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# Agricultural and Domestic Waste Contamination in Chilibre Panama and Potential Low-Cost Best Managament Practices

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# Agricultural and Domestic Waste Contamination in Chilibre Panama and Potential Low-Cost Best Management Practices

by

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## Dedication

I would like to thank my mother for all she has done to see me through to this point. Her unconditional love, emotional support, and belief in me motivated me to become a better student, a harder worker, and a better man.

I would also like to thank my Auntie Beverly who I pray is looking over me and smiling as I move past this stage of my life. I will never forget you Auntie Beverly and I am happy that I was able to reach a point where I could truly embrace the importance of having you in my life.

Lastly, I dedicate this paper to my little sister who I was able to meet for the first time at my Auntie Beverly's funeral two years ago. I never thought such a sad day could be so happy.  I pray I am able to provide a good example and support so that you can achieve your goals and never feel alone.

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**Abstract**

Sanitation coverage in the Republic of Panama is 5 to 10 percent below the Millennium Development Goals targets set for the country. Population growth, urbanization, unplanned development and waste mismanagement have resulted in improvised trash sites and waste discharges into river systems that are important components of the biologically diverse natural environment of Panama. The study sought to investigate and estimate the burden of waste from domestic and agricultural sources in three regions of the Chilibre corrigimiento (district). It was hypothesized that the water quality and land cover data would reflect that the most populated region in the study sample (Region 2) would have more water quality violations than the adjacent background and attenuation regions (Region 1 and Region 3) in the study sample. The results supported that Region 2 had the most water quality violations -- particularly at the CHIL 3 monitoring station. Based on the results the most appropriate best management practices (BMPs) were recommended for the household, community, watershed, and regional level waste management in the study region. Future research will look determine the effectiveness of microfinance programs in bolstering sanitation-based entrepreneurship in Chilibre and across Panama.

## Introduction

Domestic wastewater pollution causes deleterious effects to aquatic ecosystems, aesthetics, fishery production, biological diversity, tourism, and human health. Untreated wastewater discharges increase the burden of illness and mortality in human populations through the spread of disease containing bacteria and viruses. Some common examples of human diseases that are spread through wastewater discharges are diarrhea, gastro-enteritis, typhoid, cholera, hepatitis, and severe acute respiratory syndrome. Globally, economic losses associated with domestic wastewater pollution account for roughly US $12 billion per year (The Carribean Environment Programme, 2008). In Greece, Italy, and Spain, health impacts associated with domestic wastewater amount to roughly US $329 million annually by 2005 estimates (The Carribean Environment Programme, 2008). It is estimated that 90% of the diarrheal disease burden experienced in developing countries is related to environmental factors, among them poor sanitation (Surinkul & Koottatep, 2009).

Worldwide, roughly 2.5 billion people lack access to improved sanitation facilities[1] (The Carribean Environment Programme, 2008). A report conducted by the World Health Organization and UNICEF (2008) posited that the world is not projected to achieve the Millennium Development Goals (MDGs) on sanitation by 2015 (The Carribean Environment Programme, 2008). According to the same study, 1.2 billion people live without sanitation. The

[1] Improved sanitation facilities are defined as 'facilities that ensure the separation of human excreta from human contact; connection to a public sewer; connection to a septic system; pour-flush latrine; simple pit latrine; ventilated pit latrine' (The Carribean Environment Programme, 2008). Improved sanitation facilities are not 'public or shared latrine; open pit latrine; bucket latrine' ( (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010).

lowest coverage of improved sanitation facilities occurs in sub-Saharan Africa and Southeast Asia (The Carribean Environment Programme, 2008); however, globally disparities exist between urban and rural areas where rural communities often experience limited coverage compared to urban areas.

**Domestic wastewater pollution in Latin America and the Caribbean**

Sanitation in the Latin America and Caribbean region has been characterized by insufficient access to wastewater service and poor service quality of sanitation programs especially in rural areas (The Carribean Environment Programme, 2008). Between 1990 and 2008, urban areas throughout the region experienced a rise in improved sanitation facilities from 81% to 86 % coverage (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010). Comparatively, rural areas have experienced increased sanitation facility coverage of 39% to 55% according to the same source. Moreover, during the same period, urban areas experienced a decline in open defecation practices in the overall population from 6% to 2% compared to 43% to 20% in rural areas. It is important to mention that overall averages for this region do not reflect urban and rural differences. Regional averages reflect an increase in improved sanitation facility coverage from 69% to 80% and a decrease in open defecation of 17% to 6% (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010). Furthermore, these urban and rural differences may not reflect the actual burden as underscored by the fact that 117 million people did not use an improved sanitation facility in 2008 (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010).

**Domestic wastewater pollution in Panama**

Panama has experienced the persistent and pervasive issue of untreated domestic discharges within the Panama Canal Watershed (PCW) owing to lack of wastewater treatment facilities and infrequent sanitation services (CICH, 2007). Evidence of the effects of domestic wastewater pollution has been demonstrated by water quality data at monitoring stations situated along select rivers and streams, which suggest marked increases in certain constituents associated with domestic wastes (i.e. E. Coli). Depending on the source and collection methods of domestic wastes, a range of chemicals and specialized wastes may threaten human health (The Carribean Environment Programme, 2008).

In the context of meeting MDGs goal targets (Figure 1), Panama and Colombia (in yellow) are the only two countries in Latin America and the Caribbean that have made progress but insufficiently[2] with regard to sanitation (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010). Sanitation coverage in these countries ranged from 50% to 75%, which may not reflect urban and rural differences (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010). Of the two countries, Panama was selected for this study because pollution caused by the lack of sanitation may have deleterious effects on the Panama Canal Watershed (PCW) which:

- support the operations of the Panama Canal
- contain water used for transportation, hydropower, human and industrial use
- conserves one of the most biologically diverse ecosystems in the world

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[2] Insufficient coverage entailed that the sanitation coverage rate (in 2008) was between 5% and 10% below the rate required to meet the MDG targets (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010).

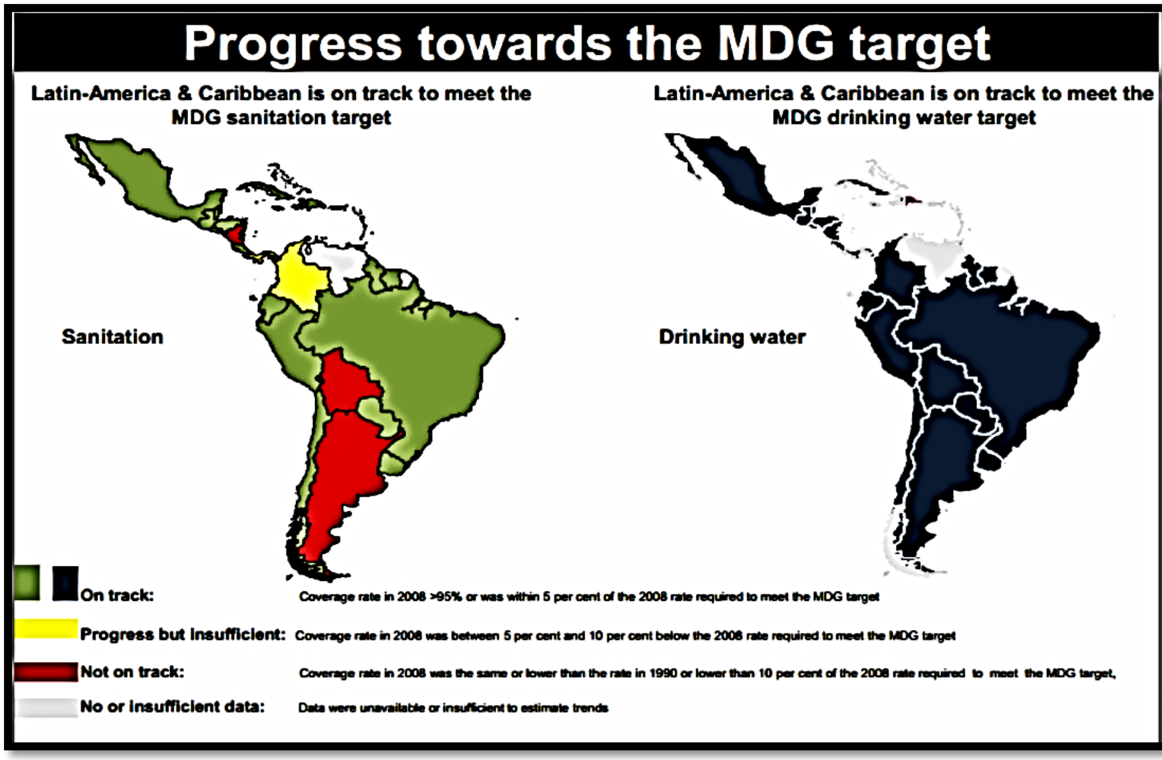


*Figure 1. Progress towards the MDG targets (WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, 2010).*

**Economic value: Panama Canal Watershed**

Protection and conservation of the central watershed of Panama has been identified as a global and domestic priority economically—particularly with regards to the Panama Canal (Ibanez et al., 2002, Saenz, 2007). Domestically, the canal  transports 30 to 50 ships daily, which generate US $8m to  $9m daily, accounts for one-fifth of Panama's exports, pays its workers 10-20 times the national average (at $200,000 to $300,000 per vessel) for the Panama Canal Authority (Thompson, 2012; Bussolo, Hoyos, & Medvedev, 2011). The Panama Canal expansion project, expected to be finished by 2014, will add to the economic benefits by (Jeong, Crittenden, & Xu, 2006):

- maintaining competiveness and value of the Canal by generating higher revenues and benefits for the Republic of Panama
- allowing transit of ships larger than Panamax ships (post-Panamax or new- Panamax[3]) to increase the Canal productivity
- increasing total exports by more than 9.5%
- increasing fiscal revenues by 31.8%
- generating US $8.5 billion dollars (2007) in National Treasury Revenues in the first 11 years
- providing 6,500-7,000 new direct jobs
- providing 28,500-33,000 indirect jobs

Globally, ports have concomitantly set plans to expand their ports and shipping operations to handle the movement of cargo that the new Panamax ships are projected to contain (Thompson, 2012). For example, The Port of Miami (in Florida) is working to deepen channels and anchoring sites and repair damage to a railroad bridge to expand capacity. Tampa, Florida is installing larger container cranes and building a new dockside rail access to receive cargo that has been off-loaded in the Caribbean (Thompson, 2012).

**Ecosystem value: Panama Canal Watershed**

Domestic natural resource protection and conservation priorities have been developed for select regions in Panama. For example, Central Panama, comprising the PCW (3,396 $km^2$) (Saenz, 2007), is one of the most diverse ecosystems on earth, whose species richness rivals biological ‘hotspots’ in the Amazon, Northern Andes, and Southeast Asia (Ibanez, et al., 2002). Panama is

[3] Up to 1200 feet long, drawing nearly 50 feet of water, and up to 170 feet wide (Thompson, 2012). Existing locks are 1000 feet long, 100 feet wide, and 42 feet deep can handle ships up to 965 feet in length (Leach, 2011).

recognized for its wide diversity of reptiles (224- 229 species), amphibians (169 to 176 species), fish (57 species), birds (122 regular migratory species and 60 occasional migratory species), mammal (259 species), algae (1200 species), and other aquatic plants (98 species) (USAID, 2006). Approximately 1500 species of plants are endemic to the country, some of which are used in medicines and foods for subsistence and market products (USAID, 2006).

The watershed forests protect water sources for the Canal and Panama City and provide resources to rural communities (Ibanez, et al., 2002). The watershed plays an important role in hosting biodiversity, capturing water, regulating yearly flow of rivers and tributaries, recharging underground sources of water, and regulating interconnectedness among rivers, lakes, especially groundwater and runoff (USAID, 2006).

Protection and conservation efforts have been implemented both to protect the quantity and quality of the PCW for the operation of the Panama Canal and to provide potable water to the population (Saenz, 2007); however, land use and resource consumption have threatened the health of habitats, key species and biological diversity.

One of the central challenges that threatens the integrity of the Panama Canal Watershed is controlling land use.  Land use changes have had impacts on ecosystem integrity and function in protected areas throughout the Atlantic regions and Pacific regions of the Panama Isthmus (USAID, 2006). A high degree of fragmentation and intervention has put unprotected regions along the Atlantic region of the isthmus at risk for further destruction, which could cascade into adverse economic and ecosystem effects. Among these regions are the Chagres and Soberania National Parks, which are contiguous with rivers and tributaries of the PCW.

**Population growth, water, and sanitation: Panama Canal Watershed**

Two of the major externalities associated with land use practices in the PCW are deforestation and water contamination. Deforestation has garnered attention as forests throughout Panama have become increasingly fragmented to the extent that the PCW is one of the last sites in the world where a corridor of forest stretches from the Atlantic to the Pacific (Condit et al., 2001). However, a substantial portion of the area covered by forests in the PCW is used very rarely by people (Ibanez et al., 2002). The uses of the resources provided by forests contiguous with the PCW are for subsistence of indigenous people (Ibanez et al., 2002). [4] Though deforestation has been documented, reforestation efforts have restored 1594 hectares between 1998 and 2009 (Saenz, 2007). Alternatively, human activity has increased near rivers and tributaries in the eastern watershed (3,396.49 $km^2$) (USAID, 2006) owing to the development of the Trans Isthmian Highway and population growth[5] (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007).

Population growth in the Panama Canal Watershed was influenced by development of the Trans Isthmian Highway (built in 1942), which enabled the movement of goods and people between major trading centers in the provinces of Colon (the Atlantic side) and Panama (the Pacific side) (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Approximately 62% of the population resides along the Trans Isthmian Highway (Castro, 2003). In 1990, the human population of the PCW was 113,000 and reached roughly 170,000 by the 2000 census (Ibanez et al., 2002).

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[4] 16 years of records have yet to link deforestation (which has occurred primarily near reservoirs of Lake Gatun and Lake Alhajuela) to increased erosion and sedimentation in the watershed (Ibanez, et al., 2002) which provides further justification for focusing on water contamination. Nevertheless studies have shown that forested streams have lower nitrates and phosphate levels which underscore the importance of forests (Ibanez, et al., 2002).

[5] Historically in Panama, communities near highways tend to experience the fastest population growth (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007).

Growth rates have climbed more rapidly near the canal and highway corridor than elsewhere in the county including metropolitan areas (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007). Between 1980 and 1990, population growth rate in the watershed was 3.8%, larger than the growth rate of the entire country at 2.1% and metropolitan areas with average growth rates of 2.7% (Ibanez, et al., 2002). At present growth rates, the population of the Eastern Panama Canal Watershed (EPCW) is expected to reach 407,000 by 2020 (Dale et al., 2005). Population growth rates in the PCW have been accompanied by urbanization, which as of 2010 was estimated at 2.8% (Trading Economics, 2012). According to Dale et al. (2005), commercial, residential, and industrial land designations are projected to increase from baseline levels of 1140 hectares by a yearly rate of 1.6% between 2000 and 2020. (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007).

Towns occupied roughly 19.1 % of total land area of the watershed in 2000 (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007) Overall, it is estimated that one million inhabitants produce over 280,000 cubic meters of wastewater across the range of land use activities in Panama per year (Inter-American Development Bank, 2012). Trends in urbanization have accelerated without adequate measures in environmental management, especially drainage systems, potable water distribution, and solid wastes (USAID, 2006) to the detriment of environs. Moreover, rapid population growth has accompanied unplanned urban development, which has contributed to added pressures on municipal services (see Figure 2). Heavily populated towns have contributed to domestic wastewater pollution of rivers that are part of the PCW (Ibanez et al., 2002). The Las Cumbres and Chilibre[6] (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007; USAID, 2006) contain rivers that are

Figure 2. An example of unplanned urban development in Panama (CICH, 2008).

severely contaminated and unsuitable for any human use (Ibanez et al., 2002). The 2000 National Environmental Strategy of Panama (NESP) identified both Las Cumbres and Chilibre as priority areas in the PCW because of the degree to which they have been degraded by human activities (USAID, 2006). Additionally, base-line studies conducted in the PCW by the National Environment Authority (ANAM) and the Smithsonian Tropical Research Institute (STRI) concluded that there was 'serious pollution in the mid-course of the Chagres River, especially in the area of Chilibre' (Castro, 2003, p. 4).

[6] Towns typified by approximately 4.5% and 4% (2000) population growth respectively and dense populations 1,114 inhabitants per km² and 297 inhabitants per km² (1980 to 1990) respectively compared to the national average of 53 inhabitants per km² (Trading Economics, 2012).

Two objectives addressed in the NESP directly related to the current investigation were to reduce the major sources of contamination and improve environmental quality of the Panama Canal Watershed (USAID, 2006). In the context of watersheds, the environmental assessment process of the Panama Canal Authority (ACP) entailed ‘manag[ing] water resources efficiently to ensure its availability in quantity and quality’ (Saenz, 2007, p. 4). To achieve the NESP objectives, ACP should consider the pressures caused by people because of population growth, urbanization, solid and wastewater discharges (Saenz, 2007).

## Study Justification, Hypotheses and Objectives

Generally, water contamination in the PCW drains into rivers of the eastern watershed (or ROR) along the Trans Isthmian Highway from swine, chicken and commercial industries, car repair shops, small-scale service outlets, and households (USAID, 2006). Illegal waste dumping has occurred along different sections of the Chilibre River. The region has typified by septic tank and latrine leakage. Additionally, the sanitation system and collection services have been characterized by poor maintenance and inadequate coverage in the Chilibre sub-district. (Panama Canal Authority, 2007; Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007). Untreated solids have accumulated in the sewerage and drainage networks throughout the Chilibre sub-watershed (Monetangero & Belevi, 2007[7]; Ibanez, et al., 2002), and certain water quality parameters such as E. coli, phosphates, nitrates, and suspended solids are indicative of the contamination and persistence of waste constituents that threaten water quality and human health (Panama Canal Authority, 2007). This study is the first of its kind to estimate the burden wastewater contamination from land uses in Chilibre, Panama.

The research question of this study was to estimate if the levels of domestic wastewater contamination in the Chilibre sub-watershed were above regional water quality standards[8] , which may threaten the health of the PCW. Some factors that were used to estimate the burden of domestic wastewater contamination were: urbanization, population density, poverty- and

[7] Findings were documented in Hanoi, Vietnam; however, informal descriptions in Chilibre support these observations.
[8] Established by the United States Environmental Protection Agency (1986)

unemployment-rates, sanitation service coverage, septic system quality, precipitation, topography, drainage areas and pollution reports.

The objectives of the study were to:

(1) provide a description of Chilibre Panama emphasizing water quality characteristics and land cover (2) to determine the relationships between land cover and water quality data

(3) recommend cost effective strategies based on land use and water quality relationships at the monitoring stations in Chilibre to reduce the burdens to the sub-watershed and PCW.

It is believed that implementation of these strategies will coincide with the 'Green Route Initiative' (GRI) of ACP to promote sustainable development activities in the PCW, will function in accordance with Law No. 41[9] and Organic Law 19 (1997)[10], and will help the country achieve MDG targets for sanitation.

[9] Established in July 1, 1998, known as the "General Environmental Law of the Republic of Panama" which stipulates that "Every natural or legal person is obliged to prevent damage and control environmental pollution
" (ANAM (National Environment Authority), 2006)

[10] This makes the PCA responsible for managing the water resources required to operate the canal and for supplying the surrounding population with sufficient water (Castro, 2003).

## Site Description

The rationale for the Panama study was to investigate the potential sites in the country for the application of low costs best management practices (BMP) on the household, community, watershed, and regional levels. In order to make BMP recommendation, it was important to characterize the physical, economic, and social features (among others) of the site discussed below.

The Inter-institutional Commission of the Panama Canal Watershed (or CICH) compiled a report in 2007 on the environmental condition of the Panama Canal Watershed. The commission provided descriptions that covered the physical aspects of the PCW including the following characteristics that were investigated in the study:

1) water availability
2) catchment sizes of tributaries
3) average annual flow
4) elevation in the catchment area
5) sediment production
6) precipitation
7) soil type
8) land cover

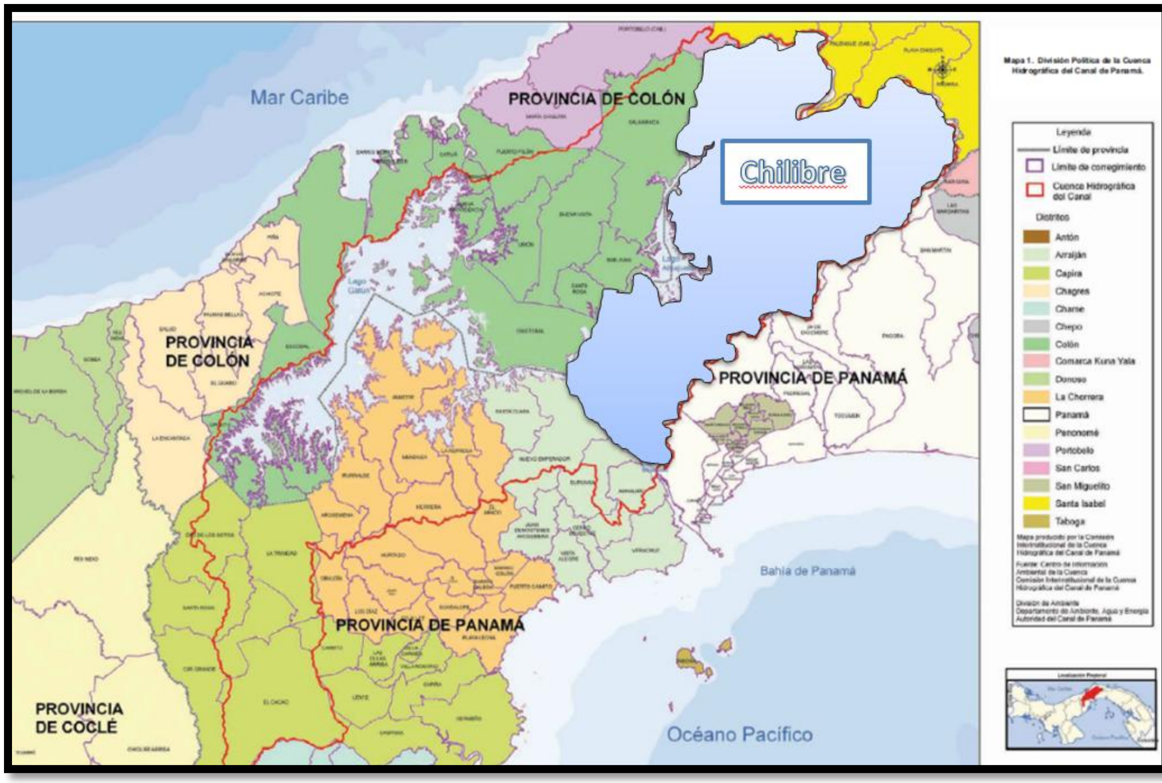



Figure 3. Political divisions (districts) in the Panama Canal Watershed (United Nations Human Settlement Programme (UN-Habitat), 2003).

The Chilibre district (Figure 3) is located within the PCW (outlined in red) and is the largest district within the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

**Water availability in Chilibre**

In the Chilibre district, water used by the Panama Canal is stored in Lake Alhajuela, a reservoir whose principal rivers are the Chagres, Pequeni, and Boqueron (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Maximum storage capacity (capacidad maxima) and the capacity of water utilized (capacidad util) are presented in Table 1.

Table 1. Storage capacity and physical characteristics of PCW reservoirs (Autoridad del Canal de Panama, 2008).

| NOMBRE | Año de creación | Superficie (Km²) | Área de drenaje (Km²) | % del total de la Cuenca | Capacidad máxima (Mm³) | Capacidad útil (Mm³) | Altura promedio (msnm) |
|---|---|---|---|---|---|---|---|
| **Lago Gatún** | 1912 | 436 | 2,314.10 | 68.14 | 5431.9 | 766.0 | 26.0 |
| **Lago Alhajuela** | 1935 | 44 | 983.94 | 28.97 | 799.5 | 651.0 | 73.0 |
| **Lago Miraflores** | 1913 | 4 | 98.35 | 2.89 | 2.5 | 2.2 | 16.5 |

Fuente: ACP. Informe de Calidad de Agua 2003 – 2005. 2006.

Mm³: millones de metros cúbicos.
Km²: kilómetros cuadrados.
msnm: metros sobre el nivel del mar.

Note that the average elevation (altura promedio) of Lake Alhajuela (at 73.0 meters above sea level) is almost three times higher than the average elevation of the second highest reservoir Lake Gatun (at 26 meters) and approximately four and a half times as high as the lowest reservoir Lake Miraflores (at 16.5 meters) (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Lake Alhajuela is, on average, operating at 81.4% of its storage capacity, which may not reflect peak months in which water demand is at or exceeds capacity; to date, no such instance has occurred (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

**Catchment size of rivers**

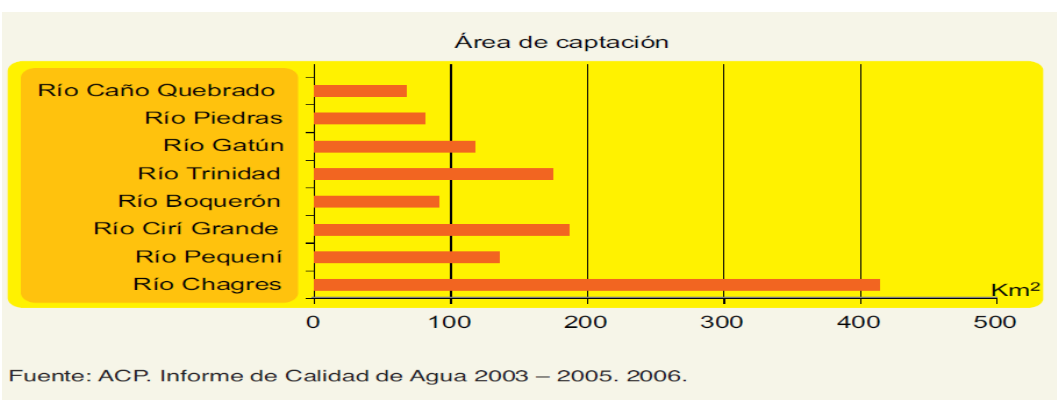



Figure 4. Catchment area of Panama Canal principal rivers (ANAM; ACP, 2006).

Of the principal rivers entering Lake Ahlajuela (Boqueron, Pequeni, and Chagres), the Chagres River contains the largest catchment area at over 400$km^2$, the Boqueron River occupies a catchment area of approximately 90 $km^2$ and Pequeni River occupies approximately 130 $km^2$(see Figure 4).

**Average annual flow rates for the principal rivers in the PCW**


Figure 5. Average annual flow rate of principal rivers in the Panama Canal Watershed. Obtained from ACP's Water Quality Reports 2003- 2005. 2006. (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Of the principle rivers entering Lake Ahlajuela, the Chagres River has an annual flow rate of 26 $\frac{m^3}{s}$ , the Pequeni River has an annual flow rate of 11 $\frac{m^3}{s}$, and the Boqueron has a flow rate of 7 $\frac{m^3}{s}$ (see Figure 4).

The region circled in Figure 6 contains the monitoring stations associated with the principal rivers entering Lake Ahlajuela. The blue line contained within the circle represents the Chagres River, the green line represents the Pequeni River and the red line represents the Boqueron River. The average annual flow rates (see Figure 5), in addition to general water parameter readings, were measured at hydrometric monitoring stations represented by orange triangles.

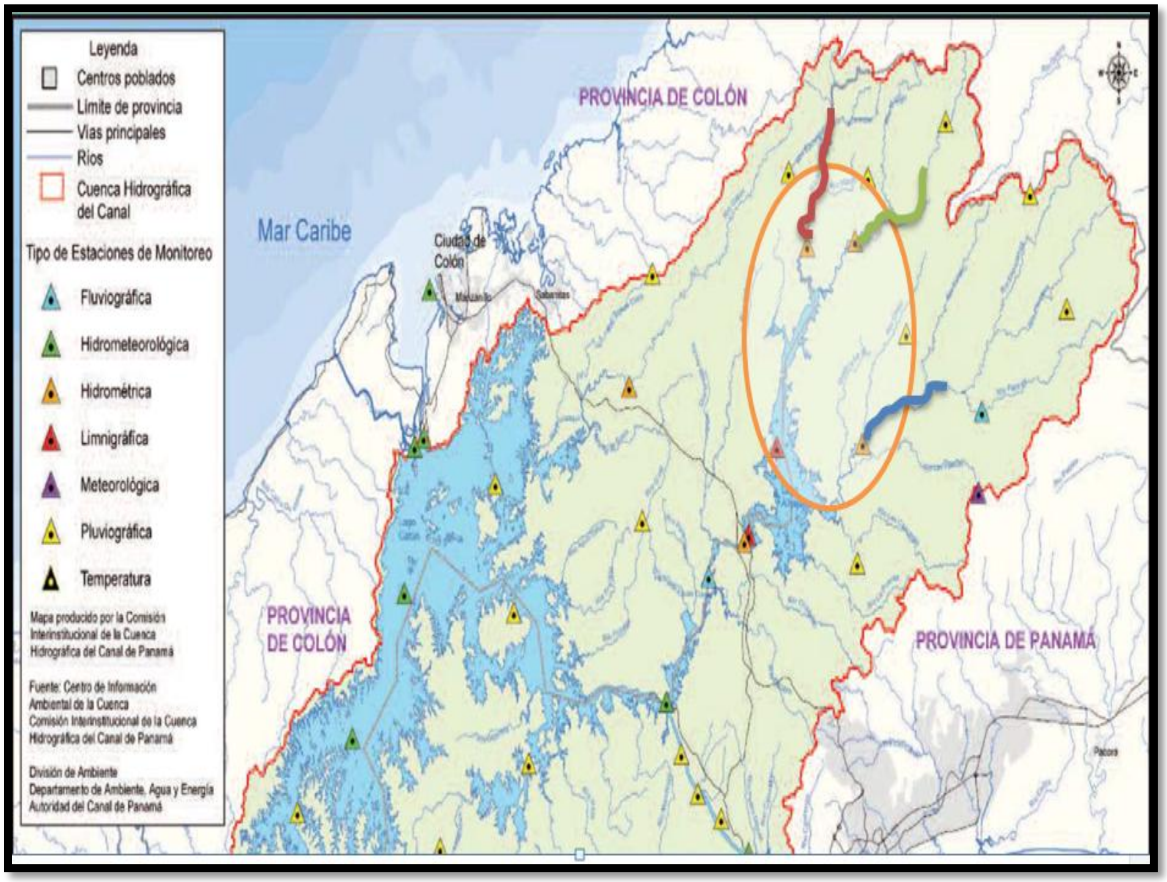



Figure 6. Network of water quality monitoring stations in the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

**Elevation distribution in Chilibre**

The average elevation in the Chilibre district (outlined in purple) ranges from 0 meters to 900 meters above sea level (Figure 7). Lowest elevations (0- 50 m) are most typical to the west of Lake Ahlajuela (outlined in black) along the banks of the Chagres River (highlighted in blue). Midrange elevations (51- 300 meters) are typical of the most populous regions of Chilibre.

