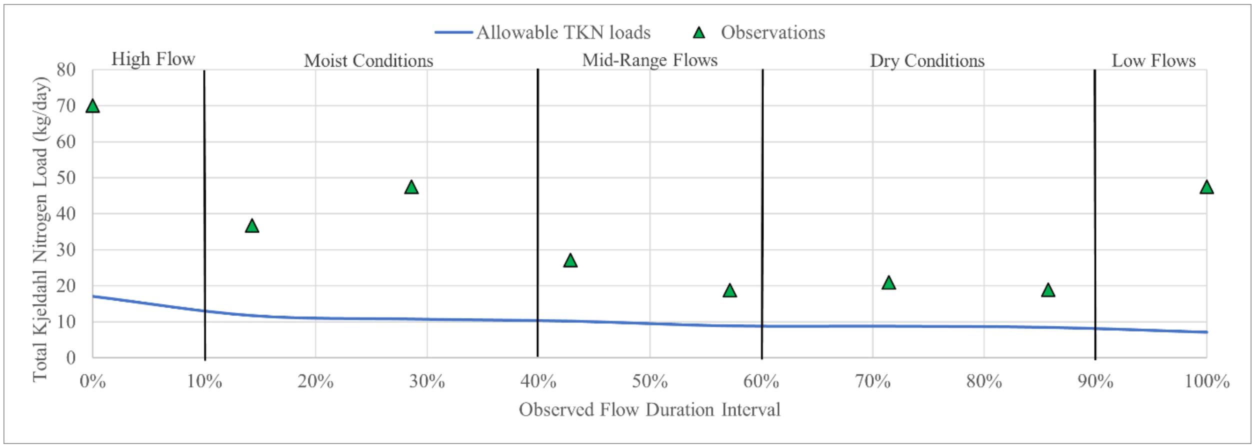


Figure 35. Load duration curve for Ditch No. 1 at Brownsville Public Works, February 2020 through November 2021. Blue line represents calculated maximum allowable TKN loads. Green triangles represent observed TKN loads at the same flow duration intervals.

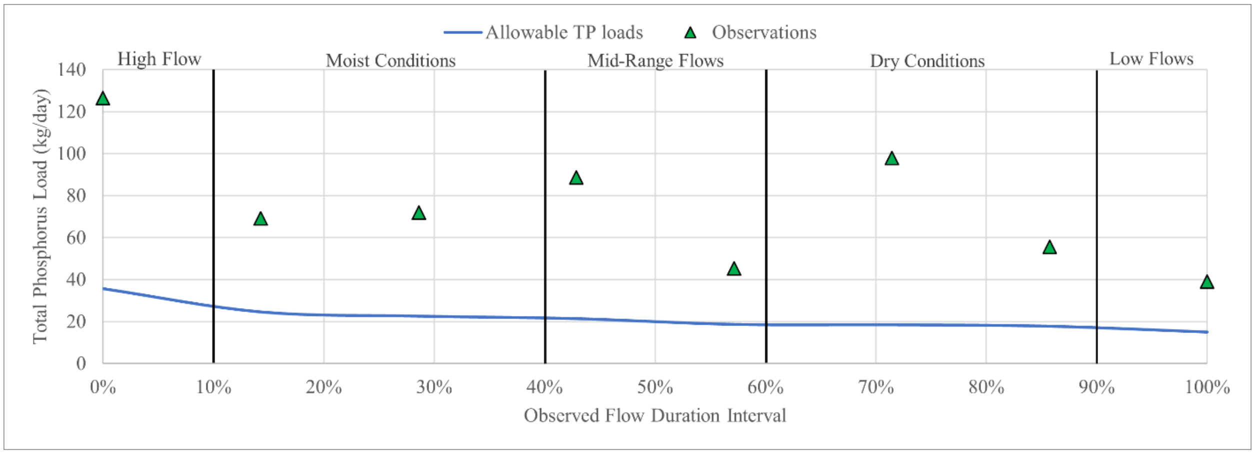


Figure 36. Load duration curve for Ditch No. 1 at Brownsville Public Works, February 2020 through November 2021. Blue line represents calculated maximum allowable TP loads. Green triangles represent observed TP loads at the same flow duration intervals.

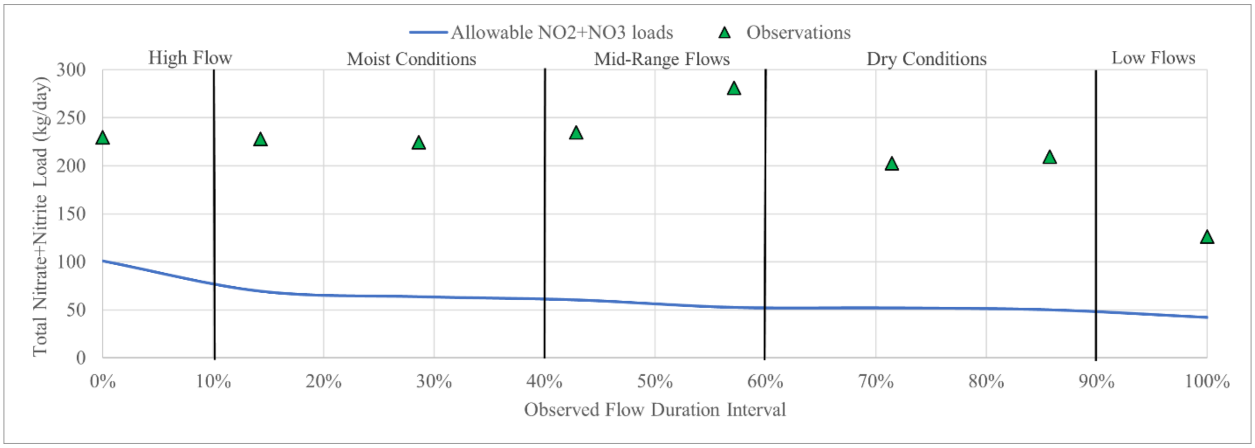


Figure 37. Load duration curve for Ditch No. 1 at Brownsville Public Works, February 2020 through November 2021. Blue line represents calculated maximum allowable NO_2+NO_3 loads. Green triangles represent observed NO_2+NO_3 loads at the same flow duration intervals.

LDCs for Station 22121 monitoring Old Main Drain. From LDCs in Figure 38, and Figure 39 can be observed that all eight load observations of E. Coli, and TKN exceeded the water quality criteria. Figure 40 shows the LDC developed for TP where only one observation did not meet water quality standards, that observation occurred during the moist conditions. In terms of NO_2+NO_3, in Figure 41, the only observation exceeding the maximum allowable load was found during the low flows condition.

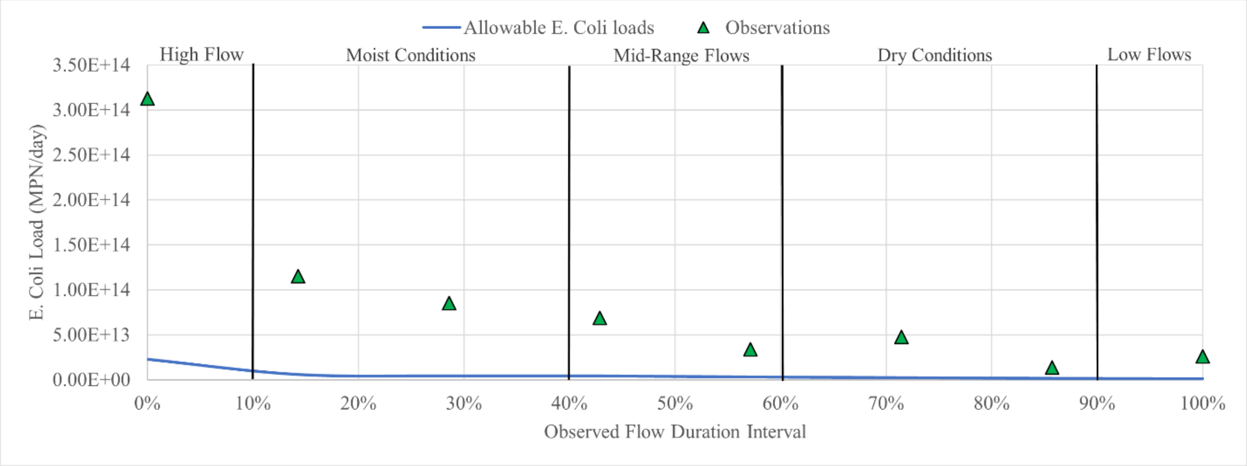


Figure 38. Load duration curve for Old Main Drain Ditch at Brownsville Landfill, February 2020 through November 2021. Blue line represents calculated maximum allowable E. Coli loads. Green triangles represent observed E. Coli loads at the same flow duration intervals.

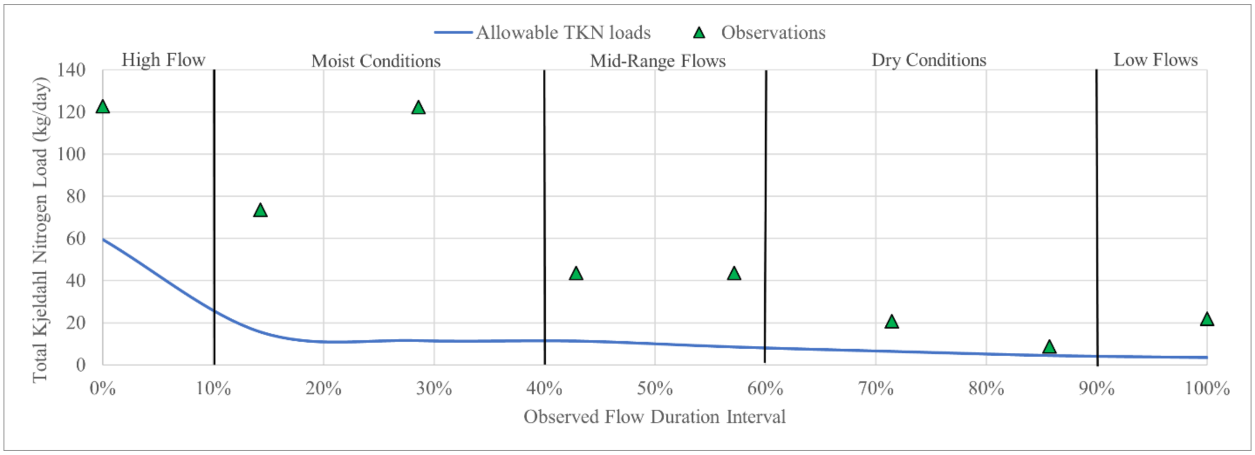


Figure 39. Load duration curve for Old Main Drain Ditch at Brownsville Landfill, February 2020 through November 2021. Blue line represents calculated maximum allowable TKN loads. Green triangles represent observed TKN loads at the same flow duration intervals.

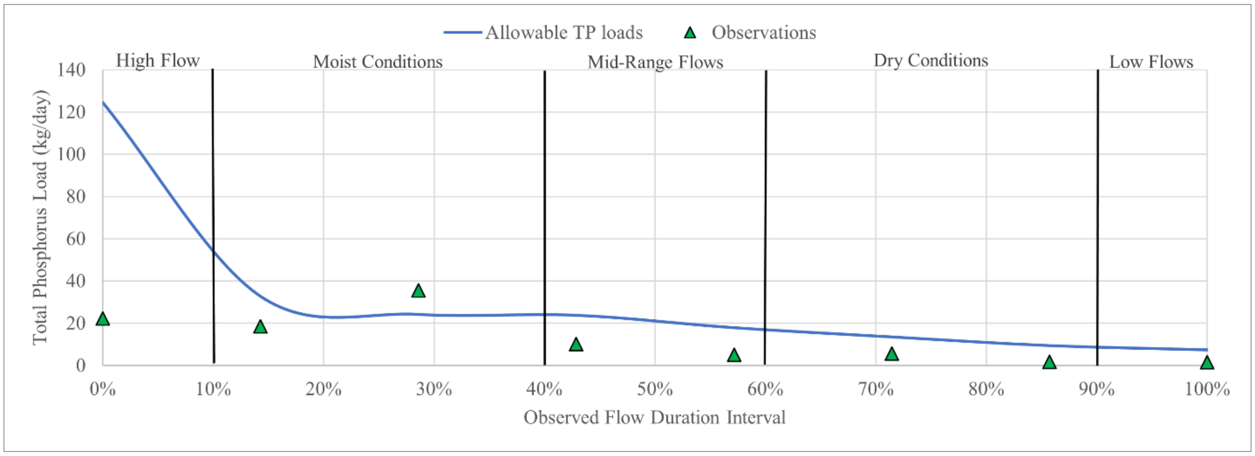


Figure 40. Load duration curve for Old Main Drain Ditch at Brownsville Landfill, February 2020 through November 2021. Blue line represents calculated maximum allowable TP loads. Green triangles represent observed TP loads at the same flow duration intervals.

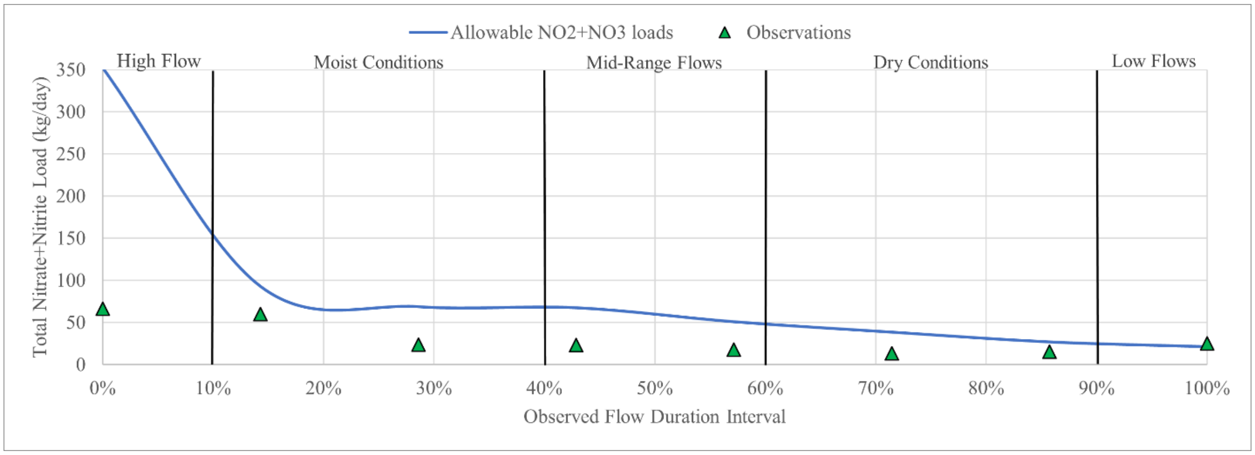


Figure 41. Load duration curve for Old Main Drain Ditch at Brownsville Landfill, February 2020 through November 2021. Blue line represents calculated maximum allowable NO_2+NO_3 loads. Green triangles represent observed NO_2+NO_3 loads at the same flow duration intervals.

Load reduction needed

Four tables were created to compare pollutant loads against the maximum allowable pollutant load with the objective of determining pollutant loads when needed.

E. Coli load reductions. All bacteriological loads exceeded water quality standards during the eight sampling campaigns. Therefore, significant load reductions are needed at the three stations, results are shown at Table 15.

Table 15. E. Coli Loads Observed Compared with Target Loads to Estimate Overall Reduction Needed to Meet Water Quality Standards.

