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Geographical Information Systems (GIS) Applied to Urban Nutrient Management: Data Scarce Case Studies from Belize and Florida

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Geographical Information Systems (GIS) Applied to Urban Nutrient Management:

Data Scarce Case Studies from Belize and Florida

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
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ABSTRACT

Nutrient inputs into the environment greatly impact urban ecosystems. Appropriate management strategies are needed to limit eutrophication of surface water bodies and contamination of groundwater. In many existing urban environments, retrofits or complete upgrades are needed for stormwater and/or wastewater infrastructure to manage nutrients. However, sustainable urban nutrient management requires comprehensive baseline data that is often not available. A Framework for Urban Nutrient (FUN) Management for Geographic Information Systems (GIS) was developed to specifically address those areas with limited data access. Using spatial analysis in GIS, it links water quality, land use, and socio-demographics, thereby reducing data collection and field-based surveying efforts. It also presents preliminary results in a visually accessible format, potentially improving how data is shared and discussed amongst diverse stakeholders. This framework was applied to two case studies, one in Orange County Florida and one in Placencia, Belize.

A stormwater pond index (SPI) was developed to evaluate 961 residential wet ponds in Orange County, Florida where data was available for land use and socio-demographic parameters, but limited for water quality. The SPI consisted of three categories (recreation, aesthetics, education) with a total of 13 indicators and provided a way to score the cultural and ecosystem services of 41 ponds based on available data. Using only three indicators (presence of a fence, Dissolved Oxygen (DO) < 4 mg/l, and water depth < 3 ft), 371 out of 961 stormwater ponds were assessed. Additional criteria based on socio-demographic information (distance to a school, population density, median household income under $50,000, percentage of population below the

poverty line, and distance to parks) identified seven wet ponds as optimum for potential intervention to benefit residents and urban nutrient management purposes.

For the second case study, a water quality analysis and impact assessment was performed for the Placencia peninsula and lagoon in Belize. This study had access to water quality data, but limited land use data and very limited socio-demographic data. Since May 2014, water quality samples have been taken from 56 locations and analyzed monthly. For this study, Dissolved Oxygen (DO), Nitrate (NO_3^--N), Ammonia (NH_3), Chemical Oxygen Demand (COD), and 5-Day Biochemical Oxygen Demand (BOD_5), *Escherichia coli* (*E. coli)*, and *Enterococci* were selected to assess spatial and temporal variation of water quality in the groundwater on the peninsula as well as the surface water in lagoon, estuaries and along the coast. A spline interpolation of DO, Nitrate, BOD_5, and COD for June 2016 indicated the concentration distribution of those parameters and areas of special concern. A spatial analysis was conducted that showed that Nitrate and *Enterococci* exceeded the effluent limits of Belize very frequently in the complete study area while the other parameters contributed to the identification of key areas of concern. As a high variability of concentrations over time was observed, a temporal analysis was conducted identifying a link between the water quality data and two temporal impact factors, rainfall and tourism. The two case studies showed the broad and flexible application of the FUN management for GIS and the great advantages the use of GIS offers to reduce costs and resources use.

CHAPTER 1: INTRODUCTION

In 2014, 54% of the world's population lived in urban areas with a projected increase to 70% in 2050 (United Nations, 2014; World Resources Institute, 2017). As the world continues to urbanize, the sustainable management and planning of cities becomes even more important. Urban development and population densification impacts landscapes, natural systems, and ecological processes (Marzluff, 2008). Impervious surfaces are increasing, altering run-off and infiltration rates. Geomorphological and hydrological processes like the flows of water, nutrients and sediment are altered (Leopold, 1968; Psaris & Chang, 2014). Excess nutrient flows of nitrogen and phosphorous are of particular concern as these lead to eutrophication (Tufford, Samarghitan, McKellar, Porter, & Hussey, 2003) and degradation of inland waterbodies, estuaries, and coastal waters (Alberti et al., 2003; Karabulut Aloe, Bouraoui, Bidoglio, Grizzetti, & Pistocchi, 2014).

Urban areas are systems that combine human and ecological characteristics and experience dynamics between those two (Marzluff, 2008). Consequently, both ecological and social conditions and their relationships play a role when assessing urban nutrient contamination and management. This asks for comprehensive and interdisciplinary baseline data. Costs, time, data sharing policies, and shortage of qualified technicians, however, limit access to this data and its quality. The lack of resources and data is a key challenge in decisions-making processes and management.

GIS visualizes spatially linked information, facilitates communication of ideas, and highlights optimal areas for intervention. It is a powerful and flexible tool for preliminary assessments in data scarce scenarios. This is demonstrated in two case studies in the context of urban nutrient management. They were selected based on requests by research partners to cooperate on data analysis. There was a high interest in conducting research, but resources were limited. Both study areas are experiencing high urban growth and are connecting to environmental sensitive areas.

Orange County, Florida is a highly-urbanized area where natural water flows have been strongly altered. Wet ponds are commonly used as stormwater management structures in residential areas. If well planned and maintained, they provide a variety of services to ecosystems and humans and can serve as urban green spaces. However, inadequate operation and maintenance highly reduces these functions and their performance (U.S. EPA, 1999, 2009). In 2014, the University of South Florida (USF) Water Institute was contracted by Orange County to conduct a bathymetric survey of 1,100 wet ponds. The information collected assists with operation and maintenance, identifying ponds in need of dredging or other types of intervention. The Water Institute manages a Water Atlas Program that uses technology to present water resource information in a variety of ways, including interactive graphs, tables, maps and graphics, to be understandable to multiple stakeholders while meeting the needs of local governments. Assessing the Cultural and Ecological Services (CES) of wet ponds, the present study ties up to studies that were previously conducted by our research group. Those studies researched on community driven stormwater beautification projects in East Tampa, Florida and the vast opportunities that process provides for K-12 and community education.

The Placencia peninsula in Belize is a resource rich region whose ecosystems are compromised through growing urbanization, tourism, and agriculture. Current wastewater discharge methods in this area include package treatment plants, septic systems, soak pits, and direct discharge without treatment. Nutrient loads to surface and groundwater are of concern for human and ecological health, as are discharge of microorganisms and other contaminants. The Government of Belize and Belize Water Services Ltd. (BWS), the main national water service provider, plan to develop a new sewage collection and treatment system in the Placencia Peninsula. Since 2014, BWS monitors water quality at 56 sample locations in the area. The Civil and Environmental Engineering Department at the University of South Florida (USF) signed a Memorandum of Understanding with BWS to visualize this collected water quality data using GIS tools.

The goal of this research was to integrate GIS as a tool for improving nutrient management in Orange County, Florida and Placencia, Belize, where certain types of data and resources are limited. The objectives were:

1. Develop a framework for urban nutrient management with GIS with enough flexibility to adapt to incomplete data sets.
2. Apply the framework to a nutrient management study where land use and socio-demographic data are available but water quality data limited
3. Apply the framework to a nutrient management study where water quality and land use data are available but socio-demographic data limited

This study shows how GIS can be applied to identify spatial and temporal areas of interest for urban nutrient management. The framework links water quality, land use, and socio-demographics to initiate and optimize future data collection. It is a powerful tool to display data and communicate issues in areas with incomplete datasets. The approach prepares for data sharing between stakeholders. It supports preliminary studies for different levels of data and information availability. The method raises awareness for complex issues where little information is available. Therefore, it is very valuable for the initiation and promotion of studies. This is applied to two different topics of urban nutrient management with different data availability: assessment of residential wet ponds in Orange County, Florida and water quality analysis and impact assessment of Placencia, Belize.

The work is structured in six chapters. After the Introduction (Chapter 1), Chapter 2 reviews literature on the effect of urbanization on nutrient loads, urban ecological systems, green spaces, and Ecosystem Services. Chapter 3 describes how the Urban Ecological Framework was used to develop the Framework for Urban Nutrient Management in GIS for incomplete datasets. Chapter 4 and 5 describe the two case studies on Placencia, Belize and Orange County, Florida. Each of these two chapters include background on the research question, study area, methods, results and discussion, and a summary. Chapter 6 includes conclusions and recommendations for the framework and proposes further research questions.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

An ecosystem describes the functional linkage of physical environment and organisms, as well as their interactions in a defined area. Ecosystems are open, dynamic, and connected systems of any size or scale (Likens, 1992). While traditional ecological research focused on the highly natural and undisturbed ecosystems, current research addresses urban areas and human activity (Pickett & Cadenasso, 2006).

The definitions of urban space vary widely between and within disciplines and countries (Marzluff, 2008). Commonly used are thresholds determining urban characteristics, for example minimum population and population density, percentage of employment in non-agricultural sectors, and presence of urban infrastructure and education or health services (United Nations, 2014). Studying urban ecosystems, researchers, particularly ecologists, widely agree on broad and flexible definitions that include subtypes of urban space with different gradients of urbanization (Pickett et al., 2001). In the present work, an urban area is considered any 'large, densely populated area characterized by industrial, business, and residential districts' (Yli-Pelkonen & Niemelä, 2005). This definition is appropriate, as any mostly impermeable and populated land covered by infrastructure is potentially affecting the ecology of the area (Pickett et al., 2011). The development of urban areas is highly flexible and varies through numerous biophysical and human factors. Even small settlements have big impacts on natural systems (Alberti et al., 2003).

Urban Ecology is the study of ecosystems that are impacted by human settlements, typically cities and urbanizing landscapes. It's an interdisciplinary approach that acknowledges urban areas as complex socio-ecological systems characterized by both biophysical and social phenomena and their dynamics. Therefore, it has been applied in many studies of humans, ecosystems, and their relationships (Marzluff, 2008). Baseline data for urban ecology includes water quality, land use, socio-demographics, hydrology, climate, soils, permeability, among others. Socio-ecological frameworks provide guidelines for the interdisciplinary analysis of these systems (Chopra, 2005).

2.1. Urbanization and Nutrients

Changes of landcover in urbanizing watersheds have great impacts on the ecological conditions; urban and agricultural lands often lead to poor surface water quality (Alberti et al., 2007; Pratt & Chang, 2012). Non-point source pollution due to agricultural activities and urbanization is significant in certain watersheds, but difficult to manage and regulate (Giri & Qiu, 2016). Human infrastructure and land use especially impact the nutrient loading of water bodies. The evaluation of existing and future impacts requires a deeper knowledge of the social-ecological systems and their dynamics. Changes in land use in urbanizing watersheds have great effects on the ecological conditions; urban and agricultural lands often lead to poor surface water quality (Alberti et al., 2007; Pratt & Chang, 2012).

The impact of urbanization on nutrient loads in watersheds has been studied on different scales and within different ecosystems all over the world. Tufford et al. (2003) assessed the impacts of urbanization on nutrient loads in the southeastern United States. Baginska, Lu, and Pritchar (2005) modeled nutrient loads to optimize the management of urbanization impacts in Australia, using a GIS framework integrated with satellite imagery. Studying the impact of urbanization on wetlands, Wright, Tomlinson, Schueler, and Cappiella (2006) found that turf and impervious covers of developments increase nitrogen and phosphorus concentrations and volume of storm water runoff. Compared to forest cover, they estimated a rise of the total nutrient load by a factor of 5 to 20. Psaris and Chang (2014) used a Soil Water Assessment Tool to evaluate the ‘impacts of climate change, urbanization, and filter strips on water quality’. They assessed how spatial patterns of urban growth impact water, sediment and nutrient yields. Cao, Zhu, and Chen (2007) studied the impacts of urbanization on topsoil nutrient balances in Fujian, China. They observed a trend to nutrient diminution in grain-dominated agricultural regions and nutrient excess in city suburbs. A hydrological and water quality modeling approach by Tong and Chen (2002) confirmed the increased production of nitrogen and phosphorus for agricultural and impervious urban land uses. Li, Li, Qureshi, Kappas, and Hubacek (2015) determined the relationship between ecological patterns and water quality in areas of rapid urbanization in coastal China, combining methods of satellite image processing, GIS spatial analyses, and statistical data analysis.

These studies emphasize the importance of nutrient management in urban areas. Water quality, land use, and socio-demographics are governing the underlying processes. Insufficient management practices highly affect ecosystems as well as the local populations. On the other hand, functional nutrient management systems can improve the quality of life of the people residing in urban settlements (Chopra, 2005).

2.2. Urban Ecological Systems

Urban ecosystem studies attempt to understand the dynamics between social and ecological systems (Pickett et al., 1997). In the past, researchers looked at society and ecology as two connected, but separated systems, the basic concept is shown in Figure 2.1. The interrelationship of human activities and bio-geophysical drivers were not considered. In more recent studies, this perspective has changed. Redman, Grove, and Kuby (2004) argue that those traditional approaches do not sufficiently explain the interactions and feedbacks between humans and ecosystems. This limits their reflection of the dynamic and complex role humans have on ecosystems. Alberti et al.

(2003) point out that the combination of human factors like pollution load, population density, and total paved area into one variable does not account for the multidimensional and variable character of urban space. On the other hand, studies with a more detailed consideration of the social aspects often underestimate the complexity of ecological and biophysical processes.

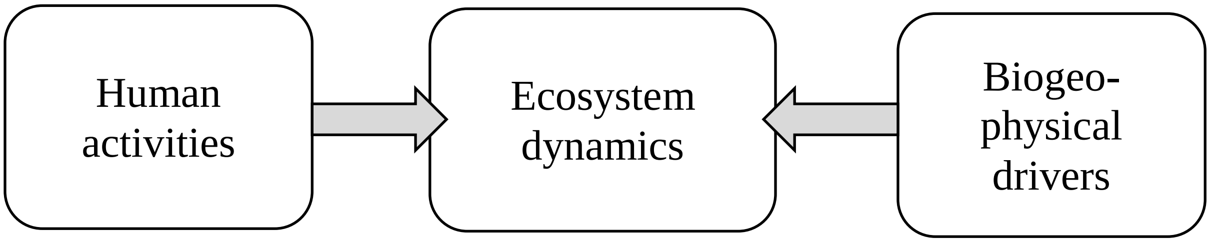

Figure 2.1 Concept of Traditional Frameworks for Ecosystem Studies
Modified after Redman et al. (2004)

To overcome these limitations, recent studies use integrated approaches. Improving the understanding of humans' role in ecosystems enhances integrated research in urban areas (Pickett et al., 1997; Pickett et al., 2011; Pickett & Cadenasso, 2006). Newer frameworks acknowledge the need to combine ecological and social dimensions (Figure 2.2).

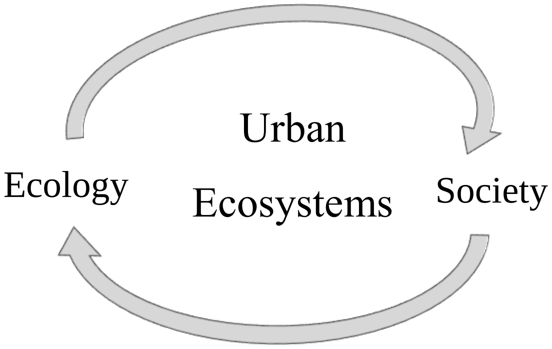

Figure 2.2 Concept of Recent Frameworks for Urban Ecosystem Studies

Existing urban ecosystem frameworks provide analytical structures and theoretical guidelines for urban ecology studies (Alberti et al., 2003). The Human Ecosystem Framework (HEF) was one of the first to merge human and ecological systems (Machlis, Force, & Burch, 1997; Pickett et al., 1997; Pickett et al., 2001). As the HEF, the Urban Ecosystem Framework provided by Alberti et al. (2003) acknowledges this unification of human and ecological systems. It adds on this the relationships between human and ecological patters and processes by explicitly linking patterns, drivers, processes, and effects/changes. Examples are shown in Figure 2.3.

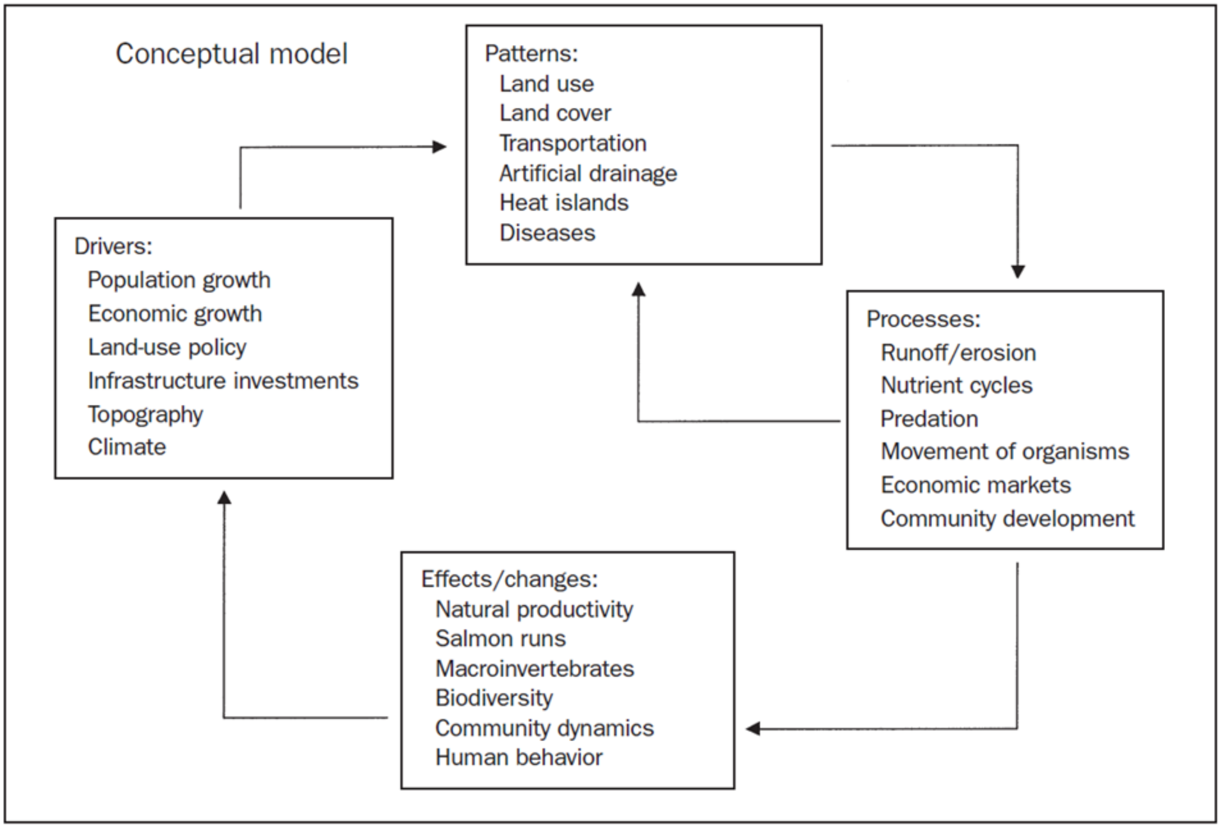

Figure 2.3 Urban Ecosystem Framework
Source: Alberti et al. (2003)

By doing so, it offers a foundation to test different types of hypotheses. First, the driver hypothesis examines how social, political, economic, and biophysical factors motivate urbanization and the urban sprawl. Second, the pattern hypothesis looks at the effect of urban-ecological patterns on the processes in both entities. Third, the resilience hypothesis describes how urban resilience is based on human and natural services. Lastly, the scale hypothesis determines how changes on one level of organization affect processes and mechanisms on another hierarchical level. This framework emphasizes the dynamics of urban-ecological processes and how these different sectors impact each other.

2.3. The Importance of Green Spaces

The benefits that people acquire from ecosystems are called Ecosystem Services (ES). The three domains to evaluate an ecosystem are ecology, socio-culture, and economy. The Millennium Ecosystem Assessment (2003) introduced a formal approach that links ecosystems and society: the Millennium Ecosystem Assessment (MEA) Framework. It is widely applied within international environmental research and policies (Groot, 2006; Groot, Wilson, & Boumans, 2002; Moore & Hunt, 2012; Nahuelhual, Benra Ochoa, Rojas, Díaz, & Carmona, 2016). The MEA framework subcategorizes ES into Regulating services, Providing services, Cultural services, and Biodiversity services.

The interactions with ecosystems improve the wellbeing of humans. Cultural Ecosystem Services (CES), the nonmaterial benefits humans obtain from ecosystems, are directly linked to human well-being, particularly to health and social relationships. Milcu et al. (2013) provide an overview on research of cultural ecosystem services. Although often addressed in the literature, ecosystem functions, goods, and services are difficult to measure and classify (Chan, Guerry, Balvanera, Klain, & Satterfield, 2012; EPA, 2015, 2016; Felipe-Lucia, Comin, & Escalera-Reyes, 2015).

Also, studies often focus on those categories that are easy to measure and most convenient for data collection. This leads to the false conclusion that the categories most discussed are more relevant; in the meantime important benefits are often marginalized (Milcu, Hanspach, Abson, & Fischer, 2013). The Millennium Ecosystem Assessment Framework (2003) has served as base for many other typologies. Yet, its weakness is the thematic overlap of categories and insufficient separation of the concepts of service, benefits and values (Boyd & Banzhaf, 2007; Chan et al., 2012). Different approaches address the complex relationship between ecosystems and humans through ecology (Groot et al., 2002; Groot, 2006), social sciences (Chan et al., 2012; Felipe-Lucia et al., 2015; Fish, Church, & Winter, 2016), and economy (Bennett & Hassan, 2003; TEEB, 2010). Table B. in Appendix A (p.93) shows a summary of selected studies that define the contribution of CES to human well-being.

The benefits, distribution and social disparity of conventional green spaces (Byrne & Wolch, 2009; Wolch, Byrne, & Newell, 2014) within the fields' of urban planning, geography, social sciences, among others (Maroko, Maantay, Sohler, Grady, & Arno, 2009) are well studied. Many studies have focused on parks (Burgess, Harrison, & Limb, 1988; Weiss et al., 2011; Wright Wendel, Downs, & Mihelcic, 2011), others look at playgrounds (Smoyer-Tomic, Hewko, & Hodgson, 2004), less conventional green spaces like urban greenways (Lindsey, Maraj, & Kuan, 2001), or informal greenspaces (Rupprecht & Byrne, 2014). It is found that green spaces are most valuable when they offer variability, social interactions, and cultural diversity (Burgess et al., 1988). Campbell, Svendsen, Sonti, and Johnson (2016) studied park use and meaning of urban parkland in the city of New York and confirmed that urban green space and nature access is crucial for the well-being and social resilience of urban populations. As proposed by the MEA, it provides important opportunities for recreation, physical and social activities, as well as promoting environmental engagement and local attachment.

Using GIS is a common approach to assess green space access, distribution and social inequity (Hirvela, 2011; Wolch et al., 2014). It has been used for the spatial analysis of environmental justice issues, mainly looking at negative environmental sites like pollution sources that affect the population. In recent years, studies started to look at positive environmental sites.

Wolch, Wilson, and Fehrenbach (2013) mapped the access to park space for children and youth as well as general residents regarding their socio-economic status and ethnicity/race in Los Angeles, California. Pham, Apparicio, Séguin, and Gagnon (2011) used GIS and remote sensing for a greenspace assessment in Montreal. Comber, Brunsdon, and Green (2008) conducted a network analysis to determine the access of green space for different ethnic and religious groups in Leicester, England. Nicholls (2001) studied levels of accessibility and equity of public parks in Bryan, Texas. Caquard, Vaughan, and Cartwright (2011) classified neighborhoods in Montreal looking at their access to vegetation. Rupprecht and Byrne (2014) give a comprehensive overview of the trends in international literature and the role of so called Informal Green Spaces for urban residents. Neema and Ohgai (2013) developed a suitability model particularly for parks and open spaces using six criteria: population, air quality, noise level, air temperature, water quality, and recreational value.

CHAPTER 3: METHODOLOGICAL FRAMEWORK

The present work connects urban ecosystem frameworks to a flexible and specialized urban nutrient management framework to be implemented with GIS tools. A wide range of research topics in the field of urban ecosystem management can be addressed, these include the following four key questions determined by Alberti et al. (2003):

> *"How do socioeconomic and biophysical variables influence the spatial and temporal distributions of human activities in human-dominated ecosystems? How do the spatial and temporal distributions of human activities redistribute energy and material fluxes and modify disturbance regimes? How do human populations and activities interact with processes at the levels of the individual (…), the population (…), and the community (…) to determine the resilience of human-dominated systems? How do humans respond to changes in ecological conditions, and how do these responses vary regionally and culturally?"*

Based on the Urban Ecology Framework discussed earlier, a new framework was developed: The Framework for Urban Nutrient (FUN) Management for GIS. Figure 3.1 shows the process of developing and applying it. In the first step, Framework development, the Urban Ecosystem Framework by Alberti et al. (2003) was used to identify the relevant factors and concepts of urban ecology that apply to nutrient management. The second step, Framework elaboration adapted the Urban Ecosystem Framework to the needs of a GIS framework in an urban nutrient context. It clarifies what the Framework serves for and how it can be used. In the third and last step, the use and function of the Framework and its application is explained.

Step 1

Framework development

- Identify factors, concepts, and relationships that guide urban ecology
- Apply the Urban Ecosystem Framework to urban nutrient management research

Step 2

Framework elaboration

- Center GIS into the framework as fundamental tool
- Link water quality, land use, and demographics using spatial and temporal analyses

Step 3

Framework application

- Visualize data to communicate ideas and information
- Raise awareness for complex issues
- Initiate and optimize data collection for next stage of research

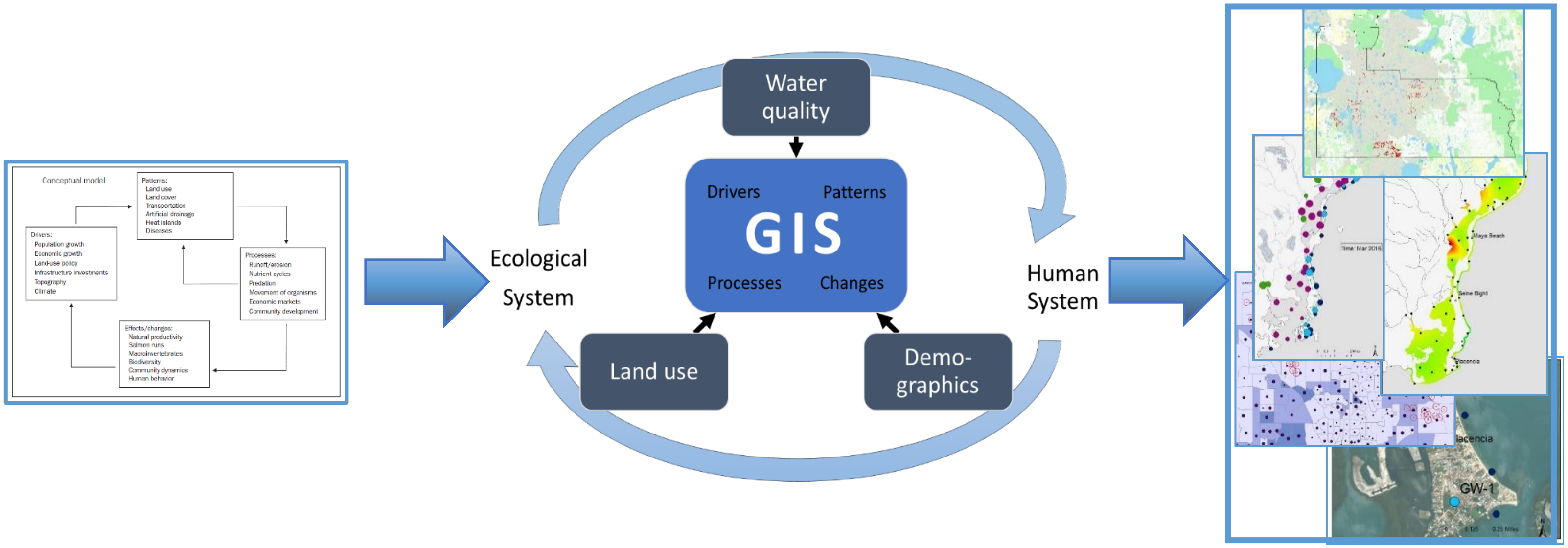

Figure 3.1 Developing the Framework for Urban Nutrient (FUN) Management for GIS

3.1. FUN Management for GIS

The Urban Ecosystem Framework (Alberti et al., 2003) considers in detail the factors, drivers and relationships governing urban ecology and therefore also directs the research related to urban nutrient management. The interactions between drivers, patterns, processes, and changes in a unified ecological and human system directly apply to this research. Adapting the framework further to the needs of urban nutrient management, the three sectors of water quality, land use and socio-demographics were identified as key components. Water quality data allows to assess the ecosystem health. Land use and socio-demographics address the human-based activities and the impacts when they change. Those three components are highly dynamic and interrelated. They are affecting each other and the urban system they are part of. The FUN management is centered around GIS and addresses those dynamics of socio-ecological systems (Figure 3.2).

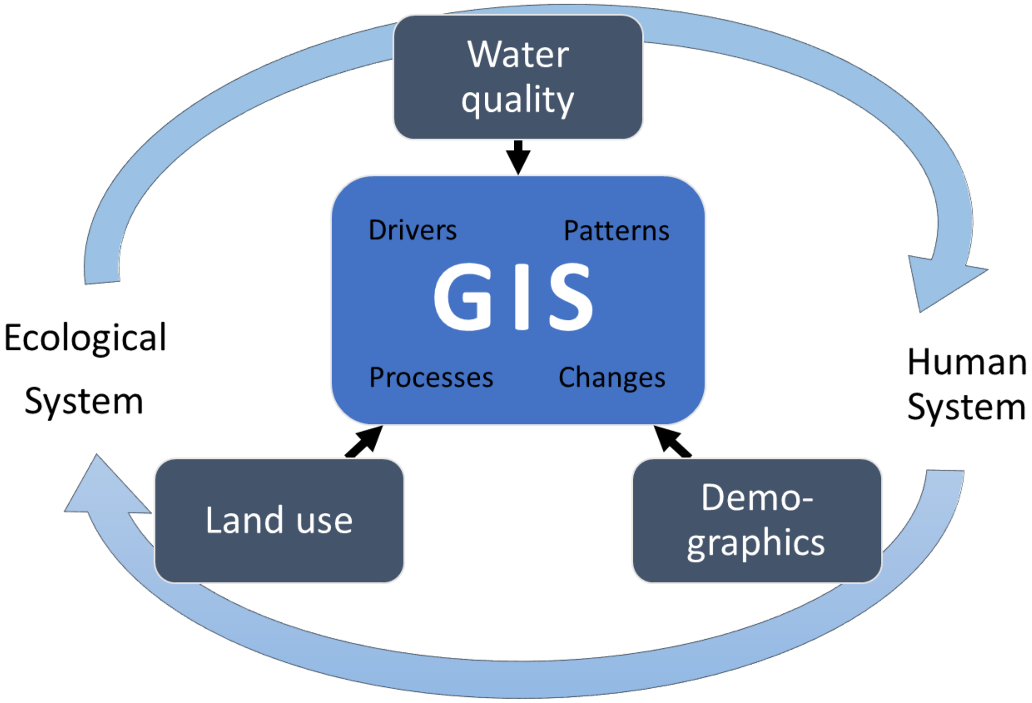

Figure 3.2 FUN Management for GIS

GIS allows flexible analysis of urban nutrient management with limited data. The framework uses existing data and accessible information and links these different data sets into a spatial context. Datasets that provide information in these three areas will be used to conduct an urban nutrient management related analysis. The spatial linkage of data allows to identify and highlight areas of interests and knowledge gaps. The results can be prepared to allow communication, promotion of further studies, or the development of a comprehensive research plan that involves the collection of missing data.

3.2. Application to the Orange County Case Study

In the first case study, the FUN management for GIS was applied to research assessing residential wet ponds in Orange County, Florida, where there is a high availability of demographical and land use data. For Florida and Orange County, several governmental institutions provide public GIS data warehouses. The U.S. Census Bureau offers up-to-date and readily processed Census data to be download for free. Water quality data are limited for the stormwater ponds. Samples were taken once per pond during different seasons and under different weather conditions. Therefore, the extensive demographic and land use data was used to support the spatial analysis using GIS.

3.3. Application to the Belize Case Study

For the second case study, the FUN management for GIS was utilized for a nutrient management analysis in the Placencia peninsula region of Belize. There exists up-to-date water quality data that carries spatial as well as temporal information. There is also information available about land use and land cover, though somewhat limited. Socio-demographic data, particularly spatially linked, are very limited for Placencia. Climate, ecological, and tourism data are also sparse. The data strong sections, water quality and land use, are used for the spatial analysis.

3.4. Using GIS for the FUN Management

Technologies like GIS, the global positioning system (GPS), and remote sensing have majorly changed the process of data collection and analysis. The recording of GPS coordinates has become a standard procedure that can be conducted with a personal smart phone. This allows data to be linked to a certain location and with other data sets that have similar spatial characteristics. The possibility to display the spatial characteristics of features is very convenient. Yet, the outstanding strength of GIS is to analyze relationships between features that occupy the same geographic space and the information associated with them (Milla, Lorenzo, & Brown, 2005).