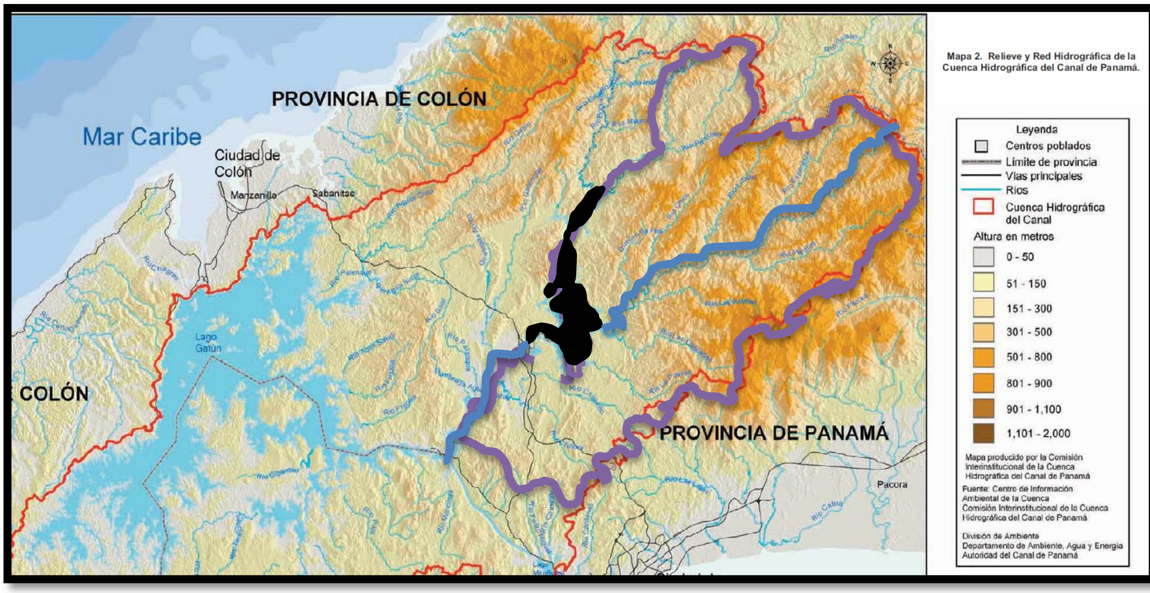



Figure 7. Average elevation and river network in the Panama Canal Watershed (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

The highest elevations (300 meters to 900 meters) are most typical in the regions containing the principal rivers entering Lake Ahlajuela particularly the Chagres River (highlighted in blue) (see Figure 7).

**Sediment production averages for six rivers in the Chilibre district**

Average sediment production per year (in tons) is provided for the principal rivers entering Lake Ahlajuela (see Figure 8). Average sediment production increased by 280% for the Chagres River between 1987 - 1996 and 2006. Pequeni River sediment averages increased by 162%, and Boqueron River sediment averages increased by 150% between measurement periods. Rivers that provided the highest average rates of sedimentation per square kilometer (1981-1994) that discharge to Lake Ahlajuela were Pequeni (664 tons/$km^2$/year) and Boqueron (870 tons/$km^2$/year) (Figure 9).

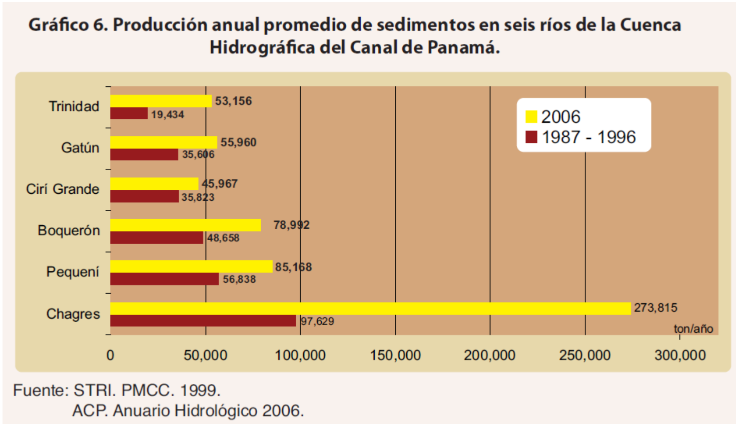



Figure 8. Average yearly sediment averages rivers in the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

During the ACP reporting in 2006, both Pequeni and Boqueron rivers had lower rates of sedimentation per square kilometer, but the Chagres River showed a 260% increase in sedimentation rates per square kilometers from previous reported values (see Figure 9).

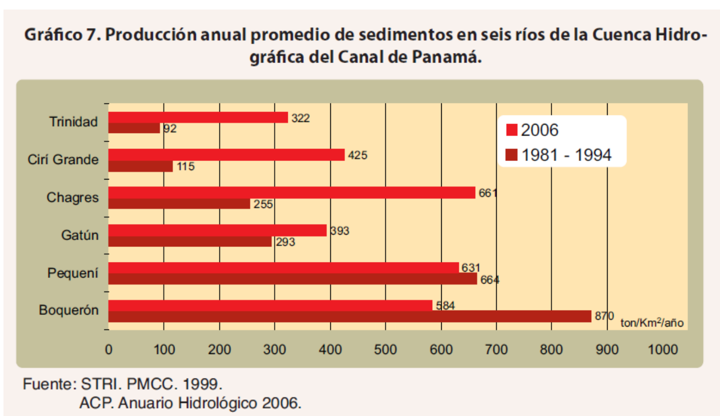



Figure 9. Average sedimentation rate per square kilometer among six rivers in the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

**Precipitation in Chilibre**

The land area of the Chilibre district below and slightly to the east of Lake Ahlajuela was characterized by an annual precipitation average of 2051 to 2550 mm per year. East of this area that contains the Chagres River (in blue), precipitation averages increased from 2551 to 3500 mm per year. Northeast to these averages the precipitation averages ranged from 3501 to 4550 mm per year (see Figure 10).

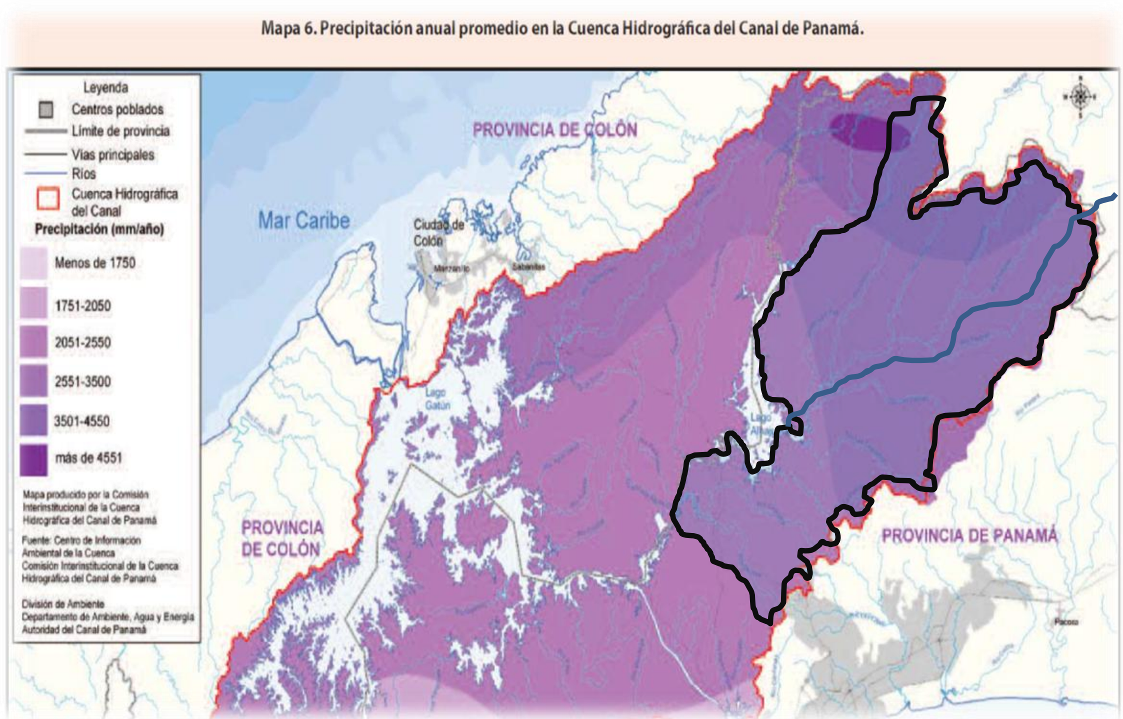



Figure 10. Precipitation averages in the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Precipitation and elevation (or more specifically slope) influence the sedimentation rates within the PCW; however, land use and soil types must be considered because they also contribute to the amount of sediment generated and transported in Chilibre district’s rivers and water bodies.

**Soil types in Chilibre**

Soils in the PCW are typical for the tropics and formed as a result of high precipitation and high temperatures of the region that promote rapid weathering (see Table 2) (i.e. leaching) (Earth Science Australia, 2012). Soil erosion from land uses associated with agriculture and-- but not limited to-- urban development can strip away topsoil, which can take between 80 to 400 years to restore 1 centimeter of topsoil naturally (Earth Science Australia, 2012).Weathering conditions and processes combined with human activity can diminish the soils' natural ability to uptake nutrients from organic material and minerals from weathered rock (Earth Science Australia, 2012).

Table 2. Major soil types in the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

| Type of Soil | Main Characteristics |
|---|---|
| **Oxisols** | Most common in the PCW; good permeability, low organic matter content; mildly acidic; low acid and base content in soil which makes soil have low natural fertility and poor agricultural productivity |
| **Inceptisols** | Mainly located at the mouths of rivers; located in floodplains; site of high silica and base accumulation and exchange; agricultural use restricted by poor internal drainage and flooding |
| **Ultisols** | Typically known as the acidic soils of humid regions; experience intense soil leaching; normally found in forested areas, but can also be found in areas that have been cleared for pasture |
| **Entisols** | Generally located on young and alluvial soils |

Reports by the Agricultural Research Institute of Panama (IDIAP in Spanish) indicate that most soils in the PCW are acidic to very acidic, iron- and phosphate-poor, reaching average levels in the parts of the Chagres River sub-basin that is dominated mostly igenous rocks (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007; Autoridad Nacional del Ambiente, 2010).

**General land cover and uses in Chilibre**

In Panama, land use is divided into two categories: current uses and potential uses (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). On 2 July 1997, Law No. 21 was put into effect to mandate the designation of land uses in Panama (CICH, 2008). In general, current uses reflect vegetation cover, farming operations and human activities within a defined region (see Figure 11). Potential uses serve as guidelines that represent land areas where there may be limitations or restrictions to development. Since potential land uses were not well represented in the Chilibre district, they were not considered in the current study. Waste generation associated with current land uses were believed to influence the health of the Panama Canal Watershed (Centro Agronomico Tropical de Investigacion Ensenanza, 2007).

In Figure 11, the area outlined in blue represents the area associated with human activity and is constituted by the following land uses (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007):

Shrubs and Bushes (matorrales and rastrojos): Found at the margins of Lake Ahlajuela and in small patches inside of the Chagres National Park. These lands are found in areas that were previously occupied by primary and secondary forest that were cleared by humans.

White Straw (*Saccharum spontaneum*)(paja blanca): This herb spreads rapidly to urban areas and colonizes forests and open areas adjacent to grasslands and plots of crops that have been abandoned (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Grassland (pastizales): This land is associated with livestock activities and processes (potrerizacion) typically along the Trans Isthmian Highway in Chilibre and northeast of Lake Alhajuela in Boqueron.

Croplands (cultivos): Lands containing crops in the Chilibre region are mainly used for subsistence and burning. Pineapple and watermelon are the most common crops grown on these lands.

Other Coverages (otras coberturas): The most important among these are populated areas, the largest of which are located along the Trans Isthmian Highway in the Chilibre District. Mining and stone extraction activities are also included in this land use type. Water constitutes a land cover designation and refers primarily to the Lake Alhajuela and minor bodies of water in Chilibre.

In Figure 11, the area outlined in brown is primarily dominated by the following land uses that occupy Chagres National Park in yellow (see Figure 12):

Mature and Secondary Forests (Bosques maduros and secundarios): Mature forests are comprised of dense canopy and tall trees mainly in the Chagres National Park (contained within the Chilibre district). The region mature forests are generally typified by rugged terrain and have high precipitation. Secondary forests are comprised of less dense canopies and shorter trees.

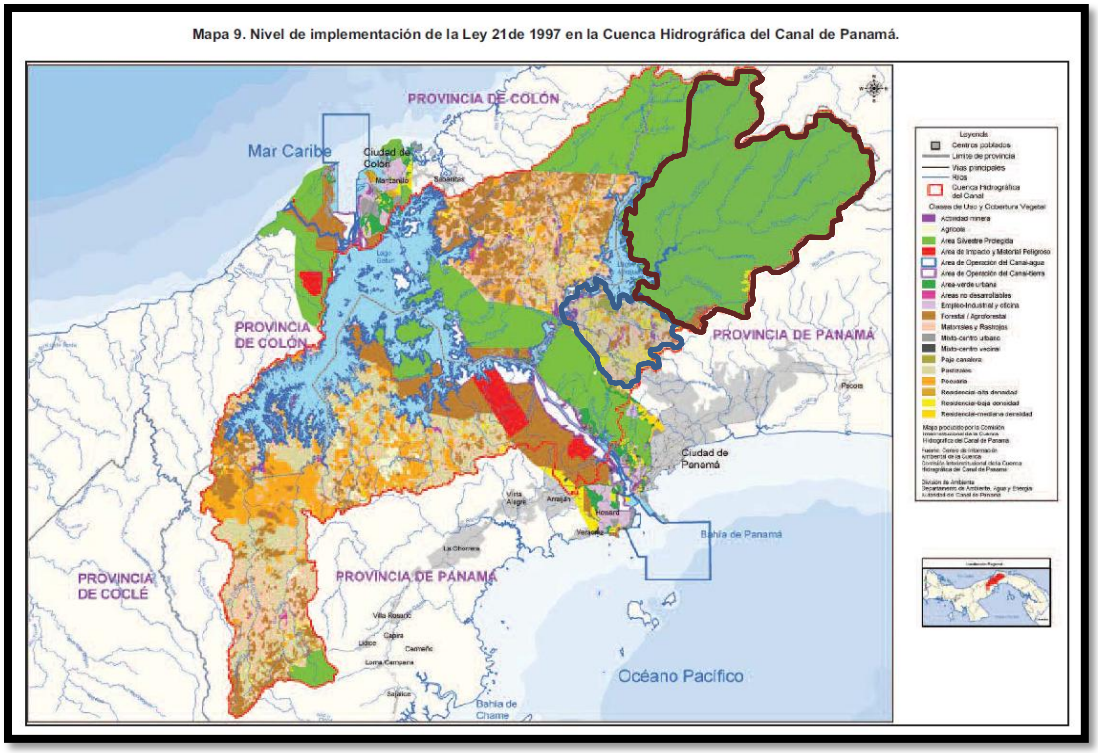



Figure 11. Land Uses in the Panama Canal Watershed (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

**Land use and vegetative coverage in the Chilibre and Chilibrillo subwatersheds**

The aerial extent (in hectares) for land-uses and vegetation coverage in the Chilibre sub-watershed are presented in Figure 13. The area occupied by human population (2007) totaled 1054 hectares (in grey). Pasture land (beige) comprised the largest land area of Chilibre at 1,263 hectares but climate, soil conditions, topography, and economic shifts from agriculture to service, commercial and finance sectors have led to the abandonment of previously operational pastureland, promoting succession of secondary forests at 1870 hectares (lime green) (see Figure 13) (Library of Congress, 1987) (Ibanez, et al., 2002); (Castro, 2003). Shrub and bush land (in orange) represent 1960 hectares of the land area contained within the Chilibre sub-

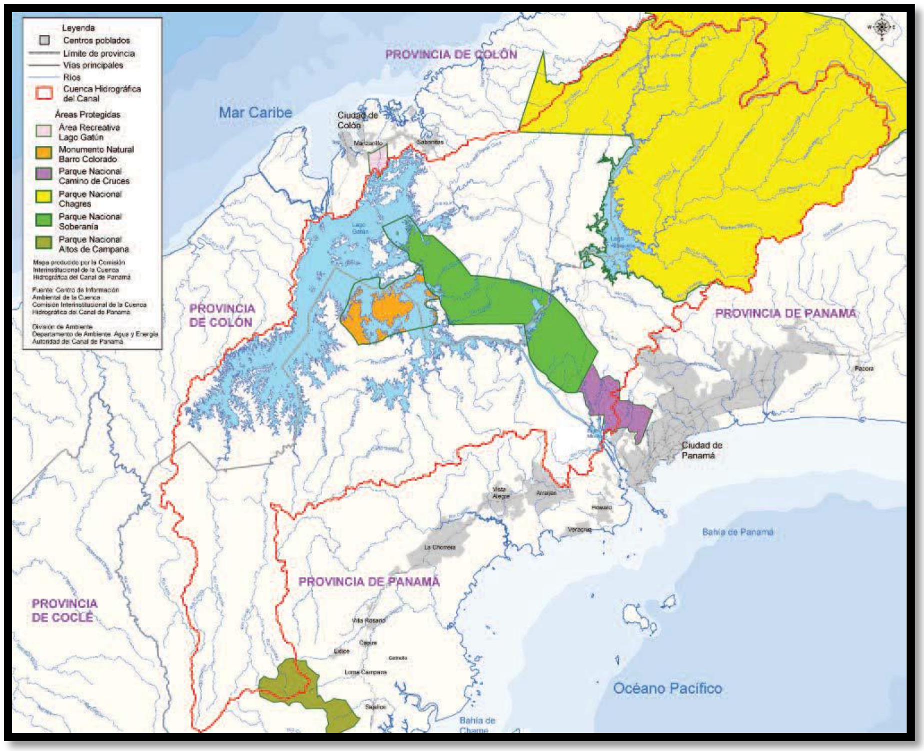



Figure 12. Protected National Parks in the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

watershed. Land use activities that occur in the shrub and bush lands, populated areas, pasture-land, cleared land, and land covered by canal grass space (or white straw) were believed to be associated with direct burden of waste water pollution (Centro Agronomico Tropical de Investigacion Ensenanza, 2007). The most likely source of the wastewater burden was assumed to stem from inadequate sanitation practices related to these land-use activities. A total of 25 towns are located within the Chilibre-Chilibrillo sub-watershed (Figure 14). Land uses are provided for each [11]. In Figure 15, the proportion of the total number of towns that

[11] Class III - The lands of this class are suitable for the production of annual crops Class IV- This land is suitable for permanent or semi-permanent crop production. Class V – This class is suitable for livestock, also allows the activity of natural forest management when there. Class VI – The lands of this class are suitable for forestry (plantations); suitable for plantations of

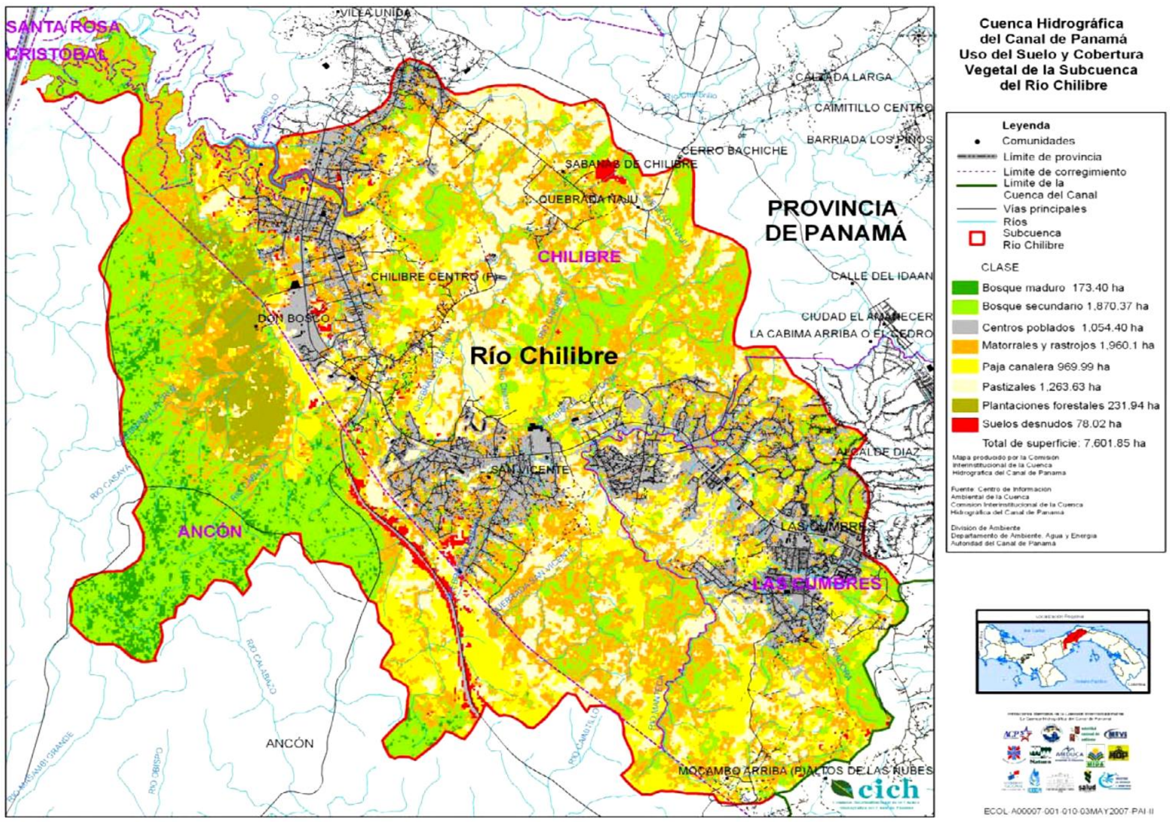



Figure 13. Usos del Suelo (Land Uses) (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007).

comprise each land use category shown. An estimated 36% of the towns occupy lands that are suitable for development and/or forest management. Another 24% of the towns occupy lands that are suitable for production of annual crops, 16% occupy  lands are suitable for forest plantations, another 16% occupy lands that are suitable for permanent or semi-permanent crop

---

permanent crops such as fruit trees; suitable for grazing. Class VII – This class is suitable for natural forest management as well as protection. Class VIII – The lands of this class have severe limitations as unsuitable for any direct economic activity using soil, so you can only spend for the protection of natural resources production and  4% of the towns, each,  occupy lands that are suitable for livestock or are unsuitable for any economic activity except for forest management. The current investigation sought to estimate the influence of land-settlement patterns with diminished water quality at the monitoring stations within the sub-watershed.

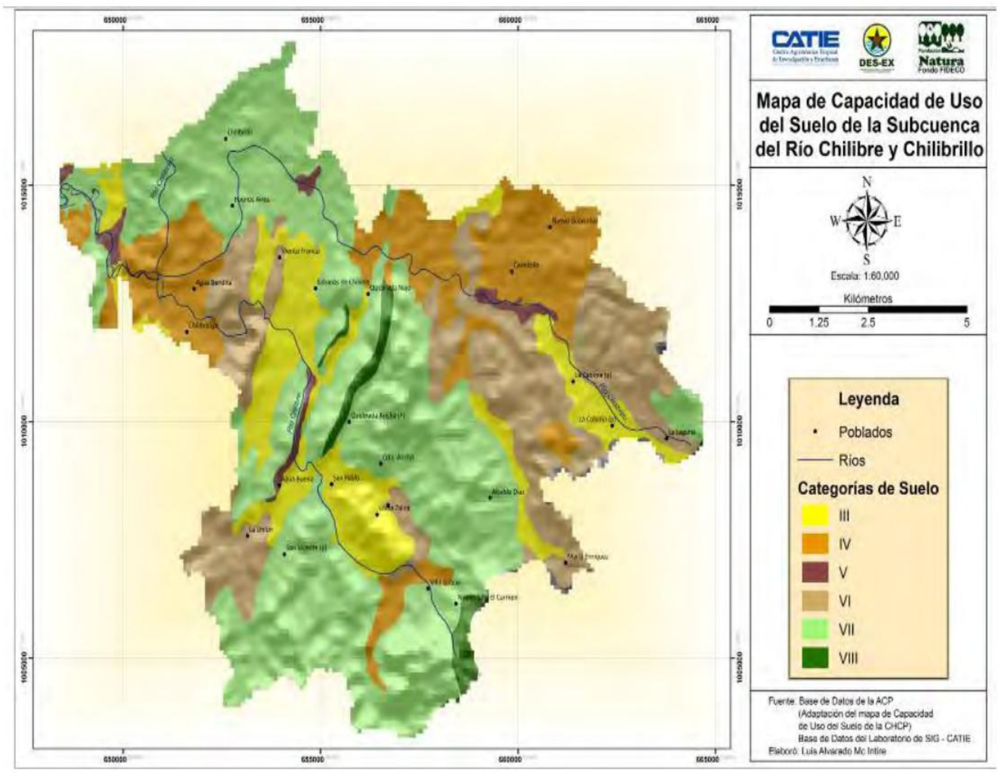



Figure 14. Potential of land-use in the sub-watershed of Chilibre and Chilibrillo. (Centro Agronomico Tropical de Investigacion Ensenanza, 2007).

**Population and economic characteristics in Chilibre**

Human activities in Chilibre threaten protected areas, natural resources, (i.e. Chagres National Park and Soberania National Park) and natural ecosystems (i.e. Chilibre River, Chilibrillo River, and Chagres River) connected with these protected areas.

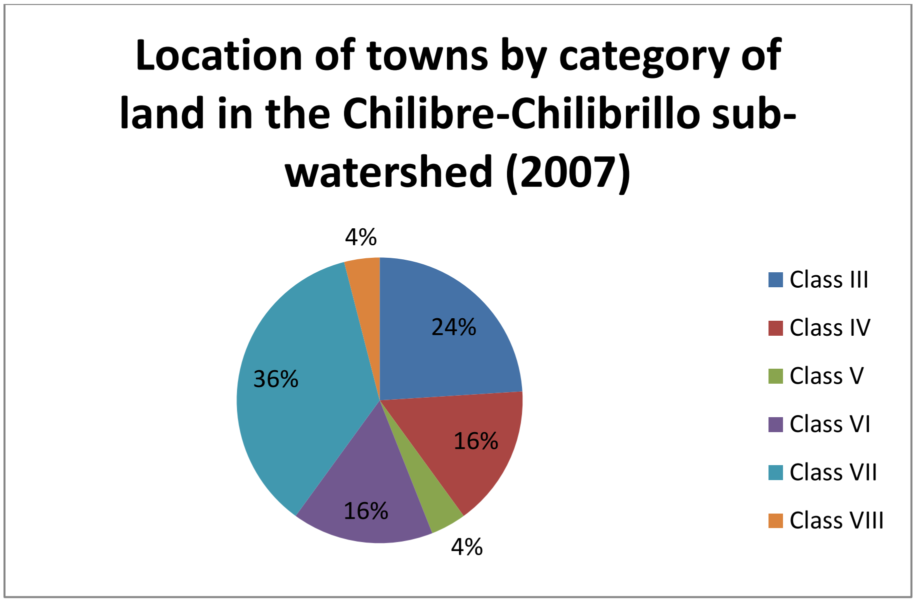



Figure 15. Location of towns by category of land in the Chilibre-Chilibrillo sub-watershed (Created by Christopher Weekes).

Activities such as (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007):

- urban growth
- unplanned human settlements
- production activities associated with agriculture, livestock, commerce and industry

contribute to degraded soil, air and water quality of ecosystems that provide resources, plants, and animals that sustain people.

In 1990, 79% of the population in the PCW lived east of the Panama Canal (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Approximately 62% of the population in the Panama Canal watershed lives on the corridor of the Trans Isthmian Highway (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Population growth has been most pronounced for the reproductive population (between 15 and 64 years); this population segment continues to increase (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

The most notable population growth has occurred in the sub-watershed of the Chilibre and Chilibrillo rivers along the Trans Isthmian corridor because of the numerous economic activities and employment opportunities available (CICH, 2008). The population of Chilibre grew from 27,135 to 53,955 inhabitants between 1990 and 2010 (Office of the Comptroller General, 2010). Current estimates place the population of Chilibre at 55,000 to 62,000 based on historical growth rates of 2.8 to 4.0% (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007).

Throughout all towns that comprise the Chilibre sub-district, the ratio of men to women has been reported as 103.8 to 100 (Office of the Comptroller General, 2010). In 2010, population density in Chilibre was reported as 58.4 inhabitants per $km^2$, which is almost double the density reported in 1990 at 29.4 inhabitants per $km^2$ (Office of the Comptroller General, 2010). In 1990, the number of occupied homes was 27,030 with roughly 4.5 residents per home (Office of the Comptroller General, 2010). This number has decreased to 3.7 residents per home; however, the number of homes occupied has increased by 14,590 units to approximately 41, 620 homes (2010) (Office of the Comptroller General, 2010).

Median incomes have been reported as 595 Balboas (monthly) (approximately $594.92 US dollars); (Office of the Comptroller General, 2010); (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007). It is estimated that 16.2 % of the population of Chilibre is unemployed and that 60% live in poverty (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007; Castro, 2003).

Economic activities of the population of the Chilibre district are divided into industrial, agricultural, and commercial. The two industries for which data were available were the swine and chicken industries. From Figure 16, the number of farms (explotaciones) focused on swine production decreased from 1981 to 2001, but the number of animals increased. The number of chicken farms increased as did the number of animals during the same period.

**Tabla 23. Número de explotaciones y cantidad de animales en las industrias porcina y avícola en la Cuenca Hidrográfica del Canal de Panamá, entre 1981 y 2001.**

| Año | Industria Porcina | | Industria Avícola | |
|---|---|---|---|---|
| | Número de explotaciones | Cantidad de animales | Número de explotaciones | Cantidad de animales |
| 1981 | 2,292 | 25,907 | 13,197 | 1,639,343 |
| 1991 | 2,243 | 38,688 | 17,833 | 3,085,466 |
| 2001 | 1,711 | 55,742 | 19,241 | 4,442,991 |

Fuente: Contraloría General de la República de Panamá. Censos Agropecuarios 1981, 1991 y 2001.