E. Coli Reductions				
Station	Hydrologic Condition Class	Target Load ($\frac{MPN}{day}$)	Daily Load observed ($\frac{MPN}{day}$)	Load Reduction Required ($\frac{MPN}{day}$)
22118 (Ditch No. 2)	High Flows	9.66E+12	8.58E+13	7.62E+13
	Moist Conditions	4.46E+12	2.17E+13	1.73E+13
	Moist Conditions	3.94E+12	3.27E+13	2.88E+13
	Mid-Range Flows	3.82E+12	4.29E+13	3.91E+13
	Dry Conditions	2.93E+12	1.27E+13	9.79E+12
	Dry Conditions	1.97E+12	3.78E+13	3.59E+13
	Low Flows	1.63E+12	9.42E+12	7.79E+12
22120 (Ditch No. 1)	High Flows	6.53E+12	4.49E+13	3.84E+13
	Moist Conditions	4.49E+12	7.08E+13	6.63E+13
	Moist Conditions	4.12E+12	7.92E+13	7.51E+13
	Mid-Range Flows	3.91E+12	2.53E+13	2.14E+13
	Mid-Range Flows	3.40E+12	2.65E+13	2.31E+13
	Dry Conditions	3.37E+12	2.18E+13	1.85E+13
	Dry Conditions	3.24E+12	3.35E+13	3.02E+13
	Low Flows	2.73E+12	1.41E+13	1.13E+13
22121 (Old Main Drain Ditch)	High Flows	2.28E+13	3.13E+14	2.90E+14
	Moist Conditions	5.99E+12	1.15E+14	1.09E+14
	Moist Conditions	4.43E+12	8.51E+13	8.07E+13
	Mid-Range Flows	4.35E+12	6.86E+13	6.43E+13
	Mid-Range Flows	3.28E+12	3.38E+13	3.05E+13
	Dry Conditions	2.48E+12	4.77E+13	4.52E+13
	Dry Conditions	1.73E+12	1.35E+13	1.17E+13
	Low Flows	1.36E+12	2.62E+13	2.48E+13

Total Kjeldahl nitrogen load reductions. TKN loads are a major concern as any of the three waterways studied met water quality criteria for this nutrient. Load reductions required are displayed in Table 16.

Table 16. Total Kjeldahl Nitrogen Loads Observed Compared with Target Loads to Estimate Overall Reduction Needed to Meet Water Quality Standards.

TKN Reductions				
Station	Hydrologic Condition Class	Target Load ($\frac{kg}{day}$)	Daily Load observed ($\frac{kg}{day}$)	Load Reduction Required ($\frac{kg}{day}$)
22118 (Ditch No. 2)	High Flows	25.29	51.50	26.21
	Moist Conditions	11.69	86.79	75.10
	Moist Conditions	10.32	51.92	41.60
	Mid-Range Flows	10.01	105.59	95.57
	Dry Conditions	7.66	37.62	29.95
	Dry Conditions	5.16	27.05	21.89
	Low Flows	4.28	20.74	16.46
22120 (Ditch No. 1)	High Flows	17.11	69.98	52.88
	Moist Conditions	11.77	36.73	24.96
	Moist Conditions	10.80	47.47	36.66
	Mid-Range Flows	10.24	27.17	16.94
	Mid-Range Flows	8.91	18.80	9.89
	Dry Conditions	8.83	20.94	12.12
	Dry Conditions	8.50	18.95	10.45
	Low Flows	7.16	47.49	40.34
22121 (Old Main Drain Ditch)	High Flows	59.59	122.79	63.20
	Moist Conditions	15.68	73.66	57.97
	Moist Conditions	11.61	122.42	110.81
	Mid-Range Flows	11.40	43.55	32.14
	Mid-Range Flows	8.59	43.73	35.14
	Dry Conditions	6.50	20.68	14.18
	Dry Conditions	4.53	8.74	4.20
	Low Flows	3.57	21.85	18.28

Total phosphorus load reductions. Findings shown in Table 17, demonstrated that most of the TP loads at station 22121 met water quality criteria, on the other hand, observed loads at station 22120 exceeded by at least two times the allowable TP loads. All observed loads at station 22118 exceeded water quality criteria, however exceedances were not as critical as four of them overpassed the criteria by less than 25%.

Table 17. Total Phosphorus Loads Observed Compared with Target Loads to Estimate Overall Reduction Needed to Meet Water Quality Standards.

TP Reductions				
Station	Hydrologic Condition Class	Target Load ($\frac{kg}{day}$)	Daily Load observed ($\frac{kg}{day}$)	Load Reduction Required ($\frac{kg}{day}$)
22118 (Ditch No. 2)	High Flows	52.88	220.71	167.83
	Moist Conditions	24.44	28.52	4.07
	Moist Conditions	21.58	26.62	5.04
	Mid-Range Flows	20.94	30.64	9.71
	Dry Conditions	16.02	26.94	10.91
	Dry Conditions	10.79	14.14	3.35
	Low Flows	8.94	10.94	2.00
22120 (Ditch No. 1)	High Flows	35.77	126.49	90.72
	Moist Conditions	24.61	69.18	44.58
	Moist Conditions	22.59	72.02	49.43
	Mid-Range Flows	21.40	88.71	67.31
	Mid-Range Flows	18.64	45.38	26.74
	Dry Conditions	18.46	97.89	79.44
	Dry Conditions	17.77	55.61	37.85
	Low Flows	14.96	39.04	24.07
22121 (Old Main Drain Ditch)	High Flows	124.60	22.21	-*
	Moist Conditions	32.79	18.49	-*
	Moist Conditions	24.27	35.53	11.26
	Mid-Range Flows	23.85	10.20	-*
	Mid-Range Flows	17.96	5.10	-*
	Dry Conditions	13.59	5.75	-*
	Dry Conditions	9.48	1.70	-*
	Low Flows	7.46	1.56	-*

*No load reduction needed.

Nitrate and nitrite load reductions. Station 22118 had two exceedances, one during moist conditions, and one at high flows. Station 22120 did not meet water quality at any of the sampling campaigns, observed load values were constant from dry conditions to high flows. Station 22121 resulted to be the site with lowest number of exceedances, only one during high flow conditions, overpassing by 4.22 $\frac{kg}{day}$ the maximum allowable load of TP.

Table 18. Nitrate and Nitrite Loads Observed Compared with Target Loads to Estimate Overall Reduction Needed to Meet Water Quality Standards.

NO_2+NO_3 Reductions				
Station	Hydrologic Condition Class	Target Load ($\frac{kg}{day}$)	Daily Load observed ($\frac{kg}{day}$)	Load Reduction Required ($\frac{kg}{day}$)
22118	High Flows	149.44	919.64	770.20
	Moist Conditions	69.08	251.86	182.79
	Moist Conditions	60.99	21.27	-*
	Mid-Range Flows	59.16	20.63	-*
	Dry Conditions	45.28	33.20	-*
	Dry Conditions	30.49	10.63	-*
	Low Flows	25.27	9.98	-*
22120	High Flows	101.09	229.65	128.56
	Moist Conditions	69.54	227.88	158.34
	Moist Conditions	63.83	224.56	160.73
	Mid-Range Flows	60.48	234.80	174.32
	Mid-Range Flows	52.67	280.91	228.24
	Dry Conditions	52.16	202.74	150.59
	Dry Conditions	50.21	209.58	159.38
	Low Flows	42.29	126.21	83.93
22121	High Flows	352.12	66.63	-*
	Moist Conditions	92.66	59.88	-*
	Moist Conditions	68.60	23.92	-*
	Mid-Range Flows	67.39	23.50	-*
	Mid-Range Flows	50.75	17.70	-*
	Dry Conditions	38.41	13.40	-*
	Dry Conditions	26.79	15.25	-*
	Low Flows	21.09	25.31	4.22

*No load reduction needed.

Conclusions

Station 22118, Ditch No. 2

E. Coli loads at station 22118 were constant from low flows to moist conditions, observation value during high flow was higher than the others and was considered as an atypical observation. Analysis of TKN loads found an average of 54.45 $\frac{kg}{day}$, the second largest from the three waterways. In terms of TP, water quality standard was never met however, exceedances were not as critical as four of them overpassed the criteria by less than 25%. Finally, NO_2+NO_3 loads were only exceeded two times during moist and high flow conditions, suggesting that non-point sources in the area contribute to increase NO_2+NO_3 concentration via runoff.

Station 22120, Ditch No. 1

Observations from low to mid-range flows at station 22120 were constant, on the other hand, during moist conditions and high flows bacteria loads increased drastically, facts that suggest that a point source is continuously contributing to Ditch No. 1 and that runoff helped to increment the load of bacteria during higher flow conditions. In terms of TKN, loads remained constant from low to mid-range flows while some increment was observed during higher flows. Ditch No. 1 discharged the largest amount of TP into the BSC with an average of 74.29 $\frac{kg}{day}$, it was also observed that this waterway had the largest NO_2+NO_3 daily load with contribution with an average of 217.04 $\frac{kg}{day}$.

Station 22121, Old Main Drain Ditch

E. Coli loads exceeded water quality standards during all sampling campaigns, observations seemed to follow an exponential trend of growth as flow increased, which suggests that runoff and non-point sources contribute to increase bacteriological loads. Findings in this study revealed that station 22121 discharge the largest amount of TKN to the BSC with an average of $57.17 \frac{kg}{day}$. Finally, NO_2+NO_3, and TP loads met water quality criteria in seven out of eight sampling campaigns, therefore, this waterway was not considered as affected by this nutrient.

CHAPTER IV

WATERSHED DELINEATION

Introduction

A watershed is the area that drains to one stream such as lakes, rivers, streams, wetlands, estuaries, or bays (USEPA, 2022a). Watershed delineation, the process of dividing a watershed into small watersheds for their future management and evaluation, is usually the first step in watershed modeling (USEPA, 2008).

Objective

Conduct a watershed delineation using the DEM Reconditioning process in order to split the BSCW into smaller sub-watersheds that allow to execute the SELECT model in BSCW.

Methodology

Requirements

The first requisite to conduct this watershed delineation was having access to the most recent version of ArcMAP, in this case version 10.8 but most of the versions can perform this task. ArcMap is a software developed by ESRI and is used to perform a wide range of Geographical Information System (GIS) tasks (ESRI, 2016). Then, obtaining the Digital Elevation Model (DEM) for the area of study with the best resolution available, it is important to use for Light Detection and Ranging (LiDAR) data when available as it provides the most accurate topographic information (NOOA, 2021), LiDAR data from 2018 is available from (USGS, 2018b). Finally, hydrography dataset containing stream networks at the region which is available through (USGS, 2019). If available, previous watershed delineations developed within the area of study to have a reference of methodology implemented before, for comparison purposes or to improve previous work. For BSCW, a watershed delineation was conducted by (UTRGV et al., 2018) as part of the LLM/BSC Watershed Characterization Report developed in 2018 by UTRGV and TCEQ.

D.E.M. Reconditioning Process

The procedure utilized to delineate BSCW is known as DEM reconditioning and commonly referred as DEM burning process, it consists of the integration of a vector hydrography layer into the DEM prior to watershed delineation, correcting the loss of detail (William Saunders, 1999). DEM reconditioning is only suggested when the vector stream information is more reliable than the raster DEM information (Tarboton, 2011), which was not the case for this project as Light Detection and Ranging (LiDAR) data is available for South Texas, however, taking in consideration the difficulties that flat topography in the study area might imply, it was necessary to run the DEM reconditing process as all efforts to ensure the most accurate watershed delineation possible must be done. Previous studies (Navarro et al., 2021; William Saunders, 1999) had confirmed that positive results are obtained using DEM reconditioning process in watershed delineation for flat terrains.

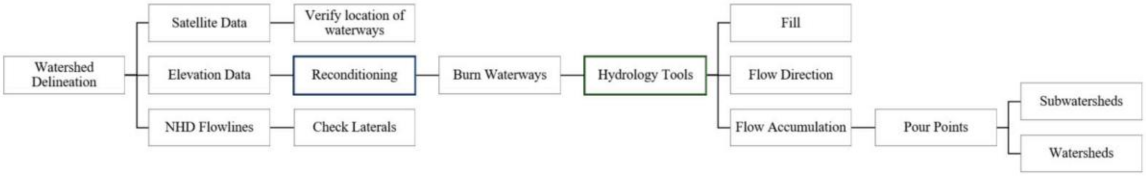


Figure 42. Watershed delineation methodology. Source: (Navarro et al., 2021)

Hydrological Analysis

Once the DEM had been burned, the last step was the hydrologic analysis of the watershed. Methodology described in Figure 4 applied by (Navarro et al., 2021) was followed to delineate BSCW for the reason that watersheds delineated in the study make border with BSCW, sharing some topographic, and hydrological characteristics. Main steps during this phase of the project include the use Fill tool to fill cells with an undefined drainage direction to remove small imperfections in the data (ArcGIS Pro, 2021a), implementation of Flow Direction tool which creates a raster of flow direction from each cell to its downslope neighbor (ArcGIS Pro, 2021c) and, the use of Flow Accumulation tool that creates a raster of accumulated flow to each cell (ArcGIS Pro, 2021b). Last step required the creation and strategic location of discharge outlets, also known as pour points, six of them were placed over BSCW based on Flow Accumulation findings from ArcMAP. The first one was placed at the outlet of BSC allowing to delineate 9 sub-watersheds, other five pour points were placed on the Northeast where BSCW discharges into Lower Laguna Madre Bay. The Hydrological Analysis was conducted twice to reach two different levels of detail, one trying to emulate the results obtained by (UTRGV et al., 2018) and a second one to obtain smaller size of sub-watersheds that were utilized to model pollutant loads in following chapters.

Results

After conducting the first watershed delineation process, the BSCW turned into fourteen new sub-watersheds, five of them (sub-watersheds 3, 6, 7, 8, and 9) draining directly into BSC, three (sub-watersheds 1, 2, and 5) draining into Ditch No. 2 that eventually discharges into BSC, and one (sub-watershed 4) that drains into Ditch No. 1, then it merges with Ditch No. 2 discharging into BSC. Sub-watersheds 10, 11, 12, 13, and 14 share the same characteristic of draining directly into Lower Laguna Madre Bay.

Table 19. Summary of Watershed Delineation results.

Sub-watershed	Sub-watershed Size (mi2)	Percentage of BSCW covered (%)	Influence over BSC
1	53.75	13.31	Indirect[2]
2	34.35	8.51	Indirect[2]
3	58.68	14.53	Direct[1]
4	25.11	6.22	Indirect[2]
5	67.71	16.77	Indirect[2]
6	18.44	4.57	Direct[1]
7	0.75	0.19	Direct[1]
8	47.67	11.81	Direct[1]
9	40.49	10.03	Direct[1]
10	4.70	1.16	-
11	5.11	1.27	-
12	7.86	1.95	-
13	23.30	5.77	-
14	15.82	3.92	-
Total=	403.74	100.00	

1 Discharges to Ditch No. 2 before discharging into BSC

[2] Discharges to Ditch No. 1 before discharging into BSC

Validation of the results came from comparing first delineation process with findings obtained by (UTRGV et al., 2018), as they also divided BSCW into 14 sub-basins, where the north side drains into Lower Laguna Madre Bay and the rest into BSC. Some differences were observed in the watersheds found at the south side of the watershed derived of a different location of their pour points or the delineation process utilized by the researchers. Table 19 has a detailed description of the results obtained, size of each of the 14 sub-watersheds, the percentage that they cover and the type of influence that they have with the BSC.

Table 20. Results from secondary Watershed Delineation process applied to BSCW

Watershed	Number of sub-watersheds	Average sub-watershed size (mi^2)
1	33	1.63
2	17	2.02
3	33	1.78
4	17	1.48
5	35	1.93
6	11	1.68
7	1	0.75
8	28	1.70
9	21	1.93
10	3	1.57
11	2	2.55
12	3	2.62
13	8	2.90
14	12	1.32
Total=	224	1.85

The secondary delineation process divided each of the fourteen sub-watersheds previously found into smaller fractions BSCW, a total of 224 new sub-watersheds were found with an average size of 1.85 mi^2, this new delineation was utilized to model bacteria loadings using Spatially Explicit Load Enrichment Calculation Tool (SELECT) where (USEPA, 2008), suggests an average size of 0.5 mi^2 per subwatershed that can be increased or decreased based on model type or spatial characteristics of the site. For this case, based on the flat topography, the model selected, and study limitations, it was determined that modeling with the obtained average size of 1.85 mi^2 was feasible and would not impact the general quality of the project. Table 20 contains a summary of geographical characteristics of the second delineation process with the number of sub-watersheds found along with their average size. Results obtained from 1st and 2nd Watershed Delineation processes are shown in Figure 43.