This study used GIS to quantify, analyze, and display the ecological and social factors governing urban nutrient management. The software utilized was ArcGIS 10.3.1 from Esri. Spatial techniques were used to process input data and prepare geographic maps. Based on GPS data, vector features were created in ArcGIS and associated with data obtained through surveys, monitoring, as well as onsite and laboratory analysis. The GIS analysis was mostly carried out through Analysis tools and Data Management tools. This included geoprocessing such as overlay and proximity functions as well as selections, field calculations and statistics, among others. The use of symbology, reclassification, and definition functions further supported the visualization and interpretation. The Conversion tool served to transform data back and forth between ArcGIS and Microsoft Office Excel 2016. The coordinate system used are listed in Table 3.1. All GIS maps were created by the author between 11/2016 and 02/2017. The sources of shape files created by others are listed in the data sources sections of the case studies (see chapter 4.3.2, p. 30 for Orange County data and chapter 5.3.1, p. 55 for Belize data). For shapefiles that were created by the author, underlying data is likewise acknowledged in those chapters.

Table 3.1 Coordinate Systems Used in the GIS Spatial Analysis

Orange County	**Belize**
Coordinate System: NAD 1983 State Plane Florida East FIPS 0901 Feet Projection: Transverse Mercator Datum: North American 1983 False easting: 656.166.6667 False Northing: 0.0000 Central Meridian: -81.0000 Scale Factor: 0.9999 Latitude of Origin: 24.3333 Units: Foot US	Coordinate System: GCS WGS 1984 Datum: WGS 1984 Units: Degree

CHAPTER 4: ASSESSMENT OF RESIDENTIAL WET PONDS IN ORANGE COUNTY, FLORIDA

4.1. Introduction

Protecting and properly managing Florida's water bodies is important for humans and the environment. Florida has approximately 7,800 natural lakes with a surface area greater than 1 acre (Schiffer, 1997). These are in addition to numerous smaller lakes and stormwater ponds. The discharge of stormwater within the State of Florida has been regulated since the early 1980s in order to prevent pollution and to protect surface waters. The Florida Department of Environmental Protection (FDEP) is the management authority at the state level whereas the water management districts operate regionally. Local governments are involved in the management, too. Chapter 62-40 of the Florida Administrative Code (FAC), the "Water Resource Implementation Rule", provides stormwater management regulations for Florida. These regulations require that developments either store and treat runoff from an inch of rainfall in the drainage area, or treat runoff from 0.5 inches of rainfall for areas less than 100 acres (FAC, 2017). According to the stormwater design criteria implemented by the FDEP and the water management districts (WMD), stormwater management structures should reduce at least 80% of the average annual load of pollutants that compromise the State Water Quality Standards.

To date, retention and detention ponds are the most common methods for managing stormwater in Florida. Definitions of these ponds vary, but in general, retention ponds are designed to be dry except for 72 hours after a storm event (FAC, 2017). Stormwater percolates through the topsoil at the bottom of the retention pond and there is no outlet to a surface water body. Detention ponds on the other hand detain water for a period of time to reach a certain level of treatment and usually have a residual level of water. Detention ponds are also referred to as wet ponds. While stormwater ponds reduce flooding and reduce pollutant loads to surface water bodies (Blecken, Hunt, Al-Rubaei, Viklander, & Lord, 2016), they also increase biodiversity (Woodcock, Monaghan, & Alexander, 2010), and more recently have been recognized for their provision of numerous social functions for humans (Hassall, 2014) and ecosystem services (Barbosa, Fernandes, & David, 2012).

Stormwater ponds, like any other infrastructure, require maintenance. For example, dredging restores pond volume ensures that there is enough retention time for the volume of water to be treated. While healthy vegetation in the form of aquatic macrophytes in the littoral zone remove nutrients and other pollutants from the aqueous environment, invasive species like hydrilla must be destroyed as they choke the water column. Local governments should include design criteria that consider maintenance, safety, and aesthetic aspects of stormwater management systems (Harper & Baker, 2007), however, this is not always the case and ponds can become eyesores that underperform. Initiatives like the Hillsborough County's "Adopt-A-Pond" program are designed to maintain stormwater ponds through volunteer stewards, however, long-term commitment and participation of volunteers present challenges. Incidentally, in East Tampa, an area in Hillsborough County not covered by Adopt-A-Pond, community driven stormwater pond revitalization projects have improved community access to surface water and green space (Wright Wendel et al., 2011). While the community's taxes paid for those improvements, the revitalization and maintenance are managed by the city's stormwater department.

Nutrient input into urban water bodies is greatly contributed by human activities like fertilizing, excessive yard trimming, pet litter, among others. One of the central strategies of urban nutrient management is behavioral change. Unfortunately, many residents do not know about nutrient removal and treatment efficiency of their stormwater ponds, it’s very challenging to educate and change their behaviors. Green infrastructure has valuable benefits to the people that live near or visit the stormwater ponds, it provides cultural ecosystem services (CES) (compare chapter 2.3). Residents can use them to do exercises and outdoor activities (recreation), learn about biological processes (education), and relax (aesthetics). People are more likely to change behavior if it’s benefiting their direct interests and needs. Their motivation to support the maintenance of ponds is higher if they are actively using and enjoying the aesthetics and recreational offers. Therefore, an approach that helps to improve the CES of ponds will at the same time help to improve the nutrient management of the ponds.

Moore, Hutchinson, and Christianson (2012) introduced an ecological health assessment for stormwater systems based on observations of the vegetation, fauna, and soil health as well as erosion. They discuss the ES provided by storm water control measures and constructed storm water ponds. They developed scoring criteria to assess recreation and educational CES shown in Table 4.1 based upon existing assessments that were developed for naturally wetlands. The scoring system ranges from 0 for poor service provision to 4 for high service provision, possible scores are 0, 2, and 4. Despite the high number of studies on the topic, there is little information and application on scoring systems available for the assessment of ES, CES, and CES in an urban water context.

Table 4.1 Scoring Criteria Developed for CES Assessment

Recreation	Legal accessibility
	Physical accessibility
	Recreational Infrastructure
Education	Location
	History of educational use
	Educational infrastructure

The conventional assessment of CES requires a high research effort. Typical methods are field visits, expert analysis, interviews, and observational studies (Campbell et al., 2016; Moore et al., 2012; Moore & Hunt, 2012). Assessing a high number of these parameters is extremely costly and time-consuming, therefore GIS offers a good alternative.

Thirty-five percent of Florida's lakes can be found in Lake, Orange, Osceola, and Polk Counties, four of the 67 counties in Florida (Schiffer, 1997). Stormwater ponds are common, especially in urban areas (Betts & Alsharif, 2013). In 2015 the University of South Florida (USF) Water Institute was contracted by Orange County to conduct a bathymetric survey of its 1,100 wet ponds. Most the ponds are managed through Municipal Service Benefit Units (MSBU) / Municipal Service Taxing Units (MSTU). The MSBU/MSTU ponds are primary located in the residential areas and property owners within these units pay the county to organize lake management activities. The bathymetric survey is used to inform the county's maintenance program. This presented an opportunity to determine the cultural ecosystem services of stormwater ponds in Orange County, Florida. Hence, this study applied the framework for urban nutrient management discussed in Chapter 3 under conditions where land use and socio-demographic data are available, but water quality data limited. GIS was used to study the distribution and quality of stormwater ponds as green spaces connected to socio-demographic factors. The three objectives were to:

1. Develop a stormwater pond index based on land use, service provision, and water quality of wet ponds
2. Visualize and apply the index in GIS to the collected data on the stormwater ponds in Orange County
3. Demonstrate how the index can be linked to socio-demographic data and be applied to urban planning and nutrient management

4.2. Study Area

Orange County is in the east central part of Florida with Orlando as the county seat (Figure 4.1). It encompasses around 1,003 square miles of which 9% are surface water bodies. According to the 2010 Census, Orange County is the fifth most populated county in Florida (U.S. Census Bureau, 2012). Since the opening of Walt Disney World in 1971, Orange County and its surroundings have become one of the most important tourist destinations of the United States (German & Adamski, 2005). In 2015, more than 65 million people from all over the world visited Orlando (Dineen, 2017). By far, the tourism industry is the most important driving factor for the job market economy of the region (VisitOrlando, 2015); former agricultural and rural lands have become urban, industrial, and recreation areas.

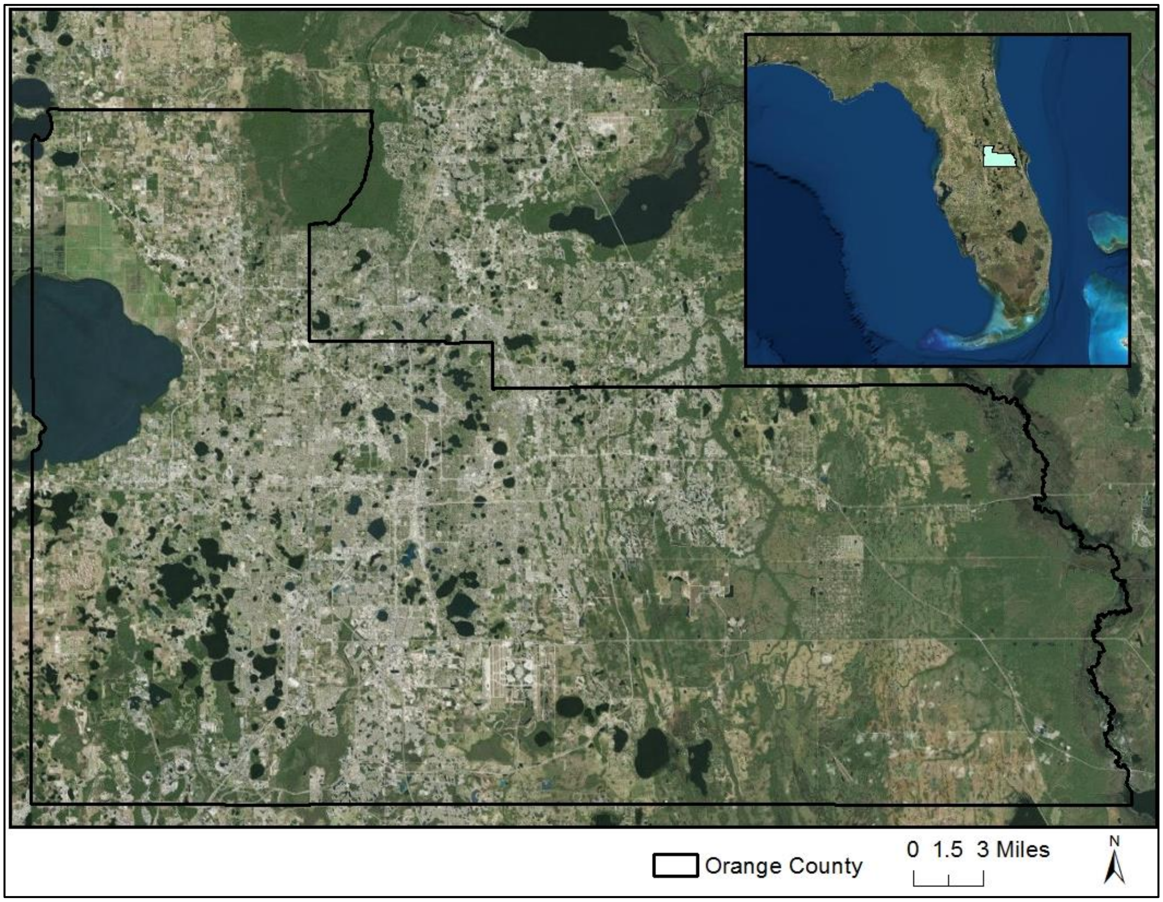

Figure 4.1 Orange County in Florida, USA

The climate is humid subtropical with mild and short winters and long and hot summers. The normal average annual temperature in Orlando is 75.5 degrees Fahrenheit and the long term average annual precipitation is 54.08 inches (National Oceanic and Atmospheric Administration, 2016). June to September is the wet season with more than half of the annual rainfall occurring during this period.

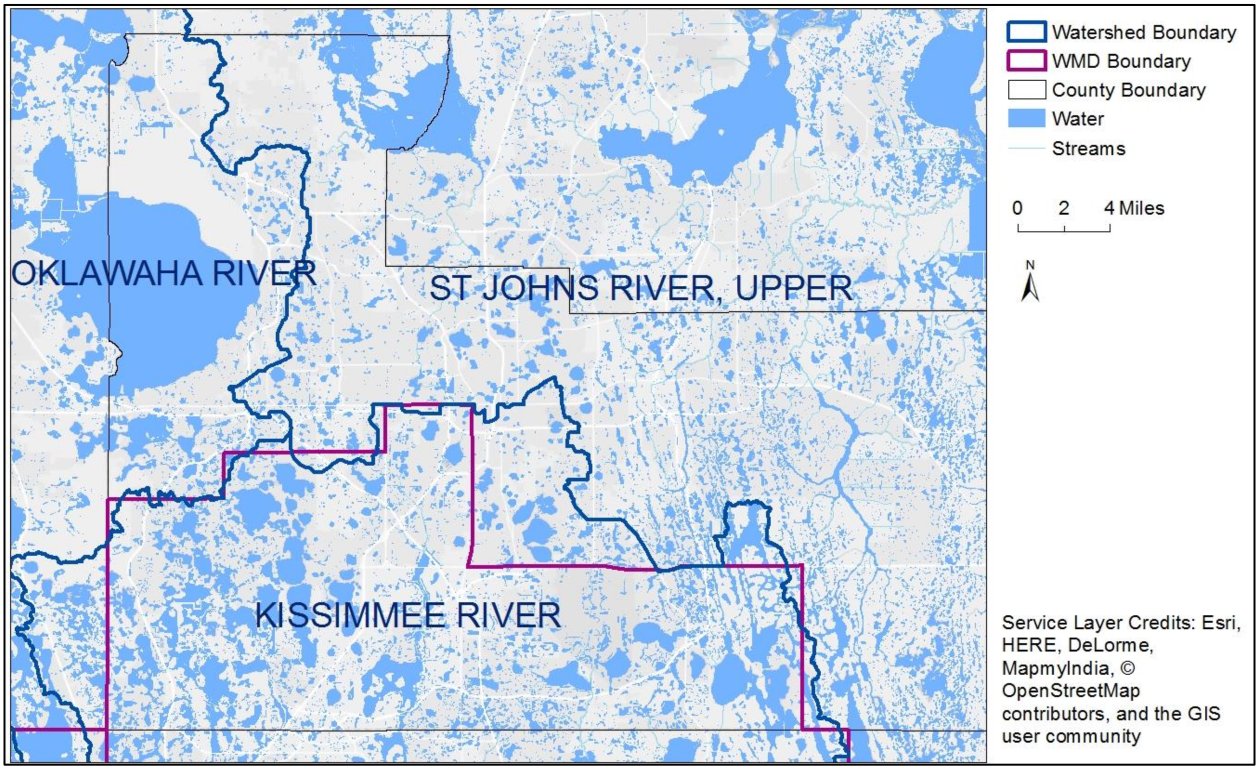

Figure 4.2 Water Management and Watersheds of Orange County, Florida

Orange County comprises two watersheds, the Kissimmee River basin and the St. Johns River basin. Surface water in southwest and southcentral Orange County discharge into the Kissimmee River basin that discharges to the south towards the Everglades. The eastern and northern part of Orange County are a part of the St. Johns River Basin that discharges near Jacksonville into the Atlantic Ocean (German & Adamski, 2005). The north of Orange County is managed by the St. Johns River Water Management District (SJRWD) and the south by the

Southwest Florida Water Management District (SWFWMD), the boundary of the WMD is shown in Figure 4.2.

4.3. Methods

The FUN management for GIS was applied to an area with limited water quality data and high access to land use and demographical data (Figure 4.3).

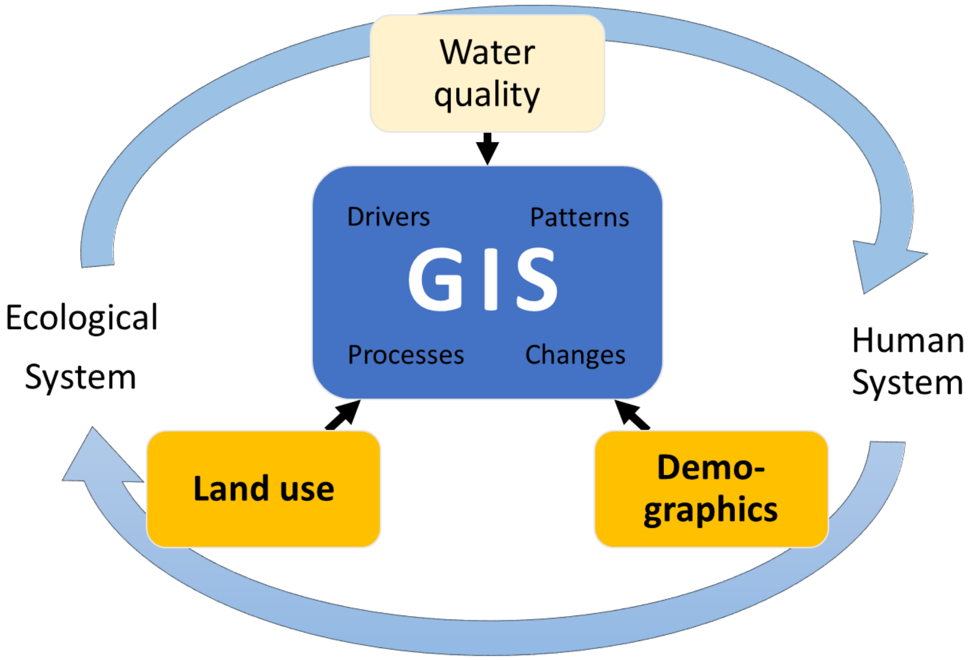

Figure 4.3 FUN Management for GIS Applied to Orange County

4.3.1. Stormwater Pond Index

A Stormwater Pond Index (SPI) was developed to assess cultural services based on existing rapid assessments and experience with stormwater beautification projects in East Tampa, Florida. This SPI groups 13 indicators into three main categories, recreation, aesthetics, and education; these are discussed below. Table 3 lists them along with how they were scored based on a certain pass-fail condition.

The first three recreational indicators (presence of fence, access, and visibility) determine if the use of a pond is possible and facilitated for the community members. Fences deter persons from accessing ponds, especially those with very steep slopes. Lower slopes will decrease human safety concerns and should be considered in pond designs and retrofits. Also, ponds surrounded by fences tend to be less maintained than those in open and visible surroundings (Jones, Guo, Urbonas, & Pittinger, 2006). Access describes if there is a way for homeowners or pedestrians to reach the pond, like a walking paths leading to it. Visibility assesses whether a pond can be seen from the road or houses or whether this is prevented by vegetation, walls, or fences. Community use and recreational infrastructure provide evidence that people use the area and there are facilities (e.g. exercise equipment) to encourage use by people.

Table 4.2 Example Indicators and Scoring for SPI

Category	**Indicator Score = 0**	**Indicator Score = 1**
Recreation	Fence present	Fence not present
	Pond not accessible	Pond accessible
	Pond not visible from road/houses	Pond visible from road/houses
	No community use	Community use
	No recreational infrastructure	Recreational infrastructure
Aesthetics	DO < 4 mg/l	DO ≥ 4 mg/l
	Water depth < 3 ft	Water depth ≥ 3 ft
	Invasive species present	Native vegetation present
	Mowing to the edge	Sustainable landscaping
	Litter	No litter
Education	Distance to schools > 0.25 miles	Distance to schools ≤ 0.25 miles
	Educational signage not present	Educational signage present
	Not used for educational purposes	Used for educational purposes

The aesthetics category gives information about the appeal of a pond for the residents and its general performance. A healthy pond has a positive appearance and reflects effective treatment of stormwater. The indicators can be water quality parameters, for example the concentration of DO. Oxygen concentrations vary strongly with temperature, atmospheric pressure, and salinity (USEPA, 1986), however, Table 4 provides guidelines for DO levels needed to sustain aquatic life.

Pond depth provides an indication of pond volume and, if compared with original depth, can assess whether siltation has occurred. Ideally, the pond depth would be compared with the original depth. Water depth was used as an indicator in this study instead of pond depth, however, as water is needed to provide a habitat for aquatic organisms, fish and birds and these are traditionally seen as positive amenities. It should be noted that stormwater ponds that serve as playgrounds and other recreational sites when dry are gaining popularity in the Orlando, again indicating that pond versus water depth could be a better indicator for future studies. The Lake Vegetation Index (LVI) is usually used to assess the biological condition of aquatic plant communities in Florida lakes (Fore et al., 2007) and has also been applied to stormwater ponds (Betts & Alsharif, 2013). While the LVI would be preferable as an indicator for pond health, this study simply used a generalized indicator based on whether the vegetation was mainly native or invasive.

Table 4.3 Guidelines for Preferred DO Concentrations
Taken from Jones, 2011

0-2 mg/l	not enough oxygen to support life
2-4 mg/l	only few kinds of fish and insects can survive
4-7 mg/l	acceptable for warm water fish
7-11 mg/l	very good for most stream fish including cold water fish

The indicator ‘Mowing to the edge’ versus Sustainable landscaping looks at sustainable maintenance activities. Mowing is not generally a negative activity. It indicates maintenance efforts and many residents prefer a well-kept lawn (Larsen & Harlan, 2006; Larson, Casagrande, Harlan, & Yabiku, 2009). Therefore, mowing could be a positive indicator for maintenance versus no grooming activities. However, in this study, ‘Mowing to the edge’ is interpreted as indicator for not sustainable landscaping. It prevents natural vegetation from growing around the ponds and leaves the banks bare and unprotected. A vegetated buffer zone around water bodies helps to stabilize the bank, improves water quality, and provides aquatic and wildlife habitat (Harper

& Baker, 2007). Trash collection was used to indicate that resources are available to beautify the pond areas.

The education category addresses if the pond is presently used or could be used for educational purposes. Use of stormwater ponds for K-12 educational purposes provide unique learning opportunities for students, and is most convenient if schools are within walking distance to a pond (Mihelcic & Trotz, 2010). The average American would rather walk 0.25 miles (5 minutes) than drive (Atash, 1994). Given that a regular K-12 class period lasts 55 minutes, a 10-minute commute to and from the stormwater pond would be reasonable. The presence of educational signage indicates that the pond site informally educates persons who access the area. The presence of signage does not indicate whether persons actually read or use them and actual observations of school trips or publications (e.g. newsletters) would provide information on this indicator.
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These indicators can be adapted to the research question and data availability. Not all indicators are meaningful for every occasion. For example, the proximity to schools can be very important to assess opportunities for community engagement and ponds for intervention, but isn't recommended to evaluate the present performance of ponds.

This assessment provides a simple and easily replicable evaluation method. All indicators can be scored following the same system. However, the method faces several sources of errors that must be kept in mind, including objectivity, accuracy of discrete assessment, and bias between the indicators. First, some indicators are obtained through surveying which requires subjective judgement. Observations also depend on other factors like season, weather, time of the day, to mention a few. The visibility of a pond can be evaluated differently through different persons. On a rainy day, a usually actively visited pond might seem unused. Therefore, it is not fully reproducible. In the case of the present study, all observations surveys were conducted by the same person. Second, all indicators are assessed discretely to unify the ranking system. However, some of the variables have a continuous character, like DO and water depths. Applying a discrete method holds the risk to have a sharp cut between values close to the selected thresholds and close to each other. Third, some of the proposed indicators might be biased. As mentioned before, a fenced pond is often observed to encourage littering. Consequently, for many ponds both indicators will score the same. If two or more indicators are correlated, this increases the weight put on those. For future application, it is strongly recommended to conduct a statistical analysis to identify bias. If necessary, indicators have to be excluded or their weight adapted.

The scores from the indicators discussed above can be combined to give one number that makes it easy to compare different stormwater ponds for their CES. This number, the Stormwater Pond Index (SPI), is a numerical value of the CES of a stormwater pond that is calculated by:

$$SPI = \sum_{i=1}^{n} w_i \cdot Indicator_i \tag{1}$$

where w_i is a number between 0 and 1 that represents the weighting placed on a given indicator. Hence, for a system with n indicators, each having a weighting factor of 1, the maximum SPI would be equal to n.

4.3.2. Data Sources

Since January 2015, the USF Water Institute has been conducting surveys in Orange County, in total they will collect data for approximately 1100 wet ponds. These surveys include the collection of bathymetric information on volume, surface area, mean and maximum depths, and water quality information on temperature, conductivity, pH, dissolved oxygen (DO in mg/l), Total Dissolved Solids (TDS), salinity, and turbidity. A Manta sub-2 multi-parameter sonde was used *in situ* for all water quality parameters, except turbidity which was measured by Secchi disk. The USF Water Institute shared data of 961 ponds, including shapefiles of the pond polygons with information such as presence, length and type of a fence and outlets. Outlet structures are located below the permanent pool, they serve to gradually release collected runoff to maintain the desired water (Harper & Baker, 2007). Given that their survey is still being conducted, different data sets are currently available for these ponds. For 41 ponds, additional data to assess CES were collected by the USF Water Institute through observation during the surveys. The data availability for different CES indicators is listed in Table 4.4, and these are further discussed in section 0.

Table 4.6 lists the source of free and public available shapefiles that were downloaded from the internet for this research. The main data source was the Florida Geographic Data Library (FGDL). Shapefiles were also sourced from ArcGIS, FDEP, and the Florida Natural Areas Inventory (FNAI). The U.S. Census Bureau (2013) provides comprehensive data from the American Community Survey (ACS) .

Table 4.4 Number of Data Points (Ponds) Available for Each CES Indicator

Indicator	**# of data points**
Recreation	
Presence of fence	961
Access	41
Visibility	41
Community use	41
Recreational infrastructure	41
Aesthetics	
Onsite WQ data by sonde	371
Bathymetric data (water depth, surface area, volume)	683
Native/ invasive vegetation	41
Mowing	41
Trash	41
Education	
Distance to Schools	961
Educational sign	-
Present or past use for educational purposes	-

4.3.3. Spatial Analysis with GIS

The SPI was used to 1. evaluate existing ponds for their CES, and 2. identify ponds for improvement based on CES indicators. The evaluation of existing ponds considered the ten recreation and aesthetic indicators shown in Table 3. Data for these indicators were obtained for 41 ponds, mainly based on field surveys conducted by the USF water institute. The data was converted from MS Excel to a GIS table and joined as fields to the pond vector layer. DO and water depth conditions were calculated in new fields using the field calculator.

If the lowest measured dissolved oxygen level was below 4 mg/l, the respective pond would not fulfill the set requirement and score 0 for DO. For a concentration of 4 mg/l or higher it scored one. Correspondingly, ponds with a mean water depths below three feet scored 0, while a mean depth of three feet or higher resulted in a score of 1. Following this approach, weighting factors of one (w=1) were used for all ten indicators, for a maximum SPI = 10. Based on the newly created columns, a score was calculated between 1 and 10 and the ponds' score distribution displayed. To verify the performance of the SPI, aerials of one pond with the highest and one with the lowest score were obtained and discussed.

Second, the SPI was used to identify areas with a high density of ponds with low CES that would benefit the most from maintenance and upgrades. To give recommendations where improvement is most needed and would be most efficient, the distance to schools and socioeconomic data including mean household income and households living below poverty line were linked to the SPI. The distance to schools was not incorporated directly into the SPI, as it was considered one of the requirements for the selection rather than a flexible part of the score.

Three parameters were selected for the SPI and used to rank 371 ponds (Table 4.5). The reduction of the number of ponds from 961 to 371 was necessary to include DO as indicator.

Table 4.5 Score System SPI for Ponds Improvement

Score	**0**	**1**
Recreation	Presence of fence	Absence of fence
Ecology/Aesthetics	DO < 4 mg/l	DO ≥ 4 mg/l
	Water depth < 3 ft	Water depth ≥ 3 ft

All three indicators were weighted the same, therefore the maximum SPI was 3 and the minimum score was 0, where a value of 0 indicates no provision of ecosystem services and a value of 3 indicates the provision of basic ecosystem services. Very low performing ponds, SPI values of 0, were then linked with socio-demographic data to identify the areas where ponds providing ecosystem services are most needed.

The five datasets linked with the low performing ponds were:

1. Distance to schools: As described above, a walking distance from schools opens the possibility for these schools to use a pond for educational purposes. Selection per Location of all ponds that have a school in a Euclidean distance of 0.25 miles was applied from the schools' layer and attributed a score of one.

2. Median household income: Ponds in the Census Block Groups from the ACS 2008-2013 with a median household income below $50,000 US received a score of 1.
3. Percentage of households below poverty line: Areas with 20% or more of the population living below poverty line were identified based on the Census Block Groups from the ACS 2008-2013 using Selection by Attributes. These thresholds were selected to support those people that have less financial resources to improve their neighborhoods.
4. Population density: this layer is organized by Census Block Groups, a high population density of at least 1000 people per square mile in 2013 was chosen to benefit a high number of people.
5. Distance to parks: Lastly, ponds more than 0.25 miles away from parks and recreation areas were selected by location to improve ponds in the areas where there is little green space available.

The last step was to find the ponds that fulfilled all those conditions, i.e. scored either a 0 for the SPI and fulfilled all five requirements. These ponds were identified as potential ponds for improvement and intervention.

Table 4.6 Data Sources of GIS Shapefiles

Source	**Weblink**	**Map name**	**Year**	**Reference**
CENSUS	www.census.org	Income	2013	U.S. Census Bureau (2013)
		Poverty line	2013	
ESRI	www.arcgis.com	Base map World Imagery	2014	ESRI (2017)
		Base map Light Gray Canvas	2014	ESRI (2016)
		Population Density	2012	ESRI (2012)
FDEP	http://geodata.dep.state.fl.us	Water	2016	FDEP (2016)
FGDL	www.fgdl.org	WMD Boundaries	2004	FDEP (2004)
		County Boundary	2016	University of Florida GeoPlan Center (2015a)
		Highways	2016	FDOT (2016)
		Water	2014	University of Florida GeoPlan Center (2015b)
		Land use	2015	U.S. Geological Survey (2015)
		Agriculture	2014	University of Florida GeoPlan Center (2015c)
		Cities	2004	National Atlas of the United States (2007)
		Rivers	1999	FDEP (1999)
		Urban Areas	2010	U.S. Census Bureau, Geography Division (2010)
		Schools	2012	University of Florida GeoPlan Center (2012)
FNAI	http://fnai.org	Managed Land	2016	Florida Natural Areas Inventory (2016)
USF Water institute	http://waterinstitute.usf.edu/	Ponds	2015/16	Data not available for download

4.4. Results and Discussion

The data sets provided by the USF Water Institute were processed and imported into GIS. They applied to the SPI and linked to socio-demographic data. The following results were obtained.

4.4.1. Land Use and Study Area

Figure 4.4 shows 961 retention ponds used for this research, located in the outer area of Orlando and managed on a state level by the Orange County Government. Their surface areas lie between less than 0.5 and over 100 acres. Water bodies such as streams, ponds, and lakes are present throughout Orange County. Figure 4.5 shows that the central parts of Orange County are urbanized with some agriculture and managed land on the outskirts of the Orlando area. Residential use and Retail/Office dominate, though there are some Public/Semi-Public lands in the Southeast.