Figure 16. Farms and number of animals by production type and year (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Chilibre was the district (or corrigimiento in Spanish) that contained the most pig farms (10,671) among all districts reported by the Panamanian Comp general in 2001 (see Figure 17). In 2001, 88% of the total number of pigs produced was found in 41 districts throughout the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Six of these production facilities were found east of the Panama Canal in the major part of population centers.

Both the chicken and pig industry present major threats to the PCW both because of the enormous amount of organic wastes generated and mis-management of animal wastes (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

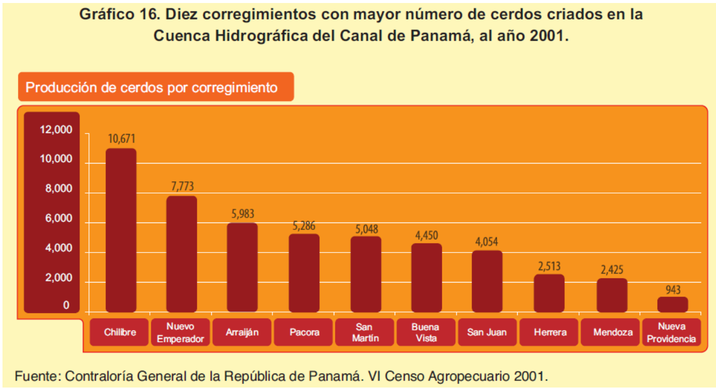



Figure 17. Number of pig farms among reported districts in 2001 (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

When organic wastes enter water bodies, dissolved oxygen levels, turbidity, and levels of bacteria and other pathogens are adversely affected. Moreover, odors are emitted from these organic wastes that may be offensive to adjacent populations, and the recreational value of the water body may be diminished (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

The commercial sector is comprised of services such as gas stations, supermarkets, pharmacies, restaurants, hotels, electronics, banks, and hardware stores (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Malls also are contained in the commercial industry designation (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

Agriculture in the PCW is mainly subsistence farming activities that practice slash-and-burn techniques (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Pineapple and watermelon are the primary cash-crops (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Approximately 86% of pineapple farms in Panama are within the PCW (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama,

2007) accounting for 88.6% of total pineapples harvested in Panama (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). Chilibre had 467 pineapple farms in 2001 (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007). It was also among the top ten districts in Panama with regard to the number of pineapple plants planted in the PCW with 15,226 plants (Comision Interinstitucional de la Cuenca Hidrografica del Canal de Panama, 2007).

These economic activities suggest sources of waste generated throughout different sections of the district. Moreover, the types of traditional wastes generated within the most dominant land uses in the Chilibre district likely contribute to water quality parameters that have been reported throughout the district (see Table 3).

Table 3. Typical waste and environmental impact by activity (USAID, 2010)[12].

| Activity | Traditional Wastes | Environmental Impact on surface water resources |
|---|---|---|
| **Industry Swine and Poultry*** | Organic: solid and liquid manure, floor wash water, food wasted, animal bedding (straw, chip), soil and other particles. Inorganic: syringes, vials, packaging, etc. | Increased organic filler, decreased dissolved oxygen, excess nutrients (especially phosphorus). |
| **Metal Mining** | Solid waste contaminated with hydrocarbons, water washing equipment and crushed stone material. | Sediment and waste modified hydrocarbons by rain natural channels, and affect the balance infiltration and runoff. Deposits are created equally sludge into receiving bodies, affecting life in the ecosystem. |

[12] Activities designated by (*) represent the land uses that are most relevant to the study area.

Table 3 (continued)

| | | |
|---|---|---|
| **Car Mechanics** | **Waste oil, rags contaminated with hydrocarbons, washing water. these wastes may contain concentrations major heavy metals.** | **It is estimated that the ratio of hydrocarbon contamination in water is 1:1. Contamination hydrocarbons are considered a chemical contamination not a biological contamination.** |
| **Domestic (septic system tanks and treatments)*** | Wastewater high in solids, organics degradable and non-degradable pathogens. | Increased organic filler, Dissolved oxygen decreased |
| **Paper Industry** | Residual water content suspended solids, soluble settleable, high BOD and COD, sulfates, sulphides, chlorides, among most important. | Increased organic filler, decreased dissolved oxygen and chemical contamination. |

**Sanitation in Chilibre**

Chilibre inhabitants rely on on-site sanitation, especially septic tanks and pit latrines. Septic tank effluents are mainly discharged into sewerage and drainage networks; however, when septic tanks are not emptied, solids accumulate in the drainage fields of the treatment system. This contaminates surface waters that flow over the drainage field during storm events and reduces the conveyance efficiency[13] of the drainage network.

Improvised and illegal trash sites exist and present serious problems that may adversely affect the health of populations and degrade the environment (see Figure 18) (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007). These sites are

[13] Represents the efficiency of water transport in canals (National Resources Management and Environment Department, 2013)

particularly common in areas characterized by unplanned development and insufficient waste management services.

Untreated sewage is discharged into the Chilibre River and its tributaries causing very high levels of organic and bacterial contamination and increased turbidity, which could adversely affect aquatic fauna and flora (see Figure 19). Sanitation issues like this have been addressed in the Sanitary Project (2006) carried out by the local health ministry (MINSA)[14] and the local water and sanitation public utility (IDAAN)[15] ,which plans to build sanitation systems to collect, treat and dispose of sewage in Panama City (encompassing Chilibre) (Inter-American Development Bank, 2012). Using US$19 million dollars from the loan for sanitation services, the director of the *Ministry of Farming Development, Household and Cleanliness Authority* in Panama, Enrique Ho Fernandez, said on 9 May 2012 that 15 new garbage trucks would be sent to the Eastern Part of the province of Panama – Chilibre comprising one of those areas (Winner, 2012). Despite deployment of these trucks, it is still believed that domestic wastewater inputs from households continue to threaten the Chilibre River as populations continue to grow and the discharges of untreated wastes persist.

[14] MINSA according to the Sanitary Code of 1948 has control of the treatment and final disposition of wastewater from households and industries (Saenz, 2007).
[15] IDAAN is responsible for the disposition of wastewater in urban centers, WWT, and oversight of the installation of pre-constructed systems for residential development; sewage project scheduled in San Miguelito (adjacent community), but no projects are scheduled in Chilibre (Saenz, 2007).

Figure 18.  Typical improvised trash site in the PCW (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007).

Figure 19. Effluent pipe discharging wastes into the Sonadora Creek in Chilibre, Panama (ANAM; ACP, 2006).

**Water  quality in Chilibre**

There are 61 active hydrometerological monitoring stations contained within the PCW -- the majority of which are able to record and transmit environmental parameters in real-time (see Figure 20) (Autoridad del Canal de Panama, 2012).  Some of the different environmental parameters that are transmitted from these monitoring stations include:

- Elevation of lakes
- Elevations of rivers
- Rainfall
- Relative humidity
- Barometric pressure
- Air temperature

At nine of monitoring stations, river gauges (which measure surface elevation and/ or flow) transmit information about terrestrial bodies of water in the PCW (Autoridad del Canal de Panama, 2012). At seven of the 61 monitoring stations, suspended sediments values are measured and transmitted once a month (see Figure 20) (Autoridad del Canal de Panama, 2012).

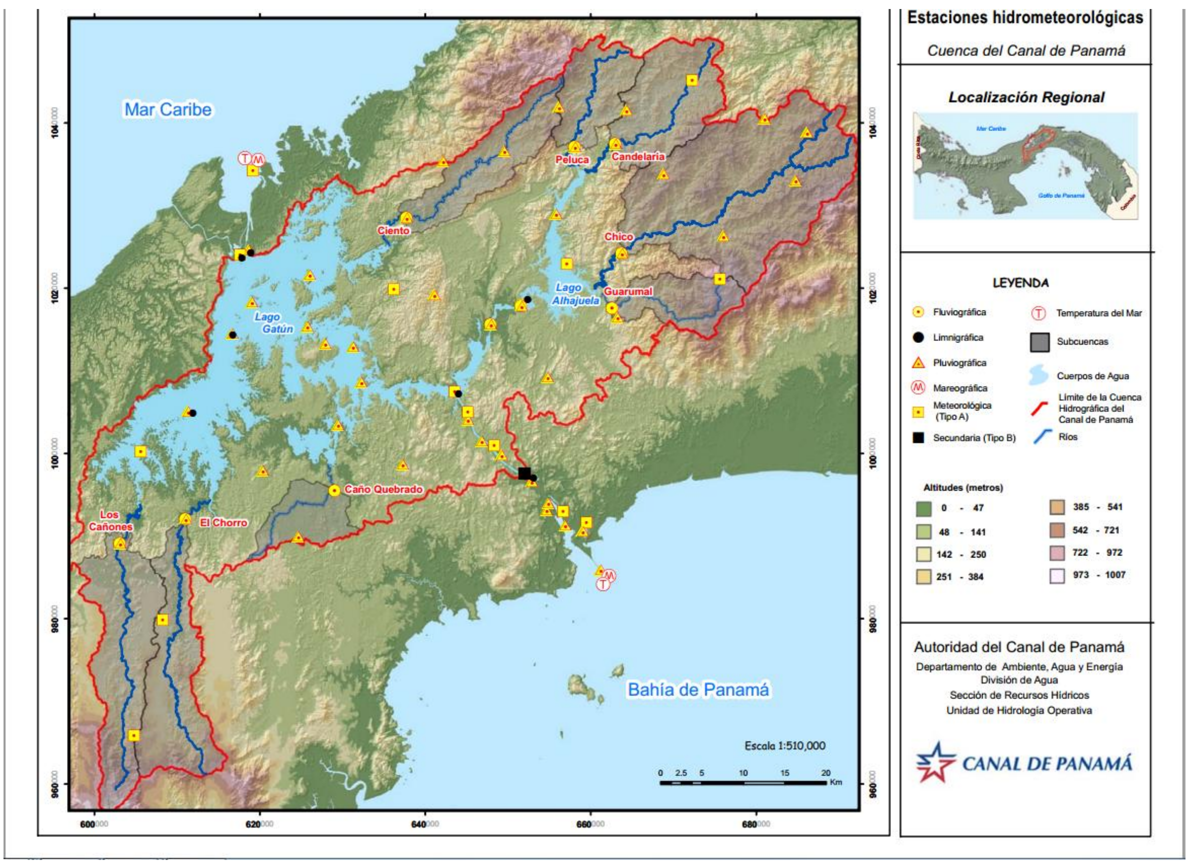



Figure 20. Hydrometeorological Stations in the PCW (Autoridad del Canal de Panama, 2012).

These water quality values from the Chilibre district monitoring stations were used to estimate what waste contributions were made from adjacent land uses.

**Monitoring stations in Chilibre**

The Chilibre district was divided into three regions, each containing water quality monitoring stations. Region 1 contained monitoring stations that were adjacent to Lake Alhajuela (see Figure 21) (see Table 4).

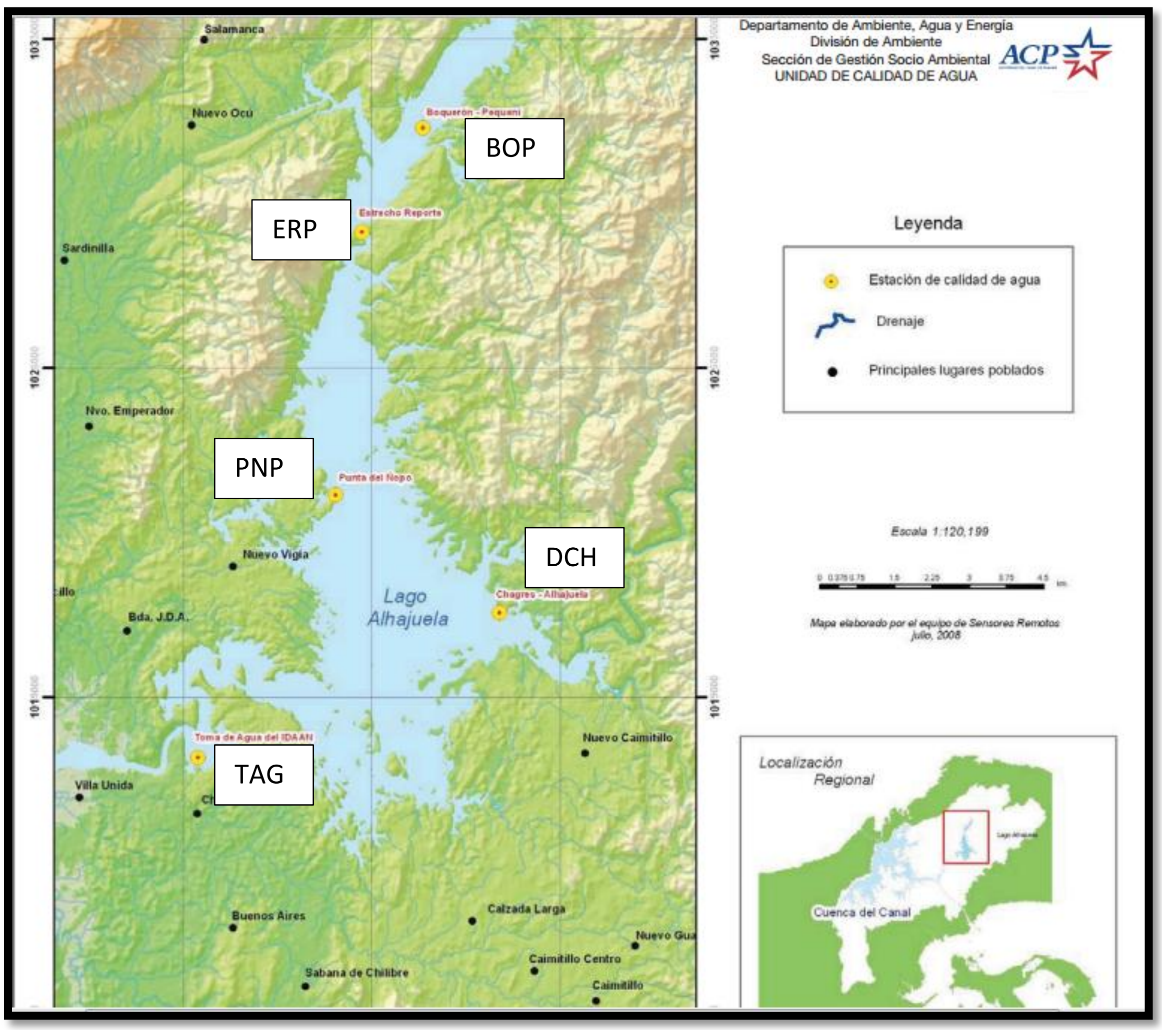



Figure 21. Region 1 monitoring points on Lake Alhajuela (Autoridad del Canal de Panama, 2008).

Table 4. Station names and their coordinates (2007) (Autoridad del Canal de Panama, 2008).

| | | | | | | |
|---|---|---|---|---|---|---|
| 54 | Lago Alhajuela | Boquerón Pequeni | BOP | Lago Alhajuela | 657096 | 1031102 |
| 55 | Lago Alhajuela | Chagres-Alhajuela | DCH | Lago Alhajuela | 658718 | 1020796 |
| 56 | Lago Alhajuela | Estrecho Reporte | ERP | Lago Alhajuela | 655796 | 1028887 |
| 57 | Lago Alhajuela | Punta del Ñopo | PNP | Lago Alhajuela | 655234 | 1023298 |
| 58 | Lago Alhajuela | Toma de Agua IDAAN | TAG | Lago Alhajuela | 652327 | 1017708 |

Region 2 contained monitoring points in the most populated section of the Chilibre district (see Figure 22). Table 5 shows the coordinates and names of the water monitoring station in the most populated section of the Chilibre district.

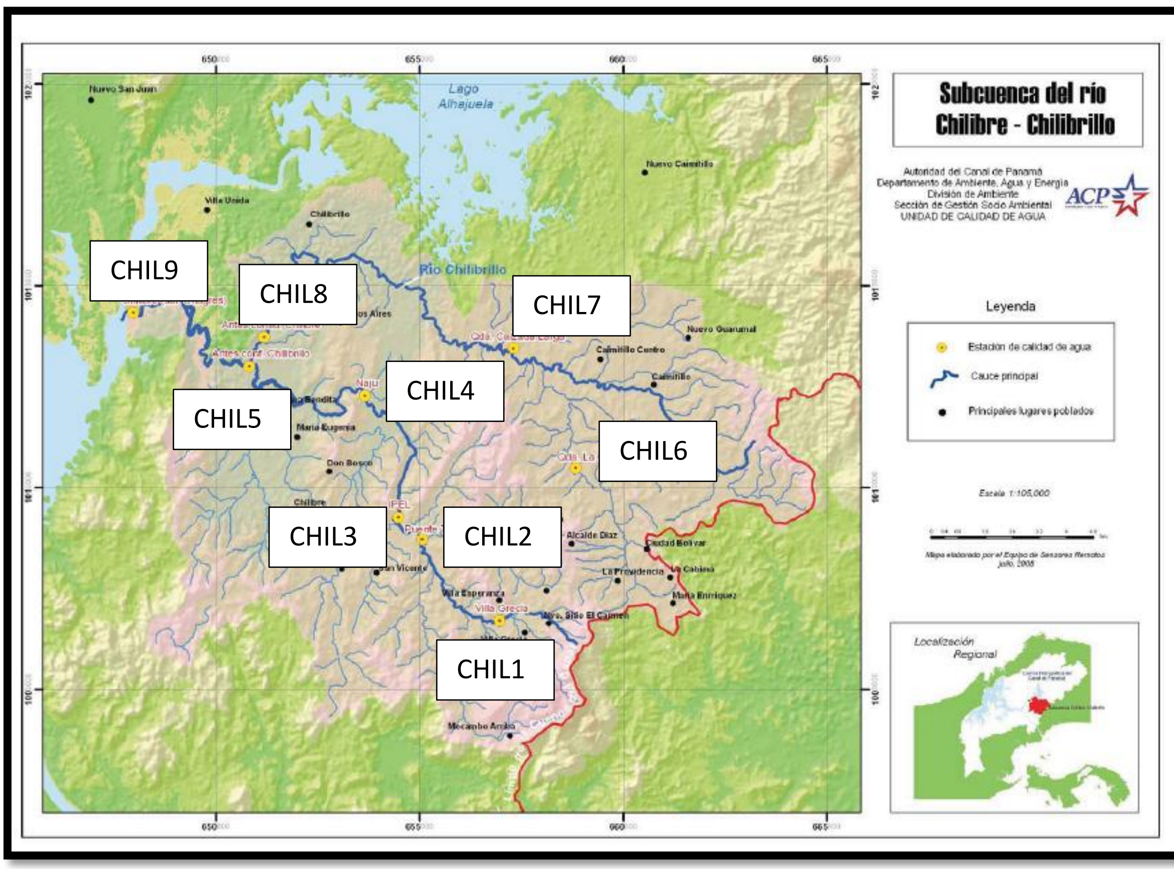



Figure 22. Monitoring stations in the population centers of Chilibre. (Autoridad del Canal de Panama, 2008).

Table 5. Names and coordinates of water monitoring stations in population centers of Chilibre.

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | Subcuenca del río Chilibre | Villa Grecia | CHIL1 | Río Chilibre | 647983 | 1014333 |
| 29 | Subcuenca del río Chilibre | Puente Transístmica | CHIL2 | Río Chilibre | 588500 | 1010485 |
| 30 | Subcuenca del río Chilibre | IPEL | CHIL3 | Río Chilibre | 653678 | 1012272 |
| 31 | Subcuenca del río Chilibre | Ñajú | CHIL4 | Río Chilibre | 650838 | 1013001 |
| 32 | Subcuenca del río Chilibre | Antes de la confluencia con río Chilibrillo | CHIL5 | Río Chilibre | 655079 | 1008708 |
| 33 | Subcuenca del río Chilibre | Queb. La Cabima (urbana) | CHIL6 | Queb. La Cabima | 657320 | 1013442 |
| 34 | Subcuenca del río Chilibre | Queb. Calzada Larga | CHIL7 | Río Chilibrillo | 651198 | 1013720 |
| 35 | Subcuenca del río Chilibre | Antes de la confluencia con río Chilibre | CHIL8 | Río Chilibrillo | 656981 | 1006692 |
| 36 | Subcuenca del río Chilibre | Chilibre (salida al Chagres) | CHIL9 | Río Chilibre | 654494 | 1009251 |

Region 3 contained the monitoring points along the Chagres River after the point of discharge for the Chilibre River (see Figure 23). Table 6 shows the coordinates and names of the water monitoring station in the most populated section of the Chilibre district (Region 2).

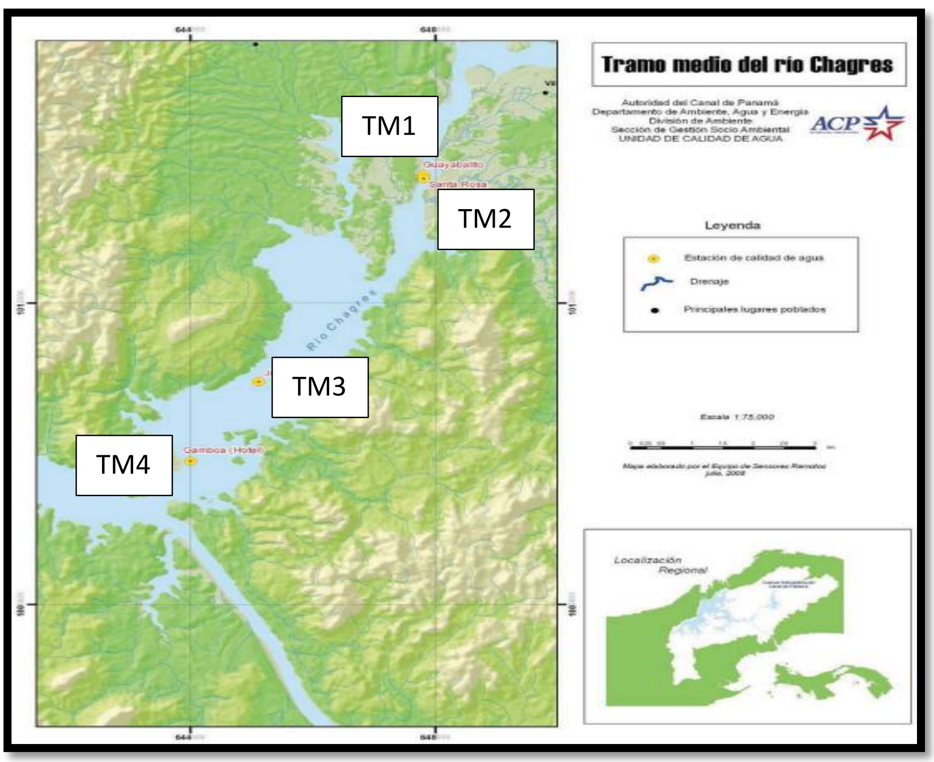



Figure 23. Monitoring stations along the Chagres River (Autoridad del Canal de Panama, 2008).

Table 6. Names and coordinates of water monitoring stations along the Chagres River (Autoridad del Canal de Panama, 2008).

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | Ríos Principales | Gamboa Hotel | **TM4** | Río Chagres | 643964 | 1008277 |
| 29 | Ríos Principales | Jujulupá | **TM3** | Río Chagres | 645120 | 1010163 |
| 30 | Ríos Principales | Santa Rosa | **TM2** | Río Chagres | 647821 | 1014774 |
| 31 | Ríos Principales | Guayabalito | **TM1** | Río Chagres | 647816 | 1014963 |

Region 1 represented the ambient levels for the water parameters investigated. Region 2 represented the water parameters associated with human activity. Region 3 represented the water parameters after the point of discharge (or region of attenuation) of the Chilibre River into the Chagres River.

**Water quality criteria guides in the PCW**

In 1986, the United States Environmental Protection Agency (USEPA) developed water-quality criteria that have since been used and amended in Panama (see Table 7) (Autoridad del Canal de Panama, 2012). Since 1999, after the United States concession of the Panama Canal to Panama, the Panama Canal Authority (ACP) has used the water analysis methods in the *Standard Method for the Examination of Water and Wastewater* (a joint publication of the American Public Health Association (APHA), the American Water Works Association (AWWA) and the Water Environment Federation) to monitor water quality in the PCW (WEF) (APHA, AWWA; WEF, 2006) (Autoridad del Canal de Panama, 2012).

Table 7. Water quality criteria standardized by the USEPA in 1986 for surface water for Class 1 and Class 2 waters[16] (Created by Christopher Weekes).

| Parameter | Class 1C | Class 2C | Tropic Level | Maintenance of aquatic life | Direct Contact | Indirect Contact | Suitability Levels for Human Consumption |
|---|---|---|---|---|---|---|---|
| Temperature (C°) | 2 | | | | | | |
| Turbidity (NTU) | 100 | 100 | | | | | |
| DO (mg/L) | | | | 5 | | | |
| pH | 6.5- 8.5 | 6.0 - 9.0 | | | | | |
| Cholrine (mg/L) | 250 | 250 | | | | | |
| TDS (mg/L) | 500 | 500 | | | | | |
| Total Alkalinity (mg/L) | | | | 20 | | | |
| $N\text{-}NO_2$ (mg/L) | | | 0.05 | | | | |
| $N\text{-}NO_3$ (mg/L) | | | | | | | |
| $P\text{-}PO_4$ (mg/L) | | | | | | | |
| $SO_4$ (mg/L) | 250 | 250 | | | | | |
| Cholorphyll (µg/L) | 20 | 20 | | | | | |
| $DBOD_5^2$ (mg/L) | 3 | 5 | | | | | |
| Fecal Coliforms (NMP/ 100 ml) | | | | | 200 | 1000 | 2000 |

Table 8 contains water quality information that corroborates and supplements the information in Table 7. Key distinctions exist for several parameters including temperature, phosphate, and nitrate values. In Table 8, the value guide indicates that a value of 2.8 ° C the maximum acceptable temperature differential for rivers and creeks. The value of 1.7 ° C is the highest acceptable temperature differential for lakes.

Increased aquatic vegetation and algae in tranquil (non-turbulent) lakes are typical in waters with nitrate values greater than 0.30 $\frac{mg}{L}$ . Phosphate values should not exceed 0.5 $\frac{mg}{L}$ in lakes that discharge into lakes and reservoirs. Phosphate values should not exceed 0.10 $\frac{mg}{L}$ for rivers that do not discharge into lakes and reservoirs. Lastly, phosphate values should not exceed 0.025 $\frac{mg}{L}$ in lakes and reservoirs. Phosphate values exceeding these value guides are characterized by eutrophication in the water body.

[16] Class 1 waters refer to all waters that are located within the boundaries of national parks and designated as wilderness areas (Wyoming State) . Class 2 waters are public water supply waters (Nugent, 1999).

Table 8. 1986 Quality Criteria for Water USEPA (Autoridad del Canal De Panama, 2008).

| Parámetro | Valor Guía | Definición |
|---|---|---|
| Temperatura | 2,8°C | Máximo incremento diferencial de 2,8°C sobre condiciones ambientales luego de la mezcla para ríos y arrollos. |
| | 1,7°C | Máximo incremento diferencial de 1,7°C sobre condiciones ambientales luego de la mezcla para lagos. |
| | 32,2°C | Máximo valor; puede variar caso por caso. |
| Oxígeno Disuelto (OD) | 5 mg/l | El valor no debe estar por debajo de 5mg/l como soporte adecuado para la vida acuática en aguas dulces. |
| Nitratos ($NO_3$) | 0,30 mg/l | En lagos con aguas tranquilas, concentraciones mayores a 0,30 mg/l (como N) estimulan el crecimiento de vegetación acuática y de algas. |
| Fosfatos ($PO_4$) | 0,05 mg/l | Como control de eutrofización, los valores no deben exceder de 0,05 mg/l (como P) en ríos que descargan a lagos o embalses. |
| | 0,10 mg/l | Como control de eutrofización, no deben exceder de 0,10 mg/l en ríos que no descargan directamenrte a lagos o embalses. |
| | 0,025 mg/l | Como control de eutrofización, no deben exceder de 0,025 mg/l en lagos o embalses. |
| Sulfato ($SO_4$) | 250 mg/l | No deben exceder este valor de referencia, excepto donde los análisis indiquen que niveles por encima de este valor no se afectan el uso designado. |
| Bicarbonatos (alcalinidad) | 20 mg/l | El valor debe ser de 20 mg/l o más como $CaCO_3$ para el soporte de la vida acuática en aguas dulces. |
| Cloruro (Cl) | 250 mg/l | Los valores no deben exceder 250 mg/l, excepto donde análisis indiquen que niveles por encima de este valor no afectan el uso designado. |
| Coliformes fecales | 200 NMP/100ml | Los valores no deben exceder los 200 NMP/100ml para uso recreacional de contacto directo. Basado en no menos de 5 muestras en un mes. |
| | 1.000 NMP/100ml | Los valores no deben exceder los 1.000 NMP/100ml para uso recreacional de contacto secundario. Basado en no menos de 5 muestras en un mes. |
| | 2.000 NMP/100ml | La media aritmética mensual no deben exceder los 2.000 NMP/100ml para uso de abastecimiento de agua para beber. |
| DBO5 [2] | 3 - 5 mg/l [2] | Estándar de control para clasificación de agua continental Clases 1-C y 2-C (subcuencas prioritarias y lago Miraflores) |
| Dureza | 0-75 mg/l $CaCO_3$ | Blanda |
| | 75-150 mg/l $CaCO_3$ | Moderadamente dura |
| | 150-300 mg/l $CaCO_3$ | Dura |
| | >300 mg/l $CaCO_3$ | Muy dura |

Fuente: United States Enviromental Protection Agency (EPA). 1986. Quality Criteria for Water 1986. Office of Water Regulation and Standards. Washington DC 20460, 477 páginas.

[2] Anteproyecto de normas de calidad ambiental para las aguas superficiales de la República de Panamá

## Methods

The visit to Panama between the August 3rd to August 24th 2012 provided some context of the sanitation problems in Chilibre. Initially, the investigation focused on water access in the sub-district, but IDAANs most recent report (presented by the Panamanian Census Bureau) of the area suggested that the majority of the residents had access to safe drinking water (approximately 91% coverage to the population with primary aqueduct water) (Office of the Comptroller General, 2010). During the research visit, two formal interviews were conducted with a representative from IDAAN and a water manager at the Panama Canal Authority (ACP-acronym in Spanish). Both interviews provided a broader context of the waste management issues facing Panama including those in Chilibre. IDAAN was able to provide water quality data that was used in the analysis, and ACP provided both water quality data and land cover layers that was later used in the GIS spatial analysis. During this time, connections were also made with the research institution CATHALAC and the University of South Florida Panama Health office. The patrons at these entities were instrumental in facilitating the meetings with IDAAN and ACP. There was a foiled attempt to meet with a health liason at the Ministry of Health (MINSA); however, a virtual connection was made to further expand future development of the research to include more tractable health information that will be used in health impact and strategic environmental assessments.