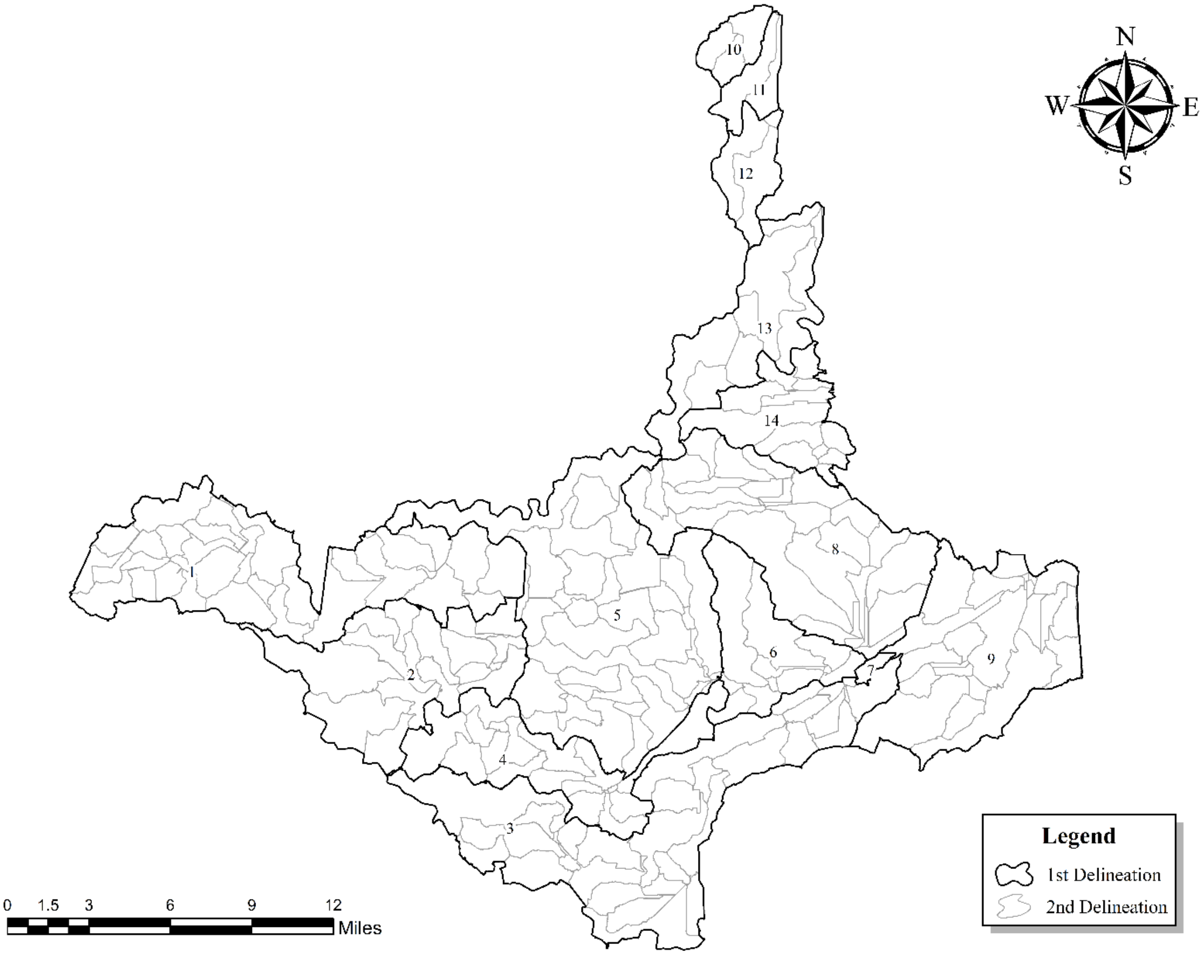


Figure 43. Watershed delineation results. 1st Delineation in black, 2nd Delineation in gray.

Conclusions

Brownsville Ship Channel Watershed is compound of 14 major sub-watersheds, and 224 minor sub-watersheds with an average size of 28.84 mi^2, and1.96 mi^2 respectively. From the first delineation was confirmed that 9 sub-watersheds drain into BSC, on the other hand, from secondary delineation was observed that 196 sub-watersheds drain into BSC and the other 28, discharge into Lower Laguna Madre Bay.

CHAPTER V

SPATIALLY EXPLICIT LOAD ENRICHMENT CALCULATION TOOL MODEL

Introduction

Spatially Explicit Load Enrichment Calculation Tool (SELECT), is an automated geographic information system (GIS) tool that can be applied to assess potential E. Coli loads in a watershed based on spatial factors such as land use, population density, and soil type (A. Teague et al., 2009). SELECT is able to calculate potential E. Coli loads and highlight areas of concern for best management practices (BMPs) to be implemented however, potential E. coli loads generated using SELECT are the worst-case scenario because the tool calculates the largest amount of contribution possible from individual sources (Borel et al., 2012).

Area of Study

Findings obtained during the watershed delineation process will be utilized to implement SELECT model. Due to time limitations, only the results obtained from the first delineation will be utilized in this study, in the future other students will implement the SELECT model in BSCW using results obtained from this study in the secondary delineation. Figure 44 shows the watershed delineation and the land use at each of the sub-watersheds.

Objectives

Analyze land uses and identify point along with non-point sources of pollution, at each of the 14 sub-watersheds, to implement the SELECT model.

Methodology

Land Use Analysis

Using the land use dataset provided by (USGS, 2021), and GIS software, a detailed analysis of the land cover present at each subwatershed was performed to identify the total area of each land use per subwatershed. Figure 44 shows land uses at each of the 14 sub-watersheds within BSCW.

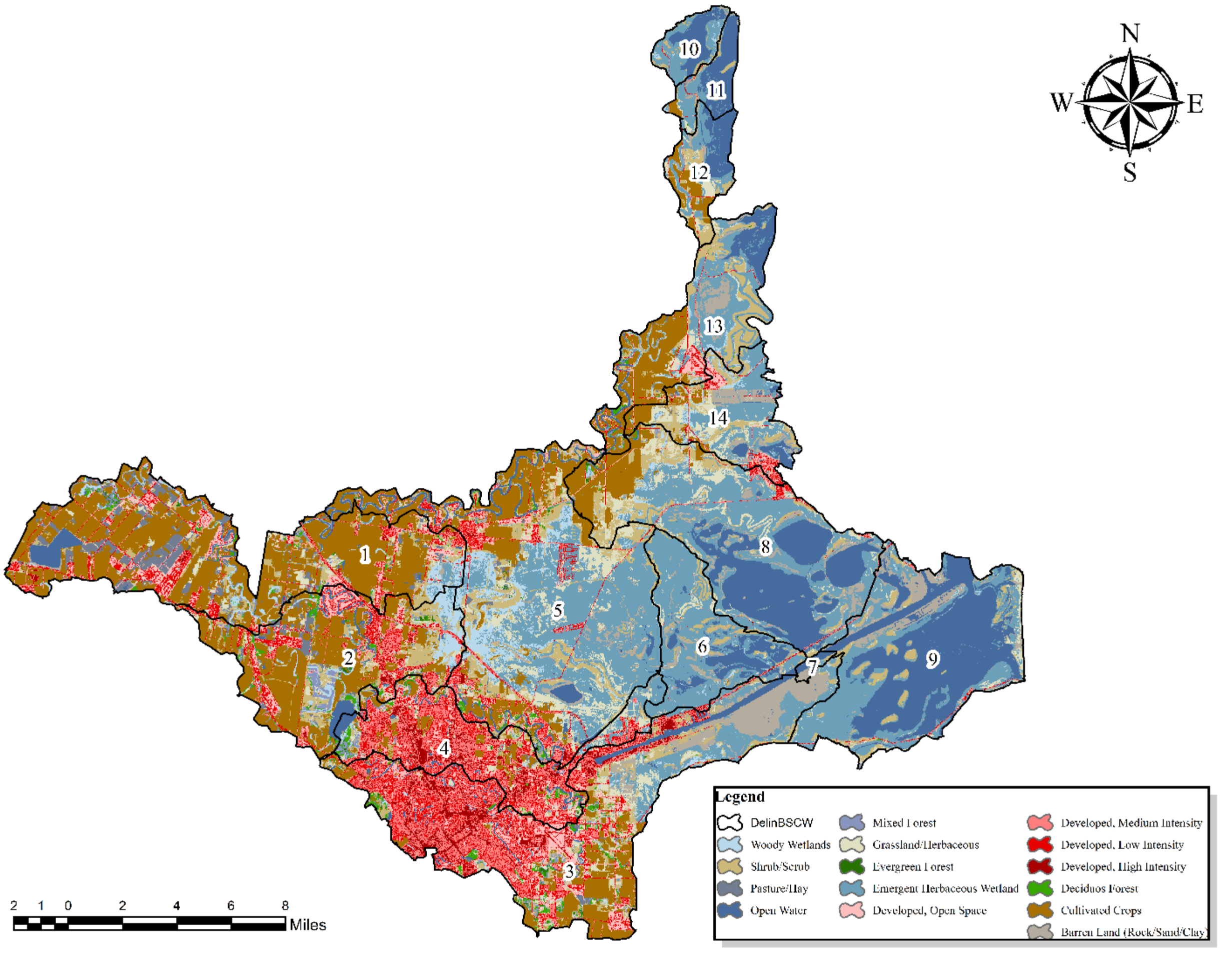


Figure 44. Land use at each of the 14 sub-watersheds within BSCW. Land cover dataset, provided by (USGS, 2021), at each subwatershed within BSCW.

The analysis was required to calculate potential E. Coli daily loads as most of the non-point sources, such as deer, cattle, or feral hogs, suitable areas are defined by land-use cover with potential bacteria loadings estimated based on the density of the source, for example, number of animals per acre, and the fecal production rate for that source (McFarland & Adams, 2014).

Identification and Calculation of Potential E. Coli Sources

Point Source (PS). Point source pollution is considered as any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship, or factory smokestack (NOAA, 2020). PS found within BSCW and utilized to model using SELECT are described below.

On-site Sewage Facilities (OSFFs). OSSFs are commonly used decentralized domestic wastewater treatment facilities in rural, suburban residential, and commercial lands where central wastewater treatment service is not available. Effluent from an OSSF septic tank is dripped into soils for natural treatment by microorganisms (Jeong et al., 2019). To estimate the number of OSFFs, 911 addresses were obtained from (Various 911 Districts, 2021) and compared against the areas covered by public wastewater systems using data from (Public Utility Commission of Texas, 2021). Households with no sewer system available were assumed to use a domestic septic treatment system. All OSSFs have the potential for adverse environmental impact if they are improperly functioning but failing systems in particular pose an elevated risk of exacerbating river water quality with nutrients from human waste (Jeong et al., 2019). By following methodology proposed by (McFarland & Adams, 2014), soils data from (NRCS, 2021) was obtained and processed with the GIS arc toolbox provided by(NRCS Soils, 2020) to calculate the potential failure rate of septic systems within BSCW based on the dominate limitation class associated with the septic tank absorption field. For severely limited a 15% failure rate was applied, 10% for somewhat limited, and 15% for not rated. With all the information available, procedure in Table 22 was applied to calculate the potential E. Coli daily load.

Wastewater Treatment Facilities (WWTFs). A wastewater treatment facility is a site in which a combination of various process, e.g., physical, chemical, and biological, are used to treat industrial wastewater and remove pollutants (Hreiz et al., 2015). Comparing data obtained from (USEPA, 2022b; UTRGV et al., 2018), the WWTFs presented in Table 21 were identified within BSCW to estimate daily potential E. Coli load following procedures stablished in Table 22.

Table 21. Wastewater Treatment Facilities identified within BSCW to model using SELECT along with their permitted discharge in million gallons per day, and their coordinates.

Wastewater Treatment Facility	Permitted discharge (MGD)	Longitude	Latitude
Southside	20	25.898758	-97.468966
Robindale	20	25.955497	-97.453661
Southmost Regional Water Authority (SRWA)	10	26.023551	-97.499567
Isla Blanca	2.6	26.063286	-97.221046
Port Isabel	1.1	26.094769	-97.308772
City of Los Fresnos	1	26.065257	-97.481984
Olmito WSC Los Fresnos	0.75	26.024994	-97.529922
Laguna Vista	0.65	26.117945	-97.314811
Rancho Viejo	0.4	26.041697	-97.547733
Fishing Harbor	0.2	25.981439	-97.337747
Bayview Detention Center	0.16	26.153822	-97.333753
Texas Pack	0.15	26.058442	-97.216283
Turning Basin	0.1	25.962572	-97.394667

Concentrated Animal Feeding Operations (CAFOs). CAFOs refers to any animal production facility, where animals are confined and fed for at least of 45 days, and in which the animal confinement areas do not sustain crops, vegetation, or post-harvest residues in the normal growing season over any portion of the facility (TCEQ, 2021c). Based on information shared by stakeholders, there was no presence of CAFOs within BSCW reason why, this PS was not included in the study.

Non-point Source (NPS). NPS of pollution are generally the result from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and ground waters (USEPA, 2021). NPS utilized to model using SELECT are described below.

Cattle. Studies conducted in Texas, (S. Glenn et al., 2017; A. Teague et al., 2009), had agreed that main land surfaces where cattle are concentrated are grassland/pasture and scrub/shrub. According to (USDA, 2017b), the number of cows and calves at Cameron County was 8,893, and 13,401 respectively, giving a grand total of 22,994 heads of cattle. By knowing the grand total of cattle in Cameron County in addition to conducting a spatial analysis using the land use dataset to compare the total area of grassland/pasture and scrub/shrub within Cameron County, and the total area of the same land uses within BSCW, it was determined that there are 0.3 cattle per acre in BSCW. The grand total of heads of cattle per subwatershed came from multiplying 0.3 for the total grassland/pasture and scrub/shrub areas per subwatershed. Finally, the potential E. Coli daily load came from following the mathematical analysis in Table 22.

Sheep and Goats. The estimated populations were 2,331 goats and 1,221 sheep (USDA, 2017a, 2017d). Same as cattle, the population of sheep and goats was distributed uniformly on shrub/scrub and grassland/herbaceous lands (S. Glenn et al., 2017). With the grand total number of sheep and goats along with the comparison of the total land surface for horses in Cameron County against the land surface for horses in BSCW, it was determined that there are 0.04 sheep per acre within BSCW. . Number of sheep and goats per subwatershed came from multiplying 0.04 for the area, in acres, of each subwatershed. The potential E. Coli daily load discharged was calculated by following the mathematical operation described in Table 22.

Horses. Similar to cattle, horse's main habitat was set to be grassland/herbaceous and shrub/scrub according to (S. Glenn et al., 2017). According to the agricultural census conducted by (USDA, 2017c), the total inventory of horses and ponies within Cameron County was 1,654, with this number and by comparing the total land surface for horses in Cameron County against the land surface for horses in BSCW, it was determined that there are 0.03 horses per acre at BSCW. To calculate horses per subwatershed it was necessary to multiply 0.03 for the area, in acres, of each subwatershed. The potential E. Coli daily load discharged was calculated by following the mathematical operation described in Table 22.

Feral Hogs. There are no direct measurements of feral hog density in Texas (S. Glenn et al., 2017), however, studies developed in Texas, (Timmons et al., 2012), estimate a feral hog density of 16.4 hogs/square mile, a value applicable for land use categories such as, grassland/pasture, scrub/shrub, mixed forest/forested wetland, and cultivated crops, additionally, a density of 50.7 acres per hog was applied to the remaining watershed land use categories (S. Glenn et al., 2017). The mathematical procedure to estimate the potential daily E. Coli load from feral hogs is shown in Table 22.