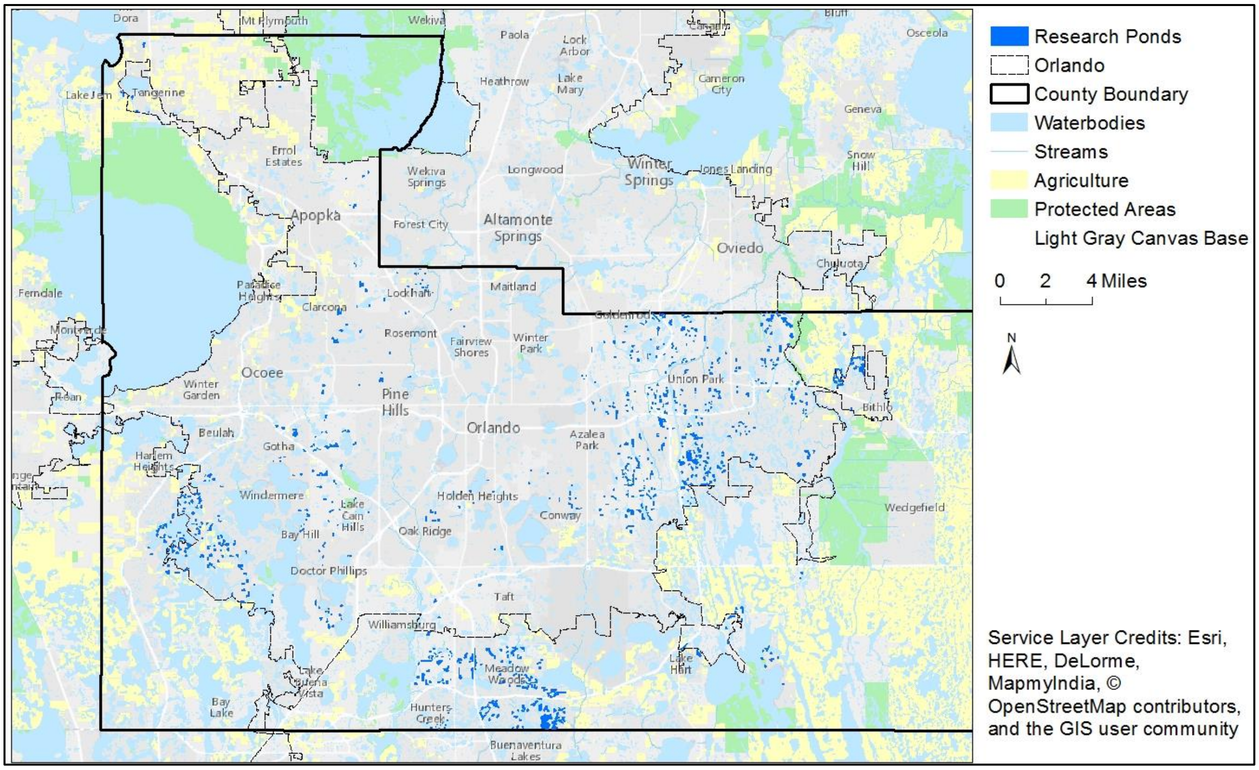


Figure 4.4 Distribution of 961 Research Ponds in Orange County, FL

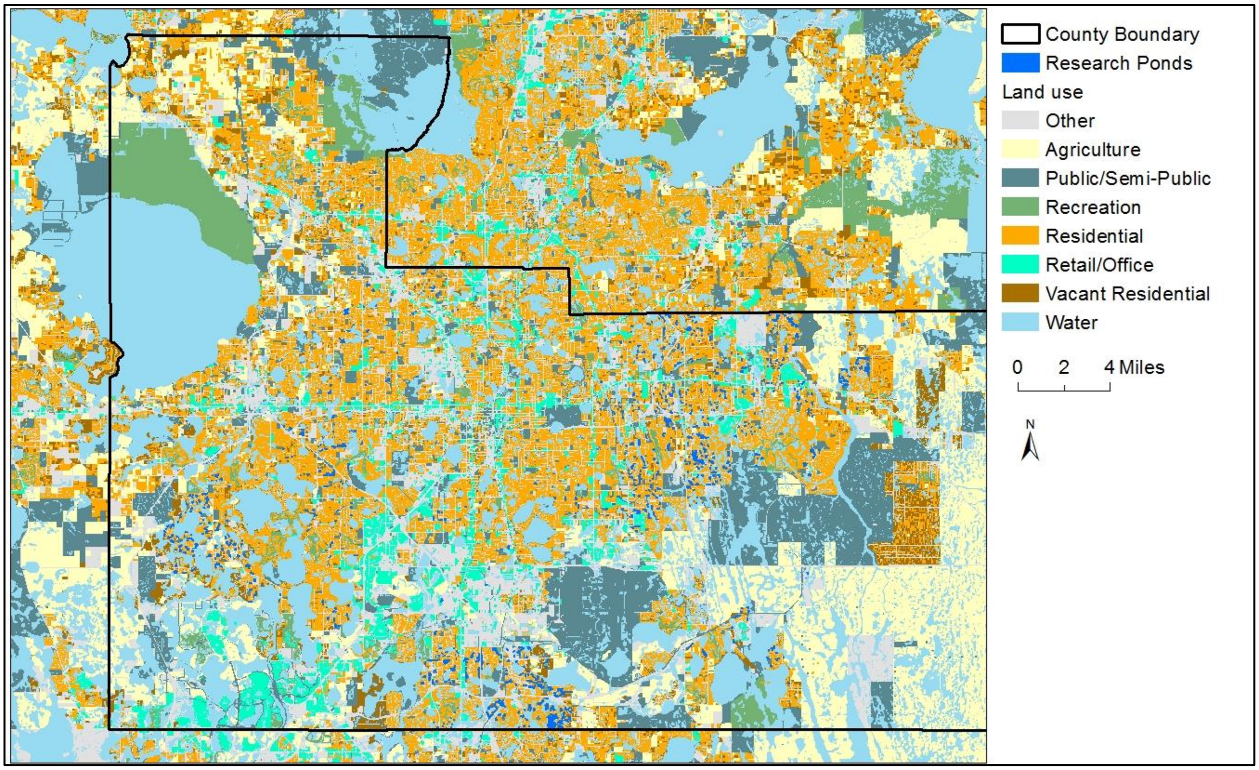


Figure 4.5 Land Use in 2015, Orange County
Based on U.S. Geological Survey (2015)

4.4.2. Using the SPI for Pond Evaluation

All ten SPI indicators in the recreation and aesthetics categories were applied to 41 ponds for which data were available (Table 4.7).

Table 4.7 Percentage of 41 Ponds with a Score of 1 for a Given Indicator

Category	Indicator (score = 1)	Percentage of ponds
Recreation	No fence	43
	Pond is accessible	58
	Pond is visible from road/houses	30
	Community use	25
	Recreational infrastructure	5
Aesthetics	DO ≥ 4 mg/l	30
	Water depth ≥ 3 ft	38
	Native vegetation present	27
	Mowing sustainably	20
	No litter	60

Of the ten indicators, “pond is accessible” and “no litter”, were the only two that were met by greater than 50% of the ponds considered. Recreational infrastructure was very rare with only

5% of the ponds considered having them. Most the ponds surveyed did not support native vegetation and did not exhibit sustainable mowing practices. Improving the landscaping and the vegetation would help the systems performance, the ecosystems, and make it more attractive to people. Figure 4.6 shows the distribution of scores for the subset of 41 stormwater ponds considered in this study. 42% of the ponds score between values of 2 and 4, and 57% below 5, whereas none of the ponds received the maximum score of 10. Figure 4.7 shows the spatial date of the ponds along with their SPI scores.

Figure 4.8 and Figure 4.9 display satellite aerials from January 2014 using ArcGIS Base Map Imagery of one pond with a 0 score (#6363) and the pond with a score of 9 (#6703). Pond #6363 is fenced, next to a highway, with sparse vegetation and a lot of litter around it. It is not attractive for any kind of recreation activities and might have a limited treatment performance. Pond #6703 looks healthier, has native vegetation planted around it, is surrounded by parkland, and has benches and a walkway.

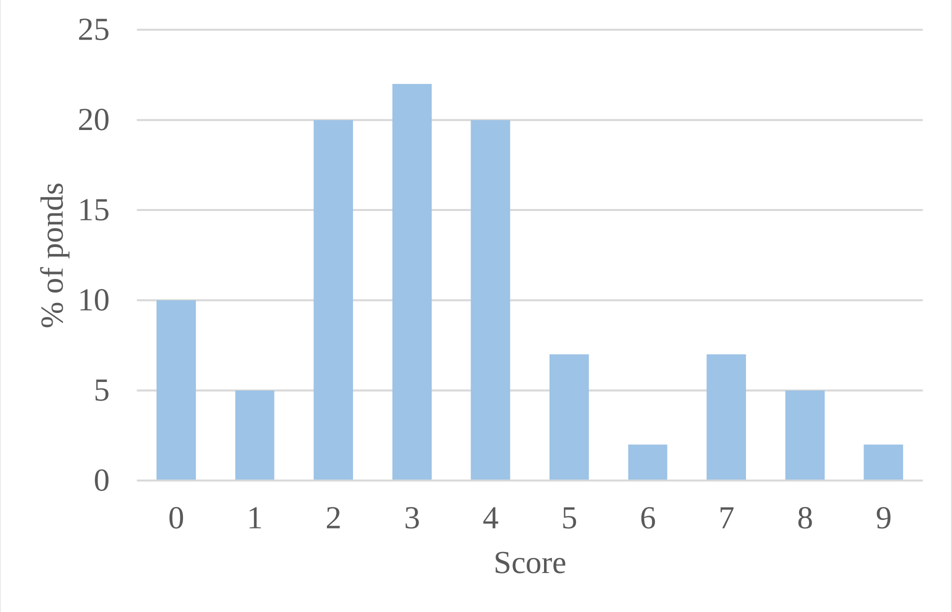
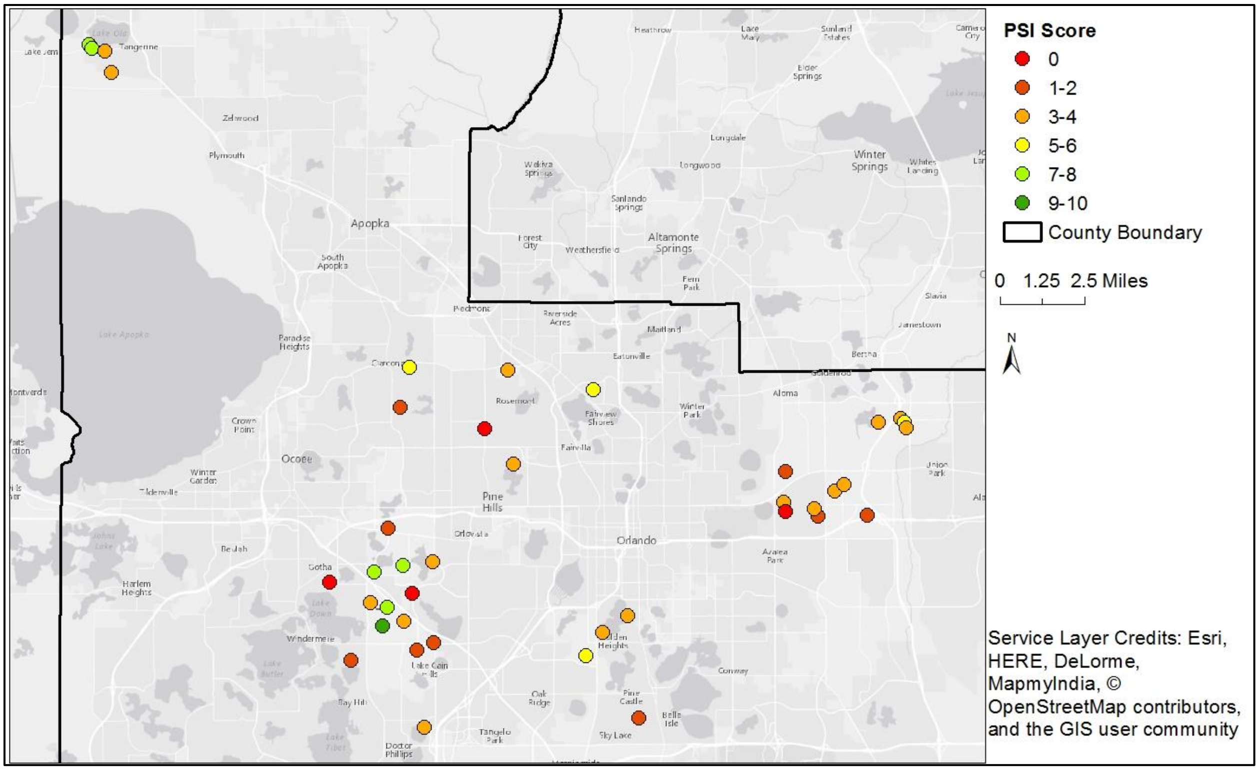
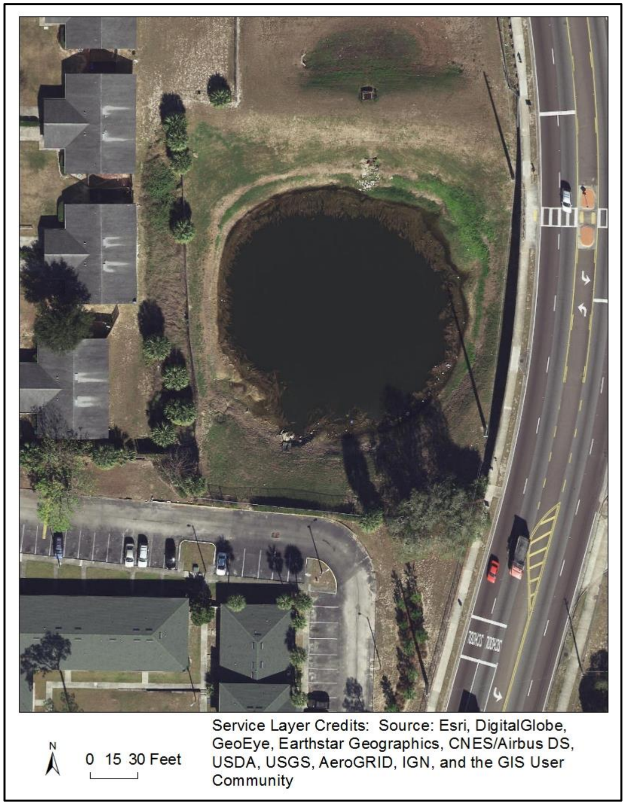


Figure 4.6 Score Distribution for Ponds Evaluation



Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 4.7 Mapping the SPI Score for Pond Evaluation
The highest possible score is 10, the lowest score 0.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4.8 Imagery of a Pond with Score 0

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4.9 Imagery of a Pond with Score 9

Overall, this assessment shows that very few ponds are designed and maintained in a way that provide CES to their area. Better management practices are needed to improve the stormwater ponds performance and attractiveness.

4.4.3. Using the SPI for Pond Improvement

The SPI was used to identify ponds in areas where improvement is most necessary. As described before, only three indicators were used for 371 ponds and the results are shown in Table 9. 75% of the ponds don't have a fence, 83% had a water depth above 3 feet, and 42% had DO levels less than 4 mg/l (Figure 4.10). For the SPI, around 55% of the ponds scored 2 or 3 out of 3 (Figure 4.11). However, the display on the map shows that scores are often grouped together with the higher values seen more outside of the urban core (Figure 4.12).

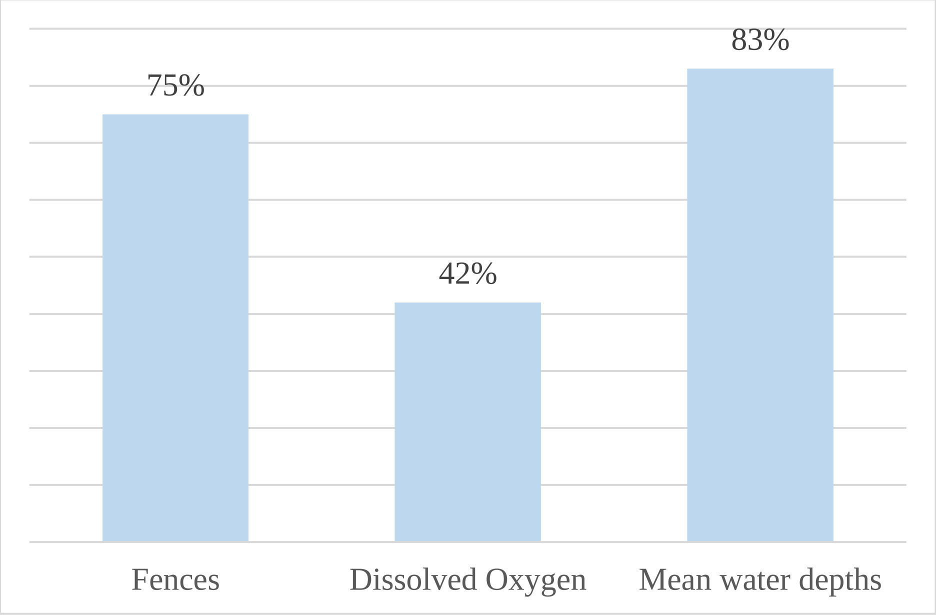


Figure 4.10 Percentage of Ponds with Score 1
for Each Indicator

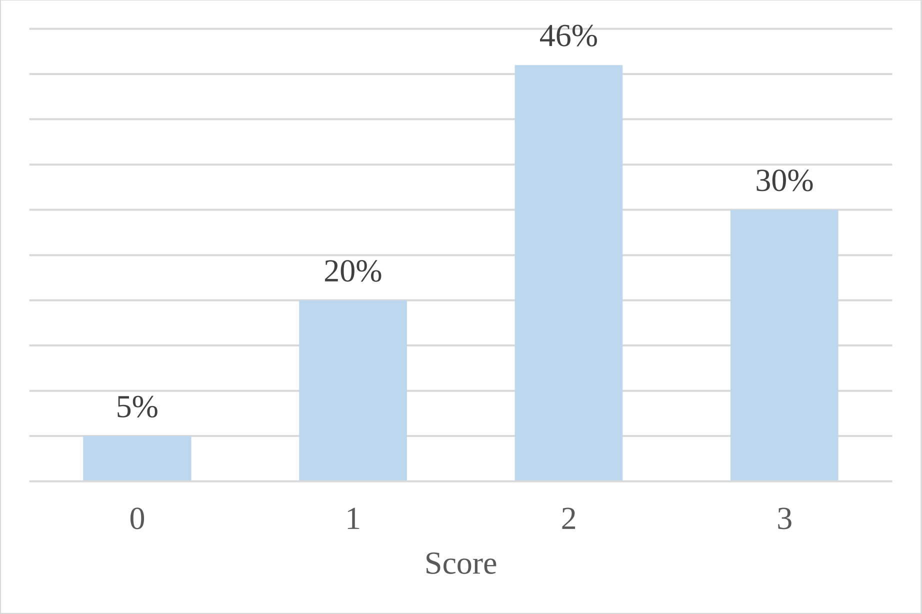


Figure 4.11 SPI Score Distribution

As potential areas of low performance ponds are identified, the next step was to link the socio-demographic data into the analysis. First, Figure 4.13 displays all the schools in the study area and surroundings and identifies the ponds that are within 0.25-mile Euclidean distance to at least one school. Figure 4.14 identifies ponds in areas with medium household incomes below US$ 50,000. Figure 4.15 displays the ponds located where at least 20% of the population lived below the poverty line in 2013. Figure 4.16 shows ponds in areas with high population density. Fifth, Figure 4.17 shows the ponds where no park or recreational area is close by. Using this threshold, ponds that meet every single of the socio-demographic criteria could be identified.

The last step was to link the selection based on socio-demographic factors to the ponds that scored 0 or 1 in the SPI. Seven ponds were identified that meet all conditions and are therefore most suitable for intervention (Figure 4.18). With the presented method, a small data set of seven ponds were identified out of 371 potential ponds. This lowers the research effort immensely.

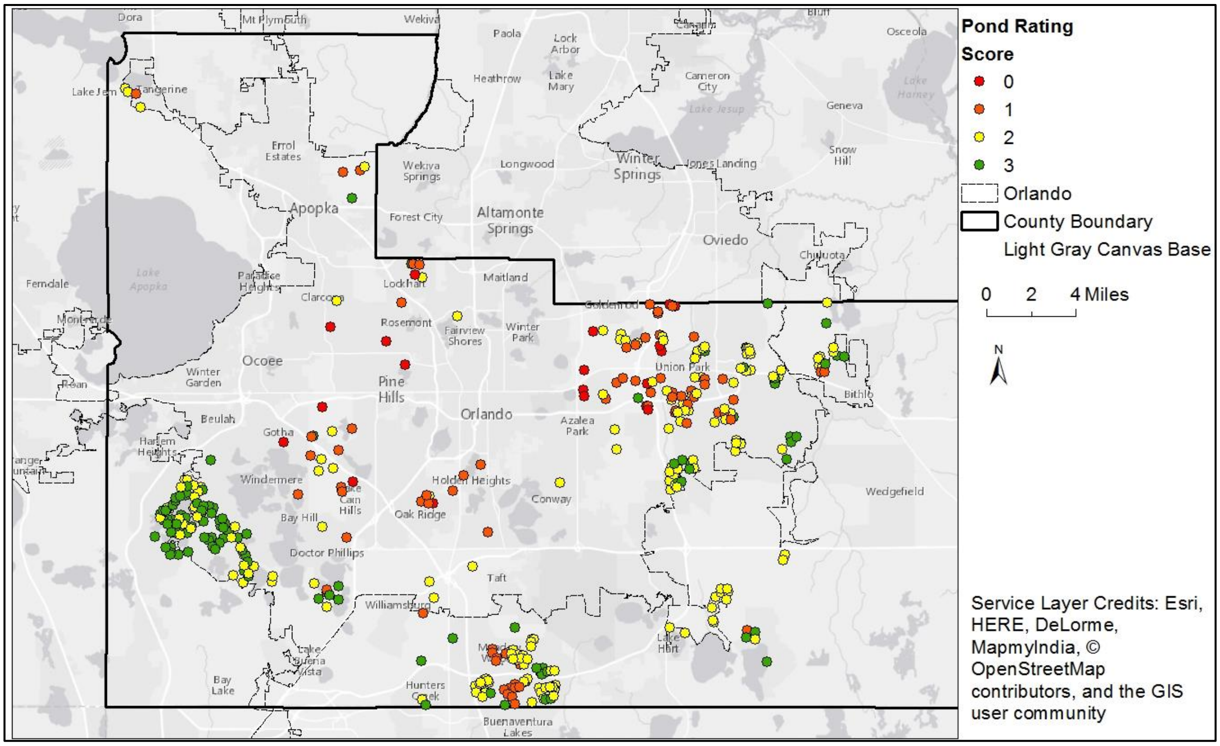


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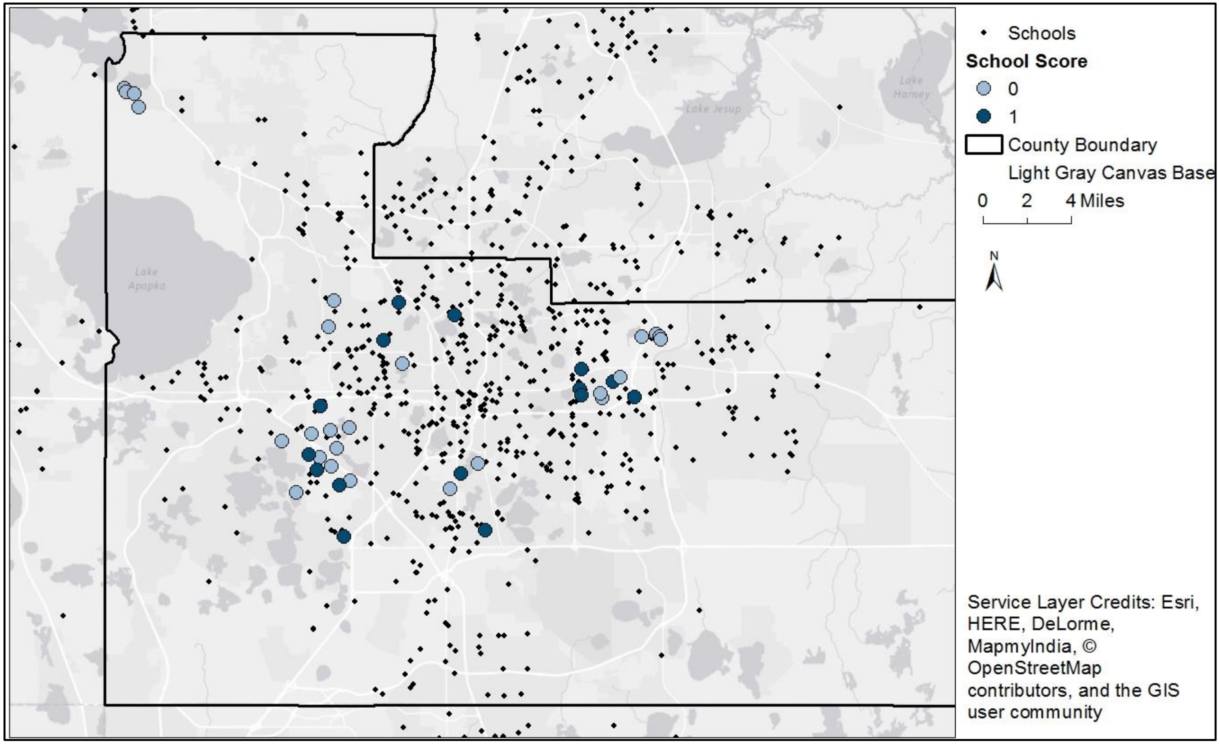
Figure 4.12 Mapping the SPI Score for Pond Improvement
3 indicating the highest score, 0 indicating the lowest score.



Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 4.13 Ponds within Walking Distance to Schools.
Based on University of Florida GeoPlan Center (2012); 1 indicates that pond is located within 0.25 miles' Euclidean distance from a school. 55 out of 371 ponds scored 1.

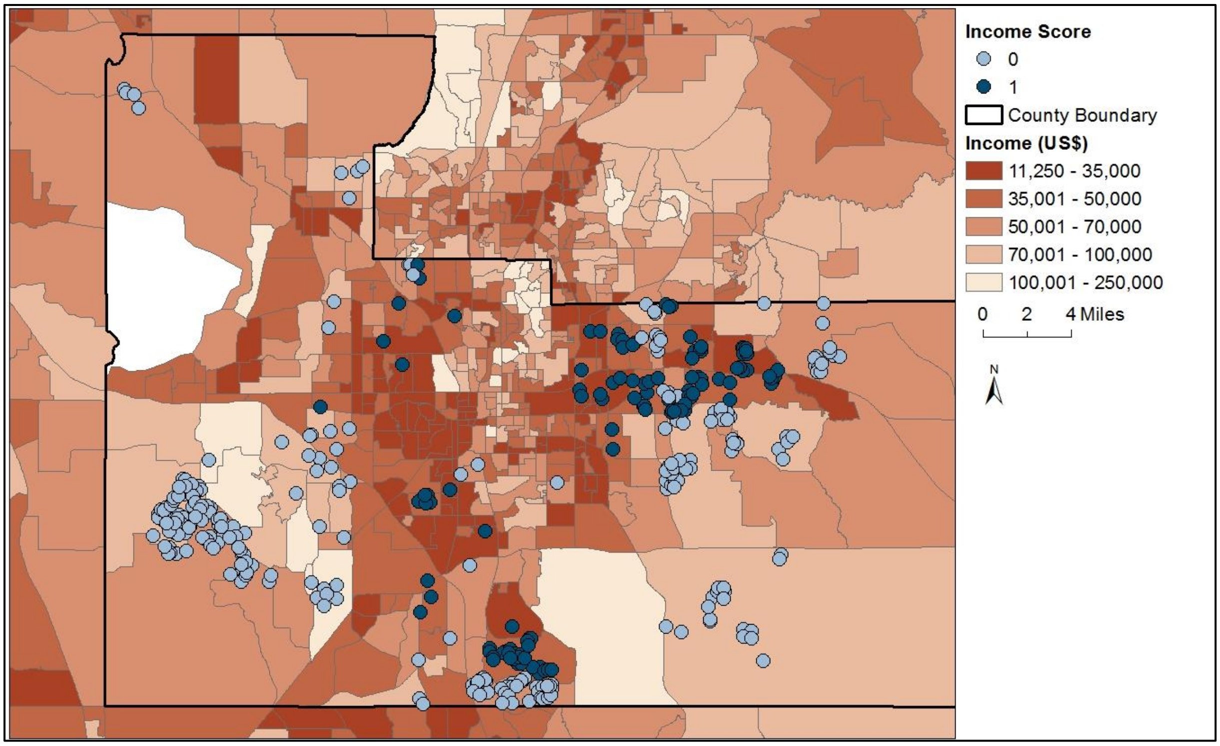


Figure 4.14 Ponds within Block Groups Indicating Median Household Income
Based on U.S. Census Bureau (2013). 1 indicates that pond is located in Block Group where median household income was below US$50.000 in 2013. 116 out of 371 ponds scored 1.

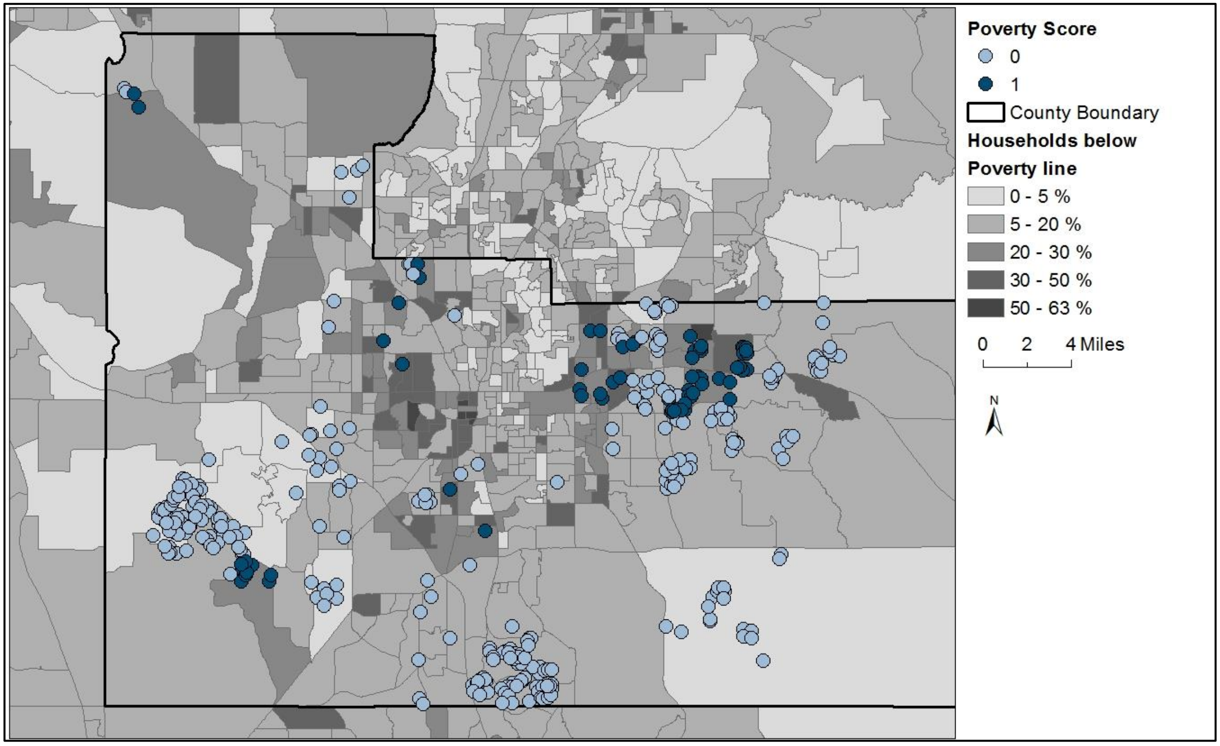


Figure 4.15 Ponds within Block Groups Indicating Households below Poverty Line
Based on U.S. Census Bureau (2013). 1 indicates that pond is located in Block Group where more than 20% of the households live below 2013 poverty line. 66 out of 371 ponds scored 1.

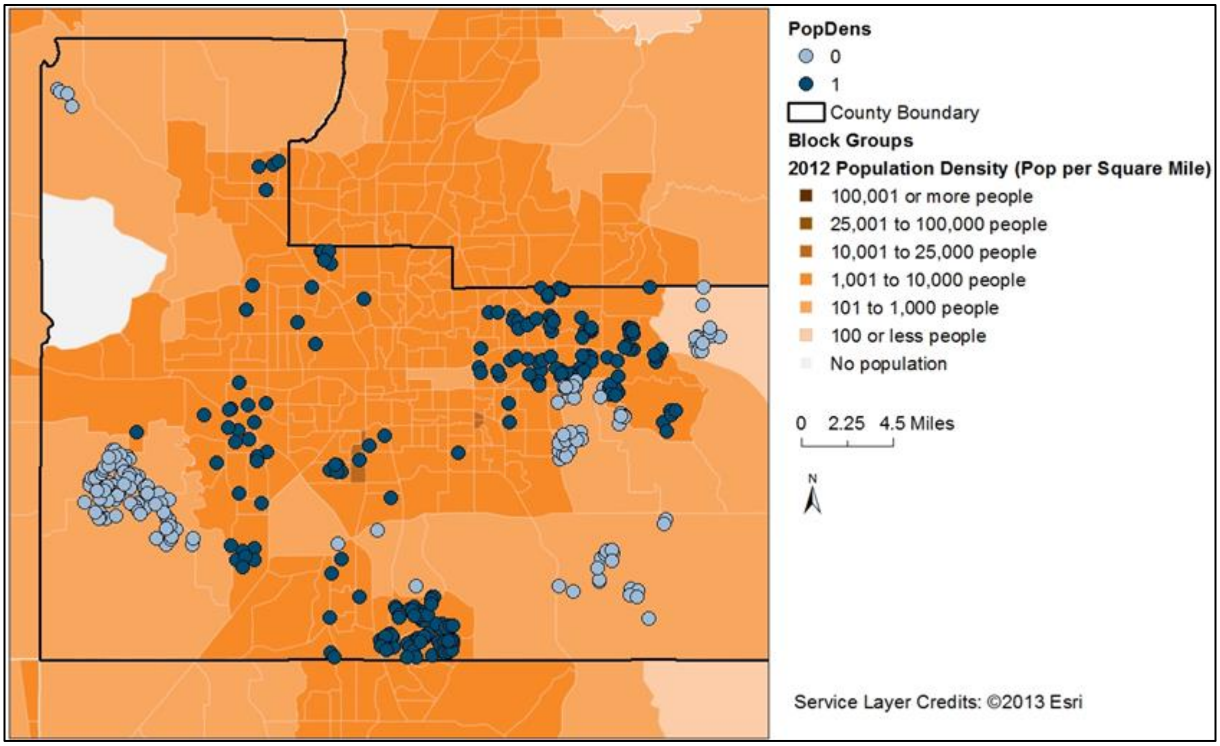


Figure 4.16 Ponds within Block Groups Indicating Population Density 2012
Based on ESRI (2012). 1 indicates that pond is located in Block Group where population density was 1000 people or higher per square mile in 2012. 210 out of 371 ponds scored 1.