In order to address the research objectives several research tools were used. To answer objective one ACP water quality reports were analyzed using *SPSS Statistics 21* which helped to generate the box and whisker plots for the water quality information presented in the results section. Microsoft Excel 2010 was used to organize the water quality information so that it could be inputted into the spreadsheet of the SPSS program. The overall description of Chilibre Panama and the Panama Canal Watershed was achieved through an extensive literature review performed through academic journal databases, general keywords searches using public access websites, and collaboration with several colleagues from Panama.

The relationship between land cover and water quality was enabled through the use of ArcGIS 10 and 10.1. Land use layers obtained from ACP, Google Earth 2013, and the open access website (http://mapserver.stri.si.edu/geonetwork/srv/en/main.home) provided by a Panamanian colleague. The land use layers were manipulated so that 500 meter multiple ring buffers were formed at 100 meter intervals around the water quality monitoring station in Chilibre Panama. Each multiple ring buffer contained land cover information; this information was parsed so that the land cover characteristics at each 100-meter interval was able to be analyzed.  The buffer distance were arbitrarily established at 500 meters; however the 100 meter interval was commonly used in similar research studies (O.Carey et. al., 2011; Chen & Lin, 2013).

## Results

### Water quality indices in Chilibre

A water quality index (ICA in Spanish), developed by the National Sanitation Foundation of the United States, provides a single number that describes the quality of a body of water at a given location and time based on several water quality parameters (see Figure 24) (ACP, 2012).

$$ICA = \sum_{i=1}^{n} W_i q_i$$

Figure 24. Weighted Arithmetic Mean Function (Autoridad del Canal de Panama, 2012).

Where:

$W_i$ (peso) = weight assigned to each parameter between 0 and 1

$q_i$ = the value generated by matching the field or laboratory parameter to the corresponding water quality graph curve. Values range between 0 and 100.

The objective of an ICA is to summarize water quality data so that it is easily understood by the public (Boulder Area Sustainability Information Network, 2005). The number provides a general picture of the water quality of a water body and is not intended to describe the water body in full detail (Boulder Area Sustainability Information Network, 2005).

For general water uses, ICA values greater than 90 are clean (limpia), 70 to 90 are slightly contaminated (ligeramente contaminada), and 0 to 70 are very contaminated (muy contaminada) (see Figure 25). Water quality variables included in the ICA are dissolved oxygen (percent saturation and concentration), fecal coliforms, pH, biochemical oxygen demand, temperature, phosphates, nitrates, turbidity, and total dissolved solids (Figure 26).

<table>
<tr><th colspan="13">Tabla 3. Índice de Calidad de Agua (ICA) en su relación con los principales usos del agua</th></tr>
<tr><td>Uso</td><td>10</td><td>20</td><td>25</td><td></td><td>40</td><td>50</td><td>60</td><td>70</td><td>80</td><td>90</td><td>100</td><td>ICA</td></tr>
<tr><td>General</td><td colspan="7">Muy contaminada</td><td colspan="2">Ligeramente contaminada</td><td colspan="3">Limpia</td></tr>
<tr><td>Categoría o clase (agua)</td><td colspan="5">V</td><td>IV</td><td colspan="3">III</td><td>II</td><td colspan="2">I</td></tr>
<tr><td>Abastecimiento público de agua</td><td colspan="5">No aceptable</td><td>Dudoso</td><td colspan="3">Tratamiento necesario; viene a ser muy costoso</td><td>Requiere purificación menor</td><td colspan="2">No requiere purificación</td></tr>
<tr><td>Recreación</td><td colspan="2">No aceptable</td><td colspan="2">Apariencia de contaminación obvia</td><td>Sólo en embarcaciones</td><td>Dudosamente para contacto con el agua</td><td colspan="2">Indicios aún de contaminación; necesidad de conteo de bacterias</td><td colspan="4">Aceptable para todos los deportes</td></tr>
<tr><td>Peces, moluscos y vida silvestre</td><td colspan="4">No aceptable</td><td>Peces para pesca deportiva</td><td>Peces para pesca de línea solamente</td><td>Dudosamente para peces sensitivos</td><td>Peces marginales</td><td colspan="4">Aceptable para todos los peces</td></tr>
<tr><td>Navegación</td><td colspan="4">No aceptable</td><td>Apariencia obvia de contaminación</td><td colspan="7">Aceptable</td></tr>
<tr><td>Transporte - agua tratada</td><td>No aceptable</td><td colspan="11">Aceptable</td></tr>
<tr><td></td><td>10</td><td>20</td><td>25</td><td></td><td>40</td><td>50</td><td>60</td><td>70</td><td>80</td><td>90</td><td>100</td><td>ICA</td></tr>
</table>

| CLASIFICACIÓN | RANGO | COLOR |
|---|---|---|
| Muy malo | 0-25 | Rojo |
| Malo | 26-50 | Naranja |
| Medio | 51-70 | Amarillo |
| Bueno | 71-90 | Verde |
| Excelente | 91-100 | Azul |

Figure 25. Water Quality Index Ranking System in relation to water uses (ACP, 2012).

| Tabla 3. Ponderación o peso de importancia para las características (variables) incluidas en el cálculo del ICA | |
|---|---|
| **Características (variables)** | **Peso** |
| Oxígeno Disuelto (%) | 0,17 |
| Coliformes fecales | 0,16 |
| Potencial de Hidrógeno (pH) | 0,11 |
| Demanda Bioquímica de Oxigeno ($DBO_5$) | 0,11 |
| Desviación temperatura | 0,10 |
| Fosfatos ($PO_4$) | 0,10 |
| Nitratos ($NO_3$) | 0,10 |
| Turbidez | 0,08 |
| Sólidos totales disueltos | 0,07 |

Figure 26. Proportion or weight given to water parameters considered in ICA calculations (ACP, 2012).

Throughout the PCW, ICA ratings in 2007 were influenced most heavily by E. coli and nitrate values that exceeded water criteria standards (Autoridad del Canal De Panama, 2008).

Lake Alhajuela (Region 1) was reported to have an ‘excellent’ ICA rating throughout 2007 for all five monitoring stations. Monitoring stations located in the Chilibre River sub-basin (Region 2), in the most populated region of the Chilibre district, were designated with ‘average (medio)’ ICA values that were attributable to E. coli, DO (%), organophosphate, nitrate and turbidity exceeding water criteria standards (Autoridad del Canal De Panama, 2008). Seven of nine monitoring stations in Region 2 contributed the overall ICA rating of ‘average’ (Autoridad del Canal De Panama, 2008). Along the Chagres River (Region 3), one of the four monitoring stations (TM3) was designated ‘average’ , exceeding water criteria values for E. coli, orthophosphate and nitrate (Autoridad del Canal De Panama, 2008).

**Water quality trends**

Figure 27 reflects the average ICA values for the water bodies sampled in the PCW in 2011. The steady decline in ICA values from April to December correspond to the rainy season, which contributed to higher turbidity, TDS, nitrate, and E. coli measures.

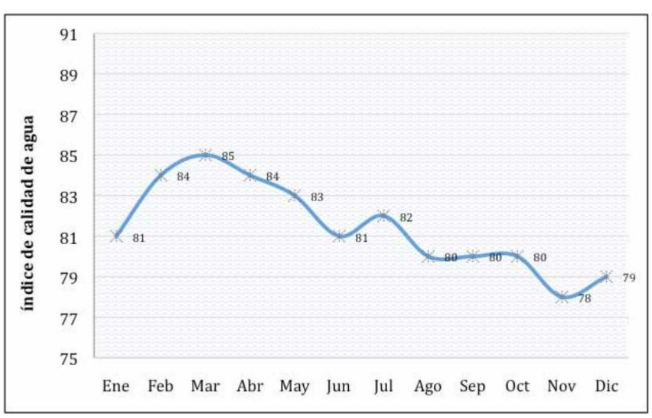



Figure 27. ICA Trends for the water bodies in the PCW in 2011 (ACP, 2012).

TM3 (Region 3) displayed increased turbidity, dissolved oxygen (concentration and percent saturation), E. coli, and total coliforms. E. coli measurements at TM3 consistently did not conform to the water criteria standards (see Figure 28). The water parameters that did not conform to the criteria standards caused an ICA rating of ‘average’ for 2011 (see Figure 29).

**Tabla 8.** Tramo medio del río Chagres: evaluación de los resultados del 2011 en relación con valores guías y con valores históricos.

| Estación | Parámetros no conformes con valores guías 1 | Condición del parámetro respecto a valores históricos[2] | | |
|---|---|---|---|---|
| | | Valor aumenta | Valor similar | Valor disminuye |
| TM1 | n/a | Turb, OD, OD%, *E. coli*, C. total | T, pH, Cl, TSD, TSS, Alc. total, S04, K+, Na+, Ca++, Mg++, Dureza total, DBO | Cond, N-N02, N-N03, P-P04, S |
| TM2 | n/a | T, Turb, OD, OD%, *E. coli*, C. total | pH, Cl, TSS, Alc. total, K+, Na+, Ca++, Mg++, Dureza total, DB05 | Cond,TSD, N-N02, N-N03, P-P04, S04, S |
| TM3 | *E. coli* | Turb, OD, OD%, *E. coli*, C. Total | T, TSD, TSS, K+, Na+, Ca ++, Mg++, Dureza total, MC, DB05 | pH, Cond, Cl, Alc. total, N-N02, N-N03, P-P04, S04, S |
| TM4 | n/a | T, Turb, OD, OD%, *E. coli* | Cl, TSD, TSS, Alc. total, K+, Na+, Ca++, Mg++, Dureza total, DB05 | pH, Cond, N-N02, N-N03, P-P04, S04, C. total, S |

Figure 28. Water quality trends in Region 3 (2003 to 2010) (ACP, 2012).

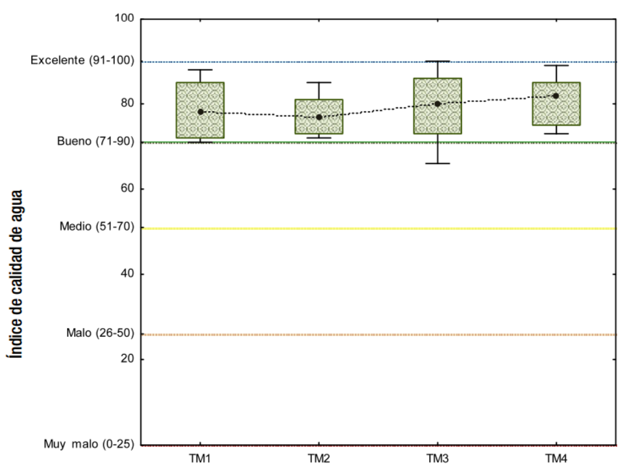



Figure 29. ICA inter-quartile ranges and central tendencies for Region 1 in 2011 (ACP, 2012).

In Region 2 at the CH9 (CHIL9) monitoring station, reported nitrate, phosphate and E. coli did not conform to the water quality criteria standards from 2003 to 2010 (see Figure 30). The most extreme value reported at CH9 caused the ICA rating to be ‘average’ when the typical ICA rating for CH9 is ‘good’ (see Figure 31)

**Tabla 16.** Subcuencas prioritarias: evaluación de los resultados del 2011 en relación con valores guías y con valores históricos.

| Estación | Parámetros no conformes con valores guías[1] | Condición del parámetro respecto a valores históricos[2] | | |
|---|---|---|---|---|
| | | Valor aumenta | Valor similar | Valor disminuye |
| CH9 | N-$NO_3$, P-$PO_4$, *E. coli* | Turb, OD, OD%, Cond, TSD, TSS, Alc. total, N-$NO_3$, P-$PO_4$, $SO_4$, $Na^+$, $Ca^{++}$, *E. coli*, C. total | S, Cl, $K^+$, $Mg^{++}$, Dureza total, MC, DBO | T, pH, N-$NO_2$ |

Figure 30. Water quality trends for CH9 (Region 2) in 2011 (ACP, 2012).

In Region 1, the water parameters that were in noncompliance were E. coli and turbidity. BOP S and BOP F reported E. coli and turbidity readings that were out of compliance (Figure 32). ERP S and ERP F had turbidity and E. coli values that did not conform to water criteria.

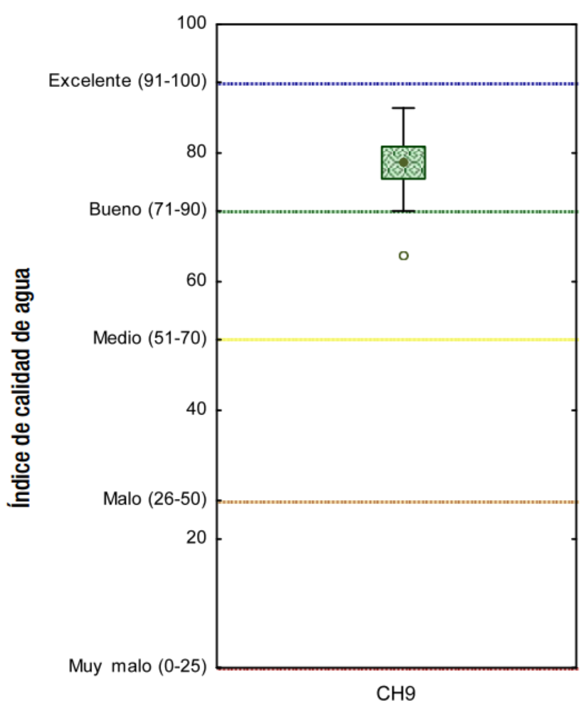



Figure 31. Inter-quartile range and central tendencies for CH9 (Region 2) in 2011 (ACP, 2012).

**Tabla 10.** Embalse Alhajuela: evaluación de los resultados del 2011 en relación con valores guías de calidad y con valores históricos.

| Estación | Parámetro no conforme con valores guías[1] | Condición del parámetro o característica respecto a valores históricos[2] | | |
|---|---|---|---|---|
| | | Valor aumenta | Valor similar | Valor disminuye |
| BOP S | *E. coli* | Turb, OD, OD%, TSS, *E. coli*, C. total | Cond, S, TSD, Alc. total, $N\text{-}NO_2$, $K^+$, $Na^+$, $Ca^{++}$, $Mg^{++}$, Dureza total, DBO | T, pH, Cl, $N\text{-}NO_3$, $P\text{-}PO_4$, $SO_4$, Clorofila, Transparencia |
| BOP F | Turb | Turb, TSS, $N\text{-}NO_3$, *E. coli* | OD, OD%, S, Cl, $N\text{-}NO_2$, $K^+$, $Na^+$, $Ca^{++}$, $Mg^{++}$, DBO | T, pH, Cond, TSD, Alc. total, $P\text{-}PO_4$, $SO_4$, Dureza total, C. total |
| DCH S | n/a | Turb, OD, OD%, $N\text{-}NO_3$, *E. coli*, C.total | S, TSD, TSS, Alc. total, $N\text{-}NO_2$, $K^+$, $Na^+$, $Mg^{++}$, DBO | T, pH, Cond, Cl, $P\text{-}PO_4$, $SO_4$, $Ca^{++}$, Dureza total, Clorofila, Transparencia |
| DCH F | n/a | Turb, OD, OD% | Cond, S, TSD, TSS ,$N\text{-}NO_2$, $SO_4$, $Na^+$, $K^+$, $Mg^{++}$, DBO, *E. coli* | T, pH, Cl, Alc. total, $N\text{-}NO_3$, $P\text{-}PO_4$, $Ca^{++}$, Dureza total, C. total |
| ERP S | Turb, *E. coli* | Turb, TSS, N- $NO_3$, *E. coli*, C.total | OD, OD%, S,$N\text{-}NO_2$, $Na^+$, $K^+$, $Mg^{++}$, DBO | T, Cond, pH, Cl,TDS, Alc. total, $P\text{-}PO_4$, $SO_4$, $Ca^{++}$, Dureza total, Transparencia, Clorofila. |
| ERP F | Turb, *E. coli* | Turb, OD, OD%, TSS, $N\text{-}NO_3$, *E. coli*, C. total | S, N- $NO_2$, $K^+$, $Na^+$, $Mg^{++}$, Clorofila, DBO | T, pH, Cond, Cl, TSD, Alc. total, $P\text{-}PO_4$, $SO_4$, $Ca^{++}$, Dureza total |
| PNP S | n/a | Turb, OD, OD%, $N\text{-}NO_3$ | Cond, S, Cl, TSD,TSS, N- $NO_2$, K+, $Na^+$, $Mg^{++}$, DBO, *E. coli* | T, pH, Alc. total, $P\text{-}PO_4$, $SO_4$, $Ca^{++}$, Dureza total, Clorofila, Transparencia, C. total |
| PNP F | n/a | Turb, OD, OD%, TSS, $N\text{-}NO_3$, C. total | S, TSD, N- $NO_2$, $Na^+$, $K^+$, $Mg^{++}$, Clorofila, DBO, *E. coli* | T, pH, Cond, Cl, Alc. total, $P\text{-}PO_4$, $SO_4$, $Ca^{++}$, Dureza total |
| TAG S | n/a | OD, $N\text{-}NO_3$, Transparencia | Turb, OD%, S, TSS, $N\text{-}NO_2$, $K^+$, $Na^+$, $Mg^{++}$, DBO, *E. coli* | T, pH, COND, Cl, TSD, Alc. total, $P\text{-}PO_4$, $SO_4$, $Ca^{++}$ ,Dureza total, C.total, Clorofila |
| TAG F | n/a | Turb, OD, OD%, TSS | T, Cond, S, TDS, $N\text{-}NO_2$, $Na^+$, $K^+$· Clorofila, $Mg^{++}$, DBO, MC, *E. coli* | pH, Cl, Alc. Total, $N\text{-}NO_3$, $SO_4$, $P\text{-}PO_4$, $Ca^{++}$, Dureza total, C. total |

Figure 32. Water quality trends in Region 1 (2003 to 2011) (ACP, 2012).

In Region 2, two of the monitoring stations were associated with high levels of human disturbance - - CHIL2, CHIL 6, and CHIL9 (ANAM; ACP, 2006). Three monitoring stations in Region 2 were associated with moderate disturbance levels from adjacent land uses—CHIL 1, CHIL 4, CHIL 5 (ANAM; ACP, 2006).

**Water quality data**

The following discussion of water quality data based on box and whisker plots presenting the median (center bar), the spread, and the overall range of the distribution of individual parameters were collected at the monitoring stations for 2003, 2004, 2005, and 2007. Parameters that violated the water quality criteria standards are described at their respective water monitoring stations. Simple tick marks (-) represent constant values reported.

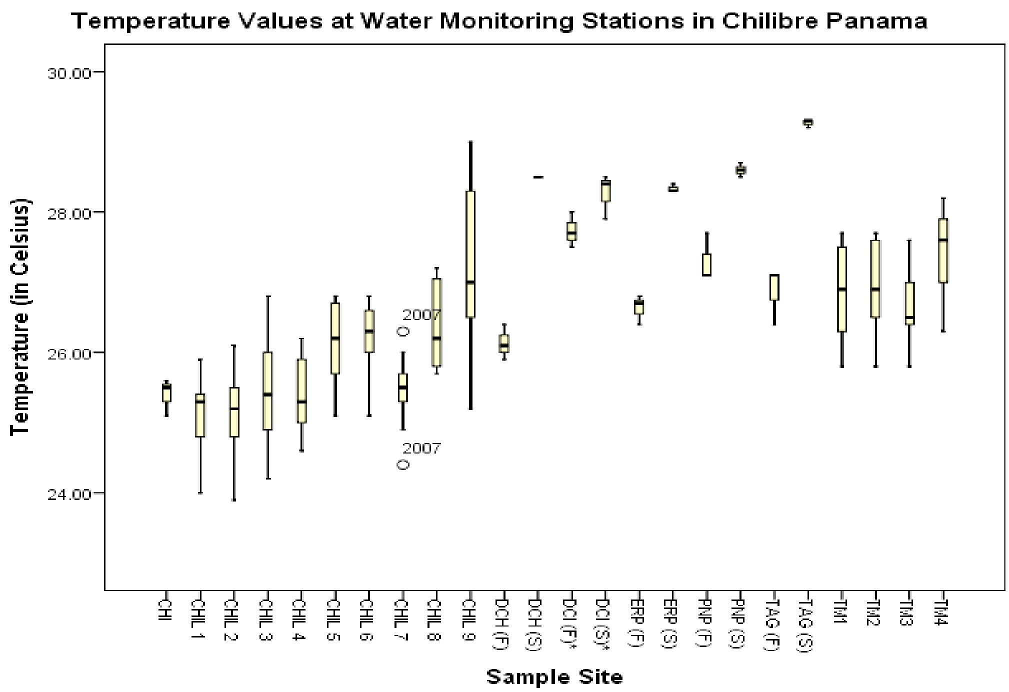



Figure 33. Temperature values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

At CHIL 9 (highlighted in blue) the median temperature (Figure 33) was 27.0 °C with a 25$^{th}$ percentile of 26.5 °C and a 75$^{th}$ percentile of 28.3° C. The minimum temperature at CHIL 9 was 25.2 °C and the maximum temperature was 29 °C. The temperature variance was 1.69 °C. The temperature difference was 3.8°C which violated the 3.2°C USEPA criteria standard for rivers but was considered a normal range for tropical rivers.

Generally, the temperatures in Region 1 are higher than those in Region 2; this is attributable to the presence of Madden Dam. A considerable volume of water is stored behind the dam. Over time, large reservoirs become stratified whereby warmer waters rise above cooler denser waters; this is supported by the high surface temperature readings compared to the respective below surface level readings in Figure 33. DCI temperature values are believed to be influenced by the same process at Lake Gatun. Region 3 temperatures generally are greater than Region 1 temperatures which may be attributable to the downstream effects of the heat released waters from the Lake Alajuela on the Chagres River.

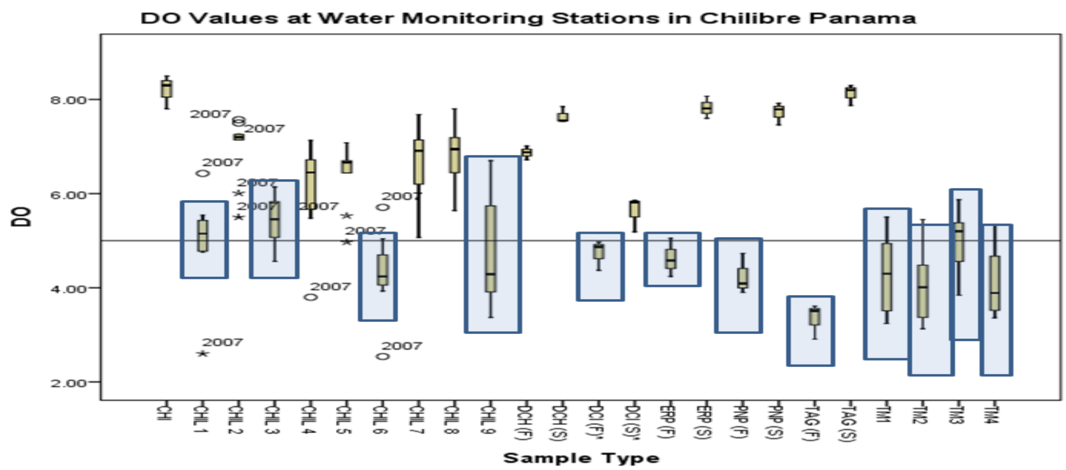



Figure 34. Dissolved oxygen ( $\frac{mg}{L}$) values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

Two stations in Region 1, 4 stations in Region 2, and all stations in Region 3 (Figure 34) violated the water criteria standards for DO which should not fall below 5 $\frac{mg}{L}$ for waters that support aquatic life. The water samples that were collected at depth (designated by F) were expected to have low DO values. Among the monitoring stations that violated the water quality standards, CHIL 9 had the most variance at 1.56 $\frac{mg}{L}$ . The median DO value at CHIL 9 was 4.29$\frac{mg}{L}$ , a 25$^{th}$ percentile DO of 3.91$\frac{mg}{L}$ , a 75$^{th}$ percentile DO was 5.74 $\frac{mg}{L}$, a minimum DO of 3.37 $\frac{mg}{L}$ and a maximum DO of 6.7 $\frac{mg}{L}$.

DO values are generally less at high temperatures. Such waters hold less oxygen than can low temperature waters. DO values are generally lower in Region 1 and 3 than they were in Region 2.

DO values are generally high in Region 2, the region that is characterized by substantial input from agricultural fertilizers, animal wastes or human sewage directly in the Chilibre and Chilibrillo Rivers. However, the high DO values might reflect that samples are collected from shallow (low elevation), well-mixed waters that have sufficient sunlight to oxygenate the surface water collected.

Several factors influence the DO including (Murphy, General Information on Dissolved Oxygen, 2007) :

- The volume and velocity of water flowing in the water body
- The climate and season
- The type and number of organisms in the water body
- Elevation
- Dissolved or suspended solids
- Riparian vegetation
- Organic Wastes
- Ground water inflow

The values below 100% represent conditions where plants remove oxygen from the water—called respiration. The values above 100% represent supersaturated conditions where many plants through the process of photosynthesis are releasing excessive amount of dissolved oxygen (Murphy, General Information on Dissolved Oxygen, 2007).

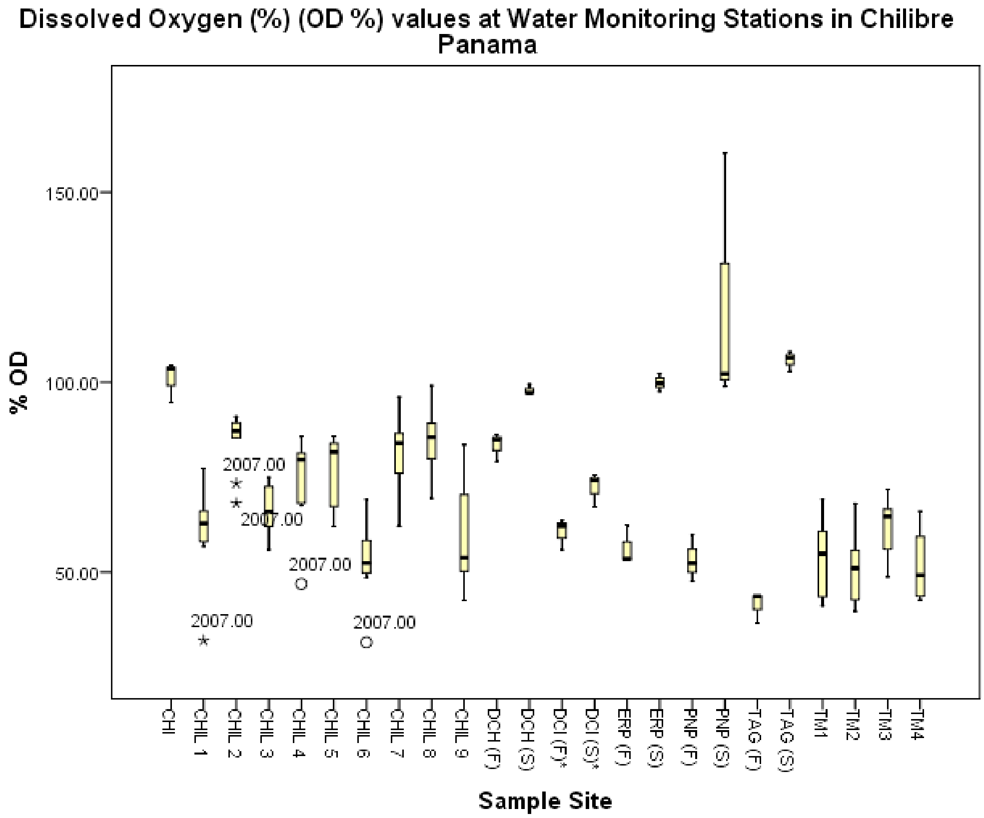



Figure 35. DO values (as %) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

Generally, Region 1 has the highest percent saturation values among its monitoring station compared to the other sampling stations (see Figure 35). PNP percent saturation values (collect at the surface) are likely a result of all factors other than organic wastes inputs, TDS, or TSS.

All nitrite values reported from all monitoring stations in the study region (Figure 36) fell below the water criteria standard (maximum contaminant level) for nitrite set at 1.0 $\frac{mg}{L}$ (Environmental Protection Agency, 2013). These levels, however, have not been included into the water criteria standards in Panama.