Dogs. From the many pets kept by owners in BSCW, only dogs were considered to contribute to urban pet waste. According to (AVMA, 2018b; A. E. Teague, 2007), dogs are the most common pets in Texas with an average of 0.58 dogs per household (AVMA, 2018a). Based on (Rio Grande Valley Stormwater Management, 2021), BSCW has a population of approximately 350,000 people while the average persons per household in Texas was of 3.3

persons per household (Census Bureau, 2021), the total number of households was assumed as 106,058. Habitat of dogs was assumed to be on human settlements found from the land use dataset. Population of dogs was calculated by multiplying the number of households by the average number of dogs per household, giving as a result 61,514 dogs in BSCW. The procedure to estimate potential daily E. Coli loads from dogs is shown in Table 22.

Deer. Studies conducted in the Lower Rio Grande Valley, with BSCW included, had stated that deer density in this region is of 3.21 deer per km^2 (Miranda & Harper, 2017), this study also remarked that suitable habitats for deer are grassland/pasture, scrub/shrub, cultivated crops, and wetlands. The mathematical procedure to estimate the potential daily E. Coli load from deer is shown in Table 22

Table 22. Calculation of potential E. Coli loads from various sources. Source: (Borel et al., 2012).

Source	E. Coli Load Calculation
Cattle	$EC = \#Cattle * 10^{10}\,\frac{cfu}{day} * 0.5$[a]
Horses	$EC = \#Horses * 4.2 * 10^{8}\,\frac{cfu}{day} * 0.5$[a]
Sheep and goats	$EC = \#Sheep * 1.2 * 10^{10}\,\frac{cfu}{day} * 0.5$[a]
CAFOs	$EC = \#Permitted\ Head * 10 * 10^{10}\,\frac{cfu}{day} * 0.2 * 0.5$[a]
Deer	$EC = \#Deer * 3.5 * \ 10^{8}\,\frac{cfu}{day} * 0.5$[a]
Feral hogs	$EC = \#Hogs * 1.10^{9}\,\frac{cfu}{day} * 0.5$[a]
Dogs	$EC = \#Dogs * 5 * 10^{9}\,\frac{cfu}{day} * 0.5$[a]
OWTSs	$EC = \#OWTSs * Failure\ Rate * \frac{10*10^{6}\ cfu}{100\ mL} * \frac{60\ gal}{\frac{person}{day}} * \frac{People}{Household} * \frac{3758.2\ mL}{gal} * 0.5$[a]
WWTFs	$EC = \#Permitted\ MGD * \frac{126\ cfu}{100\ mL} * \frac{10^{6}\ gal}{MGD} * \frac{3758.2\ mL}{gal}$

[a] Fecal coliform to E. Coli conversion factor using (Doyle & Erickson, 2006) rule of thumb estimating 50% coliform is E. Coli.

Limitations

When applying SELECT, the population densities of potential contributors are determined using stakeholder input to accurately represent the watershed (Borel et al., 2012). Due to time and COVID-19 restrictions, results from this study were not exhibited to the stakeholder group to receive their feedback. Future SELECT implementations at BSCW should discuss their findings with the stakeholder to make the proper modifications if needed.

Results

Land Uses per Sub-watershed

Subwatershed 1. With a surface area of 34,399 acres, subwatershed 1 is mainly occupied by cultivated crops, population, pasture/hay, and shrub/scrub.

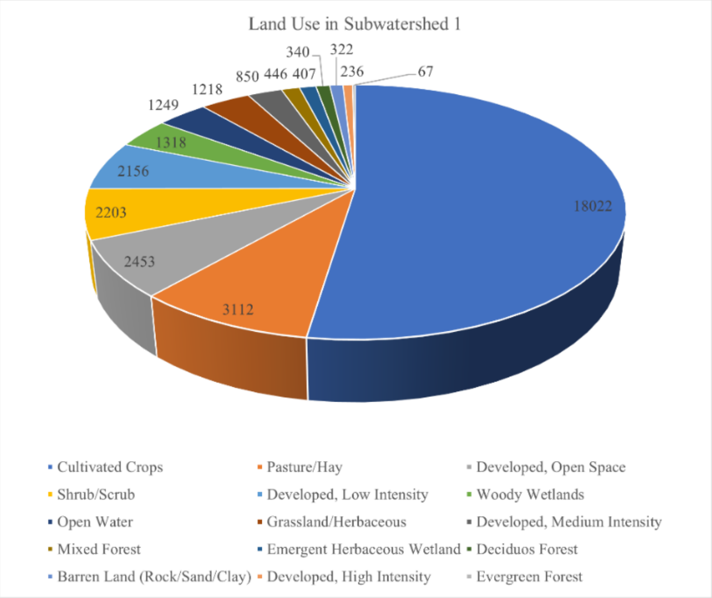


Figure 45. Land use areas expressed in acres at subwatershed 1. Predominant land use is cultivated crops, covering 52.39% of the surface.

Subwatershed 2. With a surface area of 21,985 acres, subwatershed 2 is mainly occupied by cultivated crops, human settlements, and pasture/hay.

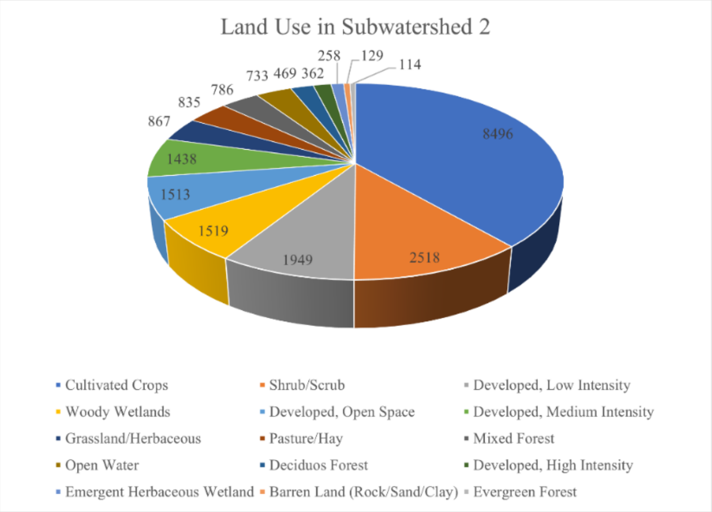


Figure 46. Land use areas expressed in acres at subwatershed 2. Predominant land use is cultivated crops covering 38.64% of the surface.

Subwatershed 3. With a surface area of 37,553 acres, subwatershed 3 is mainly occupied by human settlements, cultivated crops, and emergent herbaceous wetlands, the rest of the land uses as well as their areas are shown in Figure 47.

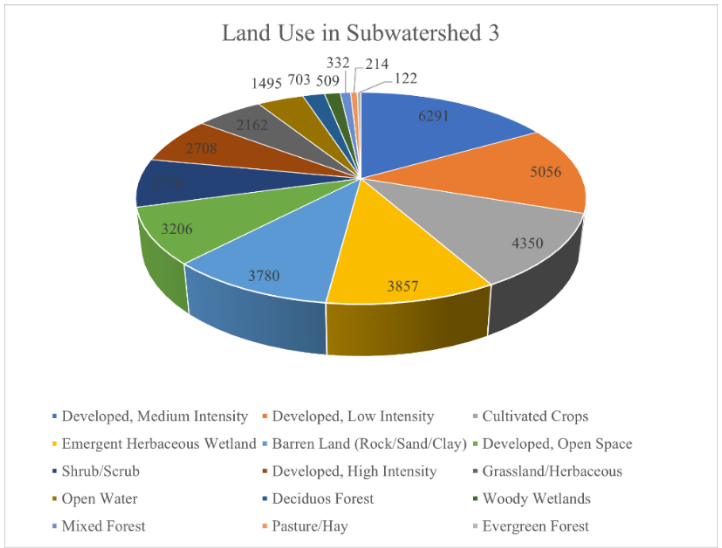


Figure 47. Land Use areas expressed in acres at subwatershed 3. Predominant land use is human settlements (medium, and low intensity) covering 30.21% of the surface.

Subwatershed 4. With a surface area of 16,073 acres, subwatershed 4 is mainly occupied by human settlements, cultivated crops, and emergent herbaceous wetlands, the rest of the land uses as well as their areas are shown in Figure 48.

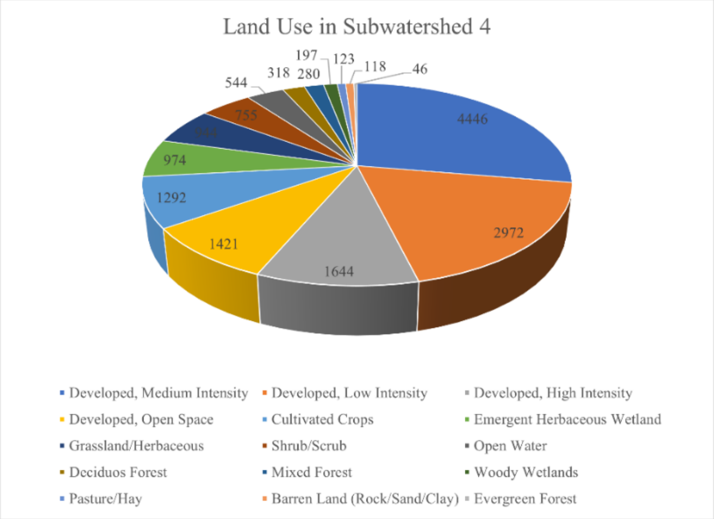


Figure 48. Land use areas expressed in acres at subwatershed 4. Predominant land use is human settlements (medium, low, and high intensity) covering 56.38% of the surface.

Subwatershed 5. With a surface area of 43,332 acres, subwatershed 5 is mainly occupied by emergent herbaceous wetlands, cultivated crops, and shrub/scrub, the rest of the land uses as well as their areas are shown in Figure 49

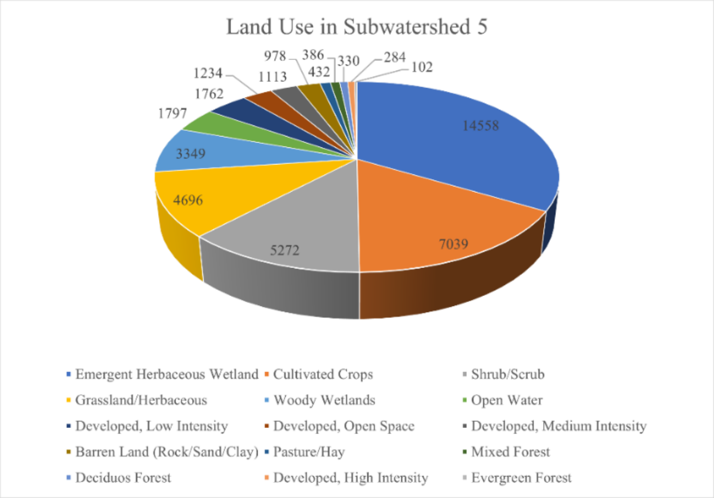


Figure 49. Land use areas expressed in acres at subwatershed 5. Predominant land use is emergent herbaceous wetlands covering 33.60% of the surface.

Subwatershed 6. With a surface area of 11,800 acres, subwatershed 6 is mainly occupied by emergent herbaceous wetlands, open water, and shrub/scrub, the rest of the land uses as well as their areas are shown in Figure 50.

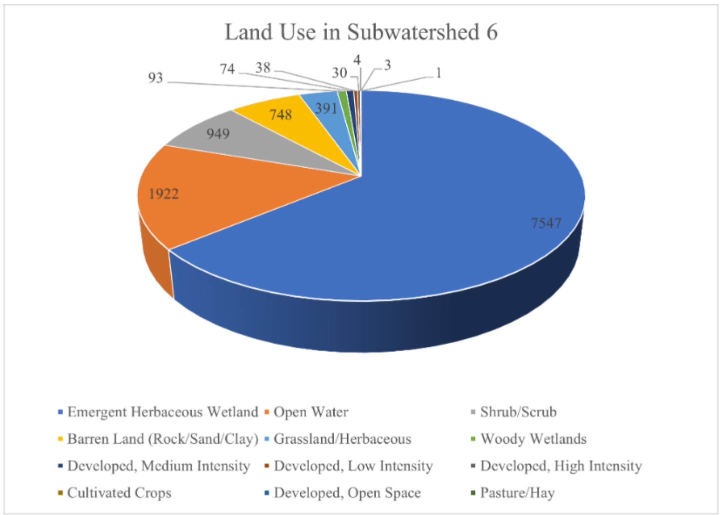


Figure 50. Land use areas expressed in acres at subwatershed 6. Predominant land use is emergent herbaceous wetlands covering 63.96% of the surface.

Subwatershed 7. With a surface area of 482 acres, subwatershed 7 is mainly occupied by open water, barren land, and shrub/scrub, the rest of the land uses as well as their areas are shown in Figure 51.

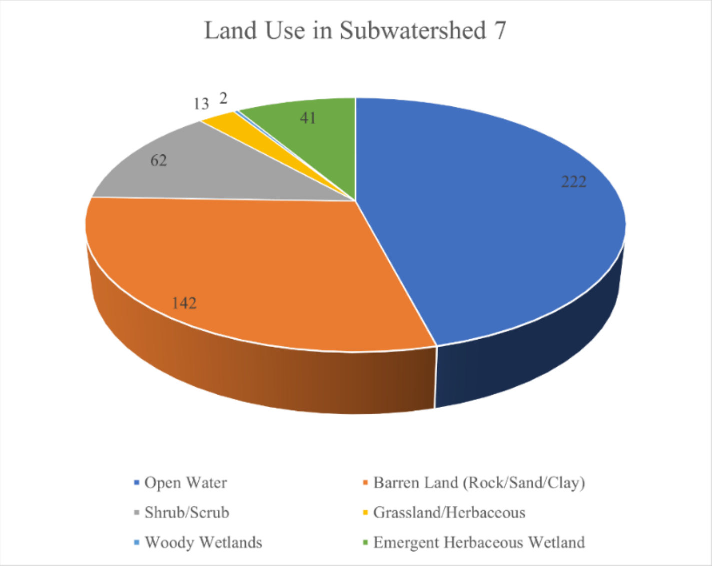


Figure 51. Land use areas expressed in acres at subwatershed 7, mainly open water covering 45.96% of the surface.

Subwatershed 8. With a surface area of 30,508 acres, subwatershed 8 is mainly occupied by emergent herbaceous wetland, open water, and shrub/scrub, the rest of the land uses along with their areas are shown in Figure 52.

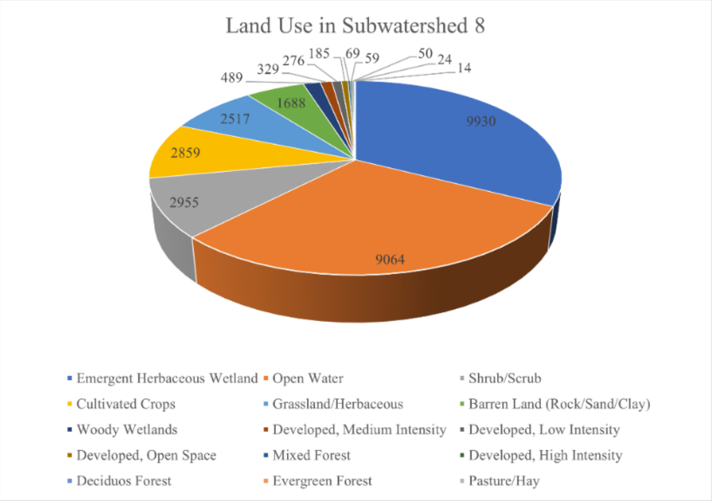


Figure 52. Land use areas expressed in acres at subwatershed 8. Predominant land use is emergent herbaceous wetland covering 32.55% of the surface.