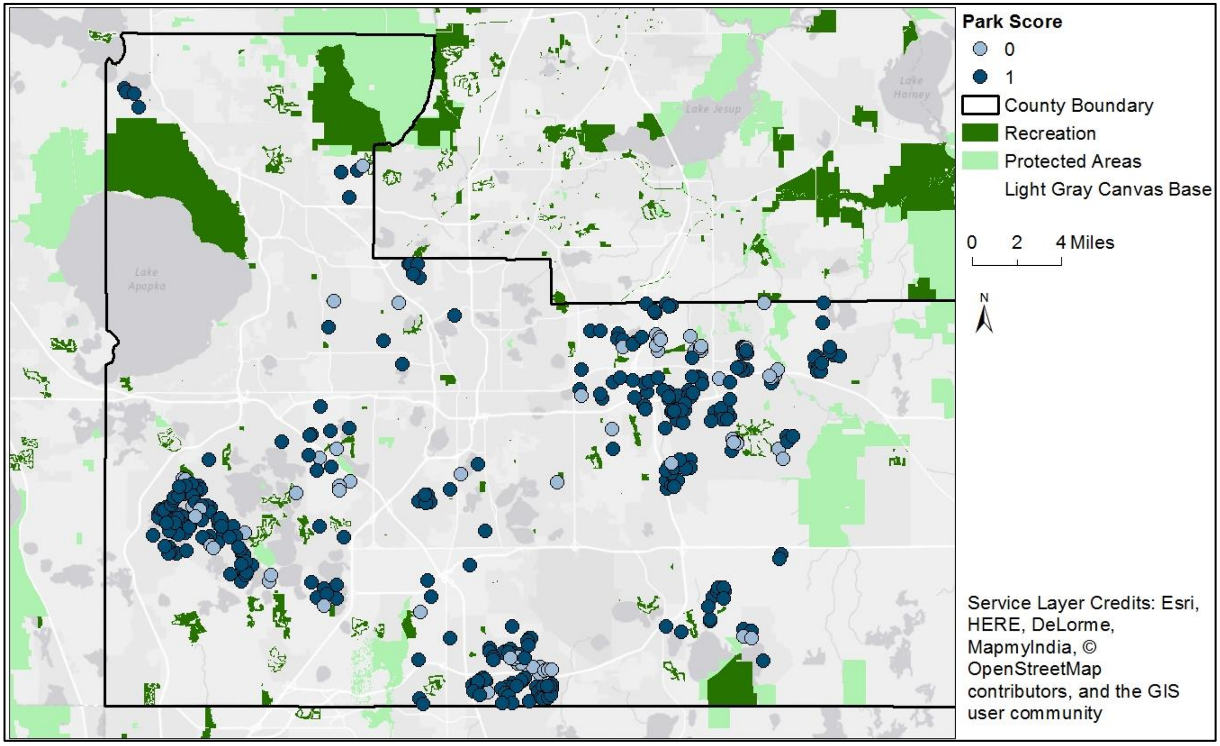


Figure 4.17 Ponds > 0.25 mi from Parks and Recreation Areas
Based on Florida Natural Areas Inventory (2016) and U.S. Geological Survey (2015). 1 indicates a 0.25-miles Euclidean distance from a park/recreation area. 302 out of 371 ponds scored 1.

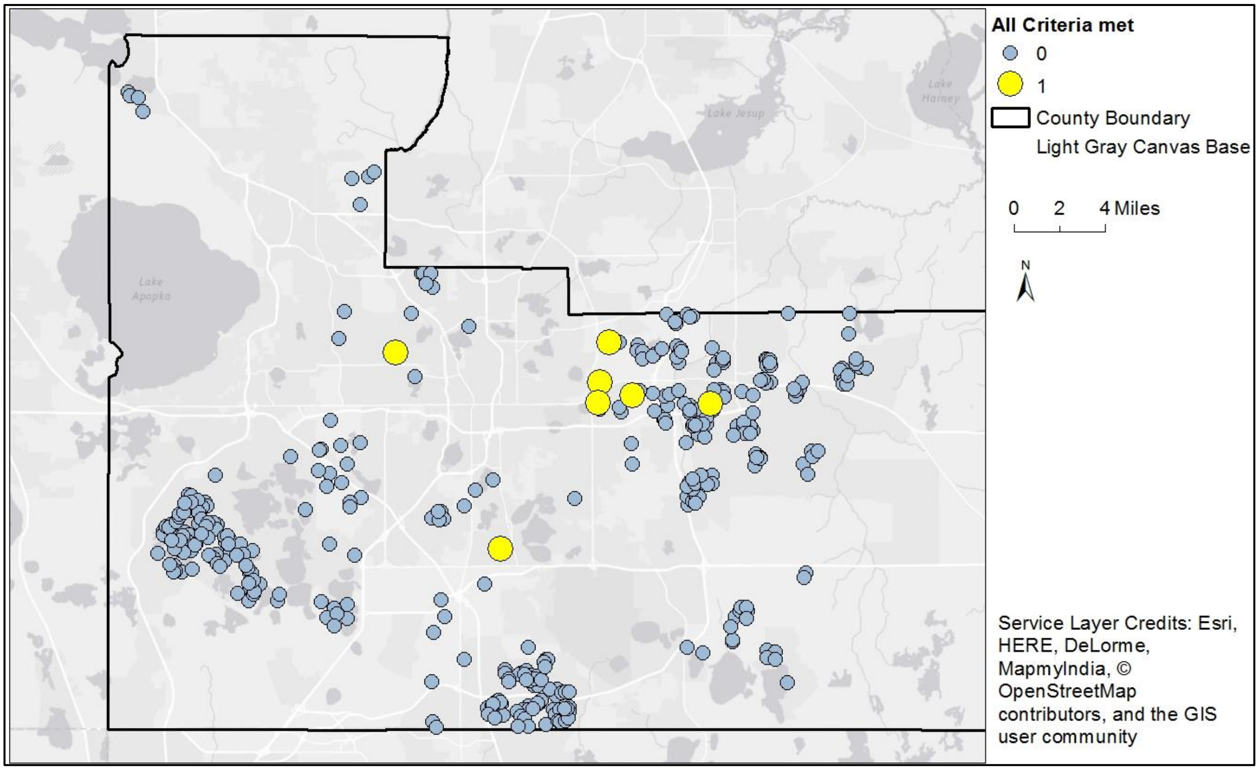


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Figure 4.18 Selection of Ponds Recommended for Improvement
7 ponds fulfilled all criteria, they are marked with yellow.

This information is a starting point for potential intervention and improvement of stormwater ponds. Five of the selected ponds form a cluster in one neighborhood. This would be a good area to initiate an education campaign and to promote stakeholder engagement in the intervention process. This would establish a relationship with the community to motivate use of the ponds for recreation and to have their support later on in the maintenance. The more isolated ponds could still be included if corporate partners support the intervention.

The SPI based on the three selected indicators is not a robust method to assess the ponds. However, it allows to link water quality, land use, and demographic data as it is available. This way it provides a simple ranking method that can be applied to very big data sets with low investment. Furthermore, it is possible to exchange the indicators depending on the data availability. In a next step, the seven final ponds need to be further researched. At this point, additional data collection, surveying, and other conventional assessment methods are recommended to analyze in detail the performance, nutrient management, and ecosystem functions of those ponds.

4.4.4. Summary

This case study in Orange County, Florida demonstrated how GIS and the SPI can be used to improve urban stormwater management through studying the performance of urban wet ponds. The first objective for this case study was to develop a stormwater pond index to assess CES. The SPI was developed based on the CES categories recreation, education and aesthetics identified from the literature. A selection of possible indicators was proposed that is adaptable to two different research questions and restrained by data availability. The second objective was to evaluate wet ponds in Orange County with the index. The present amenity value of 41 wet ponds was assessed using ten different indicators that are affiliated to recreation and aesthetics. The priority was to include a high number of indicators that would result in a robust assessment. Out of the 41 wet ponds, 23 scored below 5 out of 10. Six ponds scored 0 or 1 out of 10 and one pond scored 9 out of 10. This indicates a low performance for many of the ponds. Two aerial pictures of one of the lowest and the highest ranked ponds supported the successful evaluation through the SPI. It also highlighted the wide range of quality between different ponds.

The third objective was to identify ponds that need improvement and are suitable for intervention. The priority was to assess a high number of ponds, the SPI was composed out of three indicators. This made the assessment less robust, the selected ponds need to be further researched before taking final decisions. However, the GIS analysis allowed to link low rated ponds to socio-demographic factors. Therefore, it was possible to set specific criteria determining the best locations for intervention. For the present study, the priority was to identify low income neighborhoods with high population density and limited access to green space. Also, the schools located in these areas often have less resources. Pond improvement projects can provide useful opportunities for educational and community activities. Seven ponds were selected that scored 0 for the SPI and fulfilled the five criteria (distance to schools, income, poverty, population density, and access to green space). They are most suitable for intervention. The next step would be an onsite assessment and survey of those ponds to gather missing information.

With limited data availability, the use of the FUN management for GIS and the SPI allows to assess the performance and condition of stormwater ponds and make this information available to stakeholders. The preliminary assessment has the potential to lower the costs and effort of resource management. This method is valuable for communities and citizens that want to assess their ponds and would like to use them for amenity as well as for the governmental entities that oversee the planning and maintenance of the ponds. They can use GIS and the SPI to preliminary assess the ponds to streamline their maintenance efforts. Furthermore, it helps the county to cooperate more with the communities on how to take care of their ponds and longtermly transfer responsibility to the residents. At the same time, better communication and education about the ecosystem services and their benefits to the residents will motivate them to take their part in the maintenance.

CHAPTER 5: WATER QUALITY ANALYSIS AND IMPACT ASSESSMENT IN PLACENCIA, BELIZE

5.1. Introduction

The Belize Barrier Reef is the largest barrier reef in the Western Hemisphere and is considered one of the most diverse reef ecosystems (Cho, 2005; Gibson, McField, & Wells, 1998). Many studies have shown the negative effect of excessive nutrients on coral (Bruno, Sweatman, Precht, Selig, & Schutte, 2009; D'Angelo & Wiedenmann, 2014). Domestic sewage pollution from the urban areas and fertilizer from agriculture are main pollution sources (Gibson et al., 1998). In the past, Marine Protected Areas were created to better manage the Belize Barrier Reef system. To properly account for the impacts of land-based human activities, an Integrated Coastal Management approach was added to support the allocation, sustainable use and planned development of Belize's coastal resources (Cho, 2005).

The percentage of the population in Belize with access to an improved water source increased from 73% in 1990 to 100% in 2015 while those with access to improved sanitation facilities increased from 76% to 91% over the same time period (WHO/UNICEF JMP, 2015). BWS, the water and sewerage utility for the country, supplies 150 million gallons of water per day to 44,000 customers (Belize Water Services Limited, 2013a) and wastewater treatment to 21% of its customers in three urban communities, Belize City, Belmopan, and San Pedro (Grau et al., 2013).

The Government of Belize and Belize Water Services Limited, with the support of the Inter-American Development Bank and the Global Environment Facility entered into an agreement in 2013 to develop a new sewage collection and treatment system in the Placencia Peninsula, the fastest growing area in Belize in terms of population (Southern Environmental Association, 2015), to “support economic development and improve the quality of life of the residents” (Belize Water Services Limited, 2013b). Current wastewater discharge methods in this area include package treatment plants, septic systems, soak pits, and direct discharge without treatment. Completion of the construction of the new plant was expected to begin in 2014 and last 18 months, however, this has been put on hold until further studies are conducted (Caribbean Aqua-Terrestrial Solutions, 2017; Grau et al., 2013). With funding from the Caribbean Development Bank, BWS plants to complete an in-depth study on Nutrient Fate and Transport around the area and closed a call of interested parties for this study in January 2017. Given the sensitive ecosystems in the area that support fishing and tourism industries, a nutrient management strategy is necessary.

BWS opened a water quality testing laboratory facility in the Placencia Peninsula in 2014 and initiated a water quality monitoring program in the research area. The Civil and Environmental Engineering Department of the University of South Florida, Tampa signed a Memorandum of Understanding with BWS to analyze and visualize this collected water quality data using GIS tools. The FUN management for GIS was therefore used with this case study where data on water quality were available, but data on land use socio demographic parameters were limited.

The objectives were to:

1. Process, import and visualize the provided water quality data using GIS
2. Identify spatial and temporal areas of interest for key water quality parameters linked to land use
3. Provide analytical methods for assessing critical sites and different types of impacts

5.2. Study Area

The Placencia peninsula refers to a 15 miles long and 0.03 to 2 miles wide sand spit in the Stann Creek District of Belize (Figure 5.1). Placencia Village, Seine Bight, and Maya Beach are the three communities located on the peninsula. Traditionally, livelihoods were focused on fishing and farming but in recent years, tourism has become the dominant economic driver. The permanent population of Placencia numbers around 3300, and up to 800 tourists reside there during high season (Table 5.1). In the inhabited areas the population density is high (Halcrow, 2012).

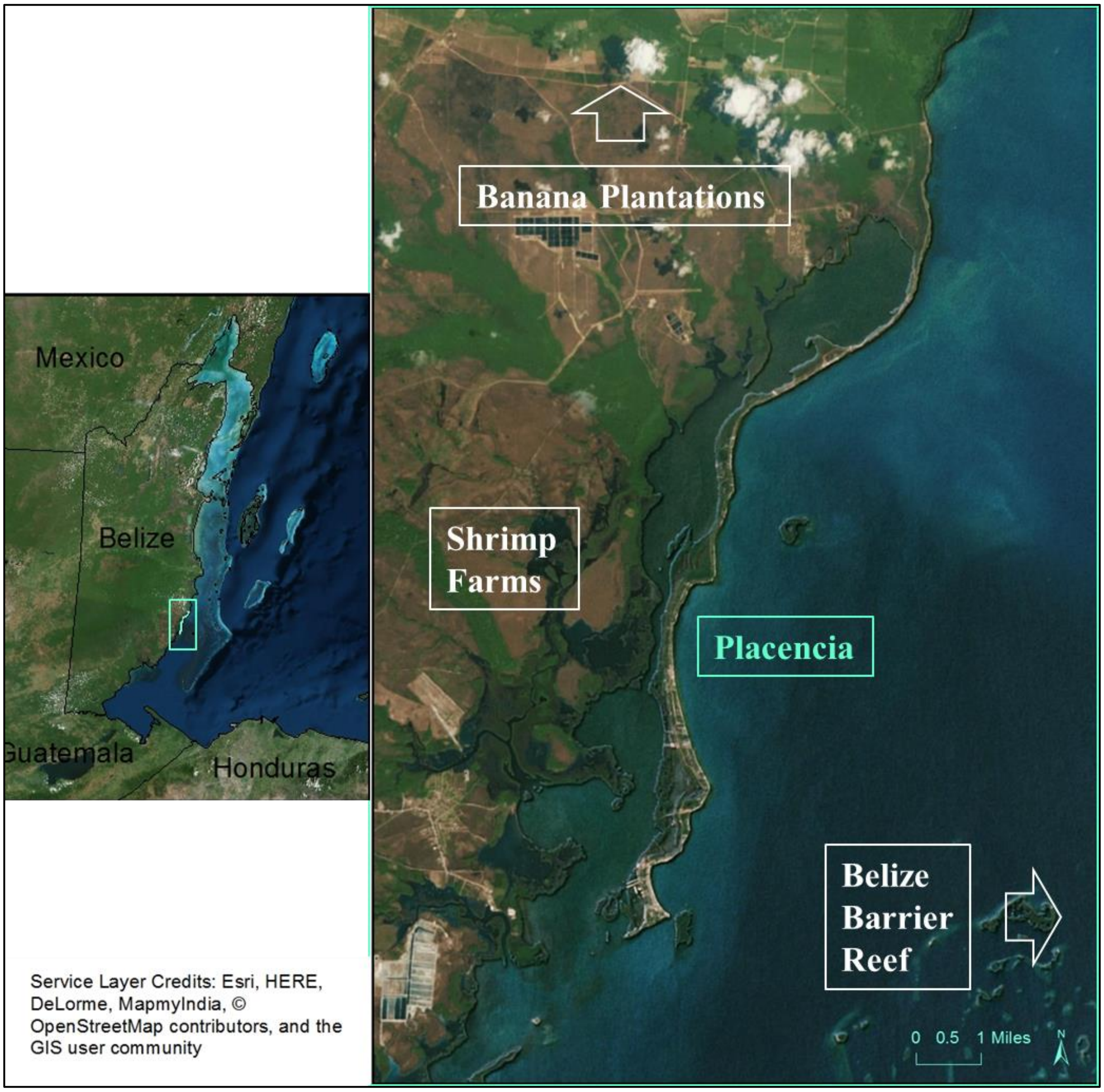


Figure 5.1 Satellite Image of the Placencia Peninsula in Belize and the Mainland

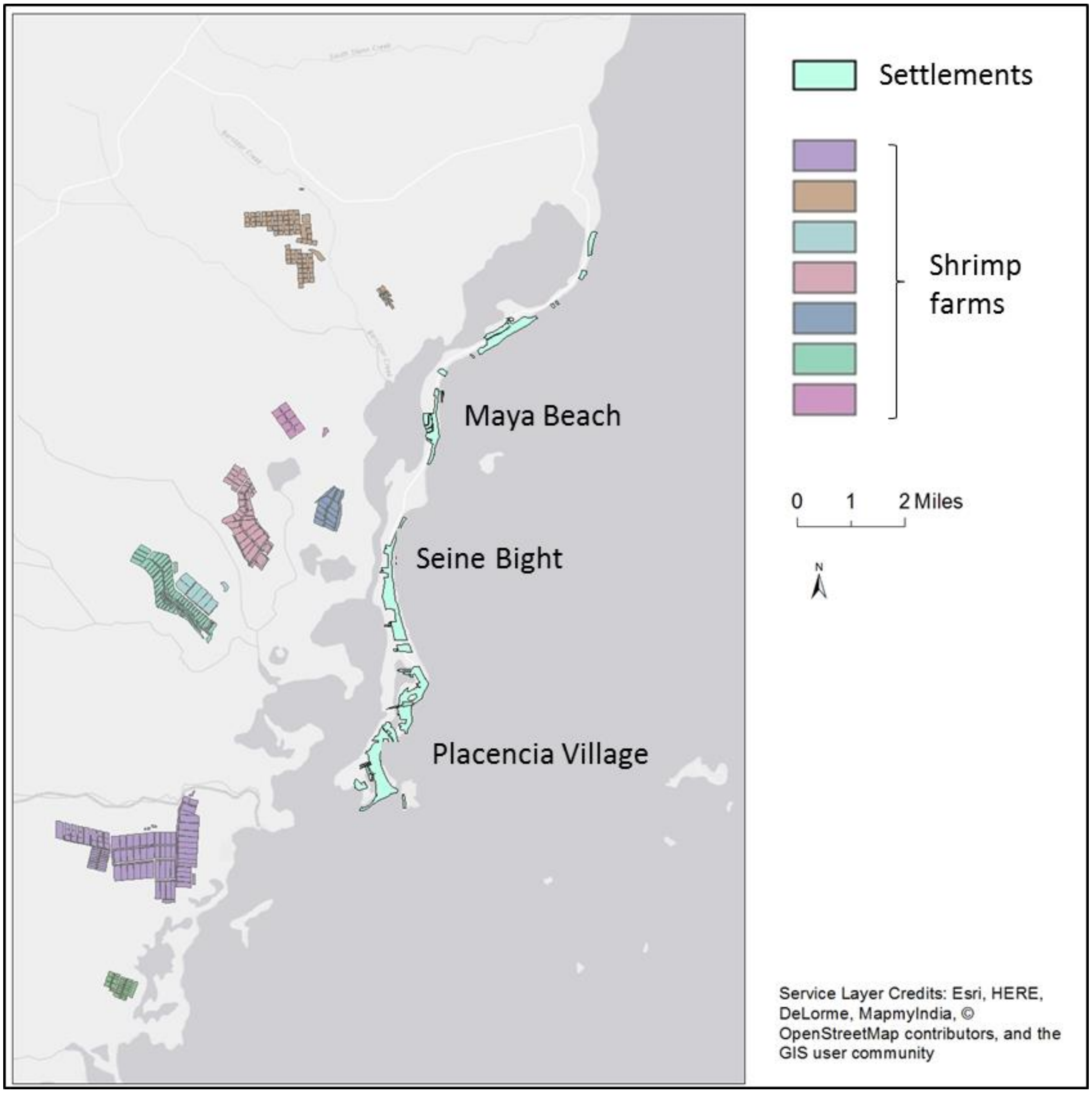
Table 5.1 Communities of Placencia Peninsula
Modified from: Southern Environmental Association (2015)

Community	**Population 2010**	**Population components**	**Description**
Placencia	1,753	Predominantly Creole	Historically a fishing community, now primarily a tourism-based economy.
Seine Bight	1,310	Garifuna	Historically a farming and fishing community, now moving towards a more tourism-based economy.
Maya Beach	229	Mixed	A retirement community, predominantly Americans, Canadians, and Europeans

Placencia lagoon is located between the peninsula and the mainland (Figure 5.1). In the north, there are extensive banana plantations and along the lagoon operate six out of Belize' seven main aquaculture shrimp farms (Southern Environmental Association, 2015). Effluents from these farming activities are discharged into creeks that mainly empty into the lagoon. The Beliz Barrier Reef lies around 20 miles east from Placencia.

Development on the peninsula has caused high losses in natural vegetation of littoral forests and mangroves (Wells et al., 2016), wildlife, and biodiversity (Halcrow, 2012). The Placencia lagoon is biodiverse and houses numerous endangered species (Southern Environmental Association, 2015). While there are many protected areas around Placencia, the peninsula and lagoon are not protected areas.

The Caribbean Sea borders the eastern coast and northern tip of the peninsula and the brackish lagoon borders its western coast. The groundwater table on the peninsula is considered very high, often below 50 cm (Halcrow, 2012). Groundwater is generally brackish to saline, though small quantities of fresh water are available. Residents get potable water from BWS and this is pumped from wells on the mainland. The three inland catchment areas, Santa Maria Creek, August Creek, and the Big Creek Watershed provide fresh water to the lagoon (Halcrow, 2012).



Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 5.2 Shrimp Farms on the Mainland and Urban Settlements on Placencia

A high variation in rainfall throughout the year impacts the water quality in the lagoon. January to June marks the dry season, with July to December being a wetter season with a very short dry phase in August and September. The highest rainfall occurs during hurricane season between September and December (Southern Environmental Association, 2015). Figure 5.3 shows the average rainfall between 2000 and 2012 for Big Creek and Figure 5.4 the average rainfall between July 2015 and 2016 for Placencia.

Extensive tourist development has taken place on the peninsula, including dredging and infilling of the lagoon and as a consequence the natural systems have been altered and demolished (Peninsula 2020 Initiative, 2011; Wells et al., 2016). Population growth, tourism infrastructure and agriculture highly increase pressure on the wetland ecosystems and water resources. The risks of contamination of ground water, the lagoon and the Caribbean Sea, are increasing.

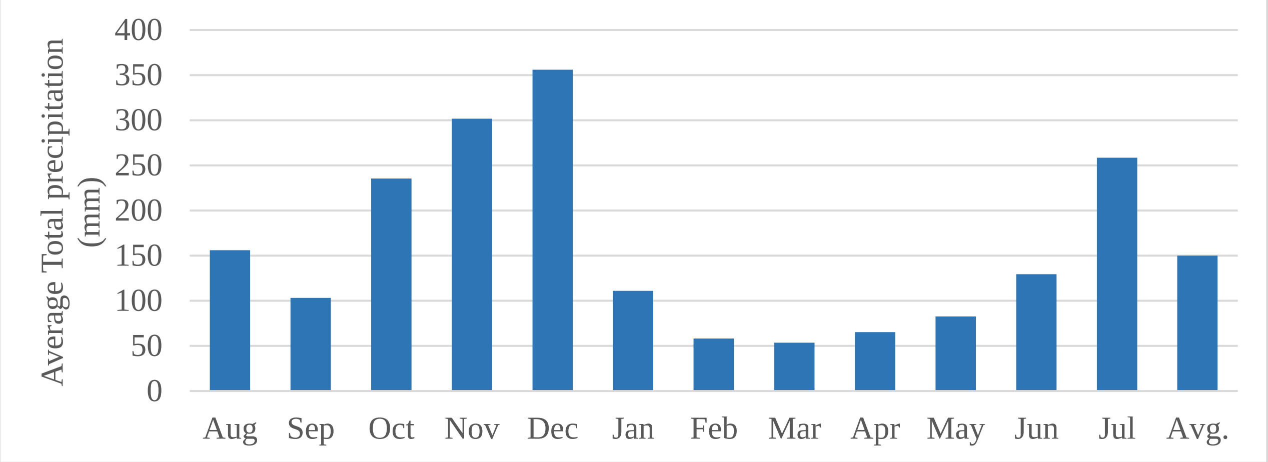


Figure 5.3 Averaged Monthly Precipitation Data for Big Creek, 2000 – 2012
Modified from: Southern Environmental Association (2015)

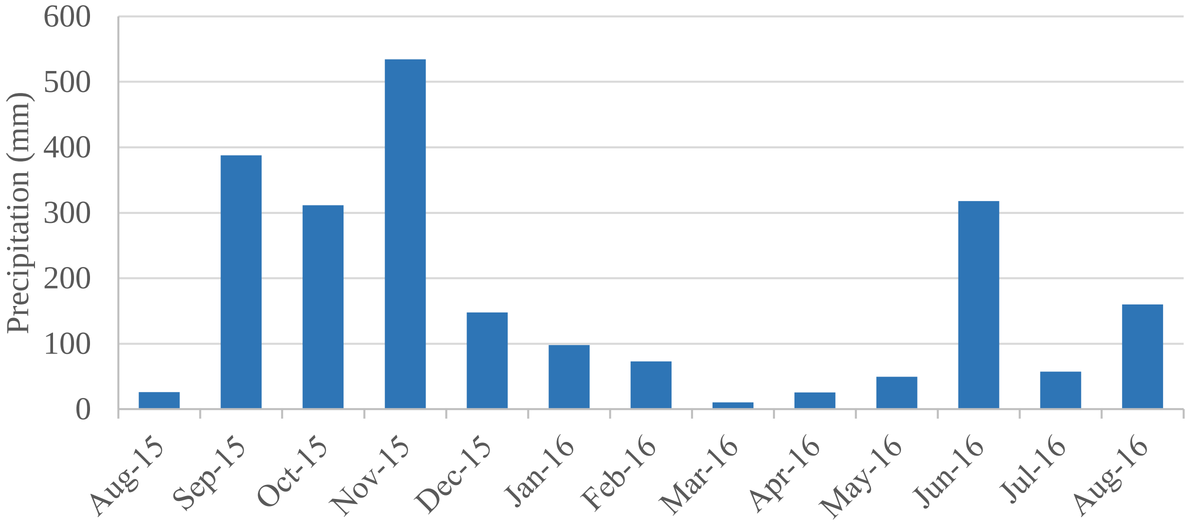


Figure 5.4 Averaged Monthly Precipitation Data for Placencia 07/2015 - 07/2016
Data Source: Belize National Meteorological Service (2017)

These developments are very recent; only few studies have been conducted in Belize and particularly Placencia in this field. The ecological and environmental conditions of the lagoon are very vulnerable to the impacts of development associated with human settlement and tourism industry (Ariola, 2003). At the time of that study, the upper lagoon was not affected by effluent from the shrimp farm operations on the mainland near Placencia Lagoon (Meerman & Boomsma, 2010), however, the area has seen significant changes in land use that likely affect this outcome. Some research has been carried out on Placencia linked to wastewater treatment. The Government of Belize commissioned two consultancies, a feasibility study and detailed design, for implementing the Placencia Peninsula Pilot Wastewater Management System. The Feasibility Study for a Pilot Wastewater Management System, funded by the U.S Trade and Development Agency (USTDA), was completed by Halcrow in 2012. It includes background information on the peninsula and analyzed existing and future conditions concerning wastewater discharge and treatment. The current wastewater management on Placencia is very limited. Halcrow (2012) identified the different discharge methods currently used by residents, hotels and businesses in Placencia (Figure 5.5). The existing methods are small wastewater treatment plants, septic systems, soak pits, and direct discharge. The latter two are considered untreated discharge. There is some bacteria removal through the filtration in the subsurface soils but the discharged water potentially contains nitrogen, phosphorus, household hazardous wastes, and viruses when it reaches the groundwater. This is a threat for health and ecosystems as wells, ponds, and coastal waters get contaminated. As population increases, so does the risk for pollution and the concern for public health. While the local population agrees that a centralized sewer system is needed, they are concerned that a system run by BWS would cut off a major source of local revenue and limit local control (Peninsula 2020 Initiative, 2011; Wells et al., 2016). An understanding of the dynamics between water quality, ecosystems, and land use is crucial to manage the development of Placencia with minimal environmental impact. Spatiotemporal analyses allow to assess how land use impacts water quality and ecology.

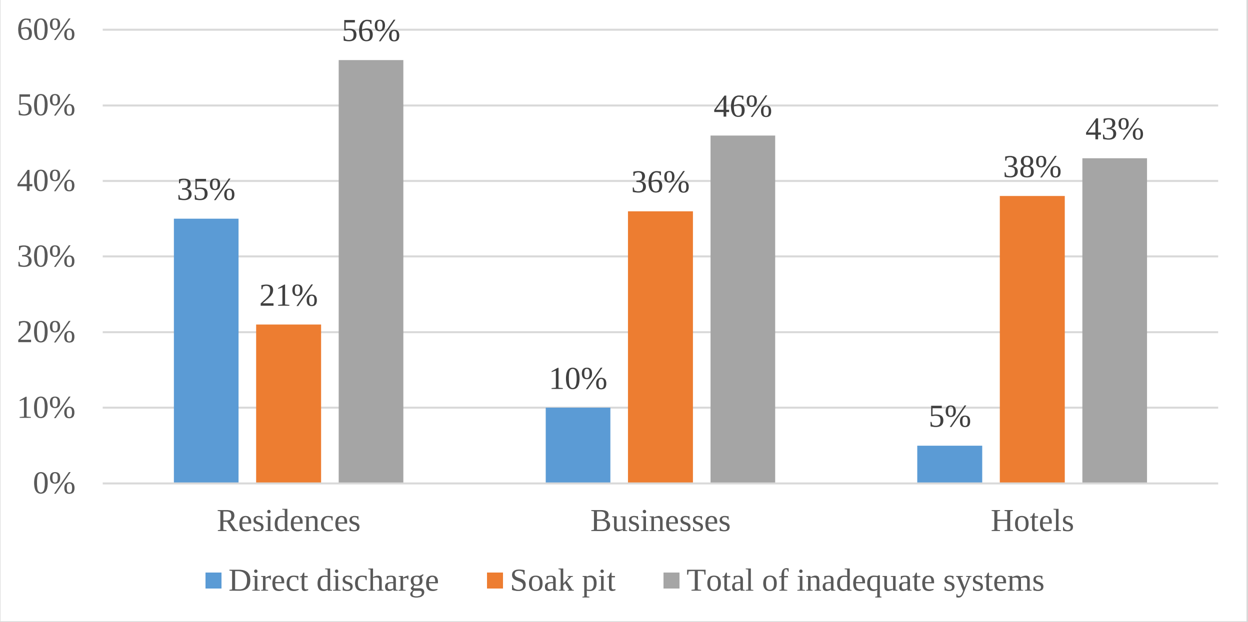


Figure 5.5 Effective Rate of Untreated Wastewater Discharging into Environment
Modified From: Halcrow (2012)

5.3. Methods

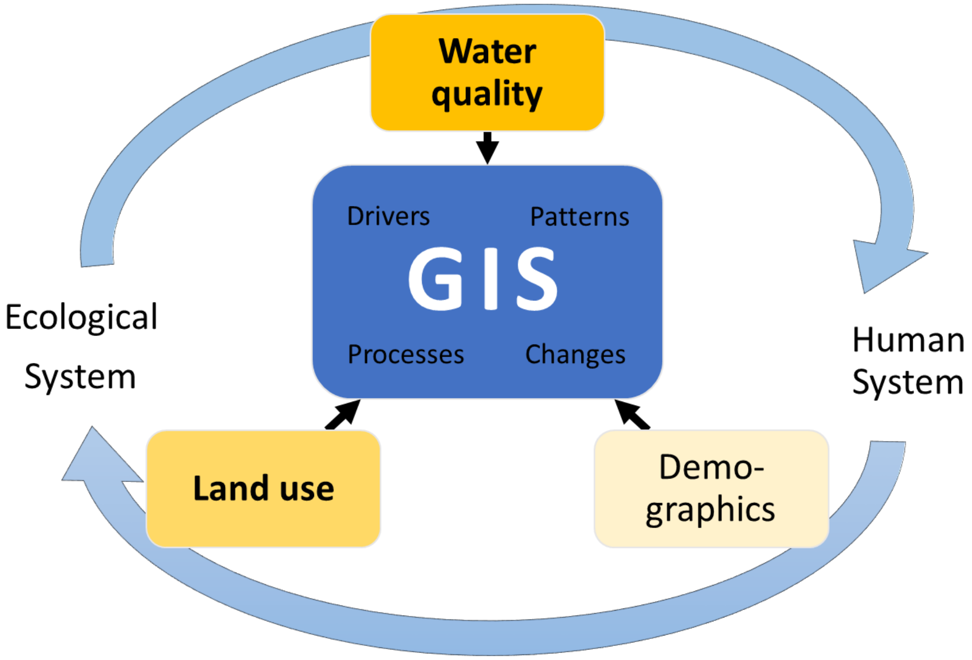


Figure 5.6 FUN Management for GIS Applied to Belize Case Study

For this case study, the FUN management for GIS was applied to an area with access to a lot of water quality data but limited land use and demographic information (Figure 5.6).