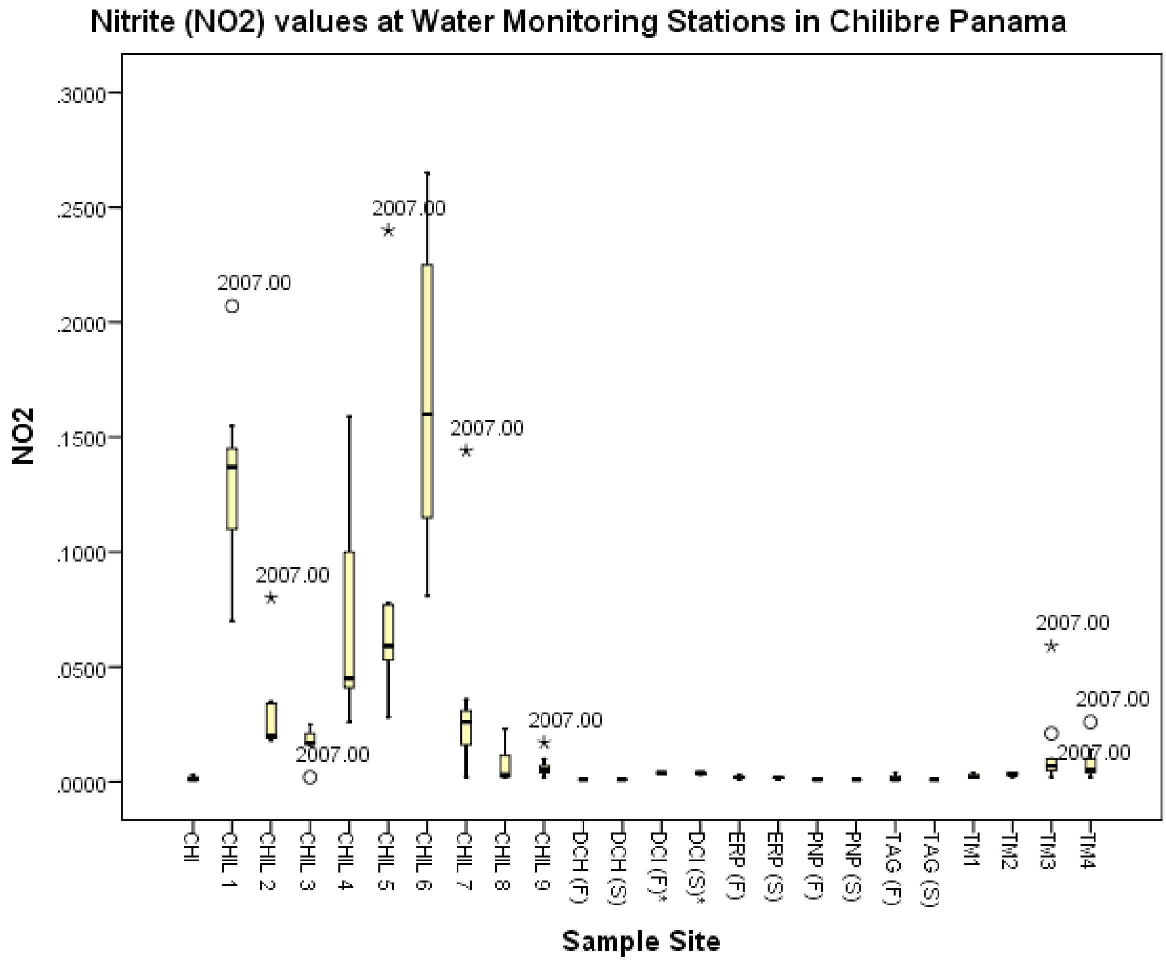



Figure 36. Nitrite values ( $\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

All stations in the study region (Figure 37) violated the water quality standards for nitrates. With the greatest variation being for CHIL 3 and TM4, 0.03 $\frac{mg}{L}$ and 0.01 $\frac{mg}{L}$ respectively, medians at 0.261 $\frac{mg}{L}$ and 0.271 $\frac{mg}{L}$, lower quartiles at 0.261 $\frac{mg}{L}$ and 0.156 $\frac{mg}{L}$, upper quartiles at 0.366 $\frac{mg}{L}$ and 0.352 $\frac{mg}{L}$, minimums at 0.09 $\frac{mg}{L}$ and 0.10, maximums at 0.661 $\frac{mg}{L}$ and 0.42 $\frac{mg}{L}$, and ranges of 0.567 and 0.317.

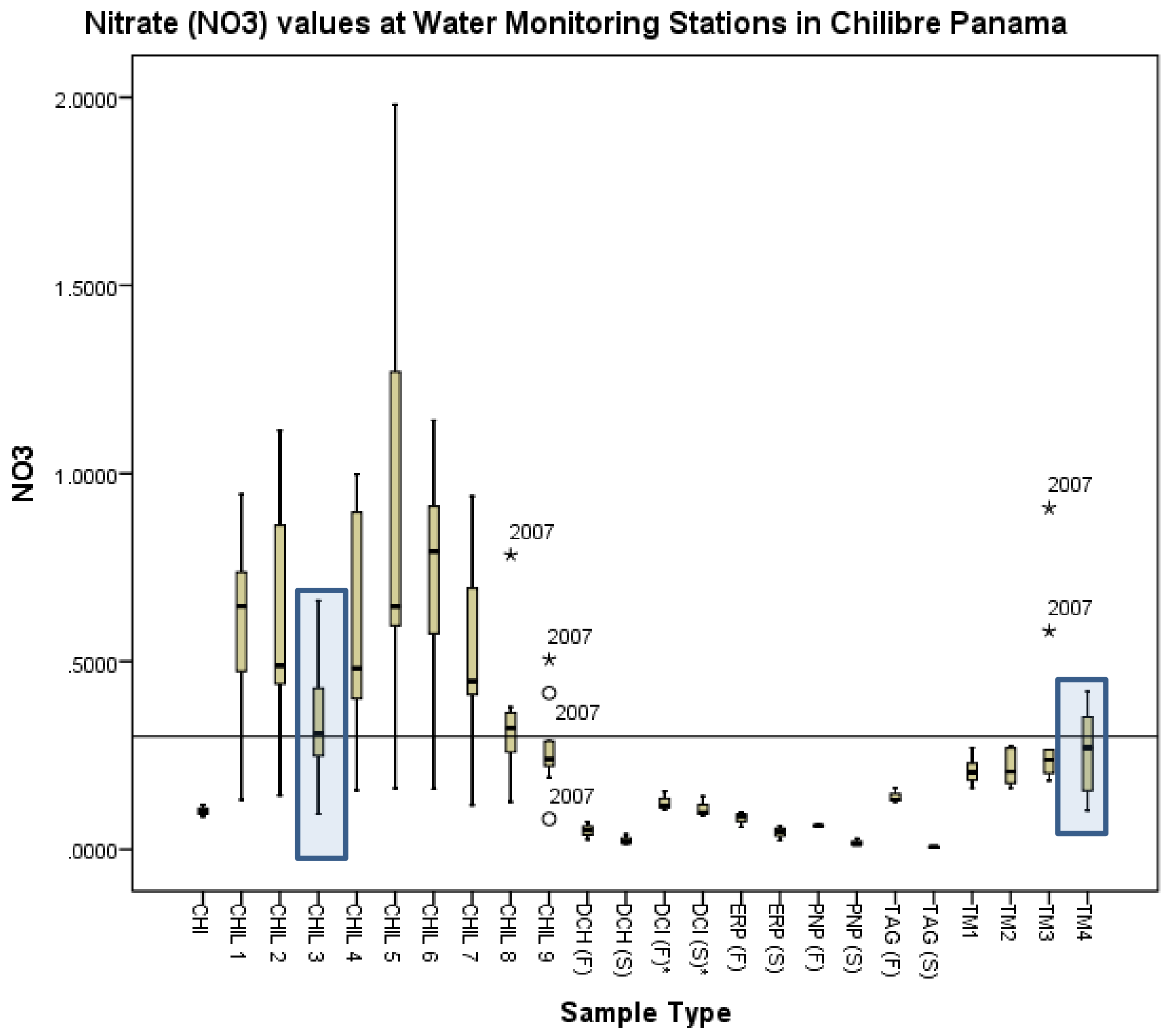



Figure 37. Nitrate values ($\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

The values in Region 1 and 3 are generally lower than those in Region 2 (Figure 37). Reservoirs act as nutrient sinks and store much of nitrogen and phosphate in sediment. In Region 3, the higher nitrate values compared to region 1 may be attributable to the nutrient-rich inflow of Region 2 rivers.

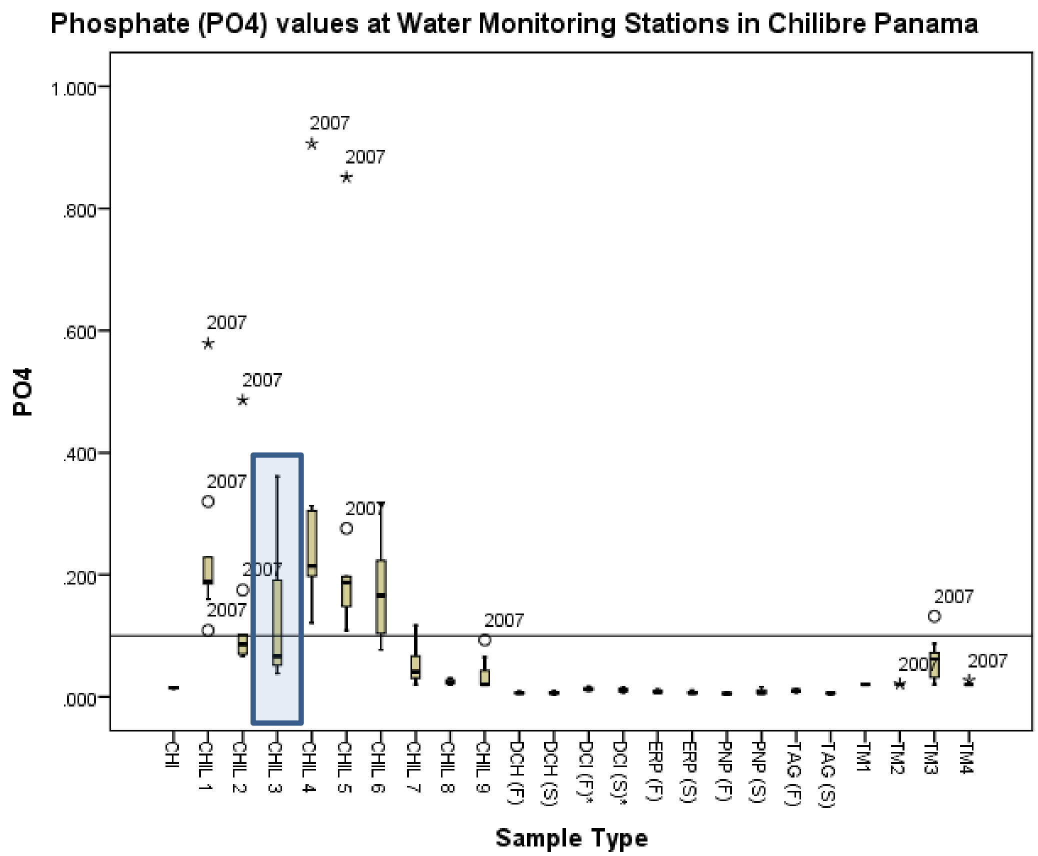



Figure 38. Phosphate values ($\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

Phosphate values that exceeded 0.10 $\frac{mg}{L}$ violated the water standards (see Figure 38). None of the monitoring stations violated the monitoring stations in Region 1, six monitoring stations Region 2 violated the standards, and one monitoring station violated the standards in Region 3. Among the monitoring stations that violated the water standards for phosphate in rivers (not discharging in lakes and reservoirs; see Figure 22), CHIL 3 had the most variance at 0.01, a median value of 0.07 $\frac{mg}{L}$, a lower quartile of 0.054 $\frac{mg}{L}$, an upper quartile at 0.156 $\frac{mg}{L}$, a minimum at 0.038 $\frac{mg}{L}$, a maximum at 0.361 $\frac{mg}{L}$, and a range of 0.323 $\frac{mg}{L}$.

The presence of these phosphates in Region 2 may be attributable to food residues, body wastes, development that causes soil erosion, and the breakdown of organic pesticides or fertilizers contains phosphates. In Regions 1 and 3, the low values levels of phosphate may be attributable to limited algae and plant productivity in the reservoir and Chagres River.

Sulfate ranged from 0 $\frac{mg}{L}$ to 50 $\frac{mg}{L}$ along the length of the sampling transect (Figure 39). No values exceeded the reference value at any of the stations in any of the regions for sulfate at 250 $\frac{mg}{L}$. The differences in sulfate values may be attributable to groundwater source differences underlying the water bodies. Organic sulfate forms with the reaction of sulfide and organic material. It is possible that the organic material (in the form of wastes) could have contributed to the higher sulfate levels in Region 2 than in Region 1 and 3 respectively. The spike at TM3 may be attributable to the sulfate inputs from Region 2.

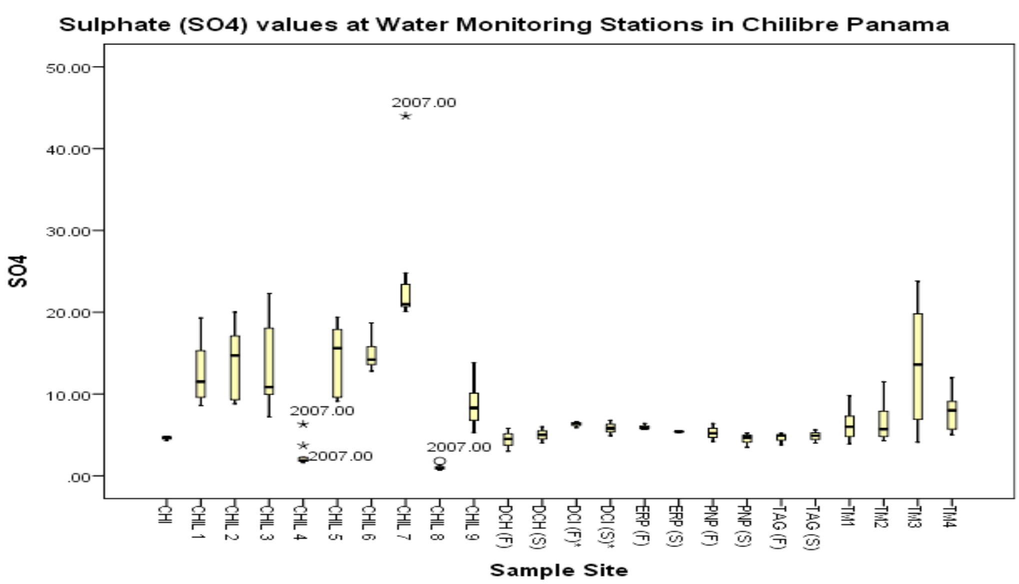



Figure 39. Sulfate values ($\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

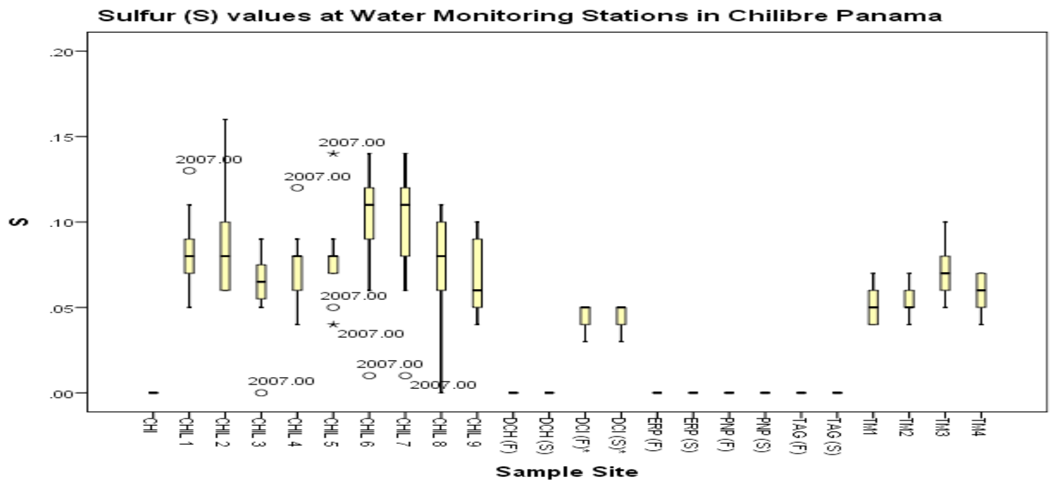



Figure 40. Sulfur values ( $\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

The differences in sulfur values may be attributable to groundwater source differences underlying the water bodies (Figure 40). Organic sulfate forms with the reaction of sulfide and organic material. It is possible that the organic material (in the form of wastes) could have contributed to the higher sulfate levels in Region 2 than in Region 1 and 3 respectively The spike at TM3 may be attributable to the sulfate inputs from Region 2.

Region 2 generally has higher TSD values than Region 1 and 3 (see Figure 41). These differences can be attributable to geological and soil properties of the watershed, the presence or absence of urban runoff, regional differences wastewater and septic system effluent, soil erosion (attributable to building and road construction), or plant and animal decay. In Region 3, TM3 has the highest TDS value which is likely attributable to inputs from Region 2.  No values were reported that exceeded the water standard for total dissolved solids set at 500 $\frac{mg}{L}$.

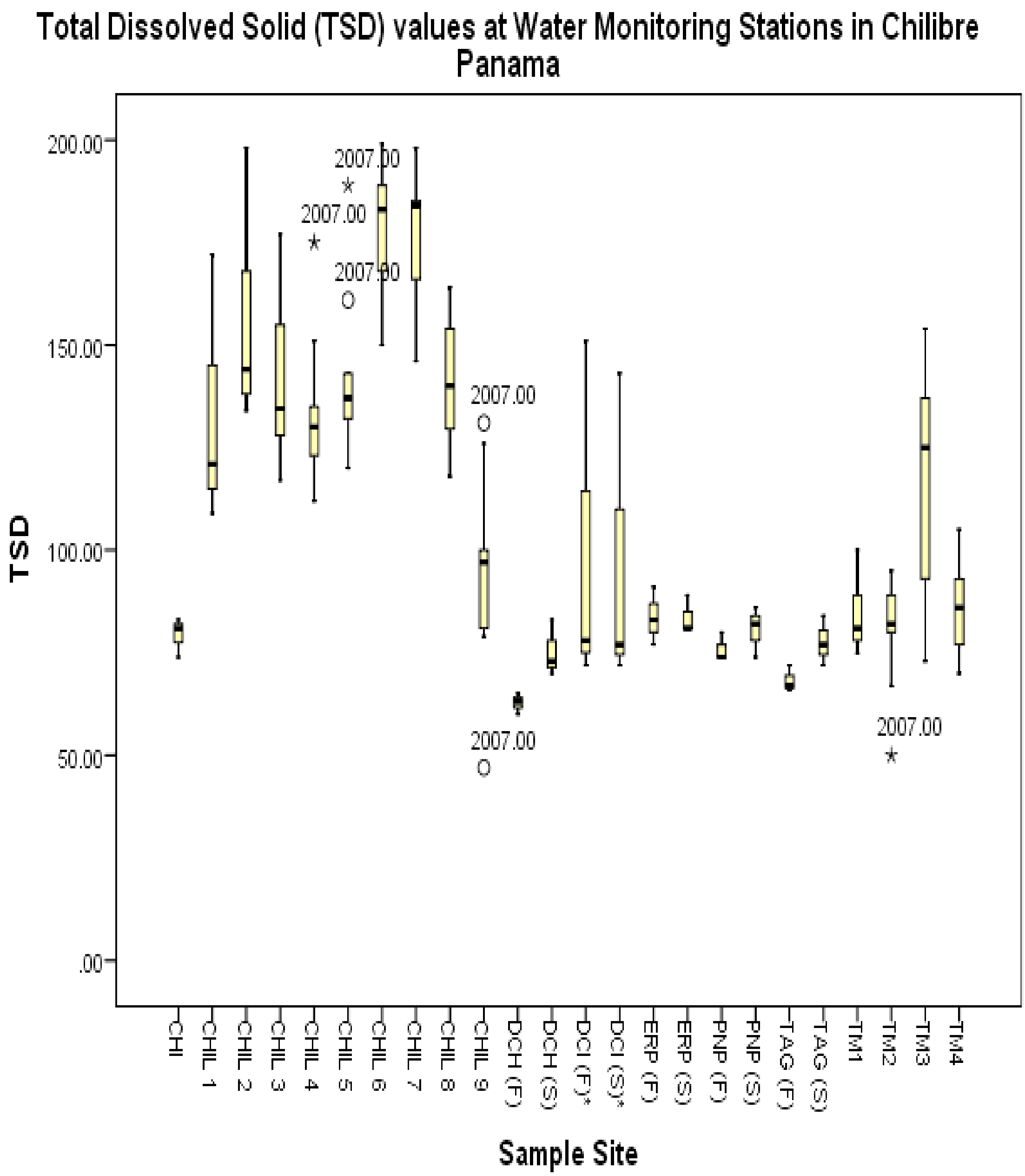



Figure 41. Total dissolved solids (or TDS (Spanish)) ($\frac{mg}{L}$) values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

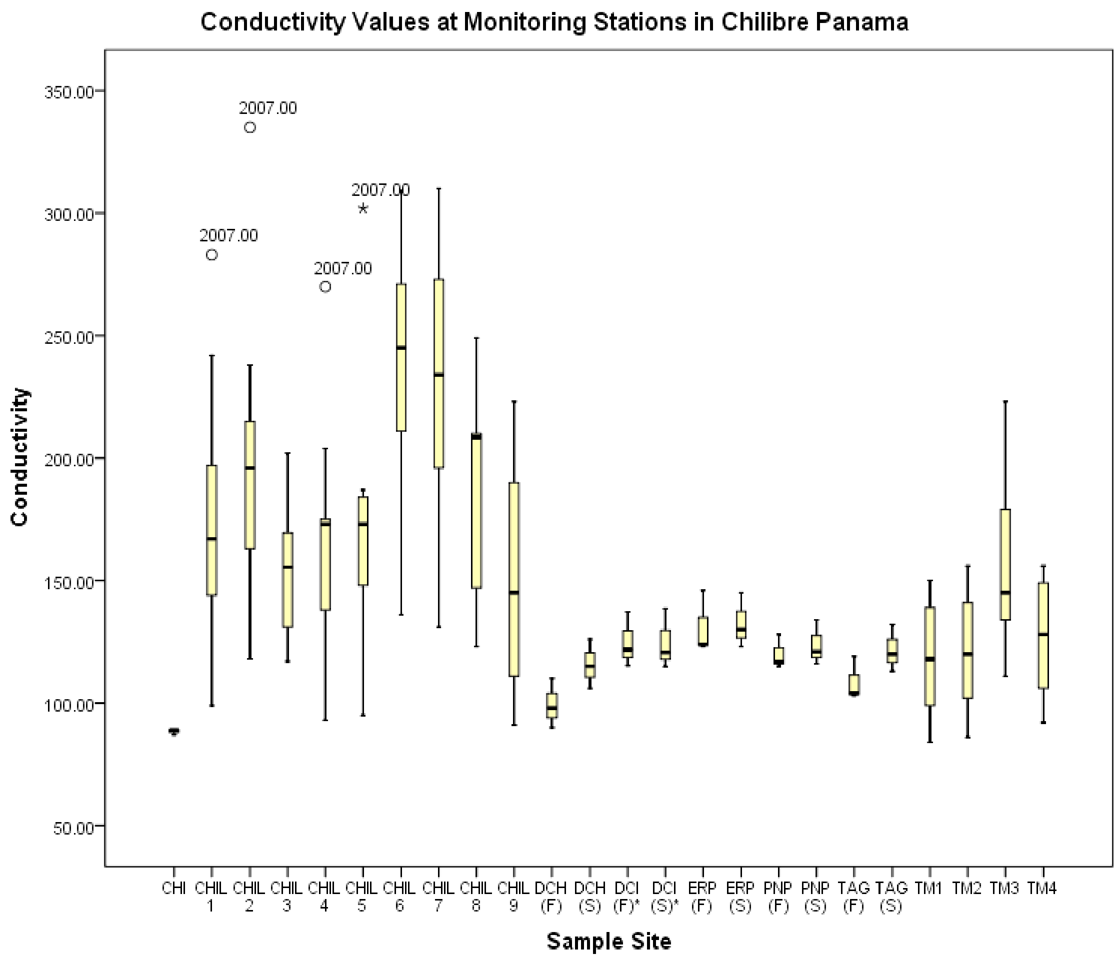



Figure 42. Conductivity values (as $\frac{\mu s}{cm}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

Generally, Region 2 has a higher conductance at its monitoring stations than do Region 1 and Region 3 (see Figure 42). This might be attributable to geologic differences (present or absent of calcite containing rocks), agriculture runoff and road run off (from leaked automobile fluids) (Murphy, General Information on Specific Conductance, 2007). The high TM3 conductivity relative to the other monitoring points in Region 3 may be attributable to the conductivity values of the waters discharged from Region 2.

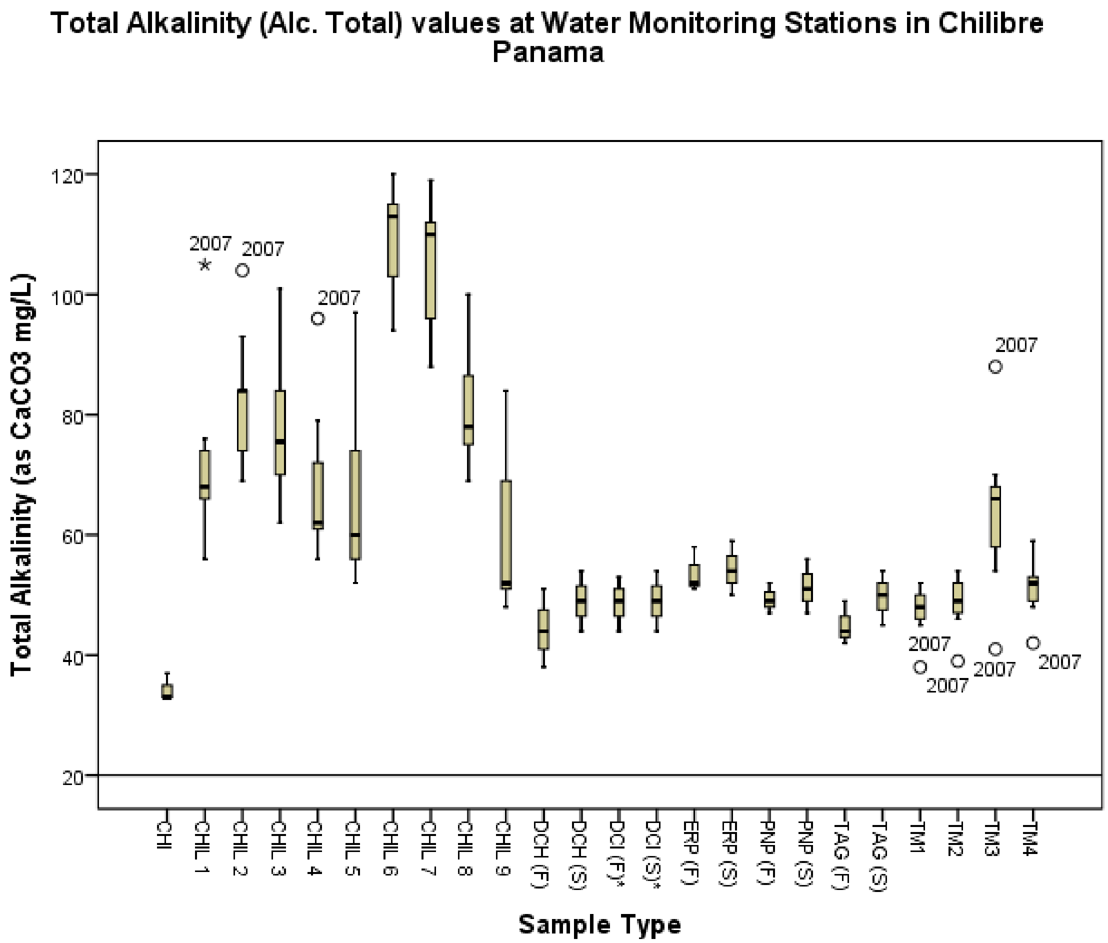



Figure 43. Total Alkalinity values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

According to the water quality standards, total alkalinity values were to remain at or above 20 $\frac{mg}{L}$ (expressed as $CaCO_3$). Some factors that may have contributed to the higher alkalinity values in Region 2 than Regions 1 and 3 may have been related to geology and soil properties of the water catchment, changes in pH, and sewage outflow (particularly from household wastewater containing cleaning agents and/or food residue) (see Figure 43) (Murphy, General

Information on Alkalinity, 2007). The relatively high TM3 value (compared to the other measurements in Region 3) may be attributable to the alkalinity of waters from Region 2.

None of the monitoring stations in any of the regions violated these standards.

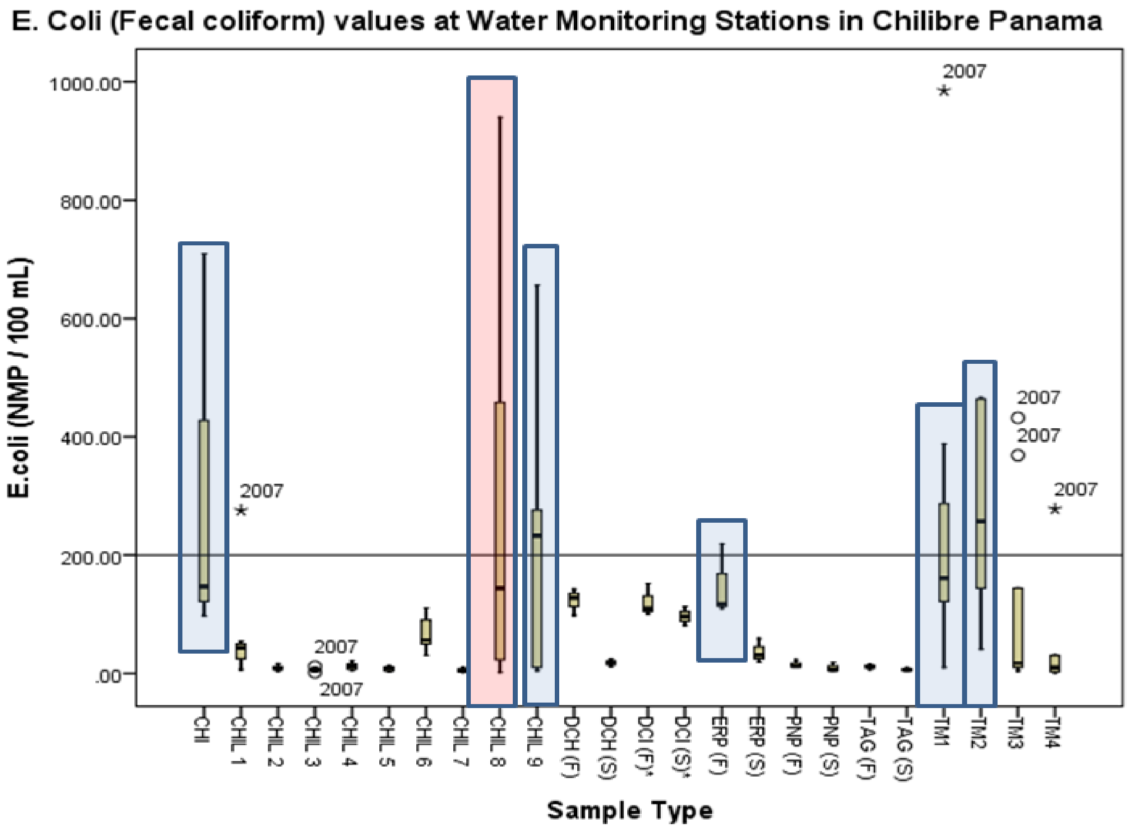



Figure 44. E. coli (NMP- Spanish acronym for 'Most Probable Number') values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

E. coli values for individual stations are presented in Figure 44. According to water quality standards, E.coli values must not to exceed 200 $\frac{NMP}{mL}$ for recreational primary contact water (waters suitable for full body contact such as swimming and scuba diving; USGS, 2005). Standards for secondary contact waters (water suitable for partial-body contact such as wading; USGS, 2005) are set at 1000 $\frac{NMP}{mL}$ (not depicted in the graphic) and 2000 $\frac{NMP}{mL}$ for drinking water. Among the water stations in violation of water quality standards, CHIL 8 had the largest variance at 120,641.4 $\frac{NMP}{mL}$ , a median of 144 $\frac{NMP}{mL}$ , a lower quartile value of 32.1975 $\frac{NMP}{mL}$ , an upper quartile value of 352 $\frac{NMP}{mL}$ , a minimum value of 1.86 $\frac{NMP}{mL}$ , a maximum value of 940 $\frac{NMP}{mL}$ , and a range of 938.14 $\frac{NMP}{mL}$ .