Subwatershed 9. With a surface area of 25,913 acres, subwatershed 9 is mainly occupied by open water, emergent herbaceous wetland, and barren land, the rest of the land uses along with their areas are shown in Figure 53.

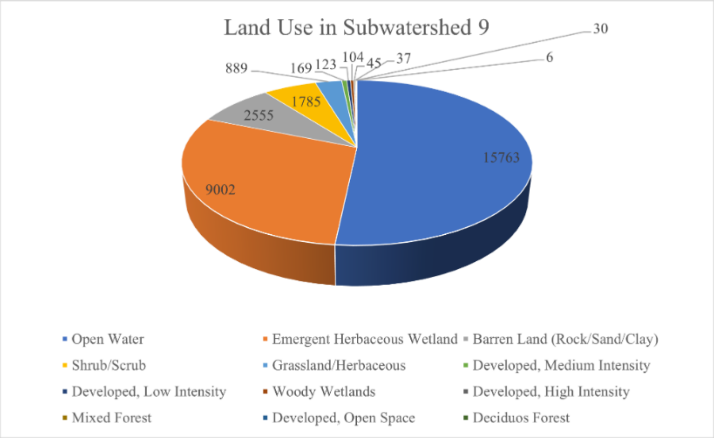


Figure 53. Land use areas at subwatershed 9 expressed in acres. Predominant land use is open water covering 51.67% of the surface.

Subwatershed 10. With a surface area of 3,010 acres, subwatershed 10 is mainly occupied by open water, emergent herbaceous wetland, and barren land, the rest of the land uses along with their areas are shown in Figure 54

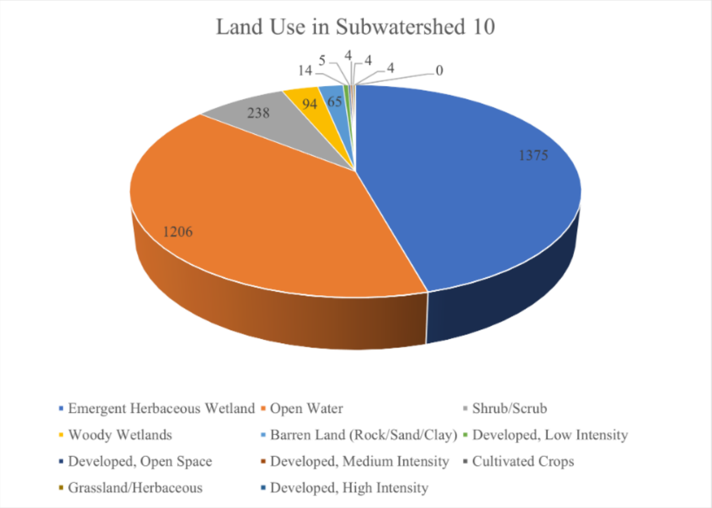


Figure 54. Land use areas at subwatershed 10 expressed in acres. Predominant land use is emergent herbaceous wetland covering 45.69% of the surface.

Subwatershed 11. With a surface area of 3,269 acres, subwatershed 11 is mainly occupied by open water, emergent herbaceous wetland, and shrub/scrub, the rest of the land uses along with their areas are shown in Figure 55.

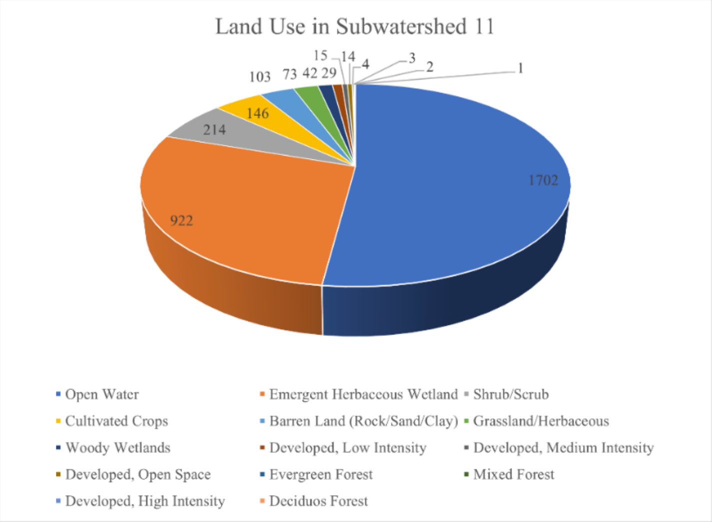


Figure 55. Land use areas at subwatershed 11 expressed in acres. Predominant land use is open water covering 52.06% of the surface.

Subwatershed 12. With a surface area of 5,030 acres, subwatershed 12 is mainly occupied by open water, emergent herbaceous wetland, and cultivated crops, the rest of the land uses along with their areas are shown in Figure 56.

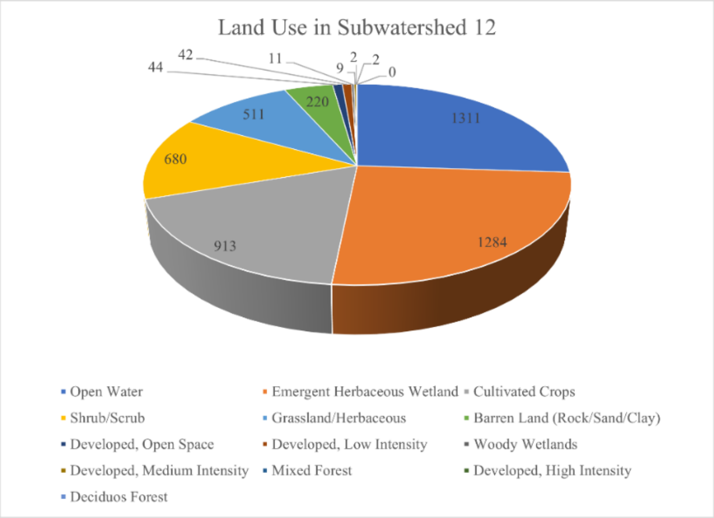


Figure 56. Land use areas at subwatershed 12 expressed in acres. Predominant land uses are open water, and emergent herbaceous wetland covering 26.05% and 25.53% respectively.

Subwatershed 13. With a surface area of 14,914 acres, subwatershed 13 is mainly occupied by emergent herbaceous wetland, cultivated crops, and shrub/scrub, the rest of the land uses along with their areas are shown in Figure 57.

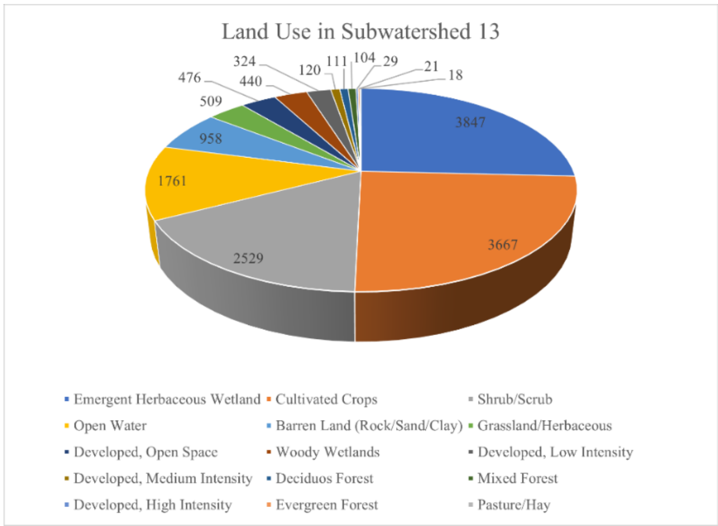


Figure 57. Land use areas at subwatershed 14 expressed in acres. Predominant land uses are emergent herbaceous wetland, and cultivated crops covering 25.80%, and 24.59% respectively.

Subwatershed 14. With a surface area of 10,126 acres, subwatershed 14 is mainly occupied by emergent herbaceous wetland, shrub/scrub, and grassland/herbaceous, the rest of the land uses along with their areas are shown in Figure 58

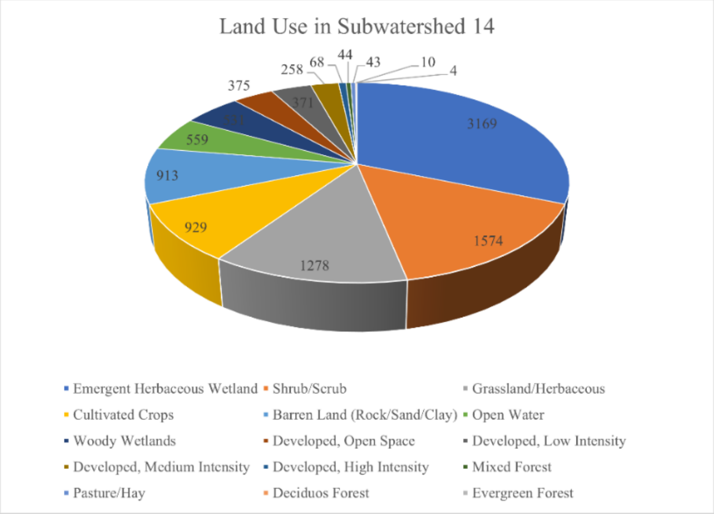


Figure 58. Land use areas at subwatershed 14 expressed in acres. Predominant land use is emergent herbaceous wetland covering 31.30% of the surface.

Daily Potential E. Coli Loads from Point Sources

On-site Sewage Facilities (OSFFs). Ten out of the fourteen sub-watersheds were found to have presence of OSSFs, from results listed in Table 23 was found that subwatershed 3 had the largest number of septic tanks therefore, the largest E. Coli daily load, 1.40E+12 $\frac{cfu}{day}$. On the other hand, subwatershed 6 had the lowest contribution, 5.58 E+09 $\frac{cfu}{day}$. In general terms, the average potential E. Coli daily load in BSCW was of 1.74E+13 $\frac{cfu}{day}$. Figure 59 is a map generated with GIS software that illustrates potential E. Coli daily loads discharged per subwatershed, yellow watersheds had the lowest discharges, those in orange an intermediate discharge, and in red are the sub-watersheds with the largest potential daily loads.

Table 23. Potential E. Coli daily loads expressed in ($\frac{\text{cfu}}{\text{day}}$), discharged by OSSFs

Subwatershed	Potential E. Coli daily load ($\frac{\text{cfu}}{\text{day}}$)
1	5.97E+11
2	1.40E+12
3	1.26E+14
4	3.42E+13
5	3.01E+11
6	5.58E+09
7	0.00E+00
8	4.75E+12
9	6.18E+11
10	0.00E+00
11	0.00E+00
12	0.00E+00
13	8.37E+11
14	5.20E+12

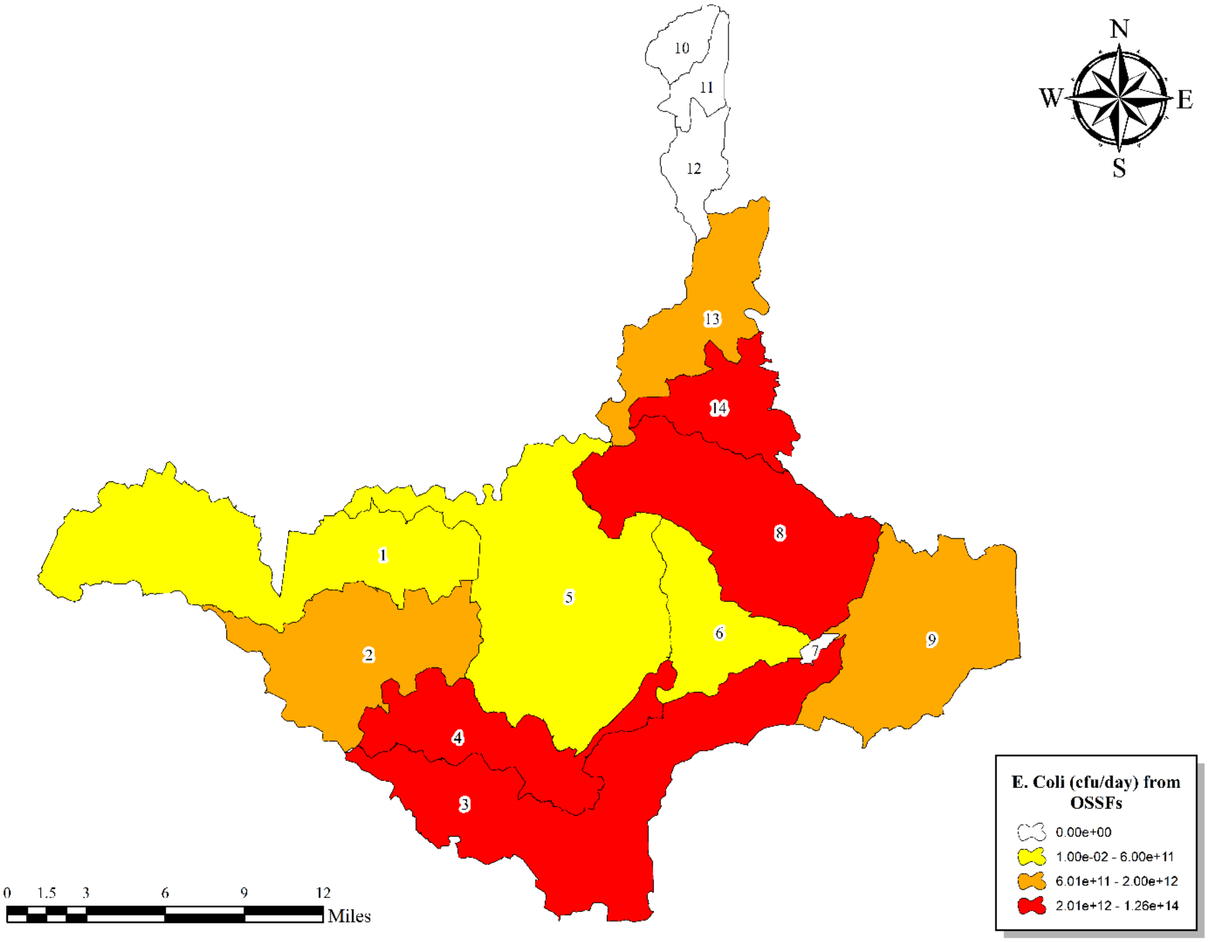


Figure 59. Average daily potential E. coli load in BSCW resulting from OSSFs.

WWTFs. Seven of the fourteen sub-watersheds had WWTFs within them, once daily discharges of E. Coli were calculated, WWTFs within BSCW were addressed to determine which sub-watersheds received discharges, where necessary, integrate the results of sub-watersheds receiving loads from more than one WWTF. Results from this procedure are listed in Table 24. Using GIS software, Figure 60 was created to illustrate potential E. Coli daily loads discharged by WWTFs, in yellow are the lowest loads while those in red represent the largest potential E. Coli daily loads.

Table 24. Total potential E. Coli daily load expressed in ($\frac{cfu}{day}$) discharged per sub-watershed.