5.3.1. Data Sources

BWS collects monthly water samples from 56 different locations around the Placencia Peninsula and analyzes them for 18 water quality (WQ) parameters (Table 5.2, compare Table C. in Appendix B, p. 94 for method and equipment). This research had access to 25 months of sample results dating back to May 2014. The samples include eight groundwater wells on the peninsula, 15 samples from the marine waters along the peninsula coast line, and 27 in the lagoon and six from adjoining rivers/creeks that drain into the lagoon. BWS takes the measurements for 18 WQ parameters tested in-situ and in the laboratory.

Table 5.2 Water Quality Parameters Measured by BWS in the Placencia Peninsula Area

Analysis	**Parameter**	**Unit**
In-situ	pH	-
	Temperature	^{o}C
	Salinity	ppt
	Dissolved Oxygen (DO)	mg/l
	Turbidity	NTU
	Conductivity	µS/cm
	Chlorophyll	µg/L
Chemical	Nitrate (as NO_3^--N)	mg/l
	Total Nitrogen (as N)	mg/l
	Phosphate (as PO_4^{3-})	mg/l
	Total Phosphorus (as PO_4^{3-})	mg/l
	Ammonia (NH_3)	mg/l
	Chemical Oxygen Demand (COD)	mg/l
	Suspended Solids	mg/l
	5-Day Biochemical Oxygen Demand (BOD_5)	mg/l
Bacteria	Total Coliform	cfu/100mL
	E. coli	cfu/100mL
	Enterococci	mpn/100mL

The data opens the possibility for a comprehensive spatial and temporal analysis of the water conditions on Placencia. Not all measurements were used for this study due to time constraints. Also, no attempt was made to assess the quality of the data provided by BWS. Table 5.3 lists the shapefiles used for the Belize analysis. The Biodiversity and Environmental Resource Data System (BERDS) of Belize is a private database that provides a spatial data warehouse with shapefiles of Belize for societal, planning, conservation and education initiatives; it's the main source for free GIS data of Belize. Shapefiles are created by Meerman and Clabaugh (2016) and shared at the BERDS Spatial Data Warehouse. CARTO is an open platform for analyzing global spatial data. It enables drag and drop analysis and visualization of spatial data. While specialized on the processing of location data for apps, it also provides access to shapefiles. A shapefile was attained of the Belize shrimp farms with information including the farm name, management, size, and type (Carto, 2014).

Table 5.3 Shapefiles and Data Sources Used for the Placencia Case Study

Source	**Weblink**	**Map name**	**Year**	**Reference**
BERDS	www.biodiversity.bz	Ecosystems	2004	Meerman and Clabaugh (2004)
			2011	Meerman and Clabaugh (2011) (Meerman & Clabaugh, 2011)
			2015	Meerman and Clabaugh (2015)
		Basemap	2013	Meerman and Clabaugh (2013a)
		Rivers	2015	Meerman and Clabaugh (2013b)
		Settlements	2014	Meerman and Clabaugh (2014), Meerman and Clabaugh (2010)
CARTO	https://carto.com/	Shrimp Farms	2014	Carto (2014)

5.3.2. Spatial and Temporal Analysis with GIS

The research addresses how the water quality of Placencia peninsula and lagoon is affected by the urban and agriculture development, as well as other impact factors variable over time like rainfall and tourism. For the analysis with GIS, dissolved oxygen, Nitrate (NO_3-N), Ammonia (NH_4^+), *E. coli* and *Enterococci* were selected as parameters determining water quality. They serve for the assessment of water quality and life in aquatic systems, as well as the impact of land use including urban areas, agriculture, and wastewater. BOD_5 and COD were addressed only marginally to support the DO analysis. The water quality data including locations and date of sampling was processed in Excel and imported into ArcGIS. Based on the GPS coordinates associated with the measuring locations, a point vector layer was created. This enabled spatial and timely selections later on. Also, the Ecosystems-Land use shapefiles were added to compare land use and landcover between 2004 and 2015 to identify important developments in the area. To get a better understanding of the water quality distributions in the study area, the point data was interpolated to a raster surface. As there is a high variation and sharp contrasts in the data points, Spline with barrier was used to create the surfaces (Akkala et al. 2010). Negative values that resulted from the interpolation were reclassified as zero.

For the spatial analysis, the objective was to identify frequently contaminated sites and areas of concern. This was achieved by looking at the exceedance of effluent limitations. For the temporal study, the concentrations of different water quality parameters were displayed for selected months. Nitrate and Enterococci were shown in bimonthly time steps between August 2015 and 2016 to observe general season changes. Then, specific months were selected to look at the two temporal impact factors rainfall and tourism to determine if those are affecting the water quality.

Table 5.4 provides Belize's domestic effluent limitations for Nitrate, Ammonia, *E. coli*, and *Enterococci* (Environmental Protection (Effluent Limitations) Regulations, 2009). It should be noted that these are for point sources of pollution and not necessarily the standards one would use for proper functioning of marine or estuarine environments. If anything, these standards will be higher than standards needed for critical criteria of aquatic life. The critical value for DO is taken from the study Ariola (2003) conducted on the area. Based on these thresholds, it was possible to identify how often the effluent requirements were not met during the study period. Between May 2014 and August 2016, there were theoretically 28 months of sampling. However, the data set was not complete for that time period (see Table C.3 in Appendix C, p. 96). To make the data comparable, for every parameter and location, the percentage of measurements was calculated where effluent limitations were exceeded:

$$Percentage\ of\ Exceedance = \frac{\#\ of\ measurements\ exceeding\ treshold}{total\ \#\ of\ measurements} \cdot 100 \qquad (2)$$

For the temporal study, the concentrations of different water quality parameters were displayed for selected months. Nitrate and Enterococci were shown in bimonthly time steps between August 2015 and 2016 to observe general season changes. Then, specific months were selected to look at the two temporal impact factors rainfall and tourism to determine if those are affecting the water quality.

Table 5.4 Effluent Limitations Requirements for Belize

Parameter	**Effluent requirements**	**Source**
Dissolved Oxygen (DO)	≥ 5 mg/l	Ariola (2003)
Nitrate (as NO_3-N)	≤ 2.5 mg/l	Domestic Effluent Limitations for Class I Waters, Environmental Protection (Regulations (2009)
Ammonia (NH_3)	≤ 0.8 mg/l	
E. coli (freshwater)	≤ 126 cfu/100 ml	
Enterococci (saline water)	≤ 35 mpn/100 ml	
5-Day Biological Oxygen Demand (BOD_5)	≤ 30 mg/l	
Chemical Oxygen Demand (COD)	≤ 100 mg/l	

5.4. Results and Discussion

The BWS water quality data was processed and improved in GIS. As will be shown in this chapter, numerous maps were created and different types of spatial analysis conducted to demonstrate different techniques. In a similar matter, it would be possible to conduct further research on different parameters, selecting other time periods and focusing on different locations.

5.4.1. Water Quality Data and Study Area

The 56 BWS water quality sampling locations are shown in Figure 5.7 (see Table C.2 in Appendix B, p.95 for coordinates). They are well distributed over the peninsula and the surroundings and represent surface water, groundwater, fresh water, seawater, and brackish water sites. Figure 5.8 shows landcover/ land use of the area for 2004, 2011, and 2015. Between 2004 and 2011, the urban area expanded over the central part of the peninsula. At the same time, some wetland, mangroves, and littoral forests recovered. Ecosystems-Land use 2011 and 2015 are identical, except for differences observed on the main land due to aquaculture. While some aquaculture facilities are new in 2015 compared with 2011, some are simply recoded from agricultural areas to aquaculture. The agricultural areas in the north are the banana plantations, and their areas increased between 2004 and 2015. Also, some efforts seem to be underway mangrove and littoral forests. More details on subcategories of urban areas, like residential, commercial, and hotel areas would be helpful, but were not available for the study.

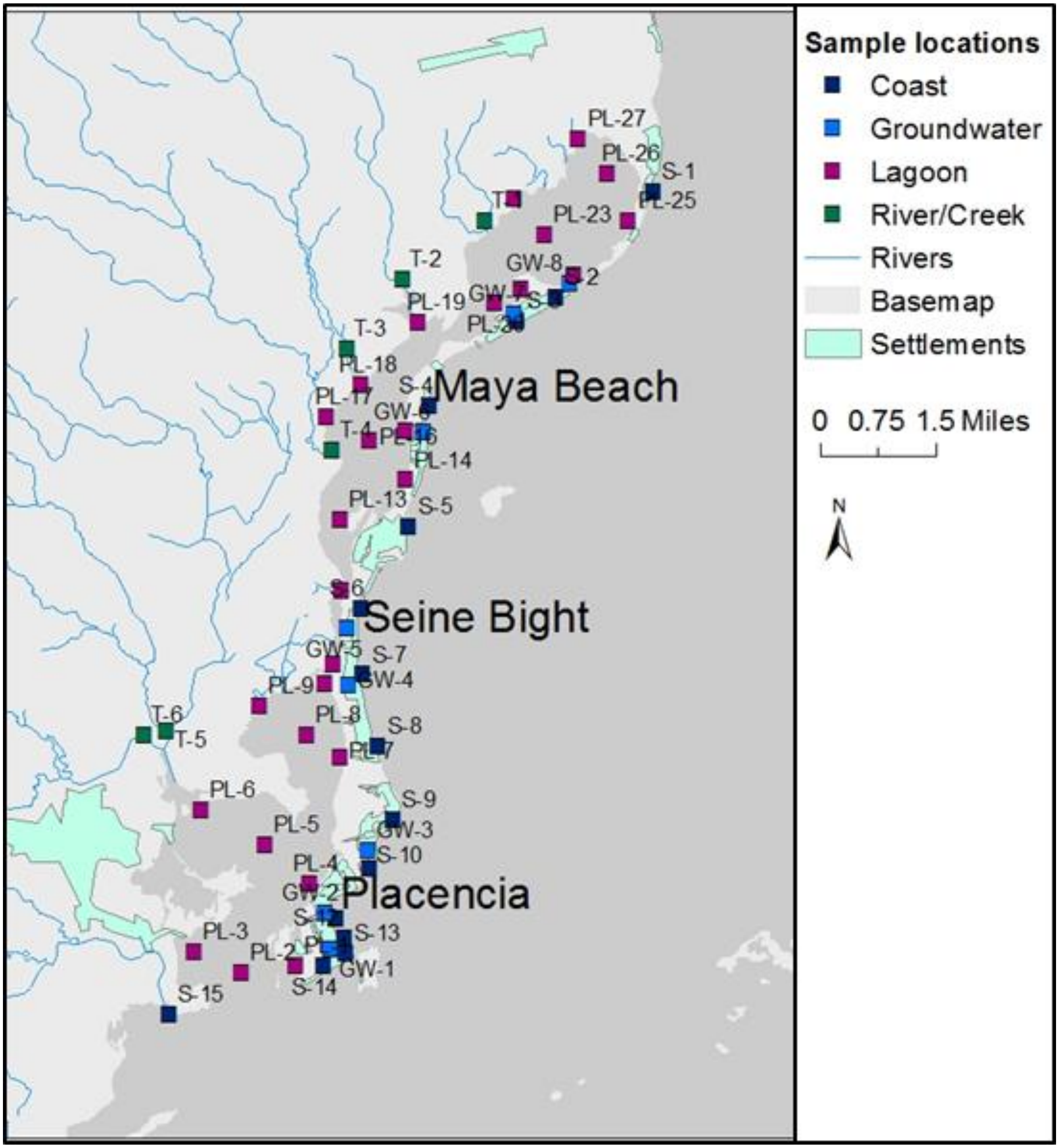


Figure 5.7 BWS Water Quality Sampling Locations on and around the Peninsula Placencia

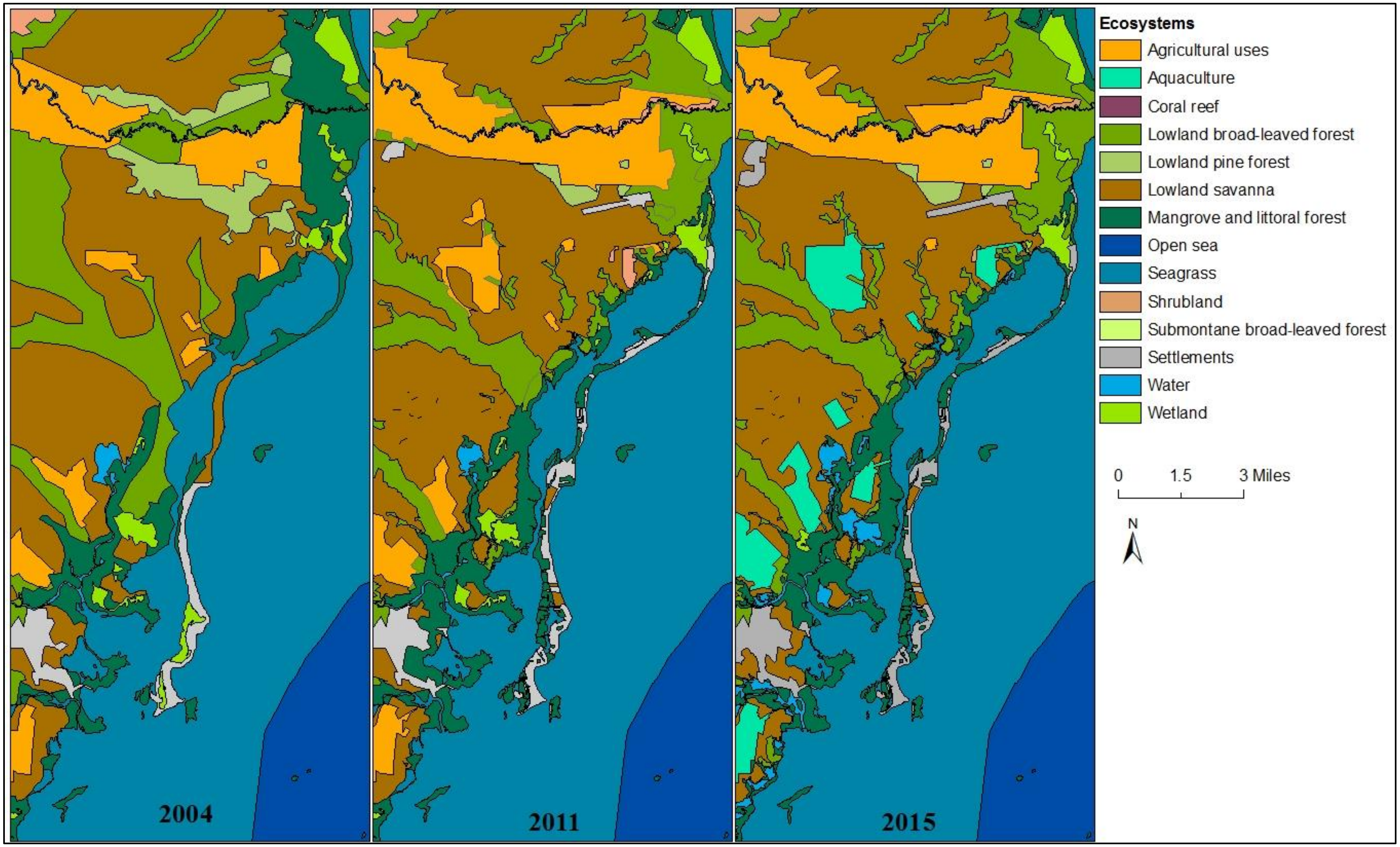


Figure 5.8 Placencia Area Land Use / Landcover Change between 2004 and 2015
Modified from Meerman and Boomsma (2010)

Figure 5.9 shows the surface water distribution of DO concentrations in mg/l for data collected in June 2016. The data was interpolated with a Spline, ignoring groundwater samples. The peninsula was indicated as barrier to avoid direct interpolation between coastline and lagoon. The DO concentrations varied from 1.3 mg/l to 9.3 mg/l, where low values usually indicate the least desirable conditions (red areas). The orange and red areas, located in the creeks and lagoon side, would be areas of most concern for their deleterious impact on aquatic life.

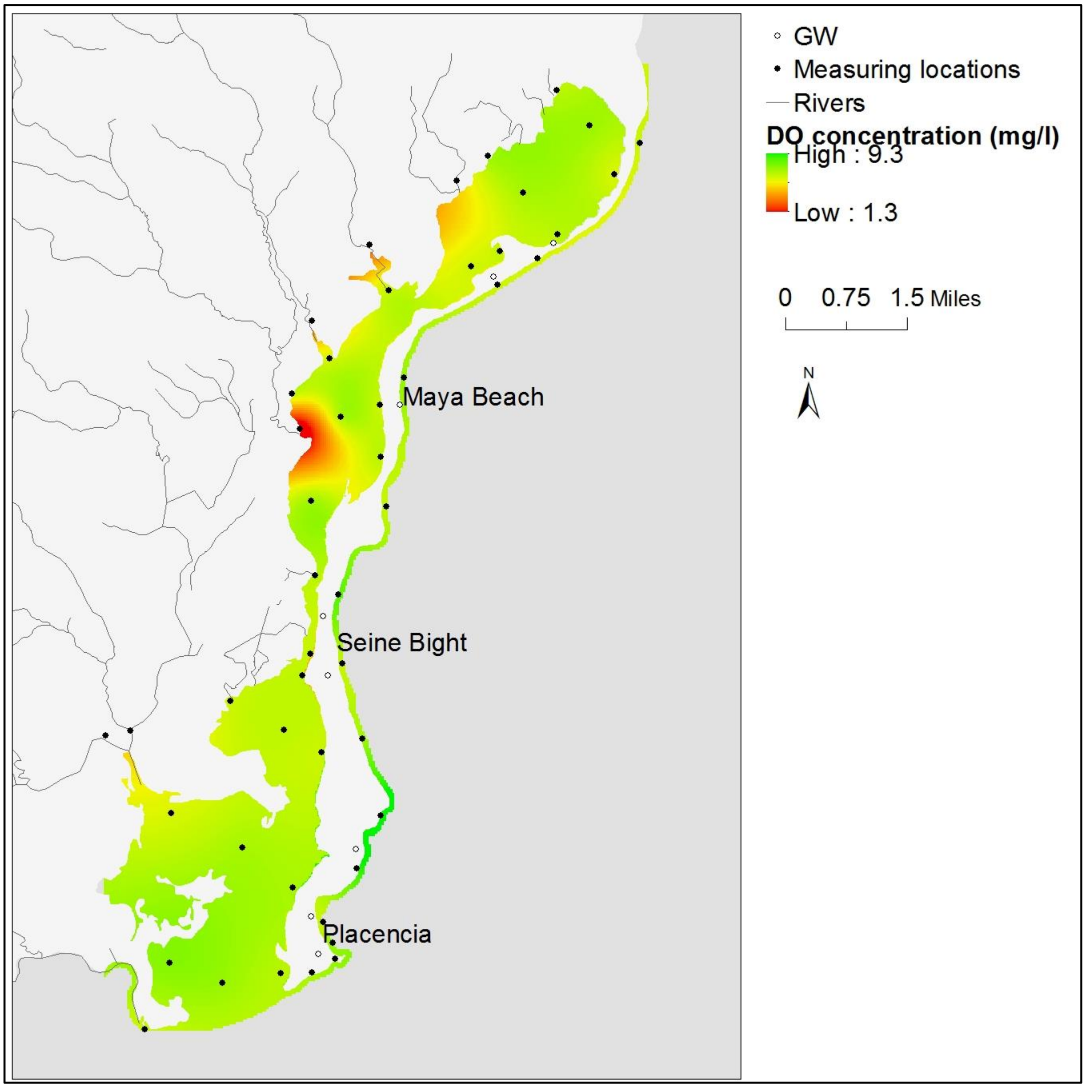


Figure 5.9 Spline Interpolation (with Barrier) for Dissolved Oxygen (DO, mg/l) Sampled in June 2016

For Nitrate, Ammonia, *E. coli*, and *Enterococci*, the same Spline interpolation with barrier was conducted, also for June 2016 (Figure 5.10 to Figure 5.13). For those parameters, the color scheme is inverted. Low values are desired, they are displayed in light green. High values indicate areas of concern, they are shown in red. Figure 5.10 shows the surface water distribution of nitrate concentrations in mg/l as N for data collected. Nitrate values varied from 0 to 11 mg/l as N. These are particularly high in the lagoon side, and high enough along the coast to warrant intervention as values above 2.5 mg/l are concerning (Table 5.4, p. 58).

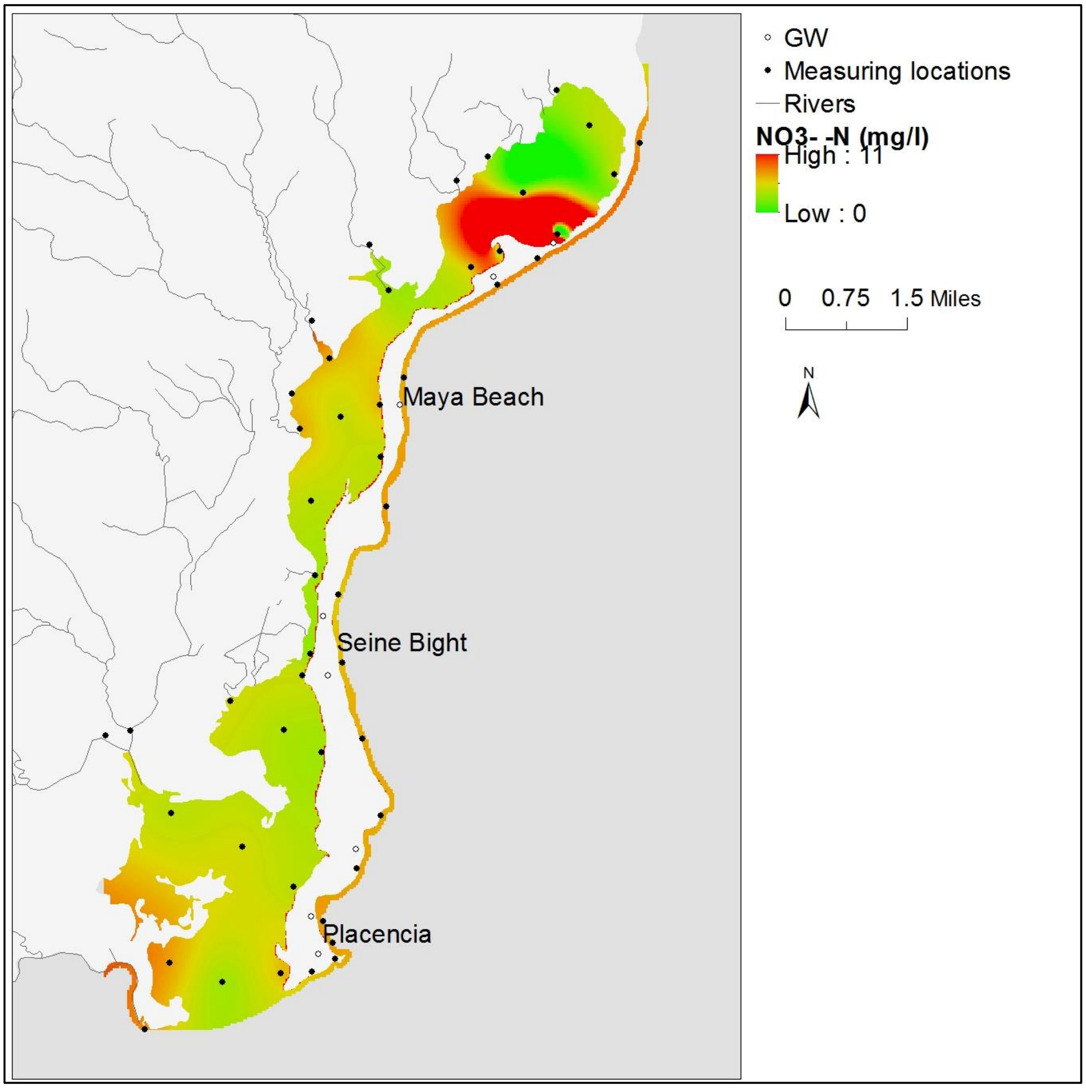


Figure 5.10 Spline Interpolation (with Barrier) for NO_3^--N (mg/l) Sampled in June 2016

Figure 5.11 shows the interpolated surface water concentrations in mg/l for Ammonia for data collected in June 2016. Values were very low, between 0 and 0.25 mg/l. Ammonia was not a concern in the surface water bodies in June 2016.

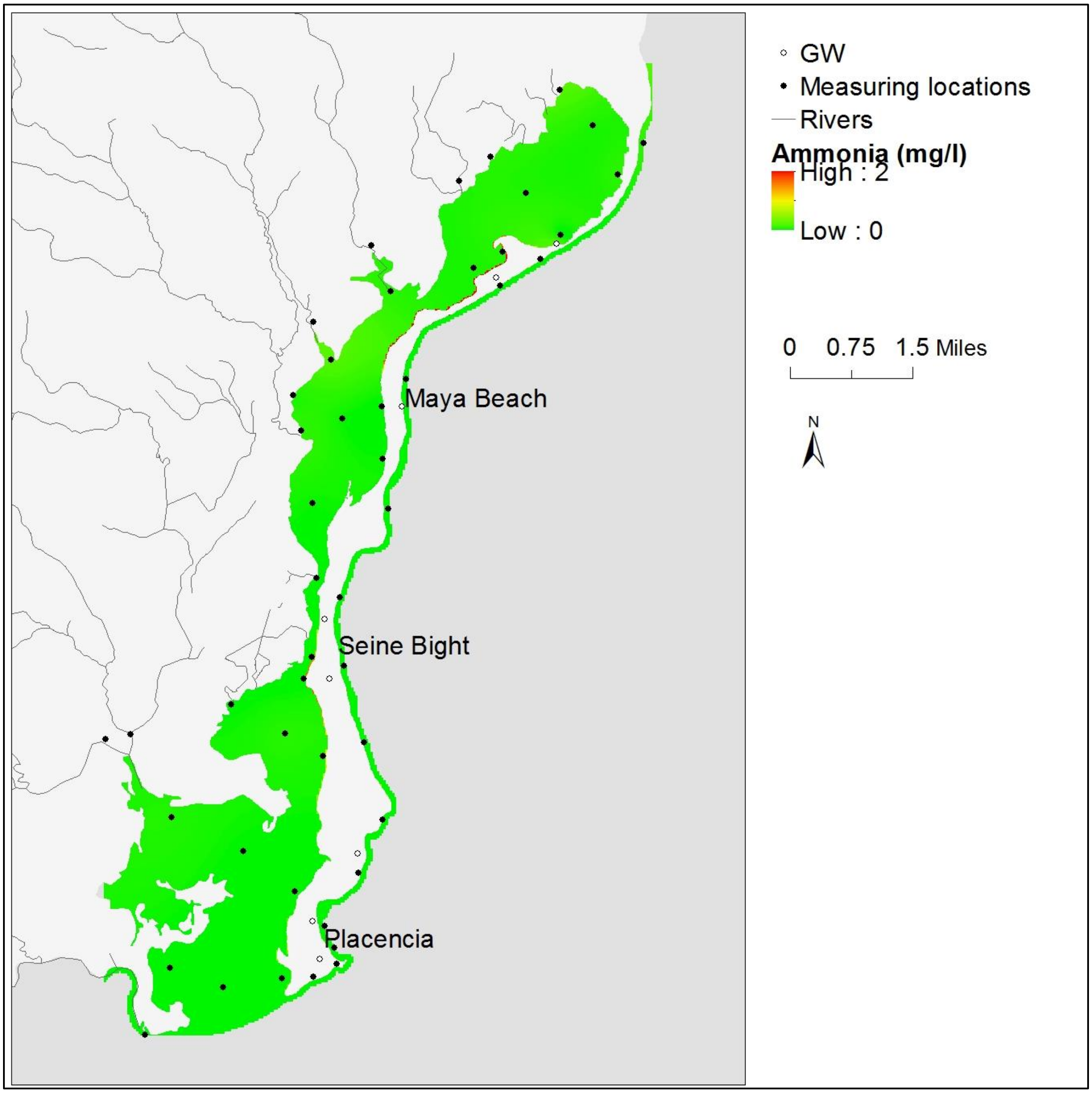


Figure 5.11 Spline Interpolation (with Barrier) for NH_3 (mg/l) Sampled in June 2016

The distribution of *E. coli* a result of the spline interpolation is displayed in Figure 5.12. Some areas of concern with concentrations of up to 2302 cfu/100ml were measured in the creeks and up to 2000 cfu/100ml in the lagoon in June 2016.

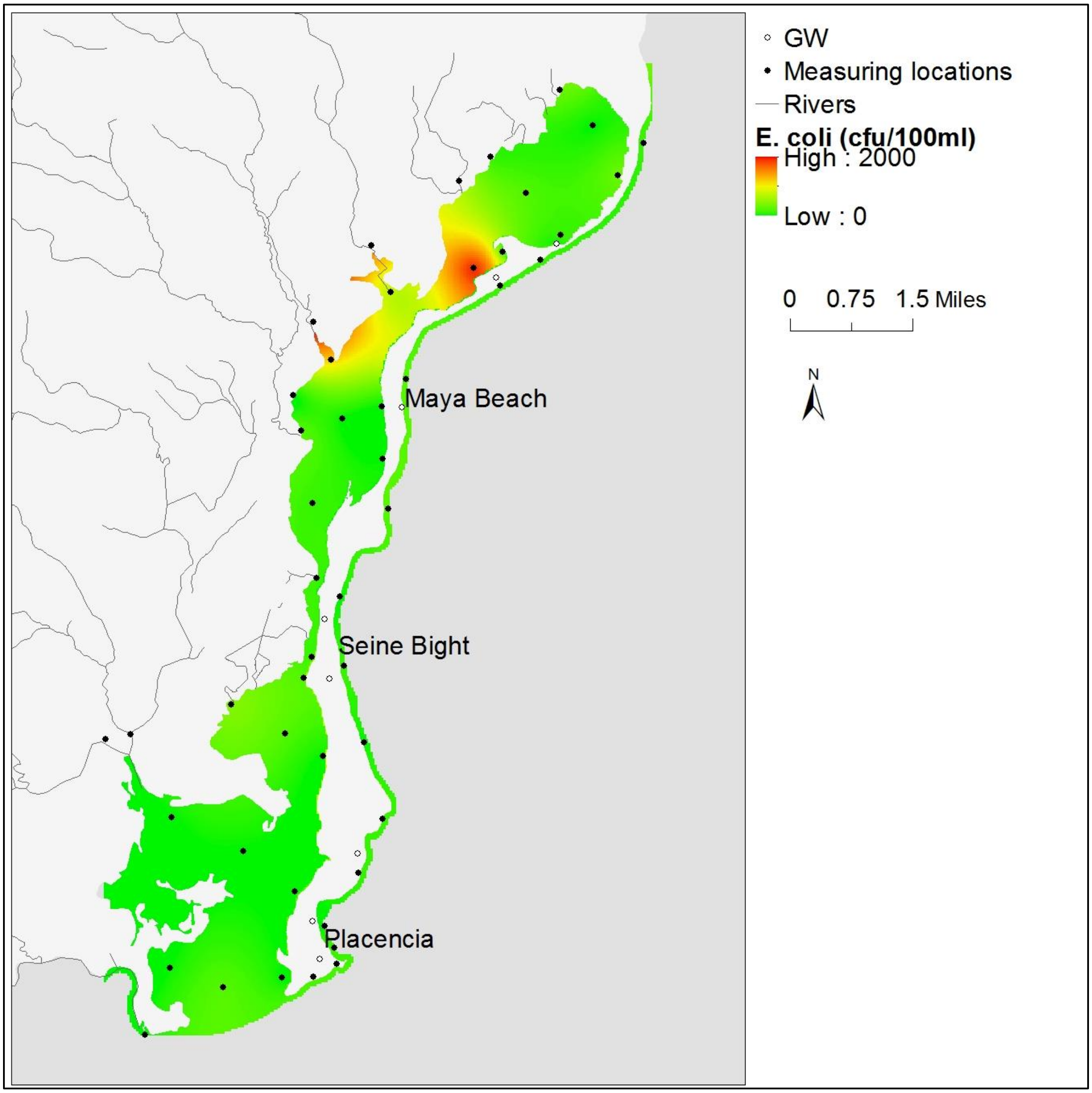


Figure 5.12 Spline Interpolation (with Barrier) for *E. coli* (cfu/100ml) Sampled in June 2016

The last interpolation, Figure 5.13, shows the distribution of *Enterococci*. Here, concentrations were only slightly increased in the creeks. However, at the same location in the lagoon where *E. coli* was measured very high, *Enterococci* also has the peak values. They reached up to 4875 mpn/100 ml in June 2016.