CHI had the highest E. coli values in Region 1. CHIL 8 and CHIL 9 had the highest E. coli values in Region 2 and TM1 and TM2 had the highest E. coli values for Region 3. The high E.coli values at these stations may have been attributable to (Murphy, General Information on Fecal Coliform, 2007):

- Waste water and septic system effluent (particularly CHIL 8 and CHIL 9 which are densely populated)
- High sediment loads which bacteria may attach to when escaping predators and in runoff events in which soils (containing large amounts of bacteria) enter waterways (typical at CHI)
- High temperatures which promote bacterial growth (all)
- High nutrient levels which can increase the growth rate of bacteria (CHIL8, CHIL9)

The water quality standards for biological oxygen demand (DBO –Spanish acronym) was to be maintained between 3 $\frac{mg}{L}$ and 5 $\frac{mg}{L}$. None of the monitoring stations violated the upper limit of the standard; however, all of the sites in all of the regions violated the lower limit of the water quality standard. Among the stations in violation of the standards, CHIL 1 had the greatest variance in DBO (or BOD) at 0.61945 $\frac{mg}{L}$, a median at 3.33 $\frac{mg}{L}$, a lower quartile value of 2.41 $\frac{mg}{L}$, an upper quartile value of 3.71 $\frac{mg}{L}$, a minimum value of 2.3 $\frac{mg}{L}$, a maximum value of 4.48 $\frac{mg}{L}$, and a range of 2.18 $\frac{mg}{L}$ (see Figure 45).

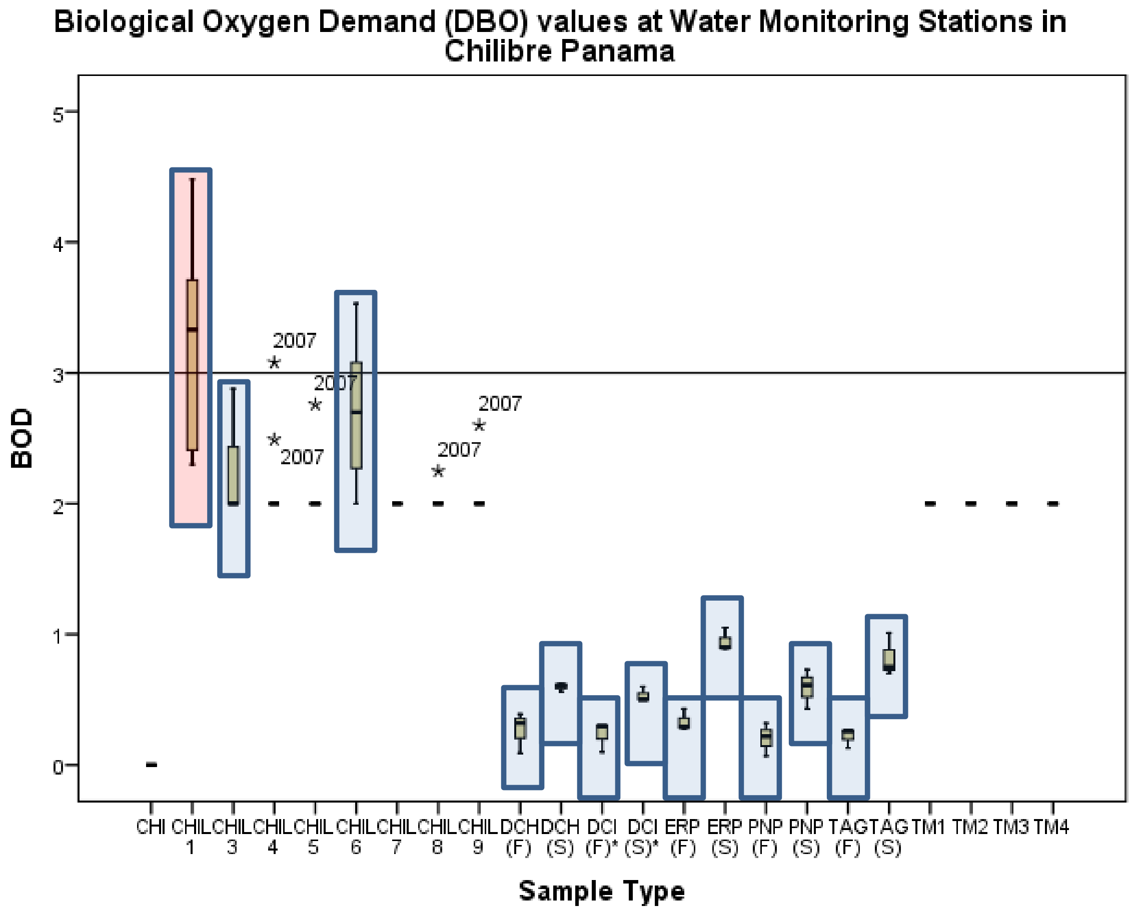



Figure 45. BOD values ($\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

The high value BOD at CHI, CHIL 1, and CHIL 3 may have been attributed to organic waste effluent which determines how much oxygen bacteria can consume. It is more likely the organic wastes were discharged at CHIL 1 and CHIL 3 which are in the most densely populated region in the study sample. The high BOD levels at CHI are likely due to runoff events that washed sediment-containing bacteria into the waterway and increased the BOD.

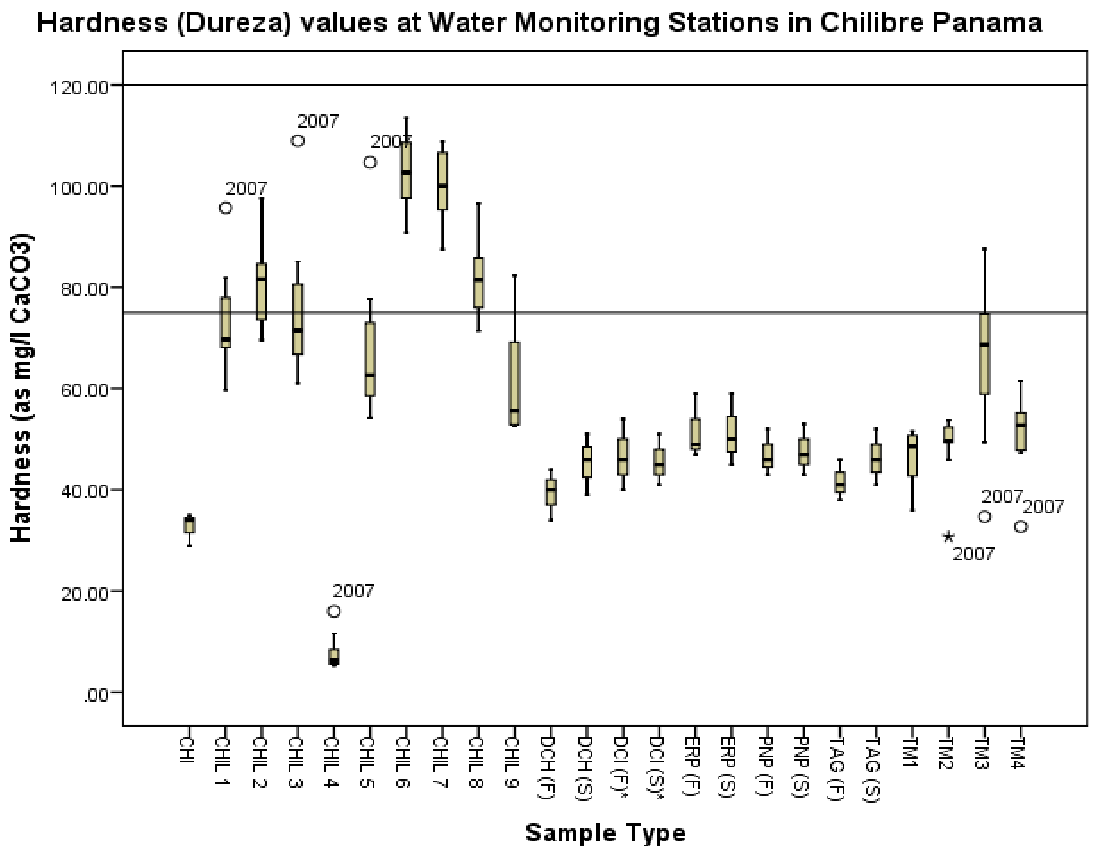



Figure 46. Hardness values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

The criteria standards stipulate that hardness values between 0 and 75 $\frac{mg}{L}$ are considered *bland (of soft)* and values between 75 to 150 $\frac{mg}{L}$ are considered moderately hard. The green section of the hardness graph (above) represents the values that are *bland* and the values occupying the blue section of the hardness graph are considered *moderately hard*. None of the values reported from the stations approached the hard designation of 150 to 300 $\frac{mg}{L}$ or exceeded 300 $\frac{mg}{L}$ which is classified as *very hard* (see Figure 46).

Generally, the hardness values for Region 2 were higher than those for Region 1 and 3. The high values in Region 2 are likely attributable to industrial processes and sewage outflow in the region. The high hardness values in Region 3 (relative to Region 1) may be attributable to the hardness from the Region 2 discharge (particularly at TM3), but also may be attributable to the underlying sediment that may  releases  calcite. In this instance since hardness is equal to total alkalinity, calcium and magnesium are the principal cationic species in the water. In other instances when hardness is greater than total alkalinity, other cationic species may be present.

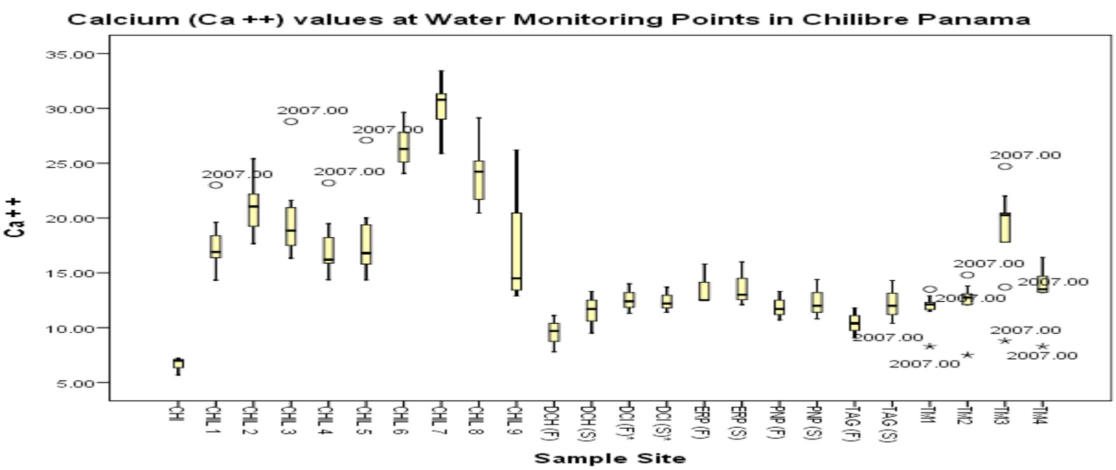



Figure 47. Calcium values ( $\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

Generally, the calcium values for Region 2 were higher than those for Region 1 and 3 (see Figure 47). The high values in Region 2 are likely attributable to industrial processes and sewage outflow in the region. The high hardness values in Region 3 (particularly at TM3) may be attributable to the calcium and positively charged elements deposited from Region 2 discharge and may be attributable to the underlying sediment that may releases calcite.

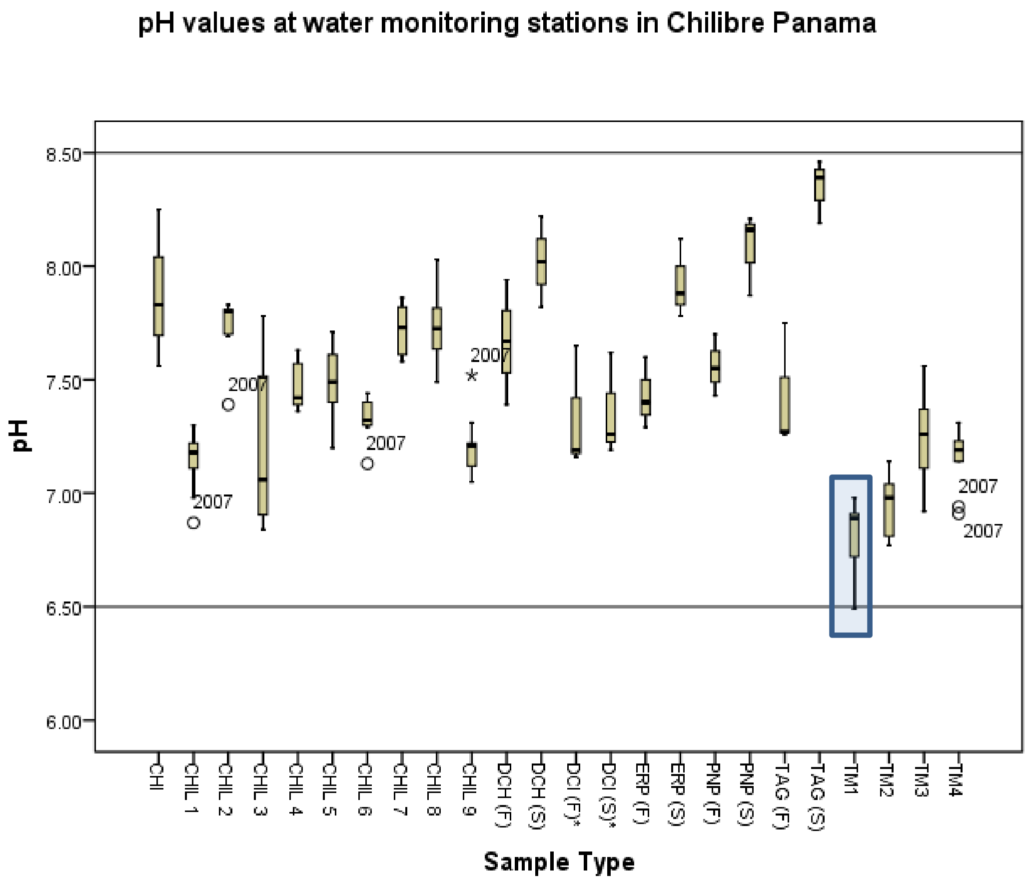



Figure 48. pH values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

TM1 was the only water monitoring station in violation of the pH standards for recreational water that ranged from 6.5 to 8.5. The median pH at the station was 8.39, the lower quartile value was 8.29, the upper quartile value was 8.425, the minimum value was 8.19, the maximum value was 8.46, and the range was 0.27 (see Figure 48).

It should be noted, however, that pH values can change dramatically throughout the day at individual stations as a reflection of the magnitude of primary production from algae and aquatic macrophytes.

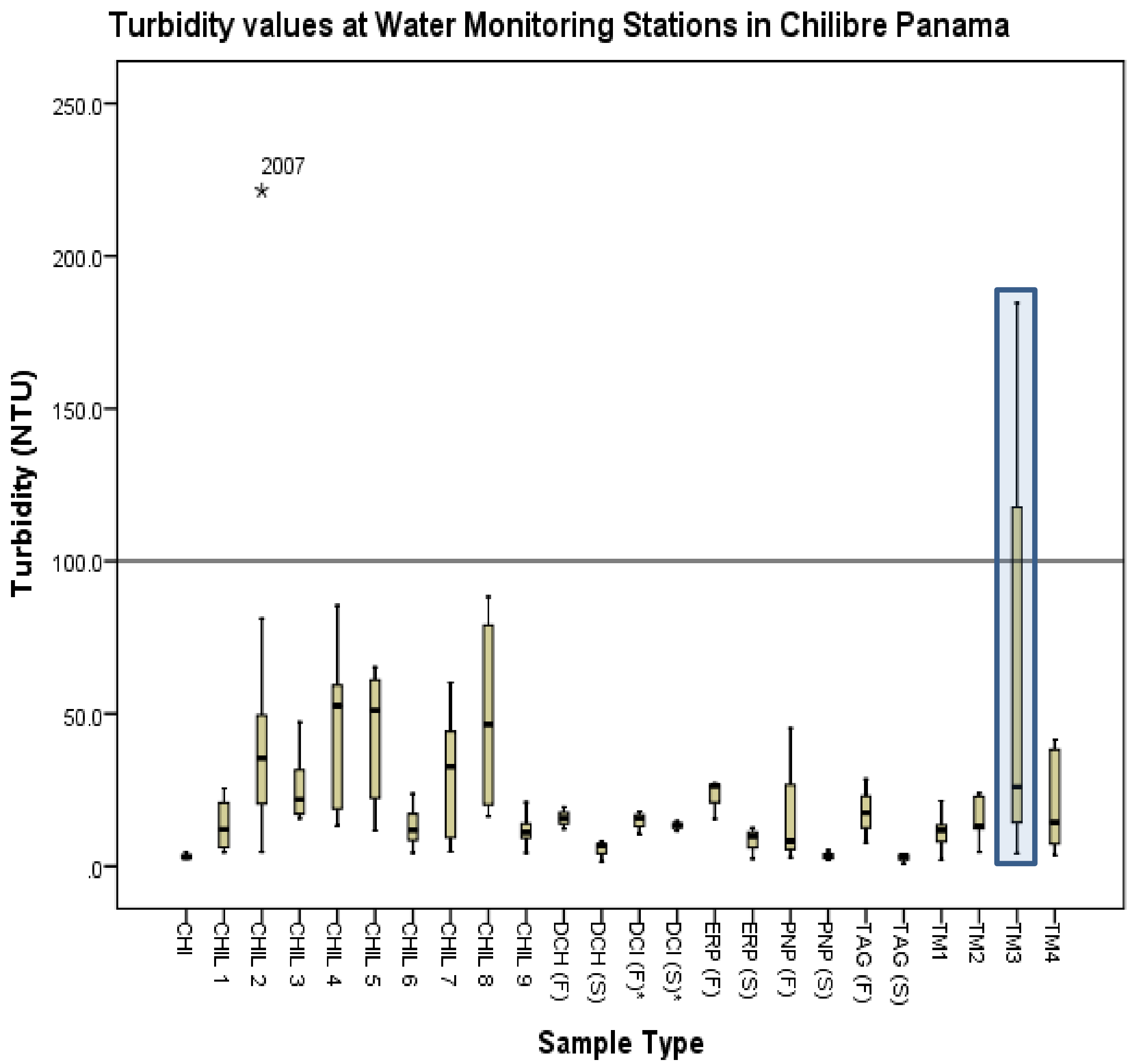



Figure 49. Turbidity values at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

TM3 was the only monitoring station to violate the water standards for turbidity set at or below 100 NTU (see Figure 49). The variance at TM3 was 4355.325 NTU. The median value was 26 NTU, the lower quartile value was 14.4 NTU, the upper quartile value was 117.7 NTU, the minimum was 4.2 NTU, the maximum value was 184.6 NTU, and the range was 180.4 NTU.

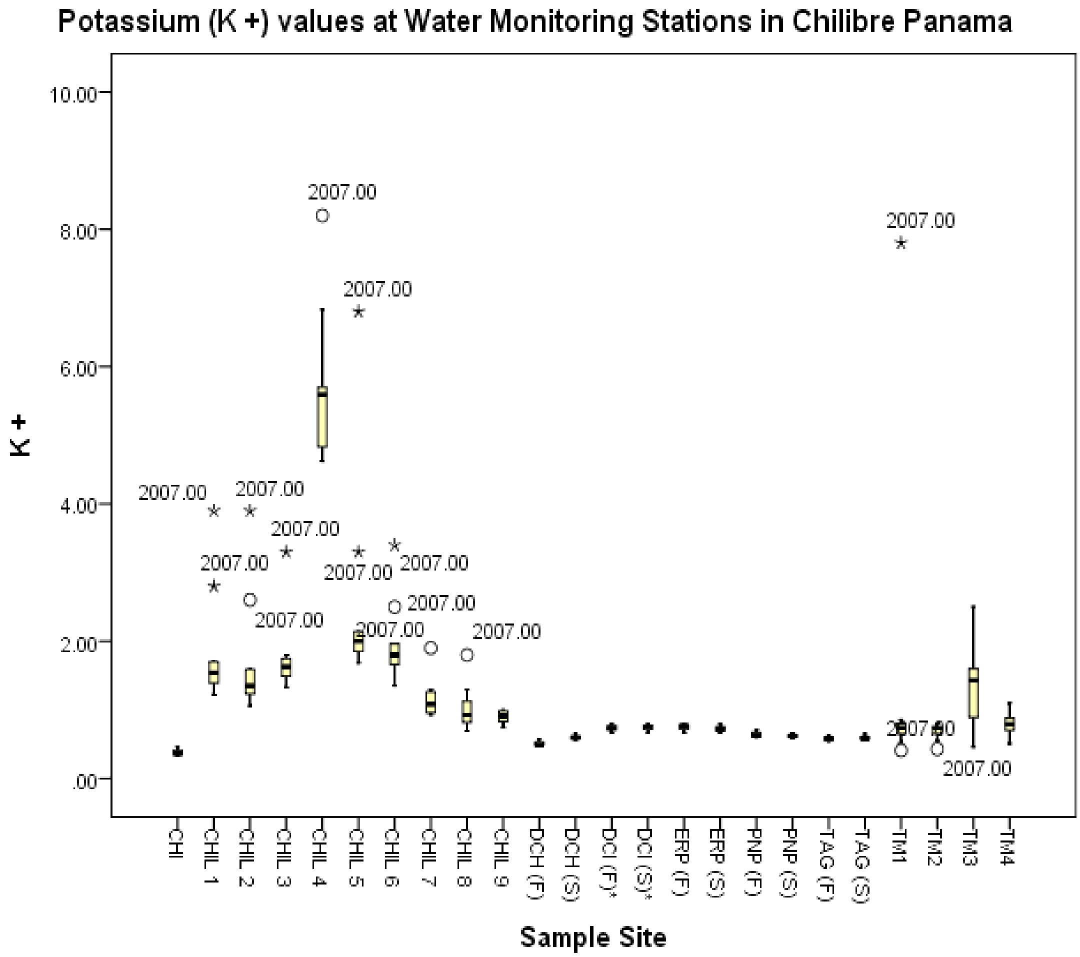
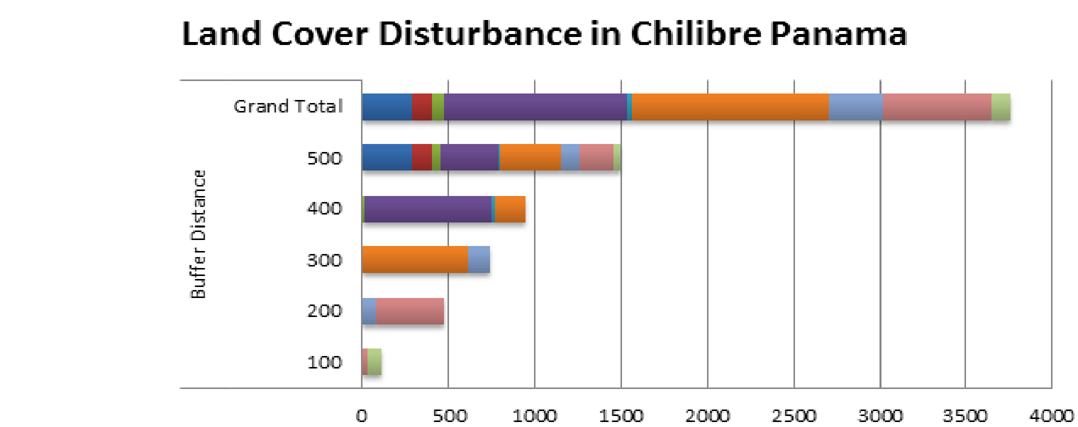



Figure 50. Potassium values ( $\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes).

Generally, the Potassium values recorded were highest in Region 2 likely owing to wastewater discharges from industry and or sewage water outflow (Figure 50). TM3 may have reported relatively high values because of potassium levels in Region 2 discharge.

**Land cover disturbance**




| | Buffer Distance | | | | | |
|---|---|---|---|---|---|---|
| | 100 | 200 | 300 | 400 | 500 | Grand Total |
| Agua | | | | | 289.38 | 289.38 |
| Areas Pobladas | | | | | 118.62 | 118.62 |
| Bosques maduros | | | | 15.99 | 49.69 | 65.68 |
| Bosques secundarios | | | | 733.78 | 331.69 | 1065.46 |
| Explotaciones mineras | | | | 17.26 | 11.65 | 28.91 |
| Matorrales y Rastrojos | | | 606.83 | 179.48 | 354.77 | 1141.08 |
| Paja canalera | | 76.39 | 129.44 | | 100.53 | 306.36 |
| Pastizales | 36.03 | 396.08 | | | 201.96 | 634.07 |
| Suelos desprovistos de vegetacion | 76.60 | | | | 33.97 | 110.56 |

Figure 51. Land Cover Disturbance in Chilibre Panama (Created by Christopher Weekes and Paul Thurman).

The overall land cover disturbances in Chilibre Panama are depicted in Figure 51. From the figure, the land cover associated with domestic wastes generation are designated as *areas pobladas*, *matorrales y rastrojos* and *suelos desprovistos de vegetacion* (or land cleared of vegetation) and the land cover associated with agricultural waste generation are designated as *paja canalera* and *pastizales*.

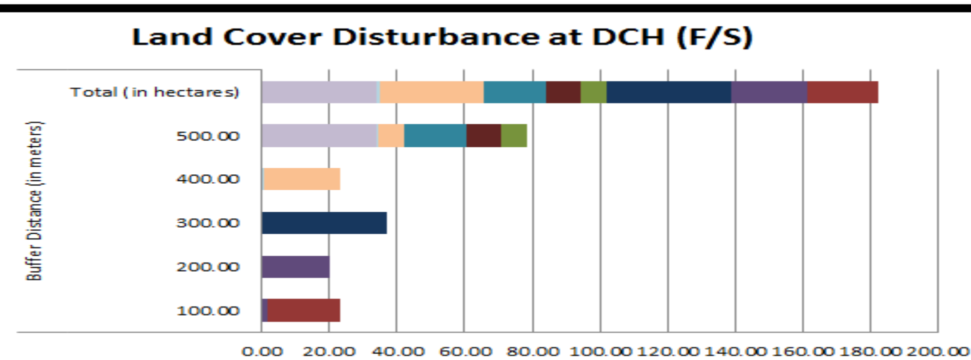
To read the graph, one should look at the left panel of table containing the names of the land cover. From the land cover names, one then should follow the graphs to the right to see the hectares for the appropriate buffer distance labeled directly above. For example, from the land cover *Agua* (water) in the table to the right one will see 289.38 (hectares) at a buffer distance of 400 to 500 meters. Immediately to the right, one will observe that 289.38 (hectares) is also the grand total hectares covered by *Agua*. Therefore, Agua is most prevalent at 400 to 500 meters from the water monitoring stations. Similarly, for *Bosques maduros* (mature forests) are most prevalent at 400 to 500 meters from the water monitoring stations with 49.69 hectares of coverage. 300 to 400 meters from the water monitoring stations 15.99 hectares are covered by mature forests. The remaining land cover can be interpreted using the graph reading method explained previously.

The multi-colored columns represent the different land cover at the corresponding buffer distances.   For example, one will observe at the buffer distance of 400 meters (representing the land cover between 300 to 400 meters) that the *Bosques secundarios* (secondary forests) are the most prevalent land cover overall at the water monitoring stations in the study area. At the same buffer distance, shrubs and bushes are the second most prevalent land cover.

For the land cover associated with domestic waste generation (*areas pobladas* and *matorrales y rastrojos*) populated areas were most prevalent between 400 and 500 meters from the water monitoring stations at 118.62. Matorrales y rastrojos (shrubs and bushes) were most prevalent between 200 to 500 meters from the water monitoring stations with the highest prevalence of land cover occurring between 200 and 300 meters from the monitoring stations at 606.83 hectares.

For the land cover associated with agricultural waste generation (*paja canalera* and *pastizales*) White (canal) straw were most prevalent between 100 and 500 meters from the water monitoring stations with the highest land coverage between 200 to 300 meters from the monitoring stations at 129.44 hectares. Grasslands were most prevalent between 0 to 500 meters from the water monitoring stations with the highest prevalence of land cover occurring between 200 to 300 meters at 396.08 hectares.

**Region 1**




| | | Buffer Distance (in meters) 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
|---|---|---|---|---|---|---|---|
| DCH (F) | Agua | | | | | 33.92 | 33.92 |
| DCH (F) | Bosques maduros | | | | 0.54 | 0.69 | 1.23 |
| DCH (F) | Bosques secundarios | | | | 22.83 | 7.60 | 30.42 |
| DCH (F) | Matorrales y Rastrojos | | | | | 18.55 | 18.55 |
| DCH (F) | Pastizales | | | | | 9.98 | 9.98 |
| DCH (F) | Suelos desprovistos de vegetacion | | | | | 7.82 | 7.82 |
| DCH (S) | Matorrales y Rastrojos | | | 36.99 | | | 36.99 |
| DCH (S) | Pastizales | 1.99 | 20.28 | | | | 22.27 |
| DCH (S) | Suelos desprovistos de vegetacion | 21.31 | | | | | 21.31 |

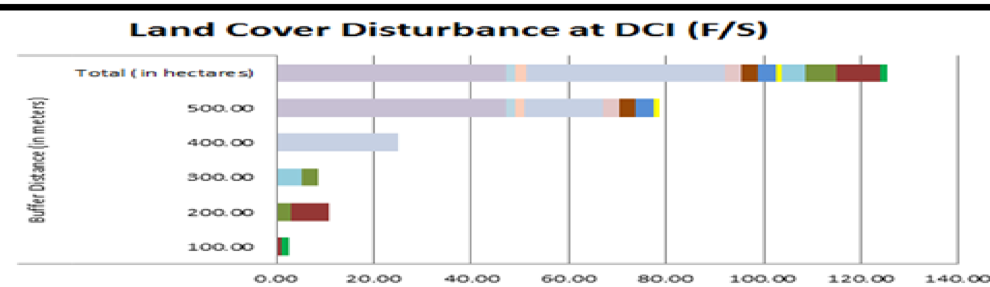
Figure 52. Land Cover Disturbance at DCH (Created by Christopher Weekes and Paul Thurman).