Subwatershed	Potential E. Coli daily load ($\frac{cfu}{day}$)
1	6.63E+09
2	5.09E+10
3	9.47E+10
4	9.52E+10
5	-
6	9.47E+08
7	-
8	5.21E+09
9	1.30E+10
10	-
11	-
12	-
13	-
14	3.84E+09

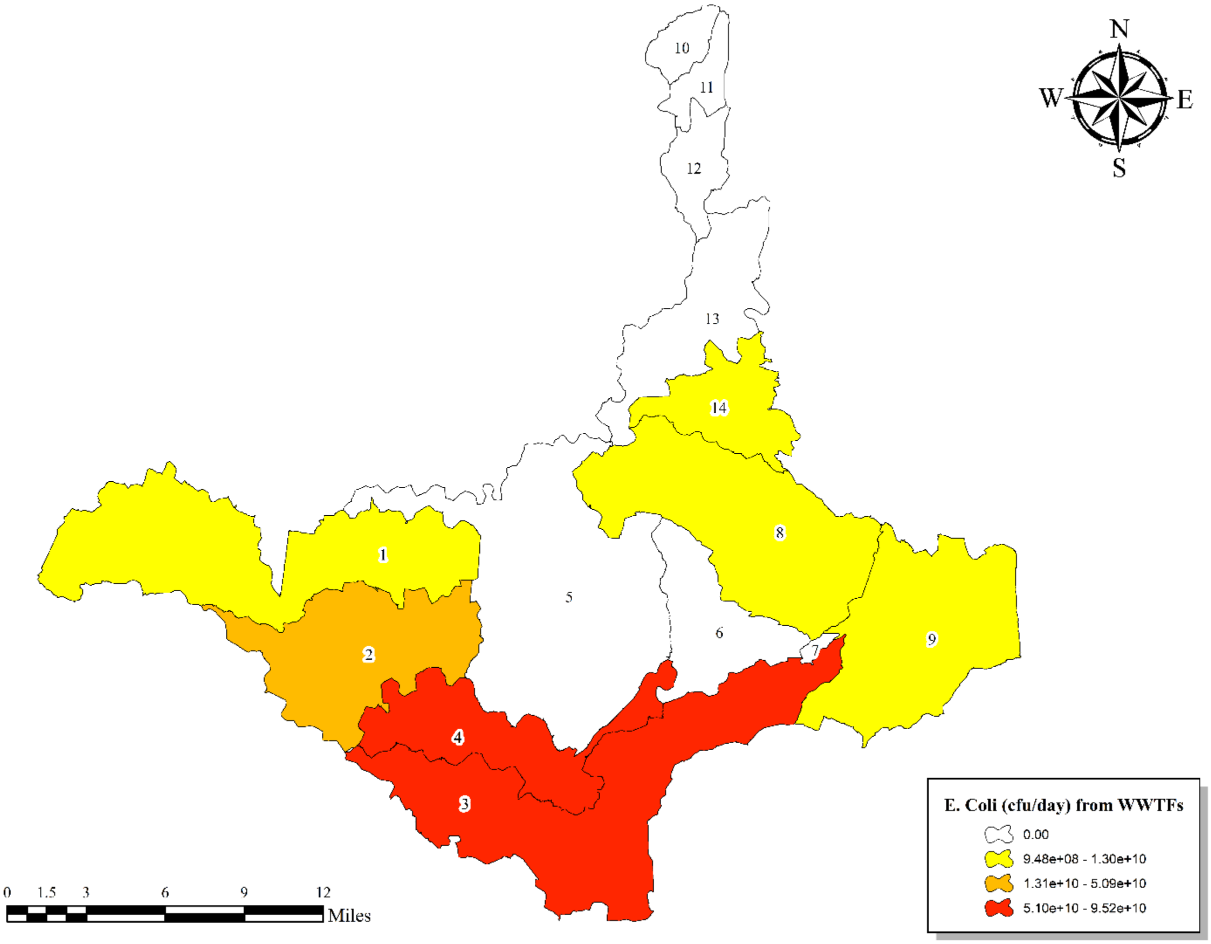


Figure 60. Average daily potential E. Coli load in BSCW resulting from WWTFs.

Daily Potential E. Coli Daily Load from Non-Point Sources

Cattle. Potential E. Coli daily loads are higher in those areas with more heads of cattle, findings from this study revealed that subwatershed 5 discharges the largest E. Coli daily load, 4.82E+13 $\frac{cfu}{day}$ while subwatershed 7 discharges the lowest daily load of E. Coli, 1.05E+12 $\frac{cfu}{day}$. Table 25 lists all potential E. Coli daily loads discharged per subwatershed along with the calculated heads of cattle, the average potential E. Coli daily load at BSCW is 4.08E+13 $\frac{cfu}{day}$. Figure 61 is a map generated to illustrate potential E. Coli daily loads discharged per subwatershed, yellow watersheds had the lowest discharges, those in orange an intermediate discharge, and in red are the sub-watersheds with the largest daily discharges.

Table 25. Heads of cattle per subwatershed along with their potential E. Coli daily load.

Subwatershed	Heads of cattle	Potential E. Coli daily load ($\frac{\mathrm{cfu}}{\mathrm{day}}$)
1	963	4.82E+13
2	953	4.77E+13
3	1388	6.94E+13
4	479	2.40E+13
5	2806	1.40E+14
6	377	1.89E+13
7	21	1.05E+12
8	1541	7.71E+13
9	752	3.76E+13
10	68	3.40E+12
11	81	4.05E+12
12	335	1.68E+13
13	855	4.28E+13
14	803	4.02E+13

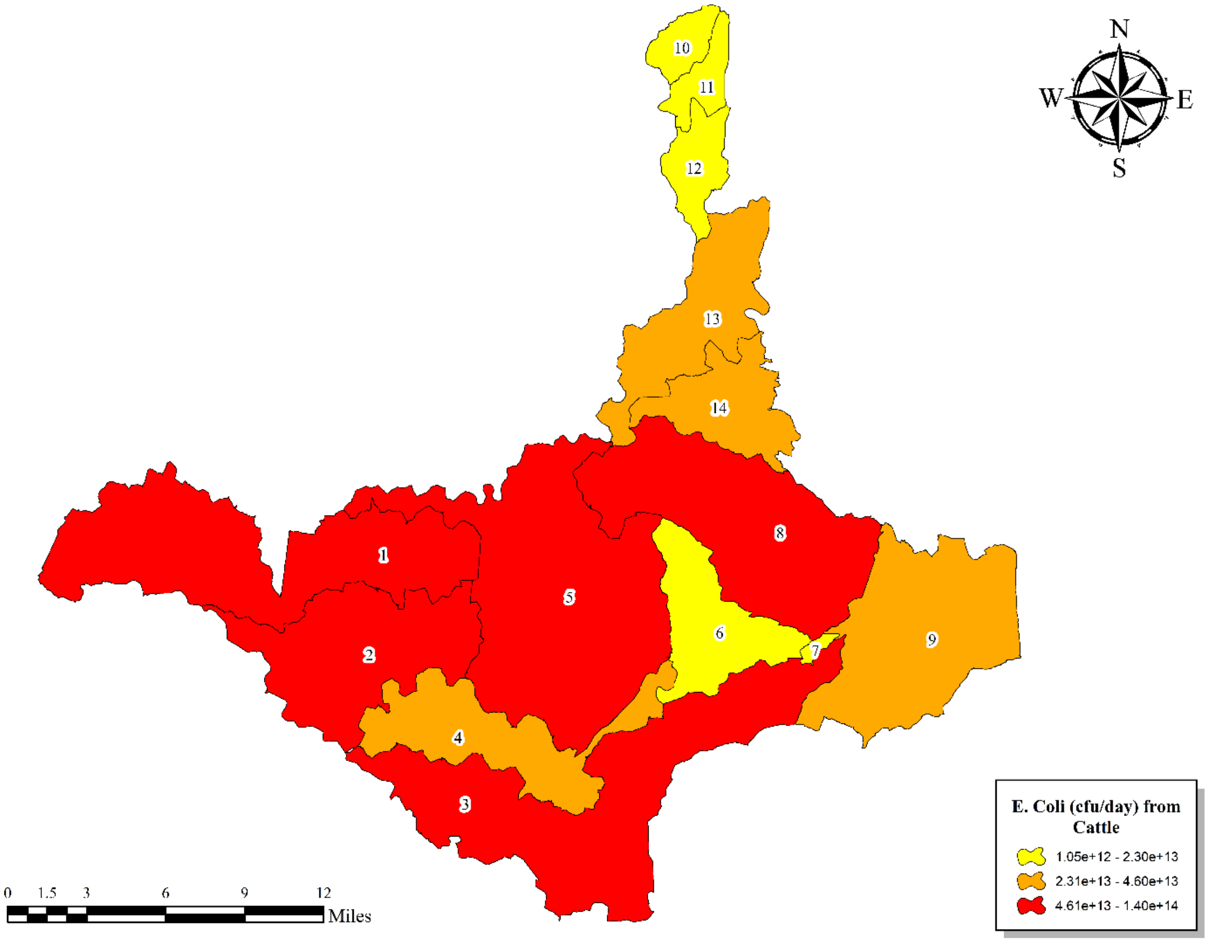


Figure 61. Average daily potential E. coli load in BSCW resulting from cattle.

Sheep and Goats. Results shown in Table 26obtained indicate that subwatershed 5 discharges the largest potential E. Coli daily load, 2.68E+12 $\frac{\text{cfu}}{\text{day}}$., on the other hand, the subwatershed 7 discharges the lowest potential daily load, 2.40E+10 $\frac{\text{cfu}}{\text{day}}$. The average daily load found at BSCW was 7.81E+11. Figure 62 is a map generated with GIS software that illustrates potential E. Coli daily loads discharged per subwatershed, yellow watersheds had the lowest discharges, those in orange an intermediate discharge, and in red are the sub-watersheds with the largest daily discharges.

Table 26. Sheep ang goats per subwatershed along with their potential E. Coli daily load.

Subwatershed	Sheep and Goats	Potential E. Coli daily load ($\frac{\text{cfu}}{\text{day}}$)
1	154	9.24E+11
2	152	9.12E+11
3	221	1.33E+12
4	76	4.56E+11
5	447	2.68E+12
6	61	3.66E+11
7	4	2.40E+10
8	246	1.48E+12
9	120	7.20E+11
10	11	6.60E+10
11	13	7.80E+10
12	53	3.18E+11
13	136	8.16E+11
14	128	7.68E+11

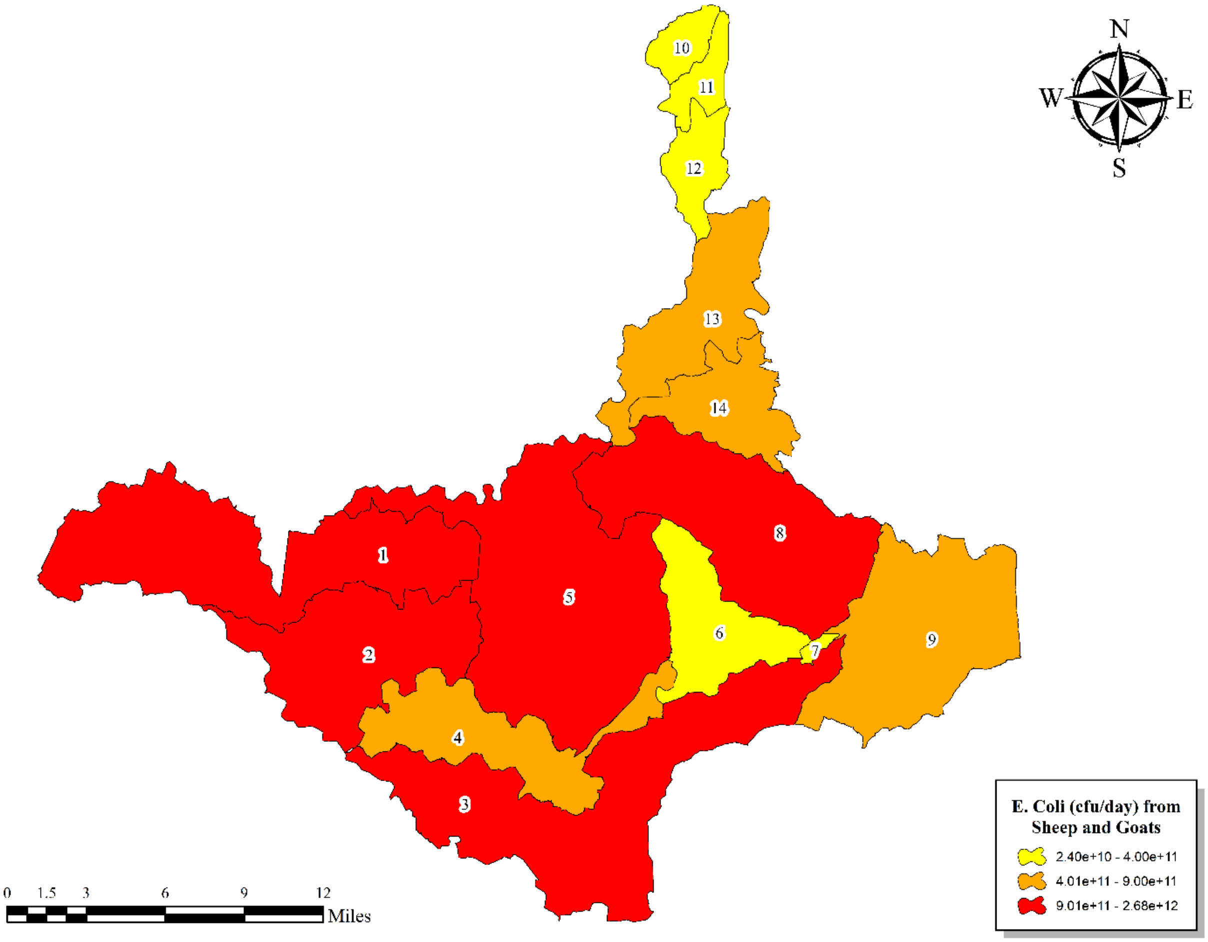


Figure 62. Average daily potential E. coli load in BSCW resulting from sheep and goats.

Horses. Findings from this study revealed that sub-watersheds 5, 8, 3, 1 and 2 discharge the largest amount of E. Coli loads as they concentrate the largest grassland, and shrub areas within BSCW. On the other hand, sub-watersheds 6, 12, 11, 10, and 7 discharge the lowest daily loads due to their lower grassland, and shrub areas. All potential E. Coli daily loads calculated are listed in Table 27 that also include the number of horses per subwatershed. The average potential daily E. Coli load from horses was 1.27E+10. As the number of horses within the watershed is relatively small, the ecological impact was lower compared with other pollutant sources such as cattle or WWTFs. Figure 63 is a map generated to illustrate potential E. Coli daily loads discharged per subwatershed, yellow watersheds had the lowest discharges, those in orange an intermediate discharge, and in red are the sub-watersheds with the largest potential daily discharges.

Table 27. Horses per subwatershed along with their potential E. Coli daily load.