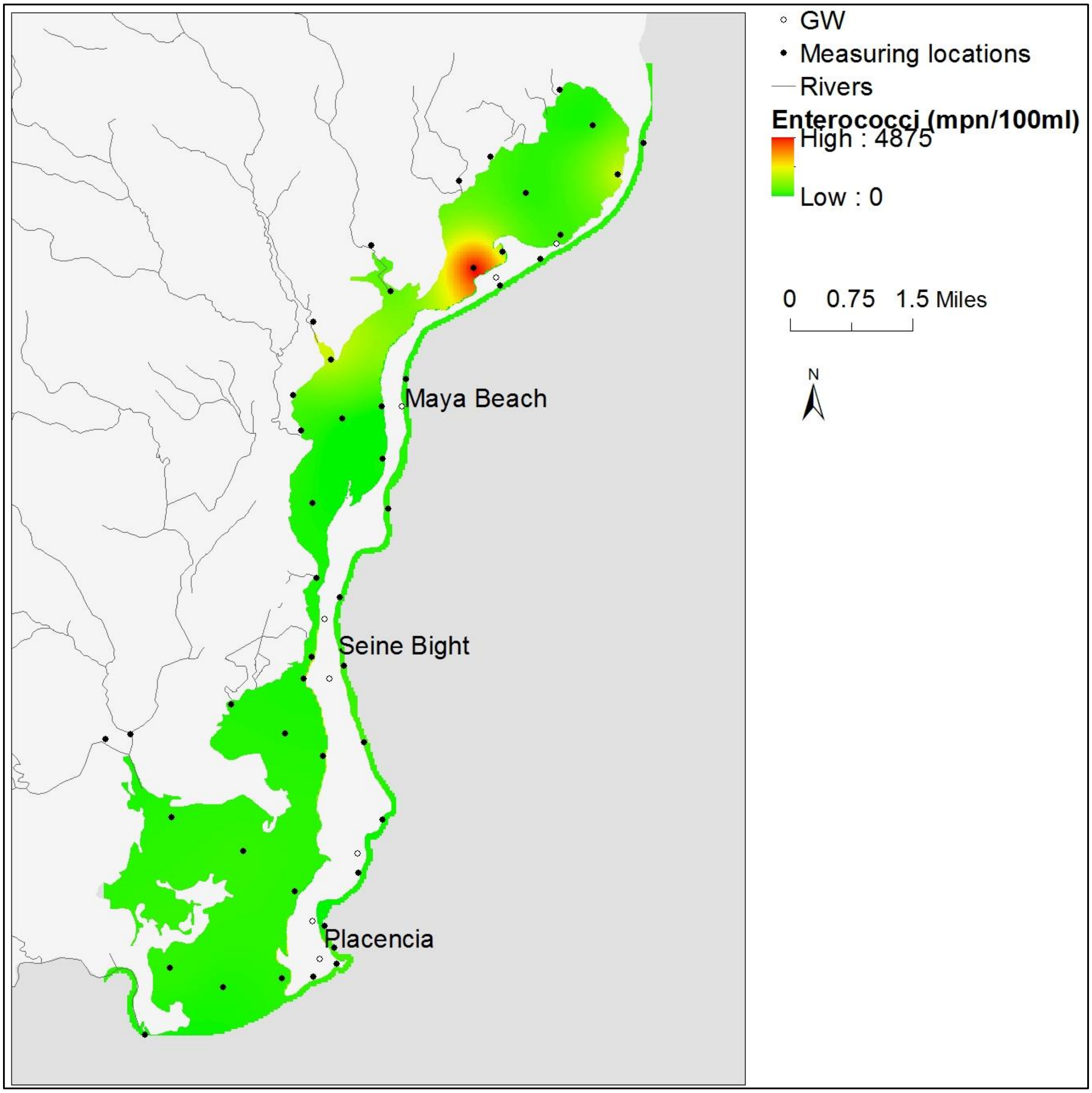


Figure 5.13 Spline Interpolation (with Barrier) for Enterococci (mpn/100ml) Sampled in June 2016

5.4.2. Spatial Analysis

Figure 5.15 displays the exceedance of effluent limitations for DO, NO_3^--N, NH_3, *E. coli*, and *Enterococci* based on water quality samples collected between May 2016 and August 2016. The size of the circles correlates with the frequency with which requirements were not met. Presenting data this way provided quick identification of locations that are of concern for individual or several the parameters. It was also possible to compare the different parameters and identify connections and relationships between.

Only 26 of the 56 sampling locations had DO concentrations below 5 mg/l at some point in time, the criteria used from Table 5.4 (Figure 5.14). While Figure 5.9 gave a snapshot in time of DO concentrations, Figure 5.14 shows areas where DO values were below 5 mg/l over the entire sampling period. The creeks and rivers had the highest percentage of exceedances, for most cases over 75% of the samples had DO levels below 5 mg/l. This could be due to wastewater effluent from the shrimp farm operations, either the release of organic compounds that would contribute to BOD_5/ COD or the release of nutrients that support algal growth that in turn consumes oxygen. It is also possible that those DO levels are natural for the creeks. For groundwater wells on the peninsula, DO was below 5 mg/l 25-50% of the time. Groundwater DO levels are not as problematic as low DO levels in the rivers/creeks, but they could be explained by bacterial processes that breakdown wastewater that is discharged into the subsurface environment.

BWS collected BOD_5 and COD measurements, next to DO, Figure 5.14 shows effluent exceedance for BOD_5 and COD. The limit concentration for BOD_5 is 30 mg/l and for COD 100 mg/l. Both rarely exceeded the effluent requirements, individually they cannot be identified as determining factors. Particularly, the values measured in the creeks/rivers were very low. However, they might still be contributing to a cumulative effect on the DO. To further investigate this, a numerical analysis seems more appropriate. The impact of COD on the groundwater wells might be significant, this should be further researched, too.

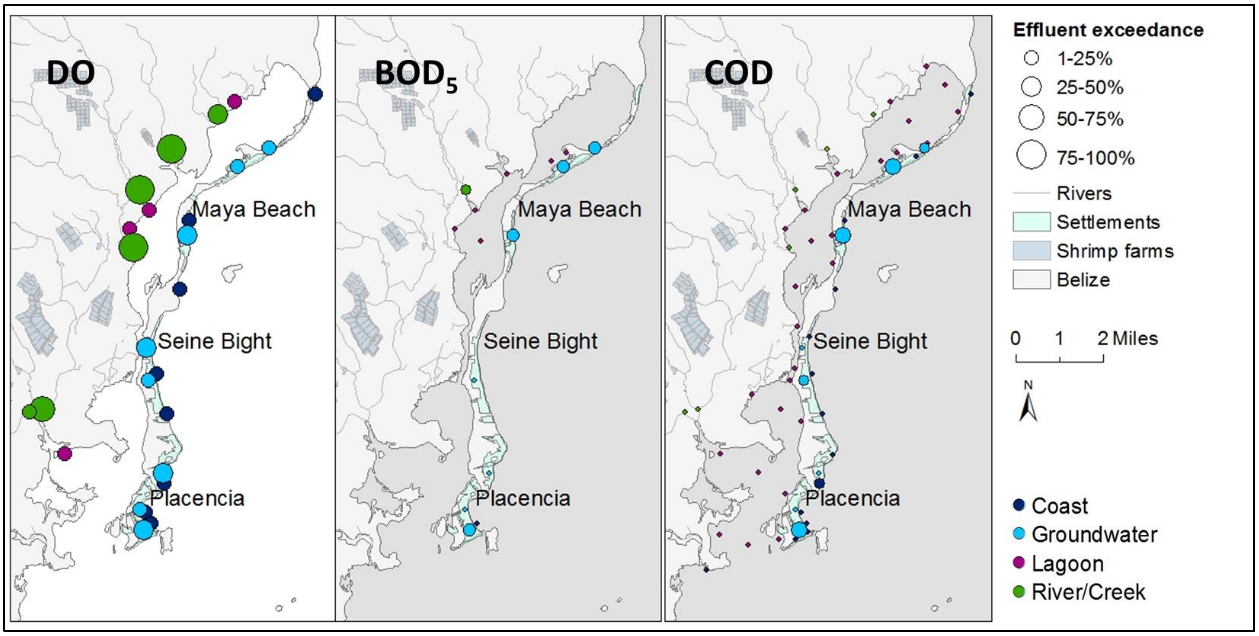


Figure 5.14 Comparison of Locations Exceeding Effluent Limits of DO, BOD_5, and COD Between May 2014 – Aug 2016

For NO_3^--N, only 30 out of 56 measuring locations exceeded concentrations recommended in Table 5.4. Nevertheless, for these 30 samples, the majority of them exceeded the recommended concentration 75-100% of the time. That means that many areas are constantly having problems with high nitrate concentrations. This is a reason for concern and needs to be addressed further.

There were few data points where NH_3 exceeded values listed in Table 5.4. This occurred in one of the creek samples for 25-50% of the times, and in all groundwater wells. High NH_3 values in groundwater wells likely reflect wastewater effluent from the various residential and commercial sites on the peninsula. Surprisingly these do not translate into values of concern in the marine and lagoon environment where aquatic organisms would be impacted by high ammonia levels. *E. coli*, the indicator of choice for freshwater samples shows occasional exceedance over the complete study area. Enterococci, the indicator of choice for saltwater samples shows exceedance over the complete area, many instances with 50-75% of samples being over the threshold of 35 mpn/100 ml. These last two parameters are closely linked with public health (e.g. urinary tract infections) and correlate with the presence of human sewage. Spatial representation of these results should spur discussions on the need for improved wastewater management practices on the peninsula.

Figure 5.16 presents data for DO and NH_3 for samples taken in the rivers and creeks. For those six sample locations, DO values were lower than 5 mg/l at some point in time with most locations having these lower DO values between 50-75% of the time. As mentioned previously, a suite of explanations is possible for the low DO levels, including lack of tidal mixing, nature of the system, and increased demand from organics in wastewater effluents. At sample location T3, DO levels were frequently below 5 mg/l while NH_3 were greater than 0.8 mg/l for 33% of the measurements. This is the only one of these sampling locations where NH_3 values exceeded the guideline. *E. coli* levels are also frequently exceeded at T3. More information is needed on the T3 site to determine whether the source of contamination comes from shrimp farms or human settlement or both. This would be an important location for further analysis.

On the southern tip of the peninsula, one of the groundwater wells (GW-1) had 33% of the DO measurements below 5 mg/l, 38% of NH_3 below 0.8 mg/l, and 25-50% of *E. coli* samples greater than 126 cfu/100 ml. GW-1 is in the center of Placencia village on the soccer field (Figure 5.17). Figure 5.18 shows the wastewater discharge methods used in Placencia village in 2012. Direct discharge indicates no wastewater treatment and Treatment Plant refers to a small hotel treatment system. These observations cannot be connected to a direct pollution source as there are many possible point and non-point sources of pollution in the area. Undoubtedly, insufficient wastewater treatment is negatively impacting the groundwater quality on the peninsula.

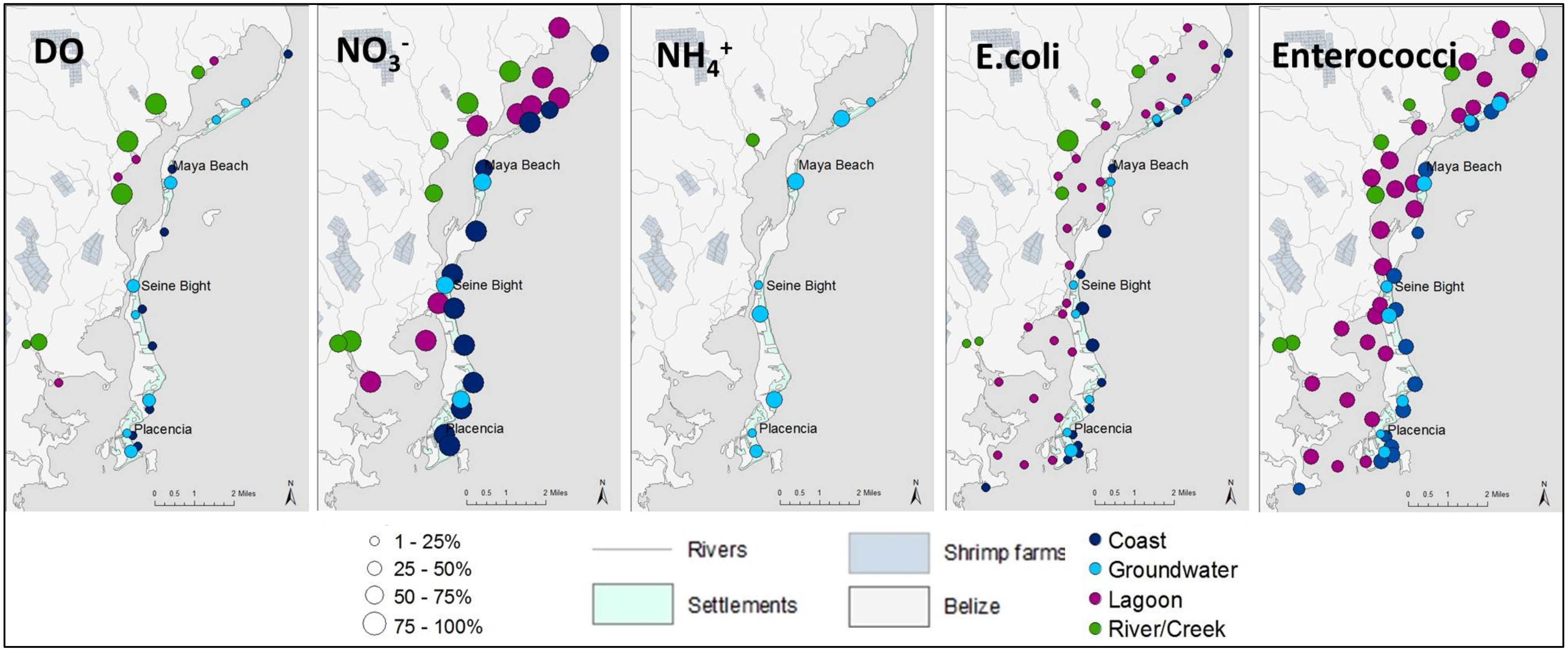


Figure 5.15 Samples Collected Between May 2014 – Aug 2016

Percent of samples that exceed guidelines for DO (< 5 mg/l), NO_3^--N (2.5 mg/l), (NH_3 (< 0.8 mg/l), *E. coli* (> 126 CFU/100 ml), and *Enterococci* (35 mpn/100 ml)

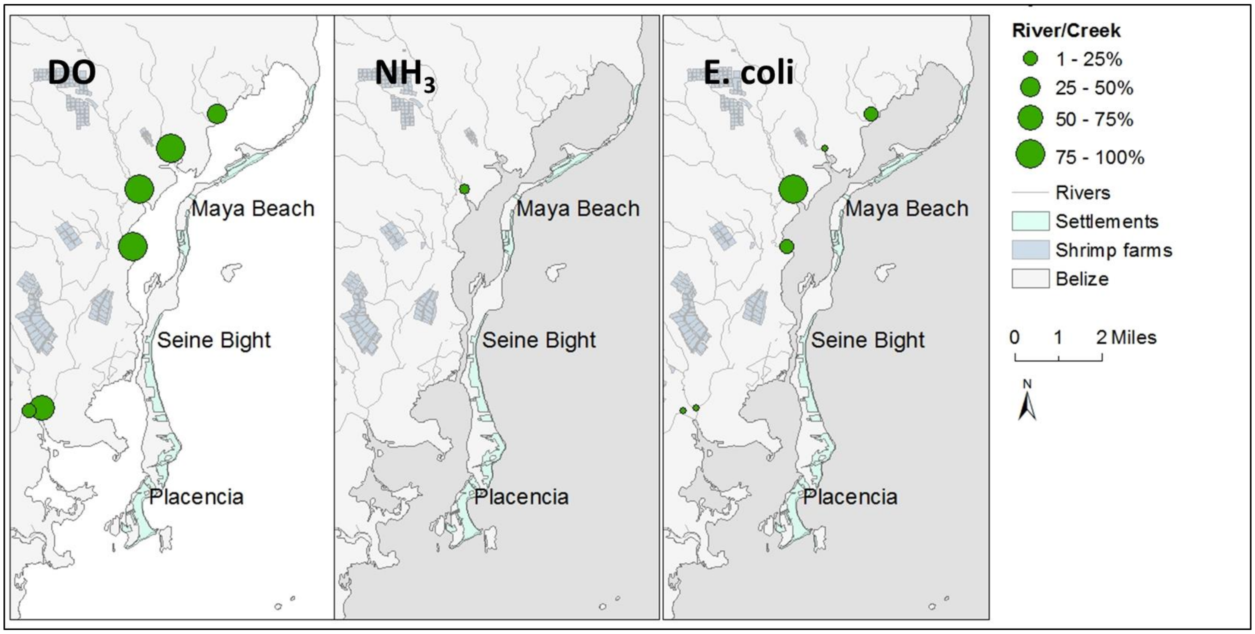


Figure 5.16 Comparison of the Percentage of Samples that Exceed Guidelines DO (< 5 mg/l), NH_3 (< 0.8 mg/l), and *E. coli* (> 126 cfu/100 ml) in Creeks and Rivers for Samples Taken Between May 2014 – August 2016

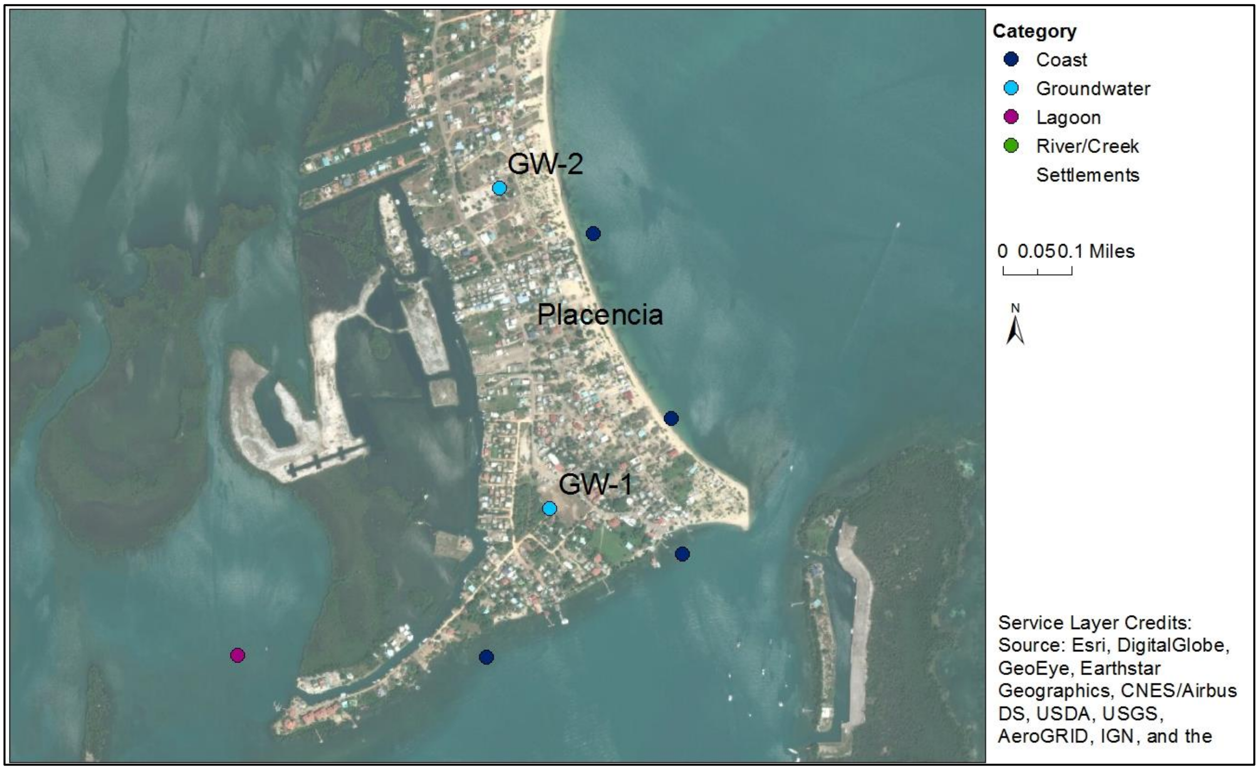


Figure 5.17 Aerial View of Southern Tip of Placencia Village

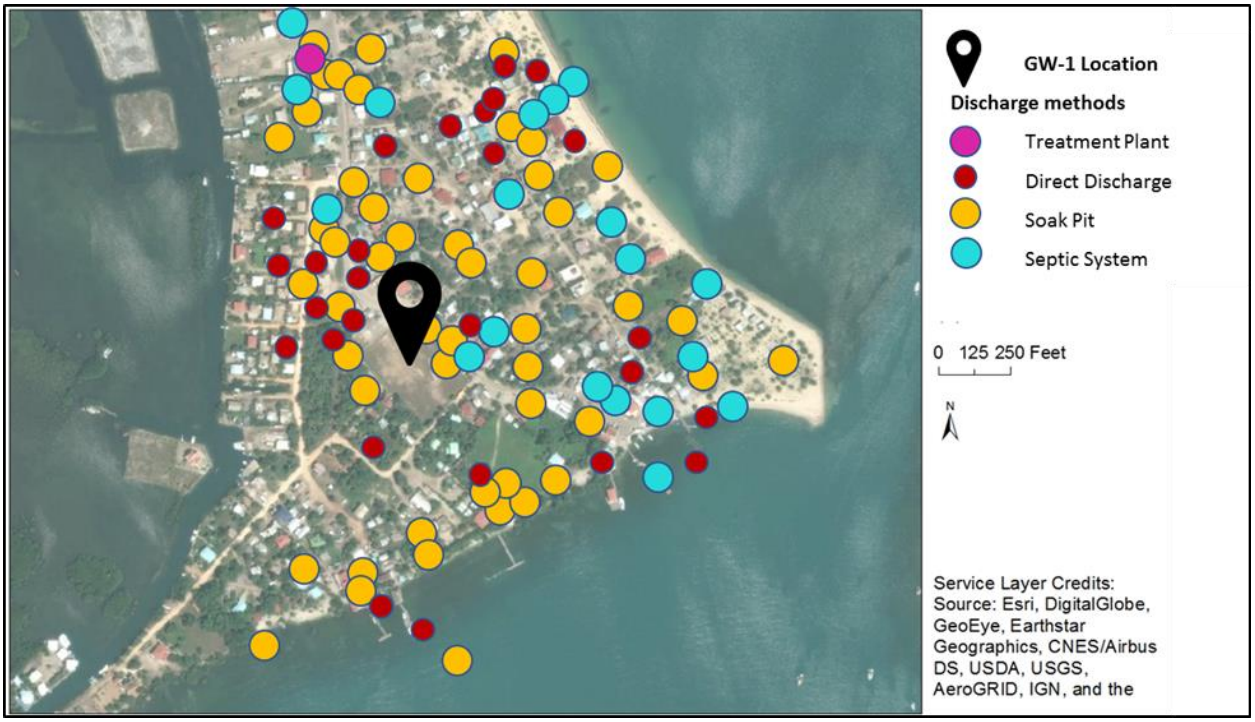


Figure 5.18 Discharge Methods in Placencia Village
Modified from Halcrow (2012)

5.4.3. Temporal Impact Analysis

Figure 5.19 and Figure 5.21 show bimonthly concentrations of Nitrate and *Enterococci* measured between August 2015 and 2016. For Nitrate, there is a high temporal and spatial variation. Different locations show high concentrations at different times of the year. *Enterococci* concentrations vary less, but there seems to be a significant decrease of contamination at the end of the sampling period. This could have seasonal reasons or be due to errors in measurement. *Enterococci* is mainly used for marine waters, however, the high concentrations measured in groundwater samples is indicative of insufficient wastewater treatment. Properties on the peninsula should be connected to BWS' water supply system, however, contaminated groundwater will affect any resident who still uses a local groundwater well for potable supply. Given the temporal variation of the parameters shown in Figures 36 and 37, it is valuable to compare the data presented with rainfall and tourism patterns of time.

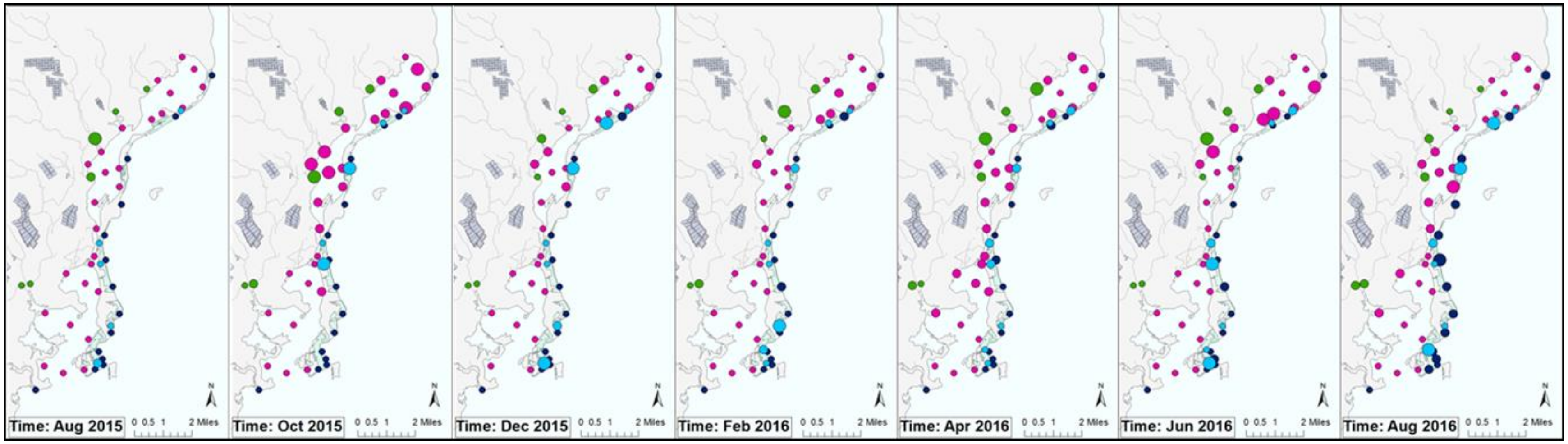


Figure 5.19 Concentrations of Nitrate (mg/l) Measured August 2015-16

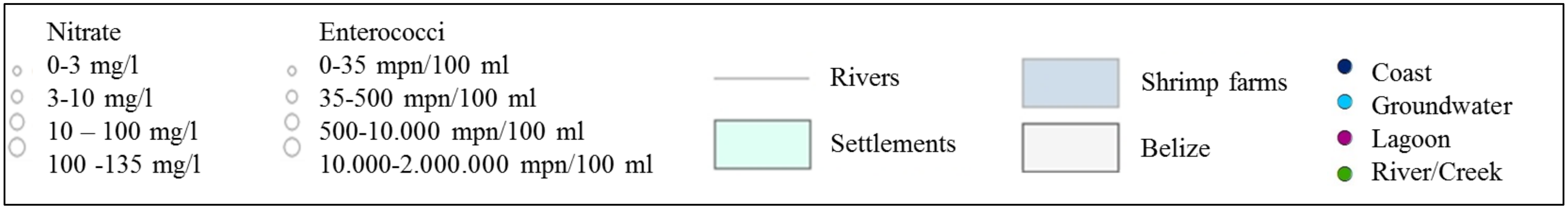


Figure 5.20 Legend for Figure 5.19 and Figure 5.21

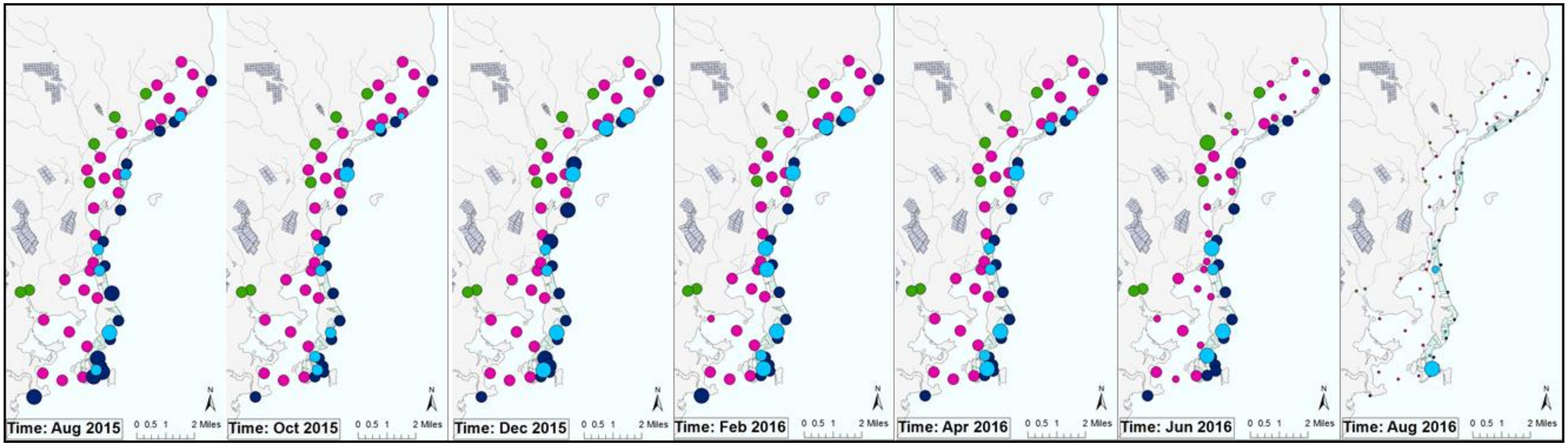


Figure 5.21 Concentrations of Enterococci (mpn/100 ml) Measured Between August 2015-16

In Belize, the main wet season is from July to December and the dry season is from January to June. Figure 5.22 and Figure 5.23 provide rainfall data for the end of the seasons for the Placencia Peninsula. In November and December 2015, there were many storm events with up to 90 mm of rainfall per day. May and June were very dry, but after a long period without precipitation, a rainfall event with more than 100 mm hit the area shortly followed by another of over 60 mm. Figure 5.19 displays Nitrate concentrations in December 2015 and June 2016, representing the end of the wet and dry seasons respectively. For the December 2015 sampling period, nitrate concentrations for all sample locations were between 5 and 20 mg/l, and could result from the relatively consistent rainfall and runoff in the area. The concentrations are all in the range between 5 and 20 mg/l in the different locations. Differences in nitrate concentrations were more distinct in June 2016 with the lagoon samples between 0 and 5 mg/l and most groundwater wells having values between 20 and 40 mg/l. Lower rainfall levels could potentially result in more concentrated groundwater samples. It is also possible that the first storm event in June flushed nutrients into the groundwater wells.