At DCH, surface (S) and background (‘F’ for fondo) land cover associated with domestic waste generation are highlighted in green (see Figure 52). The land cover highlighted in blue are land cover associated with agricultural waste generation. Surface level measurements are associated with land uses that were 100 to 300 meters from the water monitoring station and background level measurements are associated measurements above 300 meters to 500 meters from the monitoring point. Generally, DCH refers to the water monitoring station.

Shrub and bush cover the most hectares among the domestic and agricultural land cover designations at 55.54 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 36.99 hectares.

Grasslands cover 32.25 hectares at DCH. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 to 200 meters at 20.28 hectares.

Bare soils cover 0.33 hectares at DCH. This land coverage is most prevalent between 0 to 500 meters with the highest coverage between 0 and 100 meters at 21.31 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| DCI (F)* | Agua | | | | | 47.04 | 47.04 |
| DCI (F)* | Areas Pobladas | | | | | 2.16 | 2.16 |
| DCI (F)* | Bosques maduros | | | | 0.26 | 1.84 | 2.09 |
| DCI (F)* | Bosques secundarios | | | | 24.90 | 16.10 | 41.00 |
| DCI (F)* | Matorrales y Rastrojos | | | | | 3.35 | 3.35 |
| DCI (F)* | Paja canalera | | | | | 3.31 | 3.31 |
| DCI (F)* | Pastizales | | | | | 3.73 | 3.73 |
| DCI (F)* | Suelos desprovistos de vegetacion | | | | | 1.02 | 1.02 |
| DCI (S)* | Matorrales y Rastrojos | | | 5.06 | | | 5.06 |
| DCI (S)* | Paja canalera | | 3.06 | 3.31 | | | 6.37 |
| DCI (S)* | Pastizales | 0.91 | 7.80 | | | | 8.71 |
| DCI (S)* | Suelos desprovistos de vegetacion | 1.69 | | | | | 1.69 |

Figure 53. Land Cover Disturbance DCI (Created by Christopher Weekes and Paul Thurman).

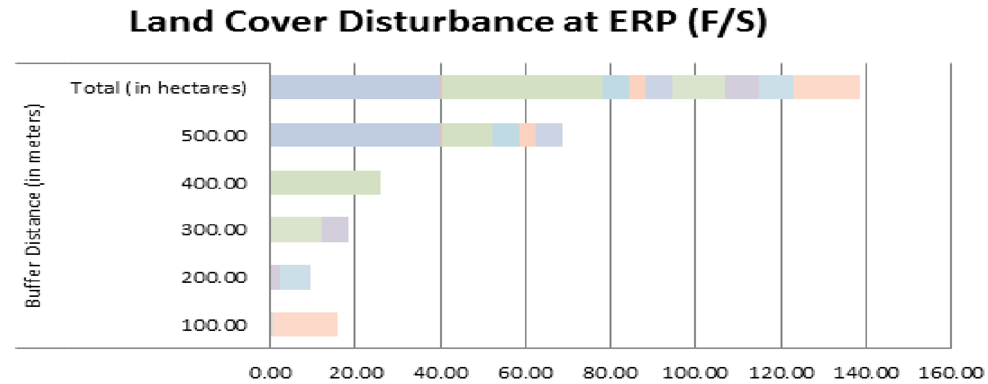
At DCI, surface (S) and background ('F' for fondo) land cover associated with domestic waste generation are highlighted in green (see Figure 53). The land cover highlighted in blue are land cover associated with agricultural waste generation. Surface level measurements are associated with land uses that were 100 to 300 meters from the water monitoring station and background level measurements are associated measurements above 300 meters to 500 meters from the monitoring point. Generally, DCI refers to the water monitoring station. The station is designated with an asterisk because it is located outside of the Chilibre study site, but the water is contiguous with the Chagres River.

Grasslands cover the most hectares among the domestic and agricultural land cover designations at 12.44 hectares. This cover is most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 100 to 200 meters at 7.80 hectares.

White straw cover 9.68 hectares at DCI. This land coverage is most prevalent at buffer distances between 100 meters to 500 meters with the highest coverage between 200 meters to 300 meters and 400 meters to 500 meters at 3.31 hectares.

Shrub and bush cover 8.41 hectares at DCI. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 to 300 meters at 5.06 hectares.

Bare soils cover 1.69 hectares at DCI. This land coverage is most prevalent between 0 to 500 meters with the highest coverage between 0 and 100 meters at 1.69 hectares. At ERP, surface (S) and background ('F' for fondo) land cover associated with domestic waste generation are highlighted in green (see Figure 54). The land cover highlighted in blue are land cover associated with agricultural waste generation.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| ERP (F) | Agua | | | | | 40.12 | 40.12 |
| ERP (F) | Bosques maduros | | | | | 0.13 | 0.13 |
| ERP (F) | Bosques secundarios | | | | 25.80 | 12.03 | 37.83 |
| ERP (F) | Paja canalera | | | | | 6.32 | 6.32 |
| ERP (F) | Pastizales | | | | | 3.60 | 3.60 |
| ERP (F) | Suelos desprovistos de vegetacion | | | | | 6.66 | 6.66 |
| ERP (S) | Matorrales y Rastrojos | | | 11.94 | | | 11.94 |
| ERP (S) | Paja canalera | | 2.13 | 6.32 | | | 8.44 |
| ERP (S) | Pastizales | 0.49 | 7.49 | | | | 7.97 |
| ERP (S) | Suelos desprovistos de vegetacion | 15.41 | | | | | 15.41 |

Figure 54. Land Cover Disturbance at ERP (Created by Christopher Weekes and Paul Thurman).

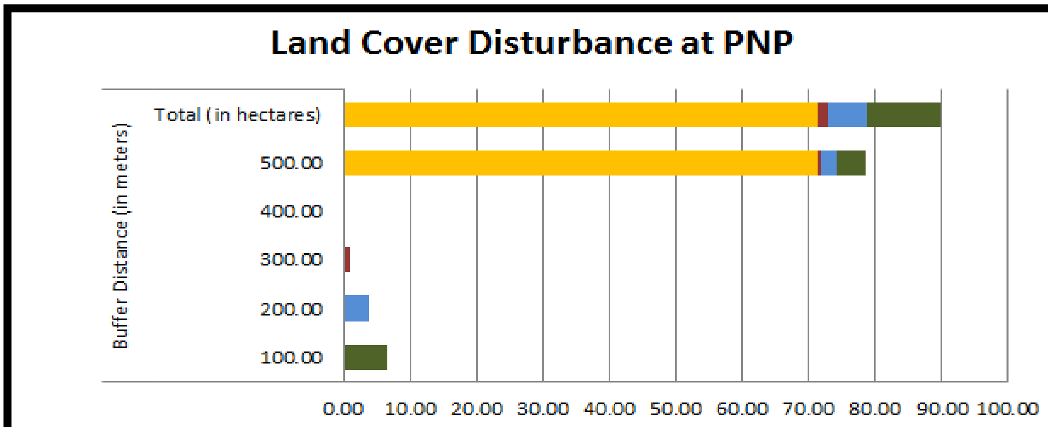
Surface level measurements are associated with land uses that were 100 to 300 meters from the water monitoring station and background level measurements are associated measurements above 300 meters to 500 meters from the monitoring point. Generally, ERP refers to the water monitoring station.

Bare soils cover the most hectares among the domestic and agricultural land cover designations at 22.07 hectares. This cover is most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 0 to 100 meters at 15.41 hectares.

White straw cover 14.76 hectares at ERP. This land coverage is most prevalent at buffer distances between 200 meters to 300 meters and 400 meters to 500 meters at 6.32 hectares.

Shrub and bush cover 11.94 hectares at ERP. This land coverage is most prevalent and has the highest prevalence between 200 and 300 meters.

Grasslands cover 11.57 hectares at ERP. This land coverage is most prevalent between 0 to 500 meters with the highest coverage between 100 and 200 meters at 7.49 hectares.



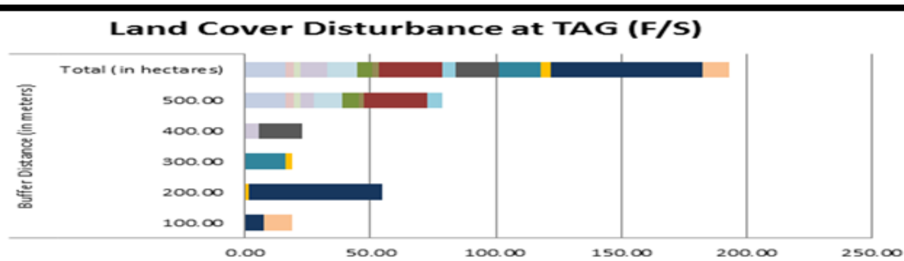

| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| PNP | Agua | | | | | 71.52 | 71.52 |
| PNP | Matorrales y Rastrojos | | | 0.88 | | 0.50 | 1.38 |
| PNP | Pastizales | | 3.81 | | | 2.17 | 5.98 |
| PNP | Suelos desprovistos de vegetacion | 6.64 | | | | 4.35 | 11.00 |

Figure 55. Land Cover Disturbance at PNP (Created by Christopher Weekes and Paul Thurman).

At PNP the land cover associated with domestic waste generation are highlighted in green (see Figure 55). The land cover highlighted in blue are land cover associated with agricultural waste generation. Bare soils cover the most hectares among the domestic and agricultural land cover designations at 11.00 hectares. This cover is most prevalent at buffer distances between 100 meters to 500 meters with the highest coverage between 0 to 100 meters at 6.64 hectares.

Grasslands cover 5.98 hectares at PNP. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 100 to 200 meters at 3.81 hectares.

Shrubs and bushes cover 1.38 hectares at PNP. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 and 300 meters at 0.88 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| TAG (F) | Agua | | | | | 16.51 | 16.51 |
| TAG (F) | Areas Pobladas | | | | | 3.31 | 3.31 |
| TAG (F) | Bosques maduros | | | | 0.37 | 2.27 | 2.64 |
| TAG (F) | Bosques secundarios | | | | 5.21 | 5.21 | 10.41 |
| TAG (F) | Explotacio es mineras | | | | | 11.65 | 11.65 |
| TAG (F) | Matorrales y Rastrojos | | | | | 6.35 | 6.35 |
| TAG (F) | Paja canalera | | | | | 2.33 | 2.33 |
| TAG (F) | Pastizales | | | | | 25.32 | 25.32 |
| TAG (F) | Suelos desprovistos de vegetacion | | | | | 5.58 | 5.58 |
| TAG (S) | Explotacio es mineras | | | | 17.26 | | 17.26 |
| TAG (S) | Matorrales y Rastrojos | | | 16.35 | | | 16.35 |
| TAG (S) | Paja canalera | | 1.85 | 2.33 | | | 4.18 |
| TAG (S) | Pastizales | 7.42 | 52.75 | | | | 60.17 |
| TAG (S) | Suelos desprovistos de vegetacion | 11.28 | | | | | 11.28 |

Figure 56. Land Cover Disturbance at TAG (Created by Christopher Weekes and Paul Thurman).

At TAG, surface (S) and background (‘F’ for fondo) land cover associated with domestic waste generation are highlighted in green (see Figure 56). The land cover highlighted in blue are land cover associated with agricultural waste generation. Surface level measurements are associated with land uses that were 100 to 300 meters from the water monitoring station and background level measurements are associated measurements above 300 meters to 500 meters from the monitoring point. However, there is one instance where a value is reported in the 300 to 400 meter range at TAG (S). Generally, TAG refers to the water monitoring station.

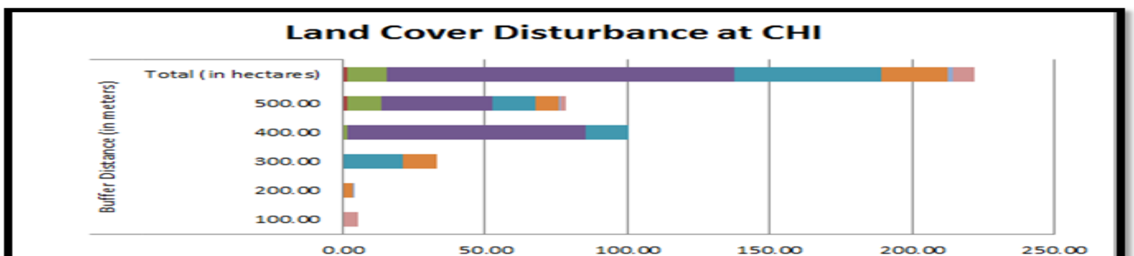
Grasslands cover the most hectares among the domestic and agricultural land cover designations at 85.49 hectares. This land coverage is most prevalent between 0 to 500 meters with the highest coverage between 100 and 200 meters at 52.75 hectares.

Shrub and bush cover 22.70 hectares at TAG. This land coverage is most prevalent between 200 meters to 500 meters and has the highest prevalence between 200 and 300 meters at 16.35 hectares.

Bare soils cover 16.86 hectares at TAG and are most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 0 to 100 meters at 11.28 hectares.

White straw cover 6.51 hectares at TAG. This land coverage is most prevalent at buffer distances between 200 meters to 300 meters and 400 meters to 500 meters at 2.33 hectares.

**Region 2**




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHI | Agua | | | | | 1.67 | 1.67 |
| CHI | Bosques maduros | | | | 1.64 | 12.01 | 13.65 |
| CHI | Bosques secundarios | | | | 83.65 | 38.74 | 122.39 |
| CHI | Matorrales y Rastrojos | | | 21.13 | 15.03 | 15.03 | 51.19 |
| CHI | Paja canalera | | 3.27 | 12.17 | | 8.28 | 23.72 |
| CHI | Pastizales | 0.06 | 1.06 | | | 0.61 | 1.72 |
| CHI | Suelos desprovistos de vegetacion | 5.02 | | | | 2.20 | 7.22 |

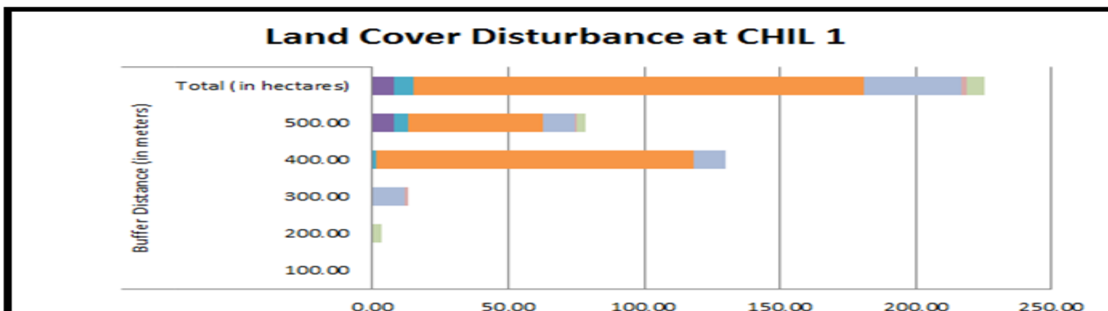
Figure 57. Land Cover Disturbance at CHI (Created by Christopher Weekes and Paul Thurman).

At CHI the land cover associated with domestic waste generation are highlighted in green (see Figure 57). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 51.19 hectares. Shrubs and bushes are most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 21.13 hectares.

White straw cover 23.72 hectares at CHI. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 400 to 500 meters from CHI.

Bare soil covers 7.22 hectares at CHI. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 0 to 100 meters from CHI.

Grasslands covers 1.72 hectares at CHI. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 and 200 meters.



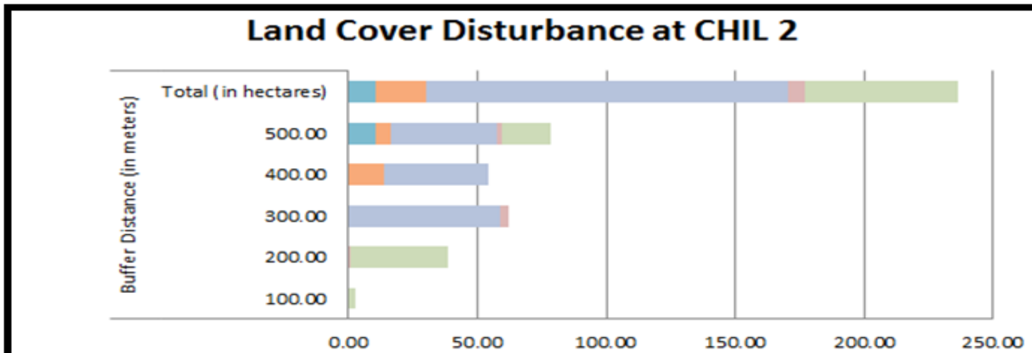

| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 1 | Agua | | | | | 7.89 | 7.89 |
| CHIL 1 | Bosques maduros | | | | 1.53 | 5.42 | 6.95 |
| CHIL 1 | Bosques secundarios | | | | 116.73 | 49.47 | 166.20 |
| CHIL 1 | Matorrales y Rastrojos | | | 11.79 | 11.96 | 11.96 | 35.71 |
| CHIL 1 | Paja canalera | | 0.17 | 1.01 | | 0.62 | 1.81 |
| CHIL 1 | Pastizales | | 3.48 | | | 3.18 | 6.65 |

Figure 58. Land Cover Disturbance at CHIL 1 (Created by Christopher Weekes and Paul Thurman).

At CHIL 1 the land cover associated with domestic waste generation are highlighted in green (see Figure 58). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 35.71 hectares. Shrubs and bushes are most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 300 to 400 and 400 to 500 meters at 11.49 hectares.

Grasslands covers 6.65 hectares at CHIL 1. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 100 and 200 meters at 3.48 hectares.

White straw cover 1.81 hectares at CHIL 1. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 1.01 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 2 | Areas Pobladas | | | | | 10.38 | 10.38 |
| CHIL 2 | Bosques secundarios | | | | 13.62 | 6.11 | 19.73 |
| CHIL 2 | Matorrales y Rastrojos | | | 58.71 | 40.71 | 40.71 | 140.13 |
| CHIL 2 | Paja canalera | | 0.82 | 3.53 | | 2.13 | 6.48 |
| CHIL 2 | Pastizales | 2.90 | 37.66 | | | 19.21 | 59.77 |

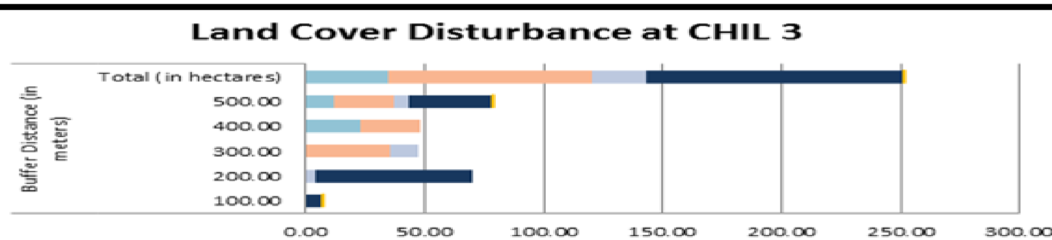
Figure 59. Land Cover Disturbance at CHIL 2 (Created by Christopher Weekes and Paul Thurman).

At CHIL 2 the land cover associated with domestic waste generation are highlighted in green (see Figure 59). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 140.13 hectares. Shrubs and bushes are most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 300 to 400 and 400 to 500 meters at 40.71 hectares.

Grasslands covers 59.77 hectares at CHIL 2. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 and 200 meters at 37.66 hectares.

White straw cover 6.48 hectares at CHIL 2. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 3.53 hectares.

Populated areas cover 10.38 hectares  at CHIL 2. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 10.38 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 3 | Bosques secundarios | | | | 23.14 | 11.55 | 34.69 |
| CHIL 3 | Matorrales y Rastrojos | | | 35.32 | 25.12 | 25.12 | 85.57 |
| CHIL 3 | Paja canalera | | 3.69 | 12.11 | | 7.04 | 22.84 |
| CHIL 3 | Pastizales | 6.76 | 66.46 | | | 34.70 | 107.92 |
| CHIL 3 | Suelos desprovistos de vegetacion | 0.18 | | | | 0.12 | 0.31 |

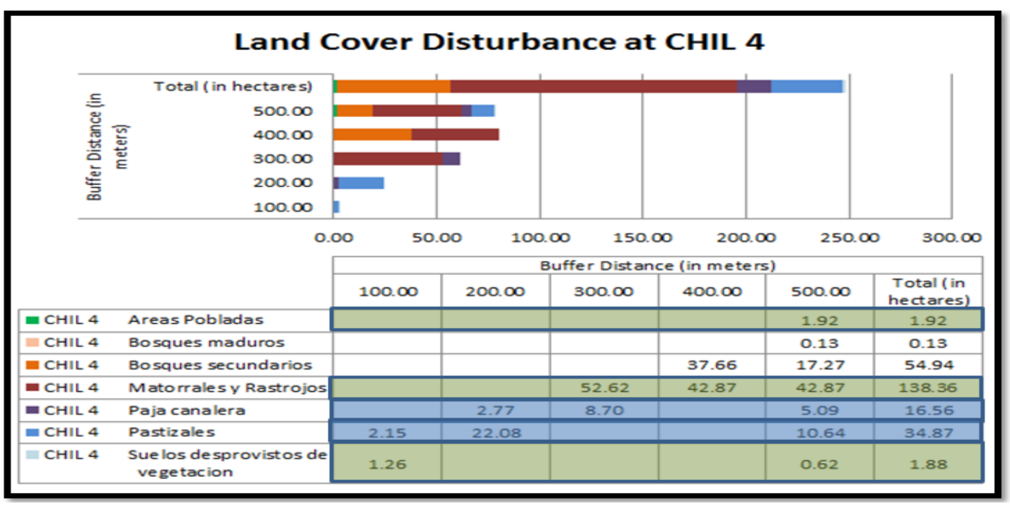
Figure 60. Land Cover Disturbance at CHIL 3 (Created by Christopher Weekes and Paul Thurman).

At CHIL 3 the land cover associated with domestic waste generation are highlighted in green (see Figure 60). The land cover highlighted in blue are land cover associated with agricultural waste generation. Grasslands cover the most hectares among the domestic and agricultural land cover designations at 107.92 hectares. This cover is most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 0 to 200 meters at 66.46 hectares.

Shrubs and bushes cover 85.57 hectares at CHIL 3. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 and 300 meters at 85.57 hectares.

White straw cover 22.84 hectares at CHIL 3. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 12.11 hectares.

Bare soils cover 0.31 hectares at CHIL 3. This land coverage is most prevalent and has the highest coverage between 0 to 100 meters at 0.81 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 4 | Areas Pobladas | | | | | 1.92 | 1.92 |
| CHIL 4 | Bosques maduros | | | | | 0.13 | 0.13 |
| CHIL 4 | Bosques secundarios | | | | 37.66 | 17.27 | 54.94 |
| CHIL 4 | Matorrales y Rastrojos | | | 52.62 | 42.87 | 42.87 | 138.36 |
| CHIL 4 | Paja canalera | | 2.77 | 8.70 | | 5.09 | 16.56 |
| CHIL 4 | Pastizales | 2.15 | 22.08 | | | 10.64 | 34.87 |
| CHIL 4 | Suelos desprovistos de vegetacion | 1.26 | | | | 0.62 | 1.88 |

Figure 61. Land Cover Disturbance at CHIL 4 (Created by Christopher Weekes and Paul Thurman).

At CHIL 4 the land cover associated with domestic waste generation are highlighted in green (see Figure 61). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 138.36 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 52.62 hectares.

Grasslands covers 34.87 hectares at CHIL 4. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 and 200 meters at 22.08 hectares.

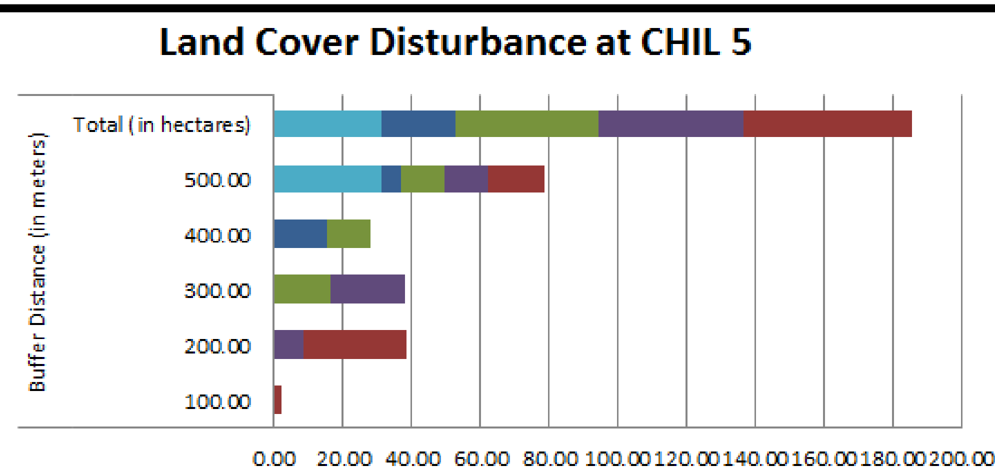
White straw cover 22.84 hectares at CHIL 4. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 8.70 hectares.

Bare soils cover 1.88 hectares at CHIL 4. This land coverage is most prevalent between 0 to 100 meters at 1.26 hectares.

Populated areas cover 1.91 hectares at CHIL 4. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 1.92 hectares.

At CHIL 5 the land cover associated with domestic waste generation are highlighted in green (see Figure 62). The land cover highlighted in blue are land cover associated with agricultural waste generation. Grasslands cover the most hectares among the domestic and agricultural land cover designations at 49.24 hectares. This cover is most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 100 to 200 meters at 30.39 hectares.

Shrubs and bushes cover 41.68 hectares at CHIL 5. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 and 300 meters at 16.54 hectares.



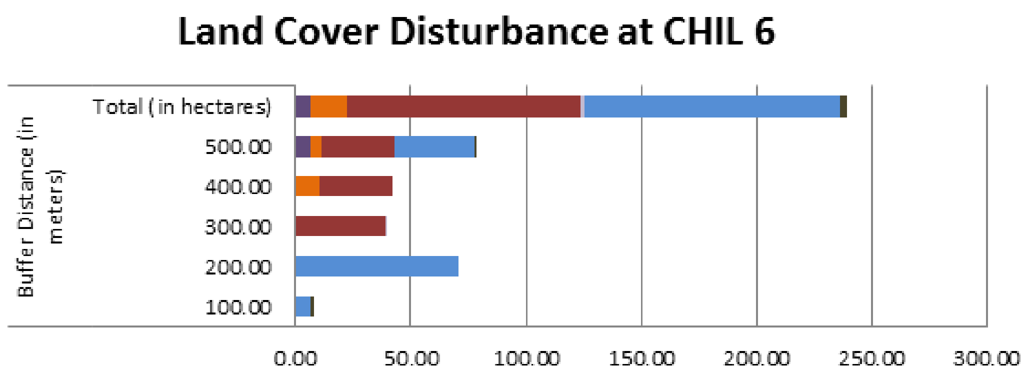

| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 5 | Areas Pobladas | | | | | 31.01 | 31.01 |
| CHIL 5 | Bosques secundarios | | | | 15.49 | 6.12 | 21.61 |
| CHIL 5 | Matorrales y Rastrojos | | | 16.54 | 12.57 | 12.57 | 41.68 |
| CHIL 5 | Paja canalera | | 8.20 | 21.34 | | 12.33 | 41.88 |
| CHIL 5 | Pastizales | 2.34 | 30.39 | | | 16.50 | 49.24 |

Figure 62. Land Cover Disturbance at CHIL 5 (Created by Christopher Weekes and Paul Thurman).

White straw cover 41.68 hectares at CHIL 5. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 21.34 hectares.

Populated areas cover 31.01 hectares at CHIL 5. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 31.01 hectares.

At CHIL 6 the land cover associated with domestic waste generation are highlighted in green (see Figure 63). The land cover highlighted in blue are land cover associated with agricultural waste generation.




| | | Buffer Distance (in meters) | | | | |
|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 6 | Areas Pobladas | | | | | 6.17 | 6.17 |
| CHIL 6 | Bosques secundarios | | | | 10.63 | 5.25 | 15.88 |
| CHIL 6 | Matorrales y Rastrojos | | | 39.30 | 31.22 | 31.22 | 101.73 |
| CHIL 6 | Paja canalera | | 0.16 | 0.76 | | 0.54 | 1.46 |
| CHIL 6 | Pastizales | 6.14 | 70.32 | | | 34.42 | 110.89 |
| CHIL 6 | Suelos desprovistos de vegetacion | 2.06 | | | | 0.94 | 3.00 |

Figure 63. Land Cover Disturbance at CHIL 6 (Created by Christopher Weekes and Paul Thurman).

Grasslands cover the most hectares among the domestic and agricultural land cover designations at 110.89hectares. This cover is most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 100 to 200 meters at 70.32 hectares.

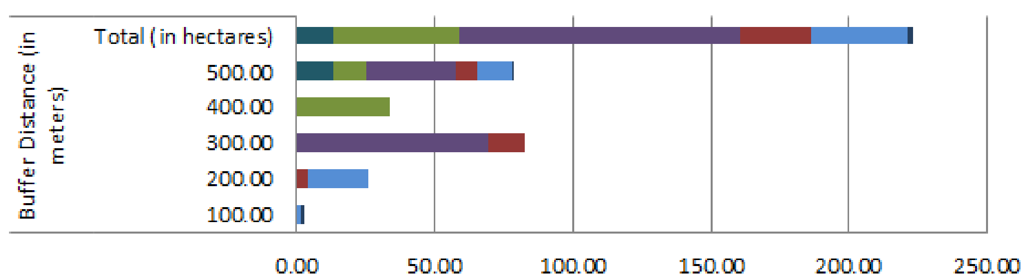
Shrubs and bushes cover 101.73 hectares at CHIL 6. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 and 300 meters at 39.30 hectares.

Populated areas cover 6.17 hectares at CHIL 6. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 6.17 hectares.

White straw cover 1.46 hectares at CHIL 6. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 0.76 hectares.

Bare soils cover 3.00 hectares at CHIL 6. This land coverage is most prevalent between 0 to 100 meters at 2.06 hectares.

**Land Cover Disturbance at CHIL 7**




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 7 | Areas Pobladas | | | | | 13.22 | 13.22 |
| CHIL 7 | Bosques secundarios | | | | 33.70 | 11.95 | 45.65 |
| CHIL 7 | Matorrales y Rastrojos | | | 69.24 | | 32.05 | 101.29 |
| CHIL 7 | Paja canalera | | 4.38 | 13.39 | | 8.08 | 25.85 |
| CHIL 7 | Pastizales | 1.15 | 21.71 | | | 12.55 | 35.40 |
| CHIL 7 | Suelos desprovistos de vegetacion | 1.27 | | | | 0.69 | 1.96 |

Figure 64. Land Cover Disturbance at CHIL 7 (Created by Christopher Weekes and Paul Thurman).