Subwatershed	Horses	Potential E. Coli daily load $(\frac{\text{cfu}}{\text{day}})$
1	71	1.49E+10
2	71	1.49 E+10
3	103	2.16 E+10
4	36	7.56 E+09
5	208	4.37 E+10
6	28	5.88 E+09
7	1	2.10 E+08
8	115	2.42 E+10
9	56	1.18 E+10
10	5	1.05 E+09
11	6	1.26 E+09
12	25	5.25 E+09
13	64	1.34 E+10
14	60	1.26 E+10

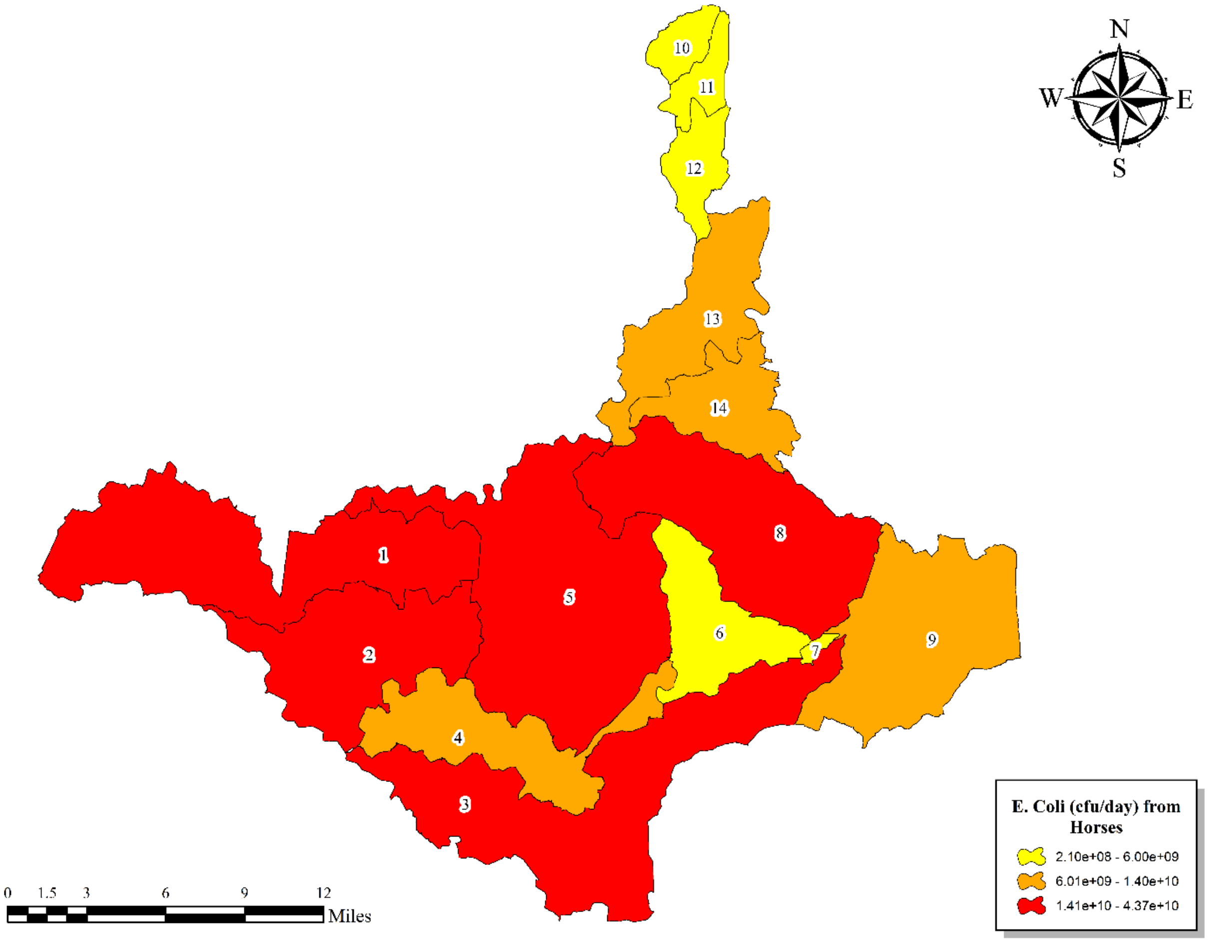


Figure 63. Average daily potential E. coli load in BSCW resulting from horses.

Feral Hogs. In total, the feral hog population was estimated to be of 4,950 within BSCW. As shown in Table 28, subwatershed 5, had the largest population of feral hogs producing a daily E. Coli load of $5.01E+12\,\frac{\text{cfu}}{\text{day}}$ while subwatershed 7, had the lowest population of feral hogs producing E. Coli daily loads of $3.30E+10\,\frac{\text{cfu}}{\text{day}}$. The average potential daily load was $1.94E+10\,\frac{\text{cfu}}{\text{day}}$. The map shown in Figure 64 was generated combining GIS software and calculations previously commented, sub-watersheds in yellow have the lowest loads while those in red discharge the highest E. Coli daily loads.

Table 28. Estimate population of feral hogs at each sub-watershed based along with their potential E. Coli daily load contribution.

Subwatershed	Feral Hogs	E. Coli daily load ($\frac{\text{cfu}}{\text{day}}$)
1	804	4.42E+12
2	498	2.74E+12
3	768	4.22E+12
4	325	1.79E+12
5	911	5.01E+12
6	203	1.12E+12
7	6	3.30E+10
8	472	2.60E+12
9	307	1.69E+12
10	36	1.98E+11
11	33	1.82E+11
12	84	4.62E+11
13	299	1.64E+12
14	204	1.12E+12
Total:	4950	2.72E+13

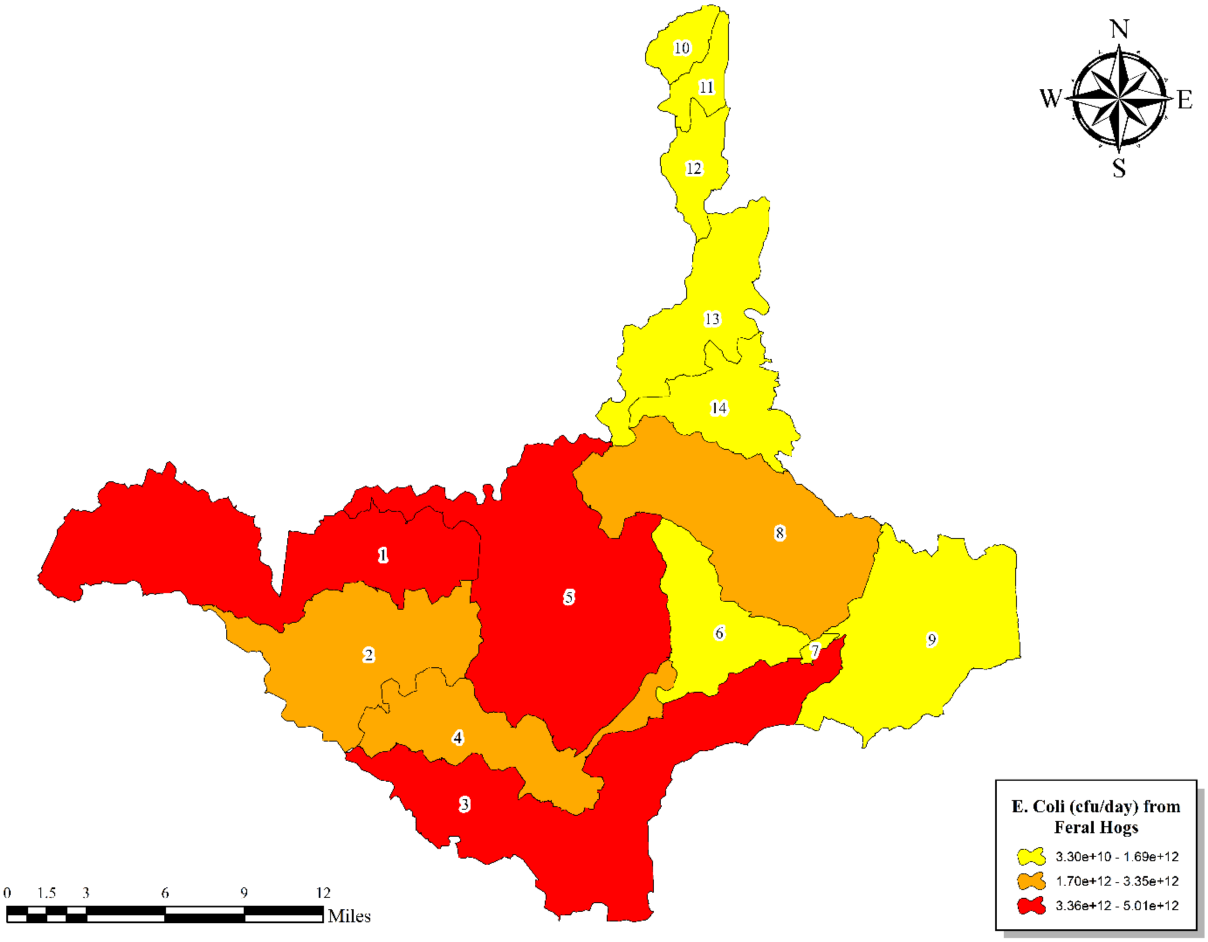


Figure 64. Average daily potential E. coli load in BSCW resulting from feral hogs.

Dogs. Calculation of dogs' population is tied to human settlements as the estimation comes from multiplying dogs per household therefore, subwatershed 7, with no human settlements, resulted with no potential E. Coli daily loads while, sub-watersheds 1, 2, 3 4, and 5, resulted with the highest potential E. Coli daily loads as those sub-watersheds concentrate the largest amount of habitants. The average potential E. Coli daily load at BSCW due to dogs was of 1.10E+13 $\frac{\text{cfu}}{\text{day}}$. All results from mathematical analysis are displayed in Table 29.

Table 29. Calculation of dogs' population, and potential E. Coli daily loads in $\frac{\text{cfu}}{\text{day}}$ from dogs at each subwatershed.

Subwatershed	Dogs' population	Potential E. Coli Daily Load ($\frac{\text{cfu}}{\text{day}}$)
1	7510	1.88E+13
2	6936	1.73E+13
3	22757	5.69E+13
4	13821	3.46E+13
5	5791	1.45E+13
6	192	4.80E+11
7	-*	0.00E+00*
8	1120	2.80E+12
9	483	1.21E+12
10	32	8.00E+10
11	79	1.98E+11
12	128	3.20E+11
13	1251	3.13E+12
14	1414	3.54E+12
Total:	61514	1.10E+13

*Population of dogs and E. Coli daily potential loads were estimated based on human settlements assessed from the land cover dataset, subwatershed 7 did not have human settlements therefore, no approach was conducted.

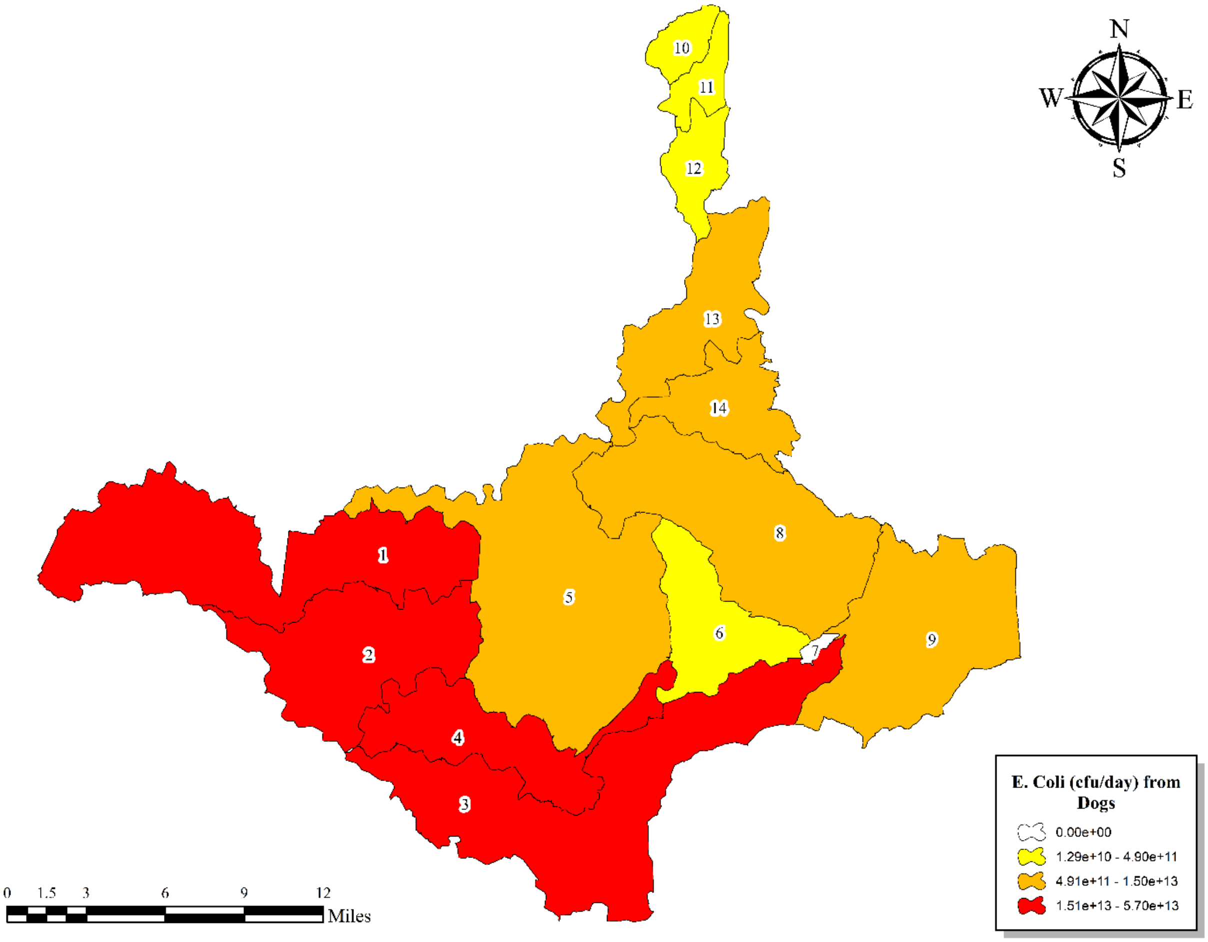


Figure 65. Average daily potential E. coli load in BSCW resulting from dogs.

Deer. Potential E. Coli daily loads contributed by deer are displayed in Table 30, results indicate that subwatershed 1 has the largest daily contribution of E. Coli with a total of 6.95E+10 $\frac{cfu}{day}$ while subwatershed 7 discharges the potential E. Coli daily load, 2.10E+8 $\frac{cfu}{day}$. The average potential E. Coli daily load discharged in BSCW was 1.76E+10 $\frac{cfu}{day}$. Figure 66 is a map generated with GIS software that illustrates potential E. Coli daily loads discharged per subwatershed, yellow watersheds had the lowest discharges, those in orange an intermediate discharge, and in red are the sub-watersheds with the largest potential daily loads.

Table 30. Estimate population of deer at each sub-watershed, and the potential E. Coli daily loads produced by them.

Subwatershed	Deer	E. Coli daily load ($\frac{\text{cfu}}{\text{day}}$)
1	331	6.95E+10
2	175	3.68E+10
3	128	2.69E+10
4	45	9.45E+09
5	171	3.59E+10
6	17	3.57E+09
7	1	2.10E+08
8	109	2.29E+10
9	35	7.35E+09
10	3	6.30E+08
11	6	1.26E+09
12	28	5.88E+09
13	89	1.87E+10
14	38	7.98E+09

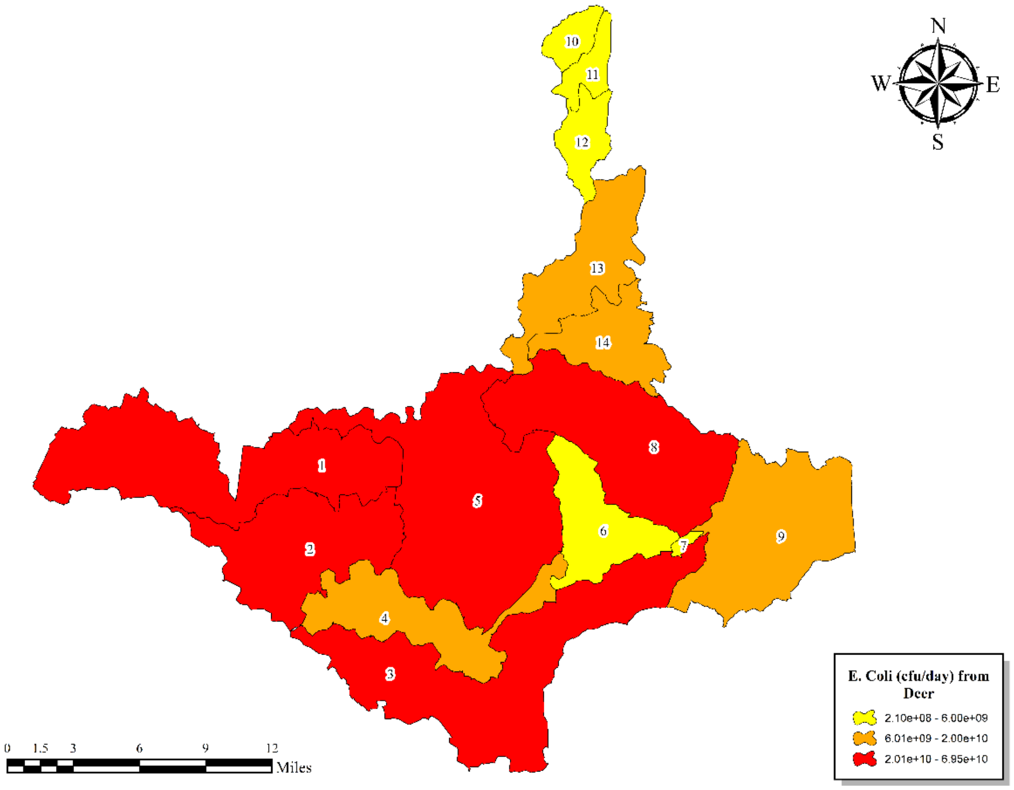


Figure 66. Average daily potential E. coli load in BSCW resulting from deer.