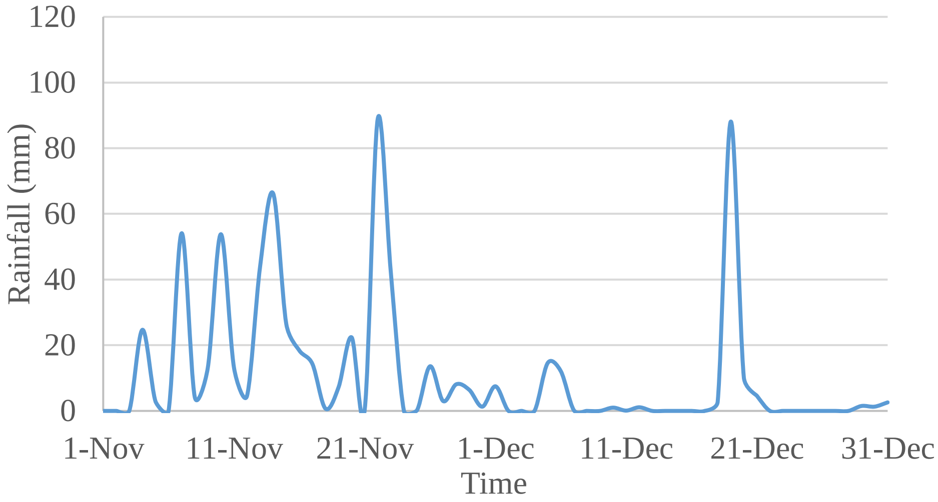


Figure 5.22 Placencia Rainfall November and December 2015
Based on: Belize National Meteorological Service (2017)

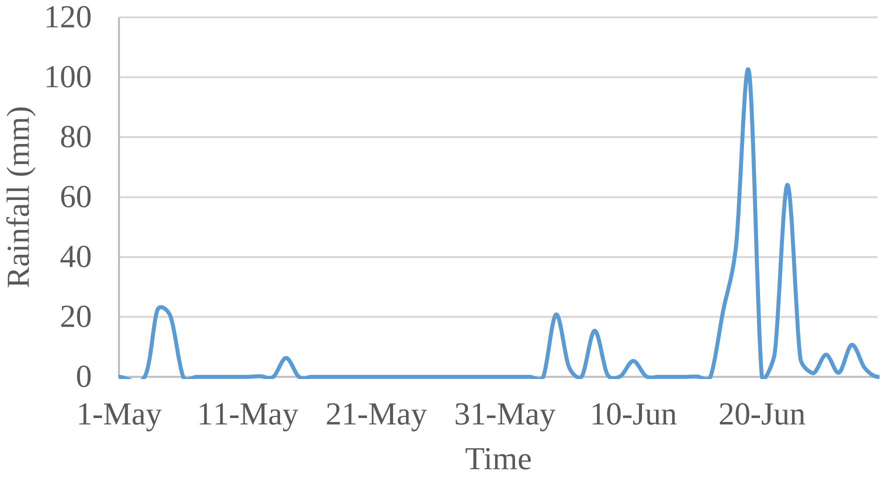


Figure 5.23 Placencia Rainfall May and June 2016
Based on: Belize National Meteorological Service (2017)

Another typical temporal impact factor is tourism. For Placencia hotel occupancy is highest in March and lowest in September (Figure 5.24). This trend could also explain the higher nitrate concentrations at the end of the high tourist season (June) compared with December. *Enterococci* concentrations from September and March, in general, show higher values for March, the high tourist season than in September. Particularly, Enterococci concentrations in lagoon and groundwater are concerningly high during peak season.

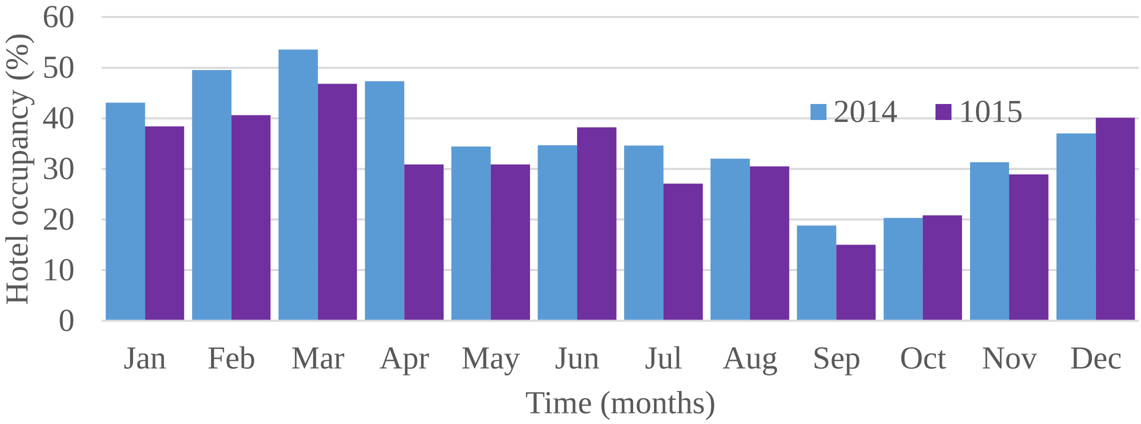


Figure 5.24 Hotel Occupancy Placencia January to December 2014/15
Based on: Belize Tourism Board (2015)

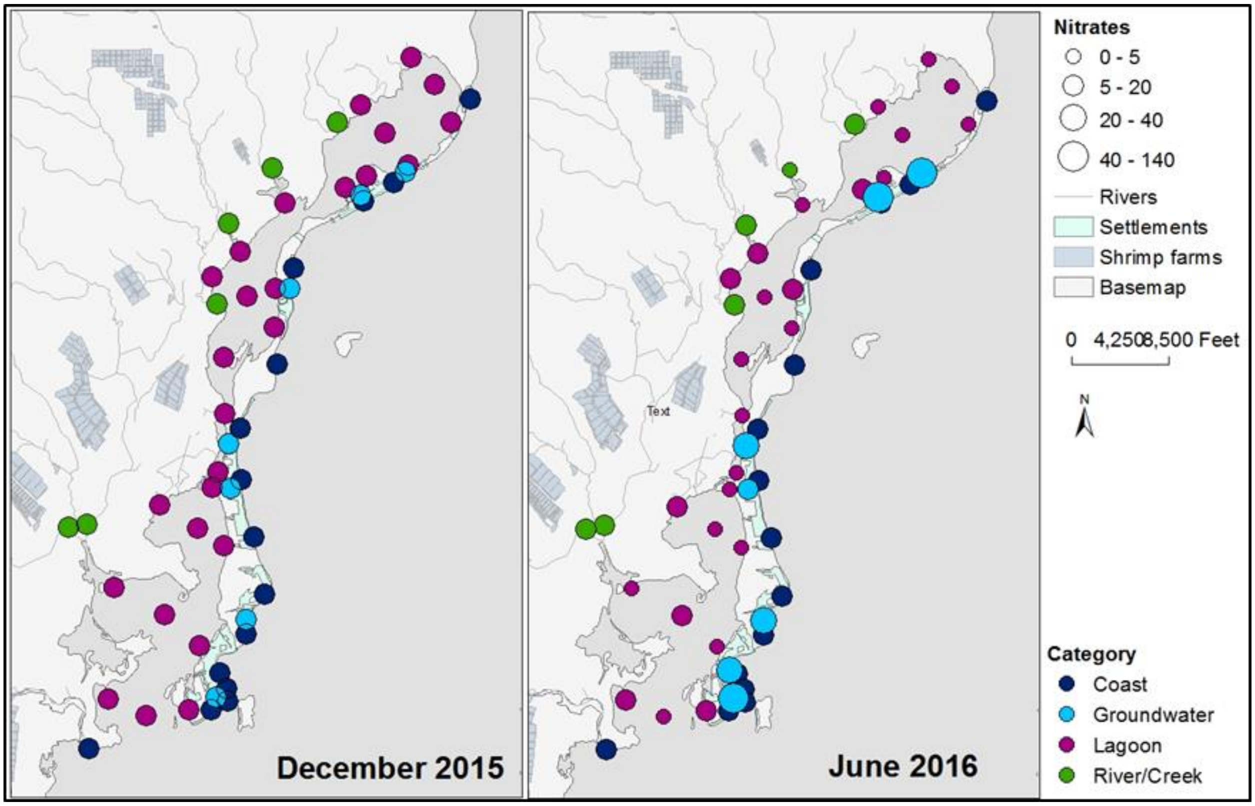


Figure 5.25 Comparison of Nitrate Concentrations (mg/l)
For Dec 2015 and Jun 2016

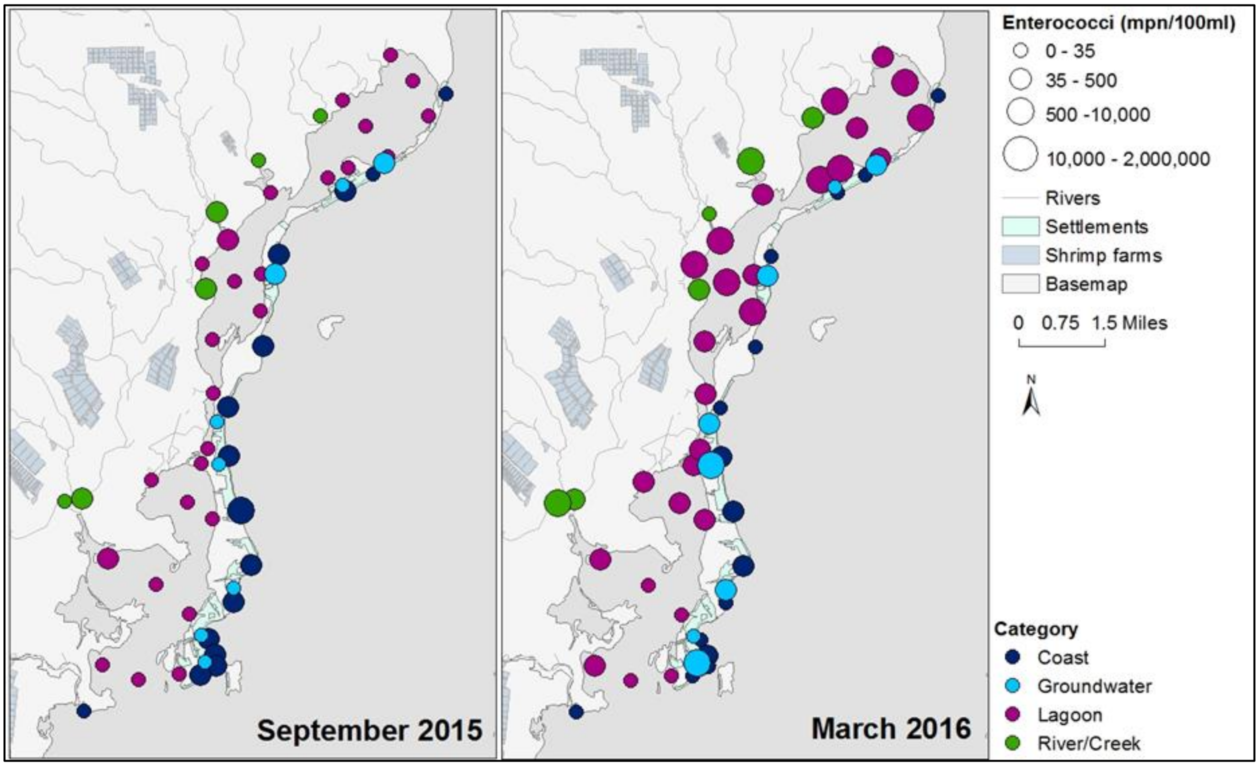


Figure 5.26 Comparison of Enterococci Concentrations (mpn/100 ml)
For December 2015 and June 2016

5.5. Summary

The case study of the Placencia peninsula in Belize showed how GIS and the FUN management can be applied to an area with high availability of water quality data, moderate access to land use data and limited socio-demographic data. The first objective was to process data provided by BWS. Water quality data was imported into GIS and numerous maps created to communicate and analyze findings.

The second objective was to conduct a spatial analysis. Different techniques of spatial analysis were used to display and process the information. Spline interpolations for the entire area were conducted on each selected parameter for one sampling time. This helps to understand the behavior of the different parameters in the lagoon and how they are related to each other. For June 2016, DO, *E. coli*, and *Enterococci* had concerning values only in certain locations of the lagoon. On the other hand, increased Nitrate concentrations could be observed over the whole study area. Ammonia results were very low in those particular samples.

The measurements taken over the whole study period, were combined for each parameter showing how frequently effluent criteria were not met. Nitrate and *Enterococci* were too high on a regular basis. For *Enterococci*, this applies for the entire area. For Nitrate, this was observed in the groundwater wells as well as in all locations with proximity to land areas. It was determined that those both parameters should be analyzed particularly regarding their change in concentration. *E. coli* showed occasional exceedance in all locations, but indicated higher frequency at the coast and in one river/creek. DO and Ammonia showed more diverse concentrations. DO was frequently too low particularly in the rivers but also regularly in the groundwater wells. Ammonia values were concerning only in the groundwater and in one river location. Based on these observations, rivers and one of the groundwater wells were exemplary analyzed.

The third objective was to conduct a temporal analysis. Nitrate and Enterococci concentrations were displayed showing measurements taken every two month between August 2015 and 2016. Nitrate showed a high variation over time and locations, but no clear pattern was observed. Enterococci showed less variation but an overall decrease at the end of this period. Furthermore, Nitrate was related rainfall. Its measurements were high in the study area at the end of the wet season. Comparing two months at the end of dry and wet season, it was observed that Nitrate concentrations in the lagoon were higher in the wet season which might be attributed to additional runoff causing increased nutrient input. The measurements after the first two rain events following the dry season showed increased groundwater values but less contamination in the lagoon. Enterococci concentrations were linked to tourism data, the contamination was extremely high in peak season, while in most parts moderate in the low season, particularly in the lagoon. These diverse methods of presenting data facilitated discussion on interdependencies and identified areas of interest. Unfortunately, socio-demographic data was not available for this site. For additional data collection and analysis, human and agricultural activities as well as demographic data could help to further analyze possible reasons for contamination patterns.

This analysis can support BWS with their design of appropriate wastewater treatment systems for the Placencia peninsula. They can optimize their resources by carrying out more targeted data collection and analyses in areas of concern, like the creeks draining the shrimp farms. The visualization of information through GIS facilitates stakeholder engagement to discuss the need and options for improved wastewater treatment in the Placencia peninsula. Data sharing of these findings can contribute to trust building between BWS and the local communities. However, publication of some of the data could potentially negatively impact the tourist industry as health of bathing waters are compromised.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

The present work demonstrated how GIS can be applied to address urban nutrient management questions when resources and data are limited. Geographic information system programs like ArcGIS can facilitate research by their ability to spatially manage, link, and analyze large amounts of information.

The first objective for this study was to develop a flexible framework to conduct research under those conditions. Based on the urban ecology framework by Alberti et al. (2003), the FUN management for GIS was developed that adapts to the needs of urban nutrient management. It links water quality, land use, and socio-demographic data through which urban-ecological areas and their dynamics can be characterized. The framework is implemented through GIS. It allows to highlight areas of interest and conduct preliminary selection of the data to be collected.

The second objective was to apply the FUN management for GIS to the case study in Orange County, Florida. The Stormwater Pond Index was developed and applied to assess residential wet ponds regarding the provision of CES. Seven locations with low performing wet ponds were identified that are located in areas where intervention is most beneficial. They can serve as a starting point to conduct an intervention activity and promote cooperation between planning entities and local stakeholders.

The third objective was to apply FUN management to Placencia, Belize. Through the framework, a water quality analysis and an impact assessment were conducted for DO, Nitrate, Ammonia, *E. coli*, and *Enterococci*. Nitrate and *Enterococci* exceeded the effluent limits of Belize frequently in the complete study area. DO, Ammonia, and *E. coli* contribute to the identification of key areas of concern that require streamlined data collection and analysis. Additionally, the impact of rainfall and tourism was addressed.

The application of the FUN management to two different case studies demonstrates its diverse and flexible uses. The study area Orange County, Florida, provided data rich sources for socio-demographic and land use, but little information on water quality. In Placencia, Belize, comprehensive water quality data was, while access to land use and socio-demographical information were limited. In both cases, there was a research interest and a study purpose but resources to conduct studies and to collect additional data were limited. Furthermore, the research objectives were both located in the field of urban nutrient management in areas that experience the challenges of high urban growth and high population densities. They are governed by water quality, land use, and socio-demographics of the study area. Both impact environmentally sensitive areas and connect to trans-regionally relevant ecosystems (the Florida Everglades and the Belize Barrier Reef). The FUN management provided the necessary guidelines to study complex areas within social-ecological systems while adapting to the needs of nutrient management and data limitation. In both case studies, efforts for data collection and surveys were considerably reduced through the application of the FUN management.

However, it’s important to be aware that the presented methods used rapid assessments and incomplete datasets. Their results are not as robust as comprehensive and thorough studies with high data collection efforts. While the demonstrated methods offer a simple and fast way to conduct preliminary assessment, they cannot substitute more conventional methods. After applying the FUN management and streamlining research efforts, many times it will still be necessary to conduct more extensive research in the identified areas or locations of interest. This includes targeted data collections.

The FUN management for GIS can be applied to streamline maintenance and management efforts. It can be widely applied by different groups, institutions and individuals. Creating solid baseline datasets is especially a challenge for countries or areas with limited financial resources and qualified technicians. If money can be saved on the research, their limited financial resources can be invested into the implementation of sustainable management practices. Therefore, ways to reduce these costs and institute more targeted studies can be very helpful.

Using the present research as a starting point, there are further aspects that would help to improve the framework and its applications. Although the framework doesn’t require complete data sets, performance still improves with increasing amounts of data. Therefore, and to provide more people the opportunity to conduct research, it would be highly useful to promote data sharing and collection platforms. Engaging communities and schools to facilitate data collection and exchange is further helping to improve research and reduce costs while at the same time educating and raising awareness.

Future research should address the following questions, among others. How can data collection be optimized and directed? How do community engagement and citizen science improve infrastructure performance and community/citizen wellbeing? What challenges and opportunities exist to facilitate communication and cooperation between facilities, communities, and universities? What are the costs and benefits associated with urban nutrient management?

REFERENCES

Alberti, M., Booth, D., Hill, K., Coburn, B., Avolio, C., Coe, S., & Spirandelli, D. (2007). The Impact of Urban Patterns on Aquatic Ecosystems: An empirical analysis in Puget lowland sub-basins. *Landscape and Urban Planning*, *80*(4), 345–361. https://doi.org/10.1016/j.landurbplan.2006.08.001

Alberti, M., Marzluff, J. M., Shulenberger, E., Radley, G., Clare, R., & Zumbrunnen, C. (2003). Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. *BioScience*, *53*(12), 1169. https://doi.org/10.1641/0006-3568(2003)053[1169:IHIEOA]2.0.CO;2

Ariola, E. A. (2003). *Characterization Of A Tropical Estuarine System: The Placencia Lagoon: Report prepared under the Coastal Zone Management Authority and Institute.*

Atash, F. (1994). Redesigning Suburbia for Walking and Transit: Emerging Concepts. *Journal of Urban Planning and Development*, *120*(1), 48–57. https://doi.org/10.1061/(ASCE)0733-9488(1994)120:1(48)

Baginska, B., Lu, Y., & Pritchar, T. (2005). *Modelling Nutrient Loads to Better Manage Impacts of Urbanization in Tweed Catchment, New South Wales,Australia: Proceedings of International Congress on Modelling and Simulation Advances and Applications for Management and Decision Making.*

Barbosa, A. E., Fernandes, J. N., & David, L. M. (2012). Key Issues for Sustainable Urban Stormwater Management. *Water research*, *46*(20), 6787–6798. https://doi.org/10.1016/j.watres.2012.05.029

Belize National Meteorological Service. (2017). Monthly Rainfall data Placencia Airstrip: (on request). Retrieved from http://www.hydromet.gov.bz/

Belize Tourism Board. (2015). *Travel Statistics.*

Belize Water Services Limited. (2013a). BWS Corporate Profile. Retrieved from http://www.bws.bz/about-us/BWS/

Belize Water Services Limited. (2013b). Ongoing Projects: Integrated Water and Sanitation Program for the Placencia Peninsula (IWSPPP). Retrieved from http://www.bws.bz/our-operations/projects-initiatives/ongoing-projects/

Bennett, E., & Hassan, R. M. (2003). *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press.

Betts, A. T., & Alsharif, K. A. (2013). Assessment of a Countywide Stormwater Pond Improvement Program. *Urban Water Journal*, *11*(1), 11–19. https://doi.org/10.1080/1573062X.2012.750370

Blecken, G.-T., Hunt, W. F., Al-Rubaei, A. M., Viklander, M., & Lord, W. G. (2016). Stormwater Control Measure (SCM) Maintenance Considerations to Ensure Designed Functionality. *Urban Water Journal*, *14*(3), 278–290. https://doi.org/10.1080/1573062X.2015.1111913

Boyd, J., & Banzhaf, S. (2007). What Are Ecosystem Services?: The Need for Standardized Environmental Accounting Units. *Ecological Economics*, *63*(2-3), 616–626. https://doi.org/10.1016/j.ecolecon.2007.01.002

Bruno, J. F., Sweatman, H., Precht, W. F., Selig, E. R., & Schutte, V. G. W. (2009). Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. *Ecology*, *90*(6), 1478–1484. https://doi.org/10.1890/08-1781.1

Burgess, J., Harrison, C., & Limb, M. (1988). People, Parks and the Urban Green: A Study of Popular Meanings and Values for Open Spaces in the City. *Urban Studies*, *25*(6), 455–473. https://doi.org/10.1080/00420988820080631

Byrne, J., & Wolch, J. (2009). Nature, Race, and Parks: Past Research and Future Directions for Geographic Research. *Progress in Human Geography*, *33*(6), 743–765. https://doi.org/10.1177/0309132509103156

Campbell, L. K., Svendsen, E. S., Sonti, N. F., & Johnson, M. L. (2016). A Social Assessment of Urban Parkland: Analyzing Park Use and Meaning to Inform Management and Resilience Planning. *Environmental Science & Policy*, *62*, 34–44. https://doi.org/10.1016/j.envsci.2016.01.014

Cao, W., Zhu, H., & Chen, S. (2007). Impacts of Urbanization on Topsoil Nutrient Balances: A Case Study at a Provincial Scale from Fujian, China. *CATENA*, *69*(1), 36–43. https://doi.org/10.1016/j.catena.2006.04.014

Caquard, S., Vaughan, L., & Cartwright, W. (Eds.). (2011). *Lecture Notes in Geoinformation and Cartography*. *Mapping Environmental Issues in the City*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Caribbean Aqua-Terrestrial Solutions. (2017). Placencia Peninsula Integrated Water & Wastewater Project. Retrieved from http://caribbeancats.org/index.php/belize/placencia/

Carto. (2014). Shrimp Farms Belize. Retrieved from https://wwfca.carto.com/viz/d90ddb68-1291-11e4-81e8-0e230854a1cb/public_map

Chan, K., Guerry, A. D., Balvanera, P., Klain, S., & Satterfield, T. (2012). Where are Cultural and Social in Ecosystem Services?: A Framework for Constructive Engagement. *BioScience*, *62*(8), 744–756. https://doi.org/10.1525/bio.2012.62.8.7

Cho, L. (2005). Marine protected areas: A tool for integrated coastal management in Belize. *Ocean & Coastal Management*, *48*(11-12), 932–947. https://doi.org/10.1016/j.ocecoaman.2005.03.007

Chopra, K. R. (2005). *Ecosystems and Human Well-being: Policy Responses: Findings of the Responses Working Group of the Millennium Ecosystem Assessment*. *The Millennium Ecosystem Assessment series: v. 3*. Washington, D.C., London: Island Press.

Comber, A., Brunsdon, C., & Green, E. (2008). Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and Urban Planning*, *86*(1), 103–114. https://doi.org/10.1016/j.landurbplan.2008.01.002

D'Angelo, C., & Wiedenmann, J. (2014). Impacts of Nutrient Enrichment on Coral Reefs: New Perspectives and Implications for Coastal Management and Reef Survival. *Current Opinion in Environmental Sustainability*, *7*, 82–93. https://doi.org/10.1016/j.cosust.2013.11.029

Environmental Protection (Effluent Limitations) Regulations, Department of the Environment 2009.

Dineen, C. (2017). Visit Orlando Hits 66 Million Tourists in 2015. Retrieved from http://www.orlandosentinel.com/business/tourism/os-visit-orlando-2015-tourist-numbers-20160502-story.html

EPA. (2015). *National Ecosystem Services Classification System (NESCS): Framework Design and Policy Application: Final report* (No. EPA-800-R-15-002). Washington, DC. Retrieved from https://www.epa.gov/sites/production/files/2015-12/documents/110915_nescs_final_report_-_compliant_1.pdf

EPA. (2016). Environmental Justice. Retrieved from https://www.epa.gov/environmentaljustice

ESRI. (2012). 2012 USA Population Density (Mature Support). Retrieved from http://www.arcgis.com/home/item.html?id=302d4e6025ef41fa8d3525b7fc31963a

ESRI. (2016). Light Gray Canvas. Retrieved from http://www.arcgis.com/home/item.html?id=8b3b470883a744aeb60e5fff0a319ce7

ESRI. (2017). Base map World Imagery. Retrieved from https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

FAC. (2017). *Regulations of Stormwater Discharge*. Retrieved from https://www.flrules.org/gateway/ChapterHome.asp?Chapter=62-25

FDEP. (1999). Major Rivers - Polygons. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

FDEP. (2004). Water Management District Boundaries. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

FDEP. (2016). Flowing Water Resources. Retrieved from http://geodata.dep.state.fl.us

FDOT. (2016). Florida Department Of Transportation - Rci Derived Major Highways - January 2016. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

Felipe-Lucia, M. R., Comin, F. A., & Escalera-Reyes, J. (2015). A Framework for the Social Valuation of Ecosystem Services. *Ambio*, *44*(4), 308–318. https://doi.org/10.1007/s13280-014-0555-2

Fish, R., Church, A., & Winter, M. (2016). Conceptualising Cultural Ecosystem Services: A Novel Framework for Research and Critical Engagement. *Ecosystem Services.* Advance online publication. https://doi.org/10.1016/j.ecoser.2016.09.002

Florida Natural Areas Inventory. (2016). Florida Conservation Lands. Retrieved from http://www.fnai.org/gisdata.cfm

Fore, L. S., Frydenborg, R., Wellendorf, N., Espy, J., Frick, T., Whiting, D.,. . . Patronis, J. (2007). *Assessing the Biological Condition of Florida Lakes: Development of the Lake Vegetation Index (LVI): Final Report*. Retrieved from http://orange.wateratlas.usf.edu/upload/documents/lvi_final07.pdf

German, E. R., & Adamski, J. C. (2005). *Hydrology and Water Quality of Lakes and Streams in Orange County, Florida: U.S. Geological Scientific Investigations Report 2005-5052*. [Place of publication not identified].

Gibson, J., McField, M., & Wells, S. (1998). Coral reef management in Belize: An approach through integrated coastal zone management. *Ocean & Coastal Management*, *39*(3), 229–244. https://doi.org/10.1016/S0964-5691(98)00007-6

Giri, S., & Qiu, Z. (2016). Understanding the Relationship of Land Uses and Water Quality in Twenty First Century: A Review. *Journal of Environmental Management*, *173*, 41–48. https://doi.org/10.1016/j.jenvman.2016.02.029

Grau, J., del Rosario Navia, M., Rihm, A., Ducci, J., Martin, D., & Kuratomi, T. (2013). *Water and Sanitation in Belize: Technical Note No. IDB-TN-609.*

Groot, R. de. (2006). Function-analysis and Valuation as a Tool to Assess Land Use Conflicts in Planning for Sustainable, Multi-functional Landscapes. *Landscape and Urban Planning*, *75*(3-4), 175–186. https://doi.org/10.1016/j.landurbplan.2005.02.016

Groot, R. S. de, Wilson, M. A., & Boumans, R. M. (2002). A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services. *Ecological Economics*, *41*(3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

Halcrow. (2012). *Feasibility Study for the Placencia Peninsula Pilot Wastewater Management System: Volume I - Final Report.*

Harper, H., & Baker, D. (2007). *Evaluation of Current Stormwater Design Criteria within the State of Florida: Final Report*. Orlando.

Hassall, C. (2014). The Ecology and Biodiversity of Urban Ponds. *Wiley Interdisciplinary Reviews: Water*, *1*(2), 187–206. https://doi.org/10.1002/wat2.1014

Hirvela, K. R. (2011). *Park Access and Distributional Inequities in Pinellas County, Florida* (Graduate Thesis). University of South Florida, Tampa.

Jones, J., Guo, J., Urbonas, B., & Pittinger, R. (2006). Essential Safety Considerations for Urban Stormwater Retention and Detention Ponds. *Stormwater magazine*.

Karabulut Aloe, A., Bouraoui, F., Bidoglio, G., Grizzetti, B., & Pistocchi, A. (2014). *Managing Nitrogen and Phosphorus Loads to Water Bodies: Characterisation and Solutions Towards Macro-regional Integrated Nutrient Management : Under Enlargement and Integration action*. *EUR. Scientific and technical research series: Vol. 26822*. Luxembourg: Publications Office.

Larsen, L., & Harlan, S. L. (2006). Desert Dreamscapes: Residential Landscape Preference and Behavior. *Landscape and Urban Planning*, *78*(1-2), 85–100. https://doi.org/10.1016/j.landurbplan.2005.06.002

Larson, K. L., Casagrande, D., Harlan, S. L., & Yabiku, S. T. (2009). Residents' Yard Choices and Rationales in a Desert City: Social Priorities, Ecological Impacts, and Decision Tradeoffs. *Environmental management*, *44*(5), 921–937. https://doi.org/10.1007/s00267-009-9353-1

Leopold, L. B. (1968). *Hydrology for Urban Planning—A Guidebook on the Hydrologic Effects of Urban Land Use*. Washington D.C.

Li, Y., Li, Y., Qureshi, S., Kappas, M., & Hubacek, K. (2015). On the Relationship Between Landscape Ecological Patterns and Water Quality Across Gradient Zones of Rapid Urbanization in Coastal China. *Ecological Modelling*, *318*, 100–108. https://doi.org/10.1016/j.ecolmodel.2015.01.028

Likens, G. E. (1992). *Excellence in Ecology: The Ecosystem Approach: its Use and Abuse*. Oldendorf/Luhe, Germany: Ecology Institute.

Lindsey, G., Maraj, M., & Kuan, S. (2001). Access, Equity, and Urban Greenways: An Exploratory Investigation. *The Professional Geographer*, *53*(3), 332–346. https://doi.org/10.1111/0033-0124.00288

Machlis, G. E., Force, J. E., & Burch, W. R. (1997). The Human Ecosystem Part I: The Human Ecosystem as an Organizing Concept in Ecosystem Management. *Society & Natural Resources*, *10*(4), 347–367. https://doi.org/10.1080/08941929709381034

Maroko, A. R., Maantay, J. A., Sohler, N. L., Grady, K. L., & Arno, P. S. (2009). The Complexities of Measuring Access to Parks and Physical Activity Aites in New York City: a Quantitative and Qualitative Approach. *International journal of health geographics*, *8*, 34. https://doi.org/10.1186/1476-072X-8-34

Marzluff, J. M. (2008). *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. New York: Springer.

Meerman, J., & Clabaugh, J. (2004). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize_Ecosystems_2004c. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2010). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize_Settlements_Point_2010_Pop. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2011). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize_Ecosystems_2011. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2013a). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize Basemap. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2013b). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize_Rivers. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2014). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize_Settlements_Polygon. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2015). Biodiversity and Environmental Resource Data System of Belize (BERDS): Belize_Ecosystems_2015, Belize_Land_Use_2015. Retrieved from http://www.biodiversity.bz

Meerman, J., & Clabaugh, J. (2016). Biodiversity and Environmental Resource Data System of Belize. Retrieved from http://www.biodiversity.bz

Meerman, J. C., & Boomsma, T. (2010). *Environmental and Social Analysis of the Construction and Operation of a Wastewater Collection, Treatment, and Disposal System for the Placencia Peninsula*. Retrieved from http://www.pcsdbelize.org/Placencia_Environmental_and_Social_Analysis.pdf

Mihelcic, J. R., & Trotz, M. A. (2010). Sustainability and the Environmental Engineer: Implications for Education, Research, and Practice. *Environmental Engineer: Applied Research and Practice*, *10*(27), 1–10. Retrieved from http://www.aaees.org/downloadcenter/EESAppliedResearchandPracticeV10P1.pdf

Milcu, A. I., Hanspach, J., Abson, D., & Fischer, J. (2013). Cultural Ecosystem Services: A Literature Review and Prospects for Future Research. *Ecology and Society*, *18*(3). https://doi.org/10.5751/ES-05790-180344

Milla, K. A., Lorenzo, A., & Brown, C. (2005). IS, GPS, and Remote Sensing Technologies in Extension Services: Where to Start, What to Know. *Journal of Ectension*, *43*(3). Retrieved from https://www.joe.org/joe/2005june/a6.php

Millennium Ecosystem Assessment. (2003). *Ecosystems and Human Well-being: A Framework for Assessment*. Washington, DC: Island.