Daily Potential E. Coli Daily Load From All Sources

Potential E. Coli daily load from PS and NPS assessed in this study were combined into one to address the total discharge per subwatershed. Results from this analysis are shown in Table 31, revealing that sub-watershed 3 contributes the largest potential E. Coli daily load, 2.58E+14 $\frac{cfu}{day}$ followed by sub-watersheds 5, 4, 8, and 1. On the other hand, subwatershed 7 contributes the lowest potential E. Coli daily load, 1.11E+12 $\frac{cfu}{day}$, preceded by sub-watersheds 10, 11, 12, and 6. Figure 67 is a map showing the total E. Coli daily loads per subwatershed, yellow watersheds had the lowest discharges, those in orange an intermediate discharge, and in red are the sub-watersheds with the largest potential daily loads. Figure 68 is a map showing major sources of E. Coli daily load per subwatershed with a pie chart.

Table 31.Total contribution of E. Coli daily loads from PS and NPS.

Subwatershed	Total E. Coli daily load from all sources ($\frac{\mathrm{cfu}}{\mathrm{day}}$)
1	7.30E+13
2	7.01E+13
3	2.58E+14
4	9.52E+13
5	1.63E+14
6	2.08E+13
7	1.11E+12
8	8.87E+13
9	4.19E+13
10	3.75E+12
11	4.51E+12
12	1.79E+13
13	4.93E+13
14	5.09E+13

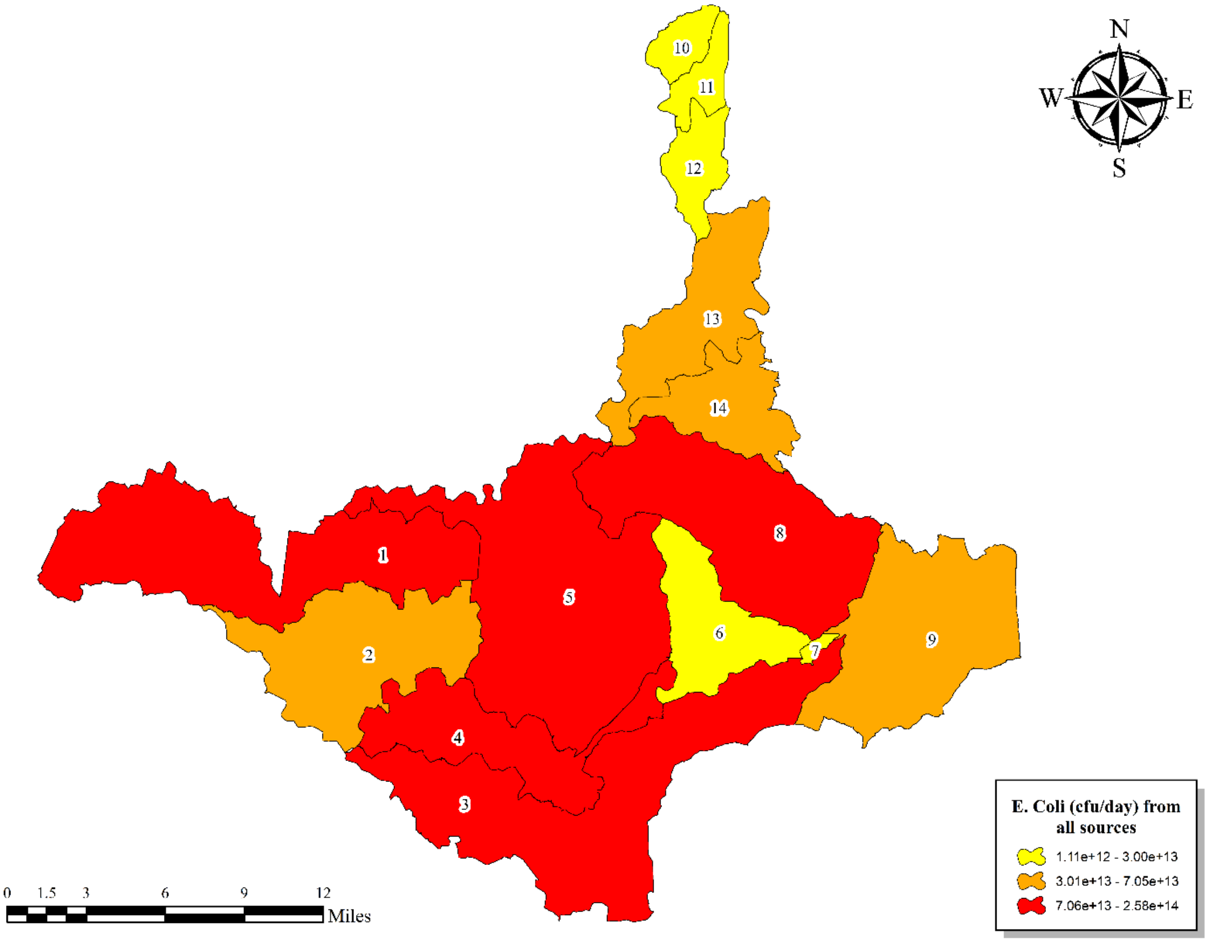


Figure 67. Potential E. Coli daily load contribution by subwatershed, all sources were to generate the map.

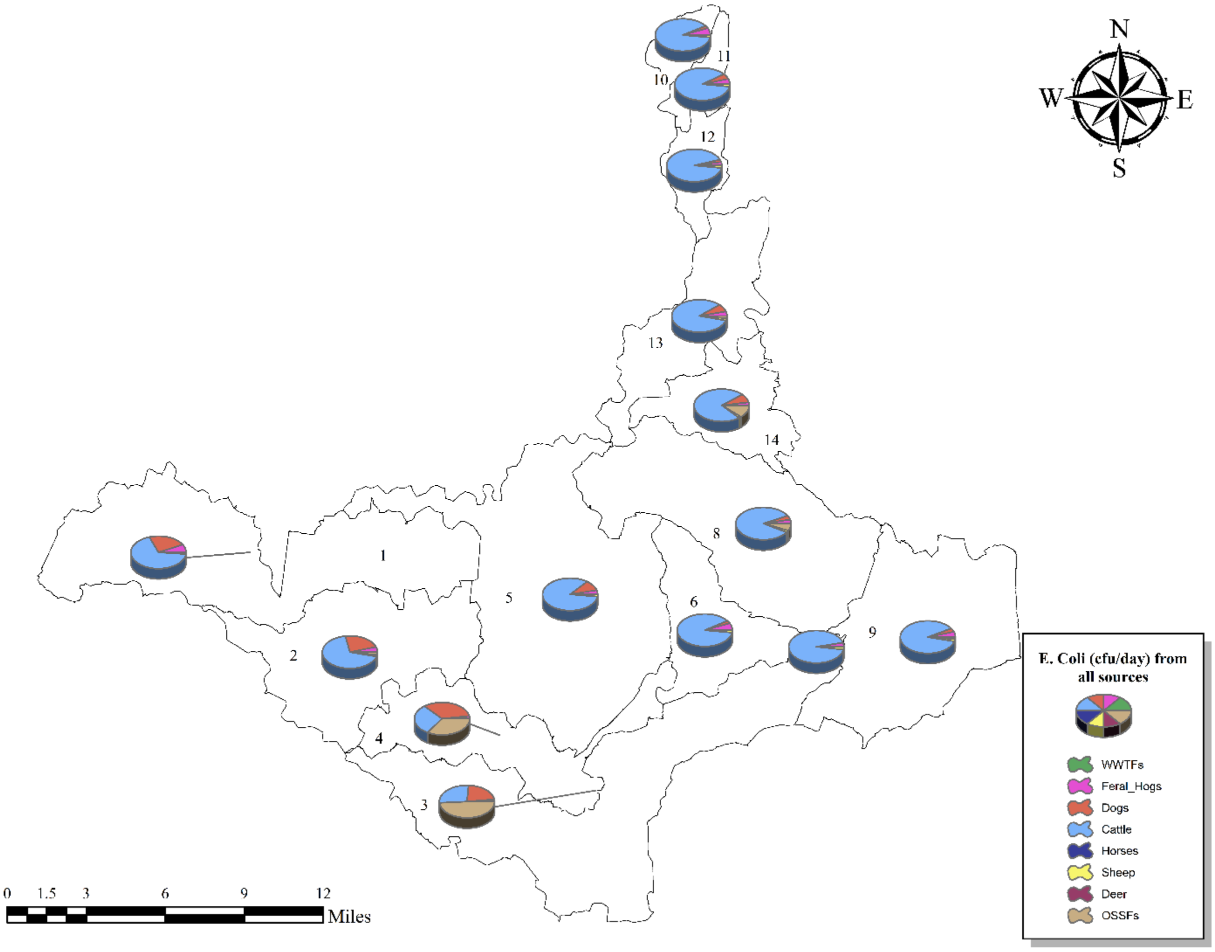


Figure 68. Total E. Coli daily load contribution by subwatershed. (Note that all sources were used in the total load calculations, but that the percent contribution of the total load for deer, goat, WWTFs, and horse were a minor portion of the overall load and therefore are not visible in the contribution pie charts).

Conclusions

From the land use analysis performed was found that BSCW is mainly compound by emergent herbaceous wetlands preceded by cultivated crops, and open water. Most of the human settlements are allocated within sub-watersheds 1, 2, 3, and 4 however, there are many neighborhoods distributed over BSCW.

In terms of NPS, 13 actively discharging WWTFs were identified over 7 sub-watersheds within BSCW, the largest contributions come from sub-watershed 3 and 4. On the other hand, OSSFs were distributed over 10 of the sub-watersheds, most of the OSSFs are concentrated at subwatershed 3 where the largest daily contribution of E. Coli was found.

From the SELECT model implementation was found that cattle are the major contributors of E. Coli daily loads in 12 out of 14 sub-watersheds. The sub-watershed that drains the largest potential E. Coli daily load is sub-watershed 5 draining 1.40E+14 $\frac{cfu}{day}$, the second largest contribution comes from subwatershed 8 with 7.70E+13 $\frac{cfu}{day}$.

Overall results indicated that major sources of E. Coli production within BSCW are cattle, OSSFs, dogs, and feral hogs, having a higher environmental impact if compared with the daily loads produced from WWTFs, sheep, horses, and deer.

Subwatershed 3 was found to be the area that drains the largest daily loads of E. Coli due to the largest contributions from OSSFs, cattle, and dogs, main land use in this subwatershed is destined to human settlements with no access to the sewage system, reason why it concentrates the largest number of septic tanks in the watershed. As the dog ownership is tied to human population, the estimated number of dogs in this subwatershed is one of the highest at BSCW. As expected, due to its size, subwatershed 7 drains the lowest potential E. Coli daily load as it has the smaller population of feral hogs, cattle, horses, sheep, and deer, as well as no presence of WWTFs, OSSFs, or dogs.

Results obtained from the SELECT model implementation will provide with scientifically supported arguments to the stakeholders, and policymakers in the region to take informed decisions that lead to the decrement of bacteriological loads within BSCW.

CHAPTER VI

GENERAL CONCLUSIONS

Observations at Ditch No. 2, monitored by station 22118, demonstrated that nitrate-nitrite daily loads met the criteria 70% of the times, exceedances were observed during high flows what suggests TKN contribution from NPS that need to be identified in future studies. On the other hand, bacteriological daily loads, along with TKN, and TP daily loads, always exceeded water quality standards during the eight sampling campaigns performed in this waterway. Results from SELECT model showed that subwatershed 5, where Ditch No. 2 is the main waterway, receives most of the E. Coli daily loads from NPS of pollution, specially from cattle, dogs, and feral hogs.

Ditch No. 1, monitored by station 22120, needs urgent attention as the maximum allowable daily load of bacteria, and all nutrients monitored, was always exceeded during the eight sampling campaigns performed in this study. From Load Duration Curve in Figure 34 was observed that E. Coli daily loads tend to be constant from mid to low flow conditions suggesting that point sources were constantly discharging into this waterway. This assumption was confirmed by results obtained from SELECT model in Table 23, and Table 24, showing that subwatershed 4, where Ditch No. 1 is located, receives the largest potential E. Coli daily loads from WWTFs and the second largest from OSSFs, both point sources that constantly contribute to Ditch No. 1, explaining the constant trend observed in Figure 34.

Results from LDC, in Figure 38, of Old Main Drain Ditch (OMDD), demonstrated that this waterway contributed the largest E. Coli daily loads to the BSC, this was reaffirmed by results in Figure 67, obtained from SELECT model, that indicated that subwatershed 3, where OMDD is the main waterway, receive the largest potential E. Coli daily load from all the 14 sub-watersheds. Cattle, and OSSFs were the main bacteriological sources within the subwatershed.

In terms of bacteriological daily loads, assumptions from results obtained in the LDCs were later confirmed by results observed from SELECT model.

The development of the LDCs was an effective selection to graphically present results from the daily loads of pollution observed during the sampling campaigns however, more direct data needs to be gathered. COVID-19 along with adverse road conditions, limited the number of observations made for this study however, this is an ongoing project, and more data will be collected by UTRGV to have a better understanding of the environmental situation within BSCW, graduate students of the Civil Engineering Department will continue monitoring the three waterways that drain into the BSC to update the LDCs with more daily load observations of E. Coli, TKN, NO_2+NO_3, and TP.

A watershed delineation was conducted using the DEM reconditioning process to divide the BSCW into smaller sub-watersheds that allowed to implement the SELECT model. Results of this procedure revealed 14 new sub-watersheds with an average size of 28.84 mi^2 were found, other findings indicated that sub-watersheds located at the south and central area of BSCW drain into the Brownsville Ship Channel while those sub-watersheds at north, drain into Lower Laguna Madre Bay.

The implementation of the SELECT model allowed to identify main point and non-point sources of bacteria threating BSCW, it also helped to highlight those sub-watersheds with higher contribution of E. Coli daily loads. Findings from this analysis provide scientifically supported arguments to stakeholders, decision-makers and policymakers that will help them to take informed decisions that lead to the development of Best Management Practices to decrease bacteriological daily loads within BSCW.

Due to time and COVID-19 limitations it was not possible to present the inputs and results obtained to receive the input of the stakeholders and make the proper modifications if needed however, findings from the development of the LDCs match with the results obtained from implementing the SELECT model within BSCW. In the near future, UTRGV graduate students will reimplement the SELECT model using the results from the second watershed delineation produced in this study in order to reach a higher level of detail, providing with more specific information on the bacteriological daily loads produced per sub-watershed.

Even when bacteriological daily loads observed at the three main tributaries draining into the BSC exceeded the maximum allowable water quality criteria, the BSC was removed from the list of impaired waterways in the Texas Integrated Report from 2020 which might suggest that E. Coli loads dilute when they enter to the BSC, further studies should consider measuring flow and bacteria concentration where the tributaries meet with the BSC.

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