Moore, T., Hutchinson, S. L., & Christianson, R. D. (2012). A Qualitative Assessment Tool for Ecologically Based Stormwater Systems. *Ecological Engineering*, *45*, 70–79. https://doi.org/10.1016/j.ecoleng.2011.03.021

Moore, T. L. C., & Hunt, W. F. (2012). Ecosystem Service Provision by Stormwater Wetlands and Ponds - a Means for Evaluation? *Water research*, *46*(20), 6811–6823. https://doi.org/10.1016/j.watres.2011.11.026

Nahuelhual, L., Benra Ochoa, F., Rojas, F., Díaz, G. I., & Carmona, A. (2016). Mapping Social Values of Ecosystem Services: What is behind the map? *Ecology and Society*, *21*(3). https://doi.org/10.5751/ES-08676-210324

National Atlas of the United States. (2007). Cities And Towns Of Florida. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

National Oceanic and Atmospheric Administration. (2016). Climatological Data Annual Summary Florida 2015, *19*(13). Retrieved from https://www1.ncdc.noaa.gov/pub/orders/IPS/IPS-98C28109-D518-45C3-8C53-941D075A581F.pdf

Neema, M. N., & Ohgai, A. (2013). Multitype Green-space Modeling for Urban Planning Using GA and GIS. *Environment and Planning B: Planning and Design*, *40*(3), 447–473. https://doi.org/10.1068/b38003

Nicholls, S. (2001). Measuring the Accessibility and Equity of Public Parks: A Case Study Using GIS. *Managing Leisure*, *6*(4), 201–219. https://doi.org/10.1080/13606710110084651

Peninsula 2020 Initiative. (2011). *A Consensual Vision of the Future of the Placencia Peninsula*. Retrieved from http://www.pcsdbelize.org/peninsula-2020.pdf

Pham, T.-T.-H., Apparicio, P., Séguin, A.-M., & Gagnon, M. (2011). Mapping the Greenscape and Environmental Equity in Montreal: An Application of Remote Sensing and GIS. In S. Caquard, L. Vaughan, & W. Cartwright (Eds.), *Lecture Notes in Geoinformation and Cartography. Mapping Environmental Issues in the City* (pp. 30–48). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-22441-6_3

Pickett, S. T. A., Burch Jr., W. R., Dalton, S. E., Foresman, T. W., Grove, J. M., & Rowntree, R. (1997). A Conceptual Framework for the Study of Human Ecosystems in Urban Areas. *Urban Ecosystems*, *1*(4), 185–199. https://doi.org/10.1023/A:1018531712889

Pickett, S. T. A., & Cadenasso, M. L. (2006). Advancing Urban Ecological Studies: Frameworks, Concepts, and Results from the Baltimore Ecosystem Study. *Austral Ecology*, *31*(2), 114–125. https://doi.org/10.1111/j.1442-9993.2006.01586.x

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E.,. . . Warren, P. (2011). Urban Ecological Systems: Scientific Foundations and a Decade of Progress. *Journal of Environmental Management*, *92*(3), 331–362. https://doi.org/10.1016/j.jenvman.2010.08.022

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2001). Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas. *Annual Review of Ecology and Systematics*, *32*(1), 127–157. https://doi.org/10.1146/annurev.ecolsys.32.081501.114012

Pratt, B., & Chang, H. (2012). Effects of Land Cover, Topography, and Built Structure on Seasonal Water Quality at Multiple Spatial Scales. *Journal of hazardous materials*, *209-210*, 48–58. https://doi.org/10.1016/j.jhazmat.2011.12.068.

Psaris, M., & Chang, H. (2014). Assessing the Impacts of Climate Change, Urbanization, and Filter Strips on Water Quality Using SWAT. *International Journal of Geospatial and Environmental Research*, *1*(2). Retrieved from http://dc.uwm.edu/ijger/vol1/iss2/1

Redman, C. L., Grove, J. M., & Kuby, L. H. (2004). Integrating Social Science into the Long-Term Ecological Research (LTER) Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change. *Ecosystems*, *7*(2). https://doi.org/10.1007/s10021-003-0215-z

Rupprecht, C. D., & Byrne, J. A. (2014). Informal Urban Greenspace: A Typology and Trilingual Systematic Review of its Role for Urban Residents and Trends in the Literature. *Urban Forestry & Urban Greening*, *13*(4), 597–611. https://doi.org/10.1016/j.ufug.2014.09.002

Schiffer, D. M. (1997). *Hydrology of Central Florida Lakes: A Primer*. *U.S. Geological Survey circular: Vol. 1137*. Washington.

Smoyer-Tomic, K. E., Hewko, J. N., & Hodgson, M. J. (2004). Spatial Accessibility and Equity of Playgrounds in Edmonton, Canada. *The Canadian Geographer/Le G?ographe canadien*, *48*(3), 287–302. https://doi.org/10.1111/j.0008-3658.2004.00061.x

Southern Environmental Association. (2015). *Placencia Lagoon Management Plan: 2015 – 2020*. Placencia Village, Belize.

TEEB. (2010). *The Economics of Ecosystems & Biodiversity: Mainstreaming the Economics of Nature : a Synthesis of the Approach, Conclusions and Recommendations of TEEB*. [Place of publication not identified]: [UNEP].

Tong, S. T., & Chen, W. (2002). Modeling the Relationship Between Land Use and Surface Water Quality. *Journal of Environmental Management*, *66*(4), 377–393. https://doi.org/10.1006/jema.2002.0593

Tufford, D. L., Samarghitan, C. L., McKellar, H. N., Porter, D. E., & Hussey, J. R. (2003). Impacts of Urbanization on Nutrient Concentrations In Small Southeastern Coastal Streams. *Journal of the American Water Resources Association*, *39*(2), 301–312. https://doi.org/10.1111/j.1752-1688.2003.tb04385.x

U.S. Census Bureau. (2012). *Florida: 2010 Population and Housing Unit Counts: 2010 Census of Population and Housing.*

U.S. Census Bureau. (2013). American Community Survey 5-Year Estimates: Block Group - Florida. Retrieved from https://www.census.gov/geo/maps-data/data/tiger-data.html

U.S. Census Bureau, Geography Division. (2010). 2010 U.S. Census Urban Areas And Clusters In Florida. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

U.S. EPA. (1999). *Storm Water Technology Fact Sheet Wet Detention Ponds: EPA 832-F-99-048*. Washington, D.C. Retrieved from https://www.uwgb.edu/facilities/documents/EPAFactSheet.pdf

U.S. EPA. (2009). *Stormwater Wet Pond and Wetland Management Guidebook: EPA 833-B-09-001*. Retrieved from https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf

U.S. Geological Survey. (2015). Generalized Land Use Derived From 2015 Parcels - Florida Dot District 5. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

United Nations. (2014). *World Urbanization Prospects: Highlights*. New York: United Nations. Retrieved from https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf

University of Florida GeoPlan Center. (2012). Florida Public And Private Schools 2012. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

University of Florida GeoPlan Center. (2015a). Florida County Boundaries - September 2015. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

University of Florida GeoPlan Center. (2015b). National Hydrography Dataset - Linear Surface Water Drainage Network 1:24k - February 2016. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

University of Florida GeoPlan Center. (2015c). Prime farmland in florida with associated level 3 water management district land use descriptions - november 2015. Retrieved from http://www.fgdl.org/metadataexplorer/explorer.jsp

USEPA. (1986). *United States Environmental Protection Agency: EPA 440/5-86-001*. Washington, D.C.

VisitOrlando. (2015). Orlando Becomes First Destination To Surpass 60 Million Visitors, Sets New Record For U.S. Tourism. Retrieved from http://media.visitorlando.com/pressrelease/index.cfm/2015/4/9/Orlando-Becomes-First-Destination-To-Surpass-60-Million-Visitors-Sets-New-Record-For-US-Tourism/

Weiss, C. C., Purciel, M., Bader, M., Quinn, J. W., Lovasi, G., Neckerman, K. M., & Rundle, A. G. (2011). Reconsidering Access: Park Facilities and Neighborhood Disamenities in New York City. *Journal of urban health : bulletin of the New York Academy of Medicine*, *88*(2), 297–310. https://doi.org/10.1007/s11524-011-9551-z

Wells, E. C., Zarger, R. K., Whiteford, L. M., Mihelcic, J. R., Koenig, E. S., & Cairns, M. R. (2016). The impacts of tourism development on perceptions and practices of sustainable wastewater management on the Placencia Peninsula, Belize. *Journal of Cleaner Production*, *111*, 430–441. https://doi.org/10.1016/j.jclepro.2014.08.050

WHO/UNICEF JMP. (2015). Belize: estimates on the use of water sources and sanitation facilities (1980 - 2015). Retrieved from https://www.wssinfo.org/documents/?tx_displaycontroller[type]=country_files

Wolch, J., Wilson, J. P., & Fehrenbach, J. (2013). Parks and Park Funding in Los Angeles: An Equity-Mapping Analysis. *Urban Geography*, *26*(1), 4–35. https://doi.org/10.2747/0272-3638.26.1.4

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities 'Just Green Enough'. *Landscape and Urban Planning*, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Woodcock, T. S., Monaghan, M. C., & Alexander, K. E. (2010). Ecosystem Characteristics and Summer Secondary Production in Stormwater Ponds and Reference Wetlands. *Wetlands*, *30*(3), 461–474. https://doi.org/10.1007/s13157-010-0057-3

World Resources Institute. (2017). WRI Ross Center for Sustainable Cities. Retrieved from http://www.wri.org/our-work/topics/sustainable-cities

Wright, T., Tomlinson, J., Schueler, T., & Cappiella, K. (2006). *Direct and Indirect Impacts of Urbanization on Wetland Quality: Wetlands & Watersheds Article #1*. Washington, D.C.

Wright Wendel, H. E., Downs, J. A., & Mihelcic, J. R. (2011). Assessing Equitable Access to Urban Green Space: the Role of Engineered Water Infrastructure. *Environmental science & technology*, *45*(16), 6728–6734. https://doi.org/10.1021/es103949f

Yli-Pelkonen, V., & Niemelä, J. (2005). Linking Ecological and Social systems in Cities: Urban Planning in Finland as a Case. *Biodiversity and Conservation*, *14*(8), 1947–1967. https://doi.org/10.1007/s10531-004-2124-7

APPENDIX A: ABBREVIATIONS

Table A.1 List of Abbreviations

Abbreviation	**Full Name**
ACS	American Community Survey
BWS	Belize Water Services Limited
BOD_5	5-Day Biological Oxygen Demand
CES	Cultural Ecosystem Services
COD	Chemical Oxygen Demand
E. coli	*Escherichia coli*
ES	Ecosystem Services
FAC	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FGDL	Florida Geographic Data Library
FNAI	Florida Natural Areas Inventory
FUN management	Framework for Urban Nutrient management
GIS	Geographic Information Systems
GPS	Global Positioning System
HEF	Human Ecosystem Framework
LVI	Lake Vegetation Index
MSBU	Municipal Service Benefit Units
MSTU	Municipal Service Taxing Units
NH_3	Ammonia
NO_3^--N	Nitrate as N
SJRWMD	St. Johns River Water Management District
SWFWMD	Southwest Florida Water Management District
USF	University of South Florida
VSA	Variable Source Area
WMD	Water Management District

APPENDIX B: CULTURAL SERVICES

Table B.1 Assessments of Cultural Services in Ecosystem Service Approaches

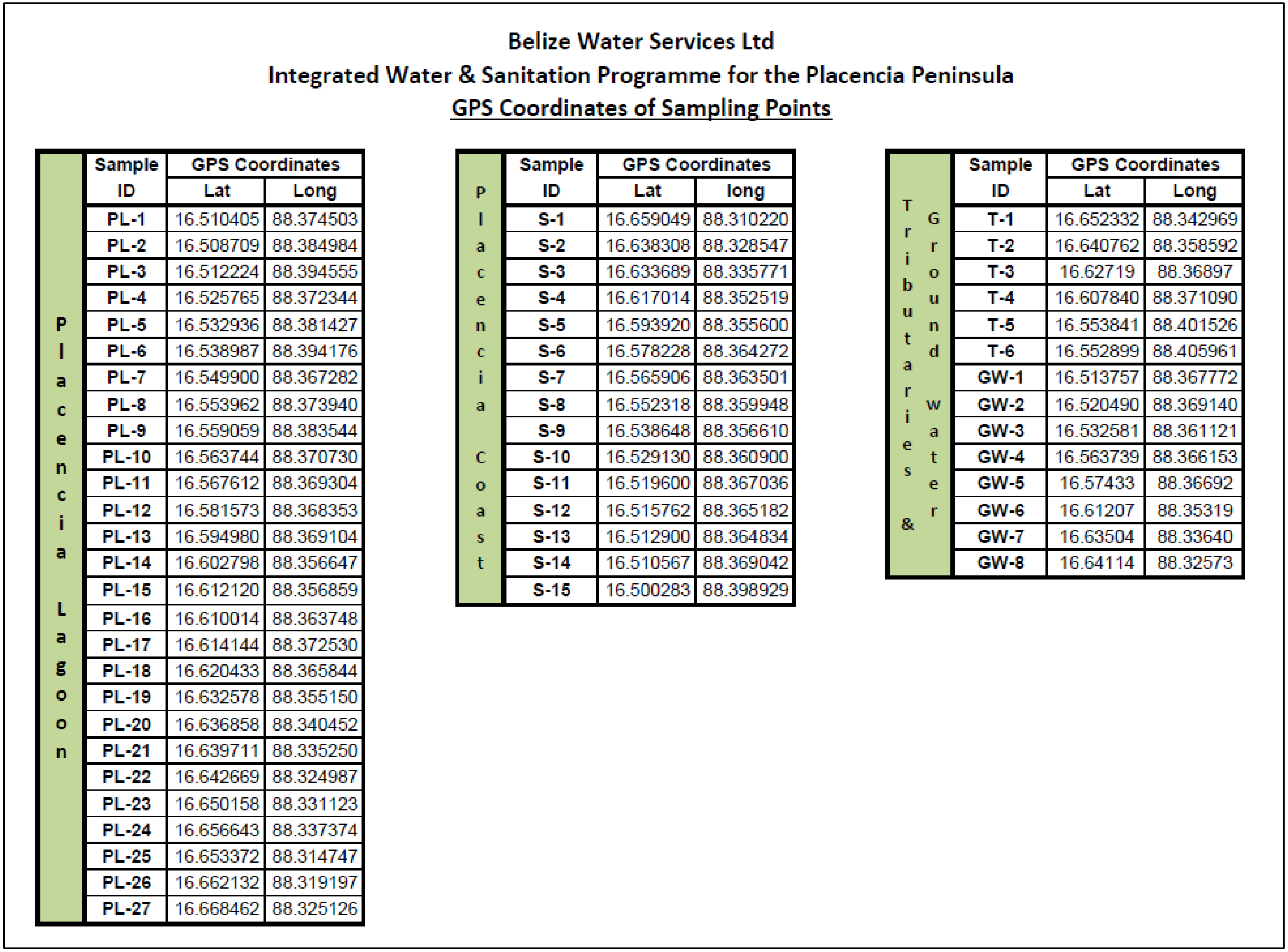
Reference	**Category**	**Subcategories**
Fish et al. (2016)	Cultural Ecosystem Benefits	- Identities - Experiences - Capabilities
Groot et al. (2002)	Information	- Aesthetic information - Recreation and (eco) tourism - Cultural and artistic information - Spiritual and historic information - Scientific and educational information
Millennium Ecosystem Assessment (2003)	Cultural Services	- Spiritual and Religious - Recreation and Ecotourism - Aesthetics - Inspirational - Educational - Sense of Place and Cultural Heritage
TEEB (2010)	Cultural Services	- Recreation and mental and physical health - Tourism - Aesthetic appreciation and inspiration for culture - Art and design - Spiritual experience and sense of place

APPENDIX C: BWS WATER QUALITY MONITORING PROGRAM

Table C.1 Complete List of Water Quality Parameters Provided by BWS

Analysis	**Parameter**	**Unit**	**Method**	**Equipment(s)**
In-situ	pH		In situ	YSI EXO2 Multi-probe; GeoTech GeoPump for ground water samples; 20' Luna Boat w/ Honda 50HP 4 stroke engine for lagoon/sea/tributary samples
	Temperature	oC		
	Salinity	ppt		
	Dissolved Oxygen	mg/l		
	Turbidity	NTU		
	Conductivity	µS/cm		
	Chlorophyll	µg/lL		
Chemical	Nitrates (as NO_3^--N)	mg/l	HACH 8171	Hach DR 3900 Spectrophotometer without RFID
	Total Nitrogen (as N)	mg/l	HACH 10071/HACH TNT826	Hach DR 3900 Spectrophotometer without RFID; HACH DRB 200 Dual Block Digital Reactor
	Phosphate (as PO_4)	mg/l	HACH 8048	Hach DR 3900 Spectrophotometer without RFID
	Total Phosphorus (as PO_4)	mg/l	HACH 8190	Hach DR 3900 Spectrophotometer without RFID
	Ammonia	mg/l	HACH 8155	Hach DR 3900 Spectrophotometer without RFID
	COD	mg/l	HACH 8000	Hach DR 3900 Spectrophotometer without RFID; HACH DRB 200 Dual Block Digital Reactor
	Suspended Solids	mg/l	HACH 8006; Standard Method	Hach DR 3900 Spectrophotometer without RFID; MB45 Moisture Analyzer w/ filtration apparatus
	5-Day BOD	mg/l	HACH BODTrak	BODTrakII; Thermo-Sci 815 Incubators
Bacteria	Total Coliform	cfu/100ml	Petrifilm Aqua Coliform Plates	Reichart Quebec Colony Counter; Thermo-Sci 815 Incubators
	E. coli	CFU/100ml	Petrifilm *E. coli* Plates	Reichart Quebec Colony Counter; Thermo-Sci 815 Incubators
	Enterococci	MPN/100mL	Quanti-tray	Idexx Labs Quanti-Tray Sealer; Spectroline UV viewing cabinet; Thermo-Sci 815 Incubators

Table C.2 GPS Coordinates of the Placencia Water Quality Monitoring Program by BWS



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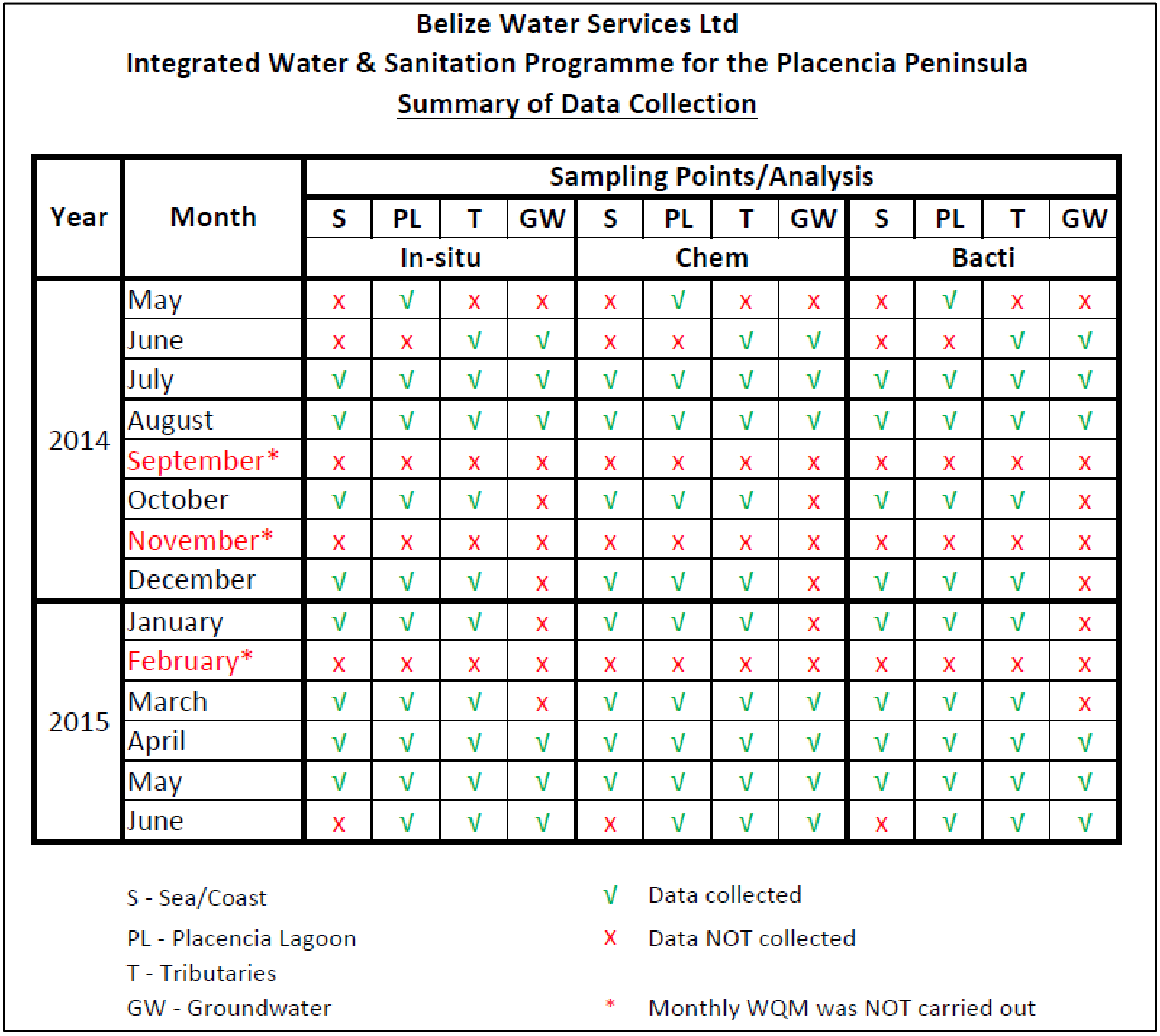
GPS Coordinates of Sampling Points

	Sample ID	GPS Coordinates	
		Lat	Long
Placencia Lagoon	PL-1	16.510405	88.374503
	PL-2	16.508709	88.384984
	PL-3	16.512224	88.394555
	PL-4	16.525765	88.372344
	PL-5	16.532936	88.381427
	PL-6	16.538987	88.394176
	PL-7	16.549900	88.367282
	PL-8	16.553962	88.373940
	PL-9	16.559059	88.383544
	PL-10	16.563744	88.370730
	PL-11	16.567612	88.369304
	PL-12	16.581573	88.368353
	PL-13	16.594980	88.369104
	PL-14	16.602798	88.356647
	PL-15	16.612120	88.356859
	PL-16	16.610014	88.363748
	PL-17	16.614144	88.372530
	PL-18	16.620433	88.365844
	PL-19	16.632578	88.355150
	PL-20	16.636858	88.340452
	PL-21	16.639711	88.335250
	PL-22	16.642669	88.324987
	PL-23	16.650158	88.331123
	PL-24	16.656643	88.337374
	PL-25	16.653372	88.314747
	PL-26	16.662132	88.319197
	PL-27	16.668462	88.325126

	Sample ID	GPS Coordinates	
		Lat	long
Placencia Coast	S-1	16.659049	88.310220
	S-2	16.638308	88.328547
	S-3	16.633689	88.335771
	S-4	16.617014	88.352519
	S-5	16.593920	88.355600
	S-6	16.578228	88.364272
	S-7	16.565906	88.363501
	S-8	16.552318	88.359948
	S-9	16.538648	88.356610
	S-10	16.529130	88.360900
	S-11	16.519600	88.367036
	S-12	16.515762	88.365182
	S-13	16.512900	88.364834
	S-14	16.510567	88.369042
	S-15	16.500283	88.398929

	Sample ID	GPS Coordinates	
		Lat	Long
Tributaries & Ground water	T-1	16.652332	88.342969
	T-2	16.640762	88.358592
	T-3	16.62719	88.36897
	T-4	16.607840	88.371090
	T-5	16.553841	88.401526
	T-6	16.552899	88.405961
	GW-1	16.513757	88.367772
	GW-2	16.520490	88.369140
	GW-3	16.532581	88.361121
	GW-4	16.563739	88.366153
	GW-5	16.57433	88.36692
	GW-6	16.61207	88.35319
	GW-7	16.63504	88.33640
	GW-8	16.64114	88.32573

Table C.3 Data Collection of the Placencia Water Quality Monitoring Program by BWS



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Summary of Data Collection

Year	Month	Sampling Points/Analysis											
		S	PL	T	GW	S	PL	T	GW	S	PL	T	GW
		In-situ				Chem				Bacti			
2014	May	x	√	x	x	x	√	x	x	x	√	x	x
	June	x	x	√	√	x	x	√	√	x	x	√	√
	July	√	√	√	√	√	√	√	√	√	√	√	√
	August	√	√	√	√	√	√	√	√	√	√	√	√
	September*	x	x	x	x	x	x	x	x	x	x	x	x
	October	√	√	√	x	√	√	√	x	√	√	√	x
	November*	x	x	x	x	x	x	x	x	x	x	x	x
	December	√	√	√	x	√	√	√	x	√	√	√	x
2015	January	√	√	√	x	√	√	√	x	√	√	√	x
	February*	x	x	x	x	x	x	x	x	x	x	x	x
	March	√	√	√	x	√	√	√	√	√	√	√	x
	April	√	√	√	√	√	√	√	√	√	√	√	√
	May	√	√	√	√	√	√	√	√	√	√	√	√
	June	x	√	√	√	x	√	√	√	x	√	√	√

S - Sea/Coast	√ Data collected
PL - Placencia Lagoon	x Data NOT collected
T - Tributaries	
GW - Groundwater	* Monthly WQM was NOT carried out

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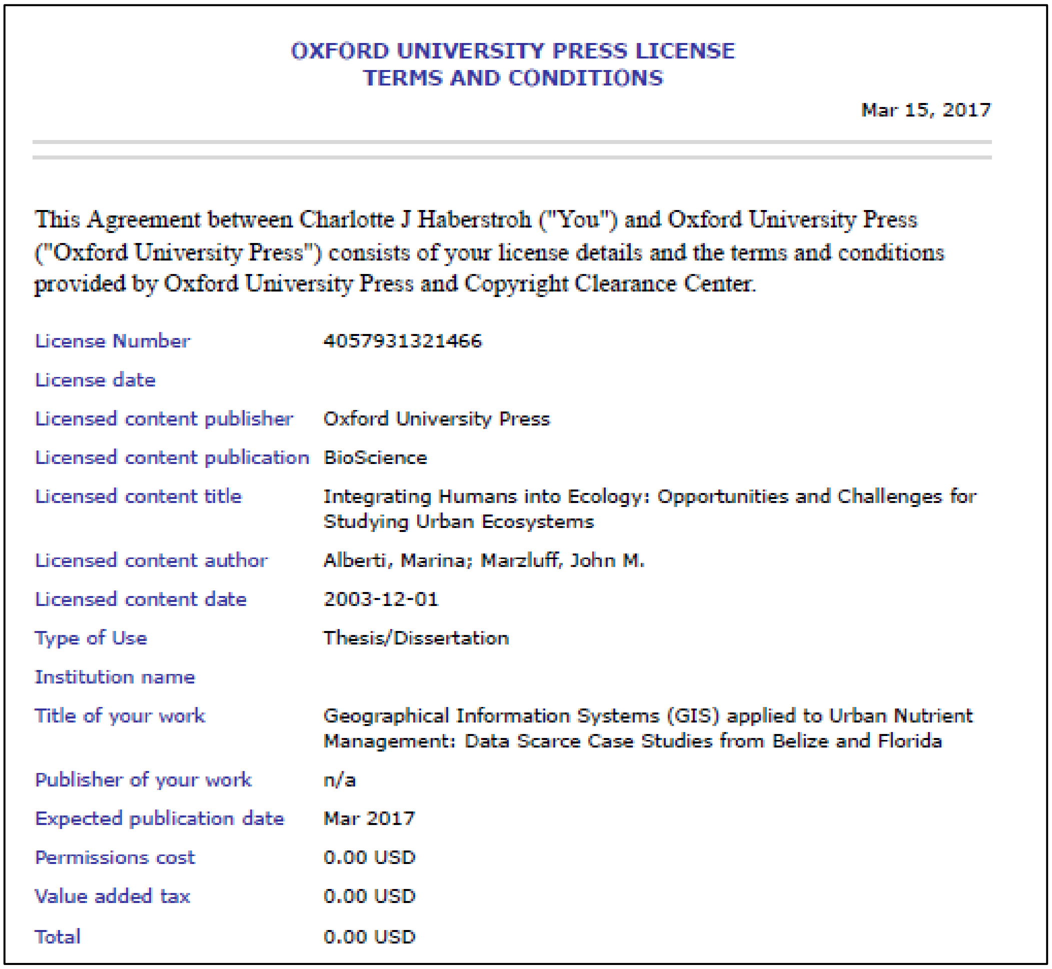

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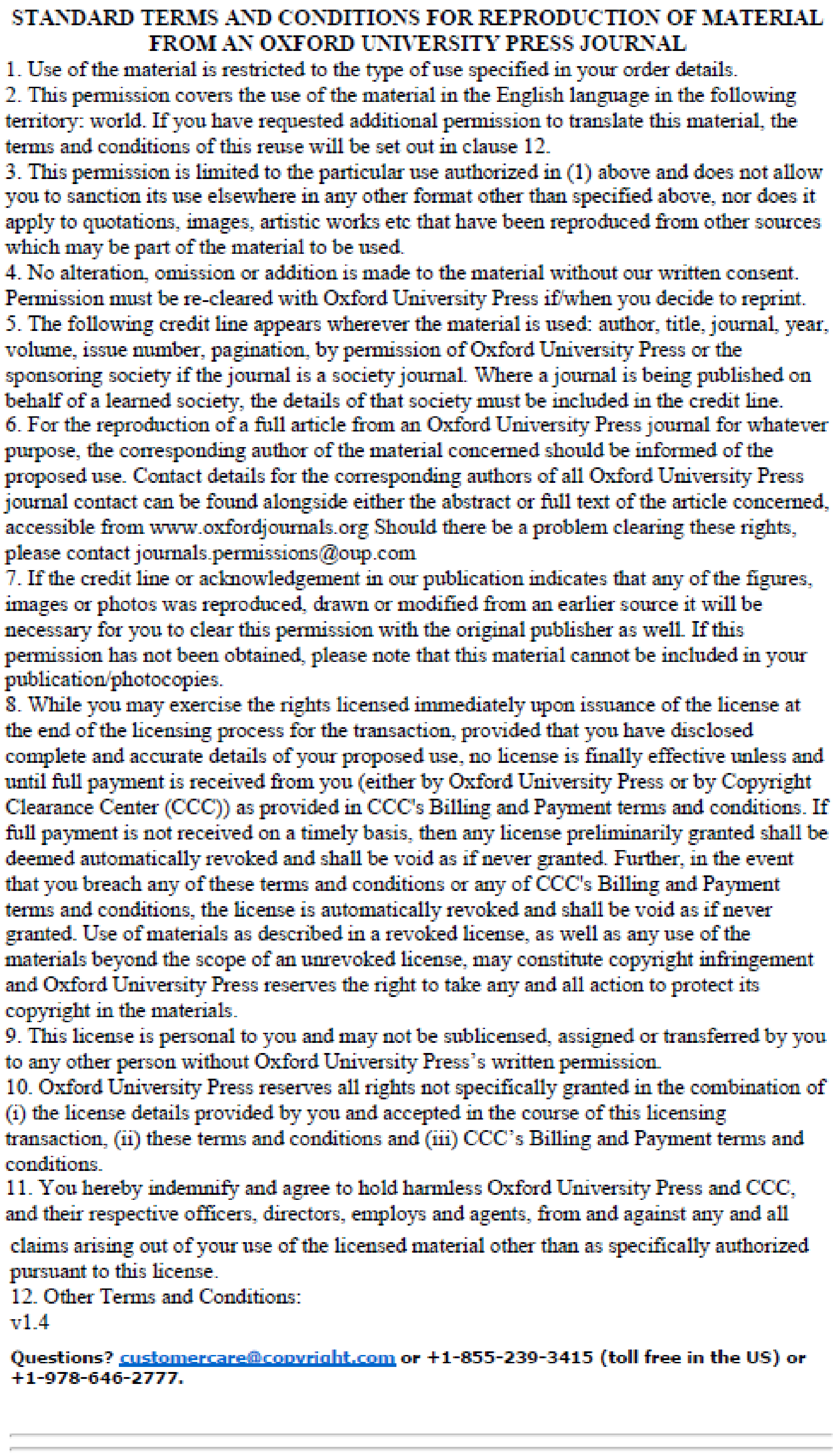

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