At CHIL 7 the land cover associated with domestic waste generation are highlighted in green (see Figure 64). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 101.29 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 69.24 hectares.

Grasslands cover 35.40 hectares at CHIL 7. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 and 200 meters at 21.71 hectares.

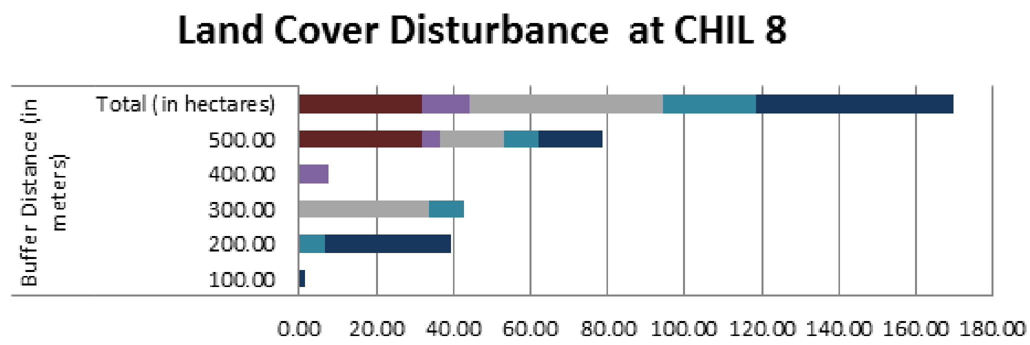
White straw cover 25.85 hectares at CHIL 7. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 13.39 hectares.

Populated areas cover 13.22 hectares at CHIL 7. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 13.22 hectares.

Bare soils cover 1.96 hectares at CHIL 7. This land coverage is most prevalent between 0 to 100 meters at 1.27 hectares.

At CHIL 8 the land cover associated with domestic waste generation are highlighted in green (see Figure 65). The land cover highlighted in blue are land cover associated with agricultural waste generation. Grasslands cover the most hectares among the domestic and agricultural land cover designations at 51.03 hectares. This cover is most prevalent at buffer distances between 0 meters to 500 meters with the highest coverage between 100 to 200 meters at 33.07 hectares.

Shrubs and bushes cover 49.87 hectares at CHIL 8. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 and 300 meters at 33.68 hectares.



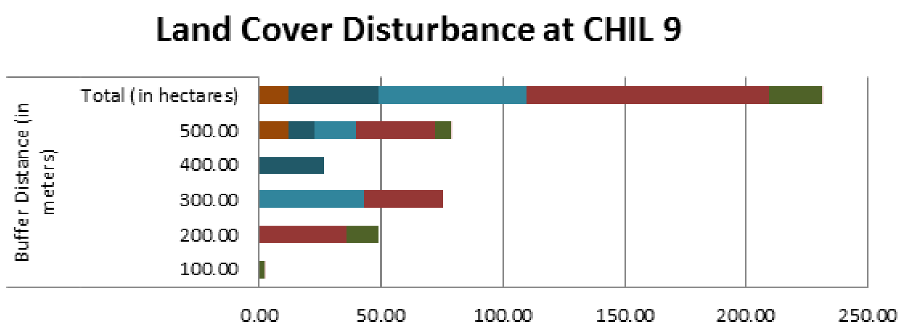

| | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|
| | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 8 Areas Pobladas | | | | | 31.95 | 31.95 |
| CHIL 8 Bosques secundarios | | | | 7.56 | 4.75 | 12.32 |
| CHIL 8 Matorrales y Rastrojos | | | 33.68 | | 16.18 | 49.87 |
| CHIL 8 Paja canalera | | 6.44 | 9.04 | | 9.04 | 24.51 |
| CHIL 8 Pastizales | 1.34 | 33.07 | | | 16.62 | 51.03 |

Figure 65. Land Cover Disturbance at CHIL 8 (Created by Christopher Weekes and Paul Thurman).

Populated areas cover 31.95 hectares at CHIL 8. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 31.95 hectares.

White straw cover 24.51 hectares at CHIL 8. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 200 to 300 meters at 9.04 hectares.

At CHIL 9 the land cover associated with domestic waste generation are highlighted in green (see Figure 66). The land cover highlighted in blue are land cover associated with agricultural waste generation. White straw cover the most hectares among the domestic and agricultural land cover designations at 100.04 hectares. This cover is most prevalent at buffer distances between 100 meters to 500 meters with the highest coverage between 100 to 200 meters at 35.70 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| CHIL 9 | Areas Pobladas | | | | | 12.19 | 12.19 |
| CHIL 9 | Bosques secundarios | | | | 26.60 | 10.40 | 37.00 |
| CHIL 9 | Matorrales y Rastrojos | | | 42.91 | | 17.34 | 60.25 |
| CHIL 9 | Paja canalera | | 35.70 | 32.17 | | 32.17 | 100.04 |
| CHIL 9 | Pastizales | 1.83 | 13.40 | | | 6.37 | 21.60 |
| CHIL 9 | Suelos desprovistos de vegetacion | 0.27 | | | | 0.06 | 0.33 |

Figure 66. Land Cover Disturbance at CHIL 9 (Created by Christopher Weekes and Paul Thurman).

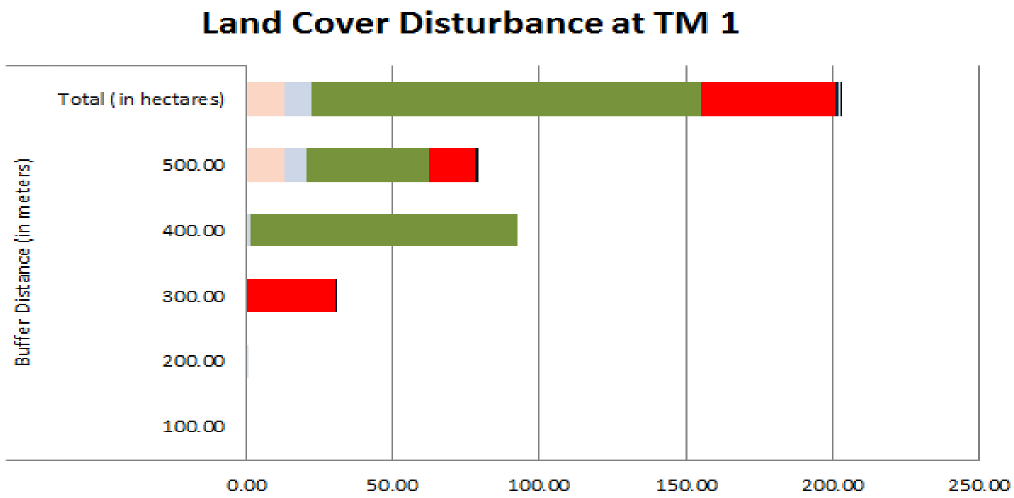
Shrubs and bushes cover 60.25 hectares at CHIL 9. This land coverage is most prevalent at buffer distances between 200 to 500 meters with the highest coverage between 200 and 300 meters at 42.91 hectares.

Grasslands cover 21.60 hectares at CHIL 9. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 to 200 meters at 13.40 hectares.

Populated areas cover 12.19 hectares at CHIL 9. This land coverage is most prevalent and has the highest coverage between 400 to 500 meters at 12.19 hectares.

Bare soils cover 0.33 hectares at CHIL 9. This land coverage is most prevalent between 0 to 100 meters at 0.27 hectares.

**Region 3**



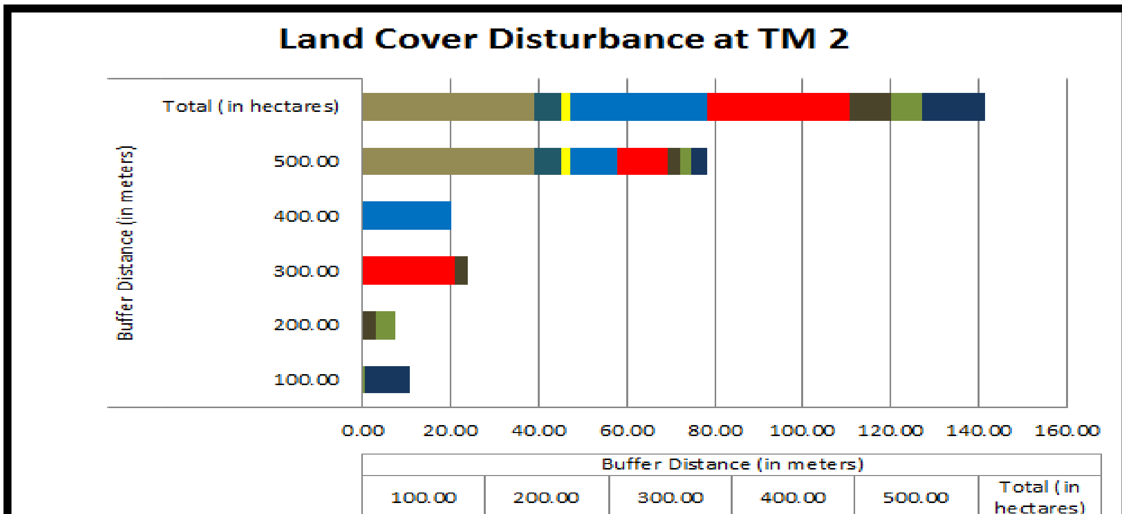

| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| TM1 | Agua | | | | | 13.21 | 13.21 |
| TM1 | Bosques maduros | | | | 1.47 | 7.67 | 9.14 |
| TM1 | Bosques secundarios | | | | 91.13 | 41.76 | 132.89 |
| TM1 | Matorrales y Rastrojos | | | 30.31 | | 15.52 | 45.83 |
| TM1 | Paja canalera | | 0.56 | 0.29 | | 0.29 | 1.14 |
| TM1 | Pastizales | | 0.06 | | | 0.06 | 0.13 |
| TM1 | Suelos desprovistos de vegetacion | 0.02 | | | | 0.02 | 0.04 |

Figure 67. Land Cover Disturbance at TM1 (Created by Christopher Weekes and Paul Thurman).

At TM1 the land cover associated with domestic waste generation are highlighted in green (see Figure 67). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 45.83 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 30.31 hectares.

Grasslands cover 5.98 hectares at TM1. This land coverage is most prevalent at buffer distances between 100 to 500 meters with the highest coverage between 100 to 200 meters at 3.81 hectares.

Bare soils cover 0.04 hectares at TM1. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 0 and 100 meters and 400 and 500 meters at 0.02 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total ( in hectares) |
| TM2 | Agua | | | | | 38.95 | 38.95 |
| TM2 | Areas Pobladas | | | | | 6.30 | 6.30 |
| TM2 | Bosques maduros | | | | 0.34 | 1.86 | 2.20 |
| TM2 | Bosques secundarios | | | | 20.08 | 10.61 | 30.69 |
| TM2 | Matorrales y Rastrojos | | | 21.03 | | 11.66 | 32.69 |
| TM2 | Paja canalera | | 3.21 | 2.97 | | 2.97 | 9.14 |
| TM2 | Pastizales | 0.56 | 4.26 | | | 2.30 | 7.13 |
| TM2 | Suelos desprovistos de vegetacion | 10.18 | | | | 3.88 | 14.06 |

Figure 68. Land Cover Disturbance at TM2 (Created by Christopher Weekes and Paul Thurman).

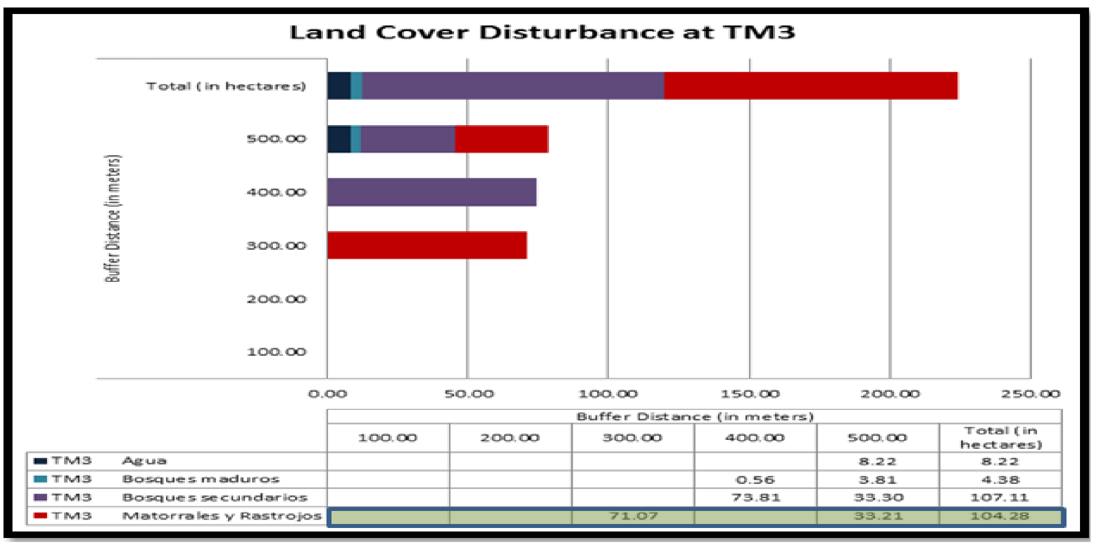
At TM2 the land cover associated with domestic waste generation are highlighted in green (see Figure 68). The land cover highlighted in blue are land cover associated with agricultural waste generation. Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 32.69 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 21.03 hectares.

Bare soils cover 14.06 hectares at TM2. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 0 and 100 meters at 10.18 hectares.

White straw cover 9.14 hectares at TM2. This land coverage is most prevalent at buffer distances between 100 meters to 500 meters with the highest prevalence occurring between 100 to 200 meters at 3.21 hectares.

Grasslands cover 7.13 hectares at TM2. This land coverage is most prevalent at buffer distances between 0 to 500 meters with the highest coverage between 100 to 200 meters at 4.26 hectares.

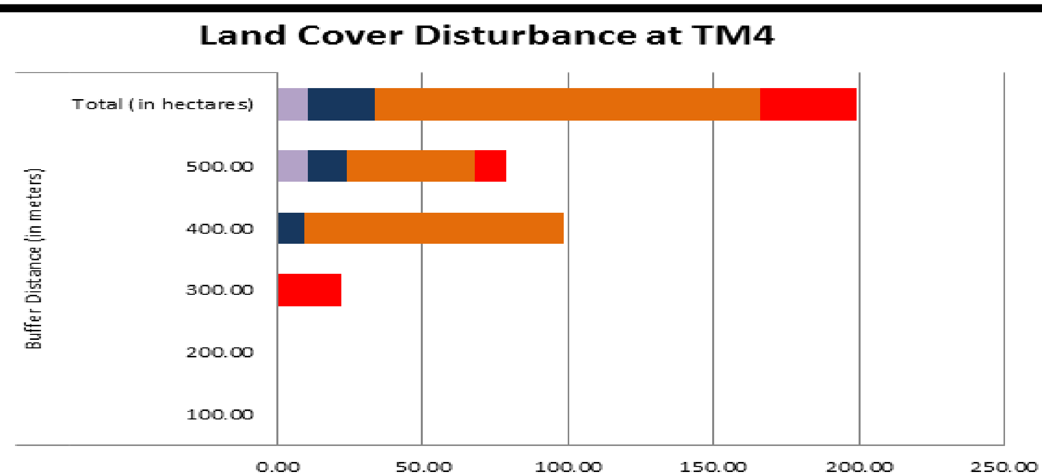
Populated areas cover 6.30 hectares at TM2. The land coverage is most prevalent between 400 to 500 hectares from TM2.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| TM3 | Agua | | | | | 8.22 | 8.22 |
| TM3 | Bosques maduros | | | | 0.56 | 3.81 | 4.38 |
| TM3 | Bosques secundarios | | | | 73.81 | 33.30 | 107.11 |
| TM3 | Matorrales y Rastrojos | | | 71.07 | | 33.21 | 104.28 |

Figure 69. Land Cover Disturbance TM3 (Created by Christopher Weekes and Paul Thurman).

At TM3 the land cover associated with domestic waste generation are highlighted in green (see Figure 69). Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 104.28 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 71.07 hectares.




| | | Buffer Distance (in meters) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 100.00 | 200.00 | 300.00 | 400.00 | 500.00 | Total (in hectares) |
| TM4 | Agua | | | | | 10.32 | 10.32 |
| TM4 | Bosques maduros | | | | 9.28 | 13.86 | 23.14 |
| TM4 | Bosques secundarios | | | | 89.38 | 43.45 | 132.83 |
| TM4 | Matorrales y Rastrojos | | | 22.28 | | 10.91 | 33.19 |

Figure 70. Land Cover Disturbance at TM4 (Created by Christopher Weekes and Paul Thurman).

At TM4 the land cover associated with domestic waste generation are highlighted in green (see Figure 70). Shrubs and bushes cover the most hectares among the domestic and agricultural land cover designations at 33.19 hectares. This cover is most prevalent at buffer distances between 200 meters to 500 meters with the highest coverage between 200 to 300 meters at 22.28 hectares.

## Discussion

### Best management practices (BMPs)

There is a pressing need to understand the influence of human activities on water quality—particularly in tropical environments (Uriarte, et.al, 2011). This task is challenging because of the varying responsiveness of water quality indicators in heterogeneous landscapes (Uriarte, et.al, 2011). Nonetheless, planning of sustainable development should consider multiple spatial scale approaches to enhance and or protect water quality (Darmawan, 2010).

Best Management Practices (BMPs) are methods used to reverse adverse environmental impacts of development (Municipal Research and Service Center of Washington, 2012). The primary purpose of implementing BMPs is to protect water resources by reducing pollutant loads and concentrations by treating runoff and reducing pollutant discharges from their source(s) (Municipal Research and Service Center of Washington, 2012). Generally, controlling the source of contamination is more cost effective than runoff treatment; however, the former is not holistically preventive—other control methods are needed to minimize pollution (Municipal Research and Service Center of Washington, 2012).

The following recommendations for technical and non-technical sustainable waste management solutions in the different zones of the study area were based on *Defra's 4E Behavioral Change Framework* (see Figure 71) (Department for Environment Food and Rural Affairs, 2008). This framework considers that waste reduction and prevention are based on behavioral change that is recommended on the household level, community level, and regional and national levels of government. Overall, the framework focuses on the need for (Department for Environment Food and Rural Affairs, 2008):

- Enabling – people need to make responsible choices
- Engaging – people need to be involved early in the creation of waste management initiatives so they understand the value of the project and take personal responsibility
- Encouraging – appropriate role of taxes, economic instruments (i.e. landfill taxes) and incentives (in the form of evaluation of programs)
- Exemplifying—what behavior can reinforce commitment from others

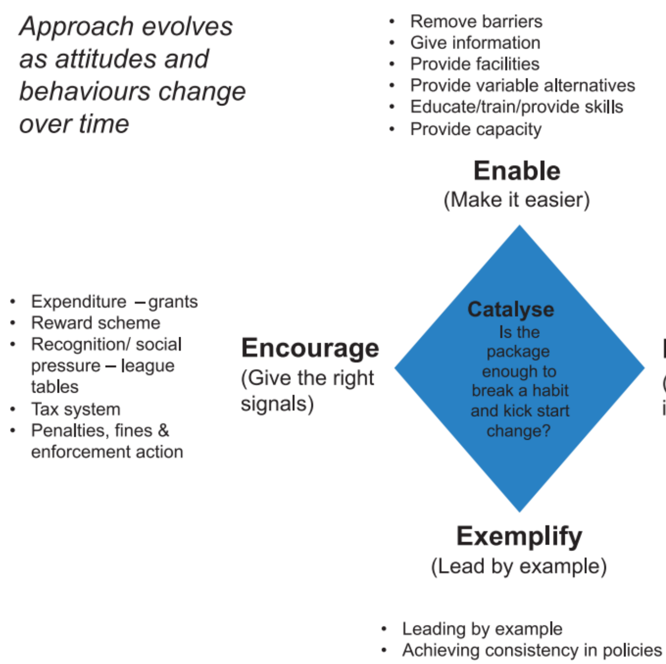



Figure 71. Defra's 4E Behavioral Change Framework (Department for Environment Food and Rural Affairs, 2008).

Relatively simple wastewater treatment technologies can be designed to provide low costs sanitation and environmental protection throughout Latin America and the Caribbean (Perez, 2005). There are three principle types of wastewater treatment systems: mechanical, aquatic, and terrestrial (see Figure 72). Mechanical treatment systems utilize natural processes within a constructed environment when there is not adequate space for the implementation of natural system technologies (Perez, 2005). Aquatic treatment systems are used to treat a variety of wastewaters and are functional across a range of environmental conditions (Perez, 2005). Terrestrial treatment systems convert nutrients contained in wastewaters into less biologically available forms of biomass which can be harvest for a variety of uses (Perez, 2005).

| Treatment Type | Advantages | Disadvantages |
|---|---|---|
| *Aquatic Systems* | | |
| Stabilization lagoons | Low capital cost<br>Low operation and maintenance costs<br>Low technical manpower requirement | Requires a large area of land<br>May produce undesirable odors |
| Aerated lagoons | Requires relatively little land area<br>Produces few undesirable odors | Requires mechanical devices to aerate the basins<br>Produces effluents with a high suspended solids concentration |
| *Terrestrial Systems* | | |
| Septic tanks | Can be used by individual households<br>Easy to operate and maintain<br>Can be built in rural areas | Provides a low treatment efficiency<br>Must be pumped occasionally<br>Requires a landfill for periodic disposal of sludge and septage |
| Constructed wetlands | Removes up to 70% of solids and bacteria<br>Minimal capital cost<br>Low operation and maintenance requirements and costs | Remains largely experimental<br>Requires periodic removal of excess plant material<br>Best used in areas where suitable native plants are available |
| *Mechanical Systems* | | |
| Filtration systems | Minimal land requirements; can be used for household-scale treatment<br>Relatively low cost<br>Easy to operate | Requires mechanical devices |
| Vertical biological reactors | Highly efficient treatment method<br>Requires little land area<br>Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment | High cost<br>Complex technology<br>Requires technically skilled manpower for operation and maintenance<br>Needs spare-parts-availability<br>Has a high energy requirement |
| Activated sludge | Highly efficient treatment method<br>Requires little land area<br>Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment | High cost<br>Requires sludge disposal area (sludge is usually land-spread)<br>Requires technically skilled manpower for operation and maintenance |

Figure 72. Advantages and disadvantages of conventional and non-conventional wastewater treatment technologies (Perez, 2005).

**Aquatic systems**

A wastewater lagoon (or treatment pond) is 0.91 to 2.29 meters deep with side slopes between 2.5:1 and 3:1 (United States Environmental Protection Agency, 2004; NewFoundland Labrador Canada, 2010). It is comprised of an aerobic zone near the water surface, an anaerobic zone near and on the bottom of the pond where the sludge deposits, and an intermediate zone known as the facultative zone (at a depth around 0.61 meters (NewFoundland Labrador Canada, 2010)) where bacteria can decompose organic matter depending on oxygen availability (see Figures 73 & 74) (United States Environmental Protection Agency, 2004).

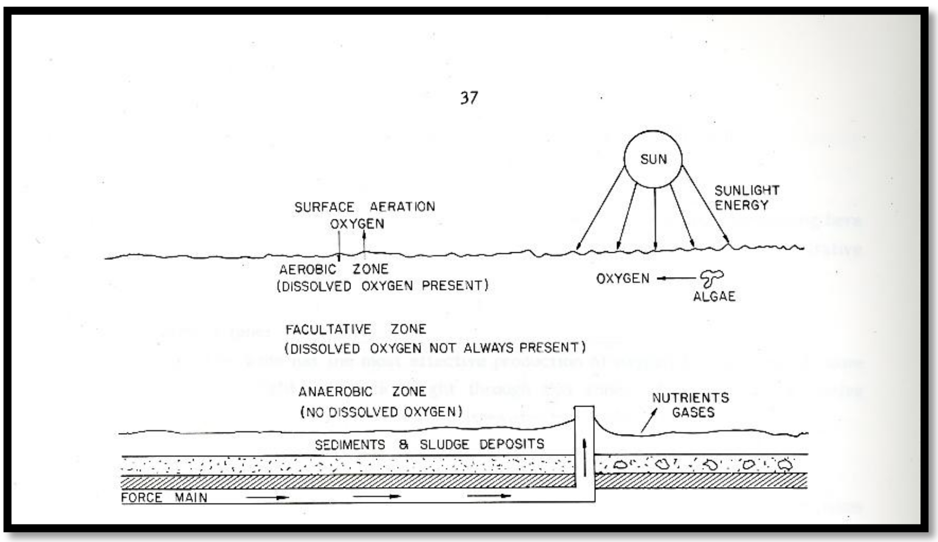



Figure 73. Zonation of wastewater lagoon (NewFoundland Labrador Canada, 2010).

Facultative ponds (or raw sewage stabilization pond) are the most common form of aquatic treatment lagoon technology (Perez, 2005). These ponds are open to air and sunlight which enable the exchange of oxygen and sunlight (thermal) energy (NewFoundland Labrador Canada, 2010). Algae introduced to the system grow in the presence of sunlight and dissolved carbon dioxide to produce new algae and dissolved oxygen.

Figure 74. Wastewater lagoon (United States Environmental Protection Agency, 2004).

The dissolved oxygen reacts with organic wastes which are then consumed by aerobic bacteria in a process known as oxidation in the aerobic zone. That which is not consumed by aerobic bacteria is consumed by facultative bacteria (at moderate levels of dissolved oxygen in the system) and anaerobic bacteria (with no oxygen). The bacteria produce dissolved methane, hydrogen sulfide, carbon dioxide and new bacteria. The dissolved carbon dioxide is used by algae and the new bacteria degrade organic wastes.  Overall, these systems are designed to reduce/remove BOD and TSS that range from 150 to 250 $\frac{mg}{L}$ for normal domestic sewage respectively.

The major advantages of facultative ponds is that (Mountain Empire Community College, 2008):

- They do not require equipment to transfer oxygen to the water
- They are very simple to construct
- They are very cost-effective requiring only one visit a day to monitor pH and DO, they are effective at the removal of pathogens
- They can deal with fluctuations in waste water flows

- ‘with a retention time of at least 22 days it is the only treatment system considered by WHO to achieve the effluent standard required for unrestricted irrigation’ (The World Bank Group, 2013, para 12).

The major disadvantages of facultative lagoons are (The World Bank Group, 2013):

- They requires a large land area (3 to 5 $m^2$ per person) to retain sewage compared to municipal treatment facilities
- They can create excessive amounts of algae that can deplete the water’s dissolved oxygen
- They have detention times of 45 days compared to a couple hours for municipal treatment facilities (Mountain Empire Community College, 2008)

Based on the removal potential of facultative ponds for pathogens (i.e. E.coli), total coliforms, BOD, and TSS in addition to size requirements of the facility CHIL 3 was determined to be the most suitable site for the placement of system. CHIL 3 was dominated by 130.76 hectares of land most closely related to swine waste generation with the highest coverage of pastureland at 66.46 hectares occurring between 100 to 200 meters from the monitoring station.

**Terrestrial wastewater treatment systems**

Constructed Wetlands are often used in tandem with wastewater treatment lagoons and function as polishing ponds. Polishing ponds remove solids, fecal coliforms, and some nutrients (i.e. ammonia) from the facultative pond effluent (Mountain Empire Community College, 2008). Generally, a constructed wetland is a treatment system that is designed to treat wastewater passing through a wetland (United States Environmental Protection Agency, 2004). These wetlands are different from natural wetlands in that the plant and soil microbes are greatly simplified (typically monocultures), design and operation are modified to meet higher pollution capacity, climate variation, and treatment standards for effluent (Fuchs, 2009).

There are two types of constructed wetlands: free-water surface (FWS) wetland and subsurface flow (SSF) wetland (Fuchs, 2009).

In the FWS system, the majority of the surface area has aquatic plants rooted below the water surface (Fuchs, 2009). Water travels over the ground material (soil or sand) and through the aquatic plant stems (Fuchs, 2009). There are three zones through which the influent water travels (see Figure 75).

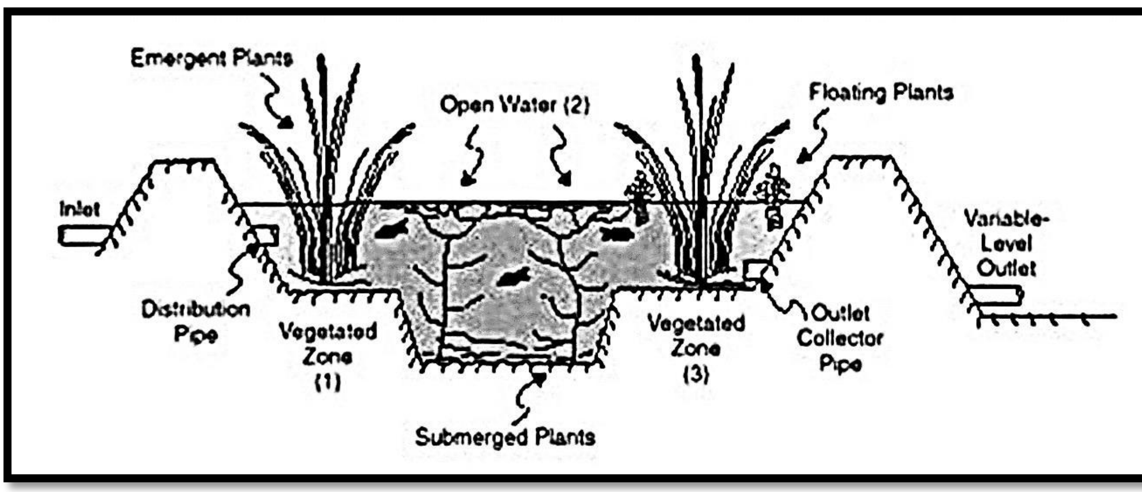



Figure 75. FWS constructed wetland (Newton, 2006).

Zones 1 and 3 are zones with significant vegetation and DO concentrations close to 0 $\frac{mg}{L}$. Zone 2, the area with no surface vegetation is exposed to open air and sunlight which facilitates oxygen transfer (Fuchs, 2009). Zone 2 may have submerged vegetation which can enhance DO content in the water column (Fuchs, 2009). Aeration of the influent is enabled by angling the inlet pipe downward (Fuchs, 2009). Having the three zones in series increases retention time of the influent and increase influent quality (see Figure 75) (Newton, 2006).

Figure 76 shows the removal efficiency of the different zones. The main components of the influent wastewater that are removed by FWS wetlands are BOD, TSS, phosphorus, fecal coliforms and pathogens, and metals (Newton, 2006).

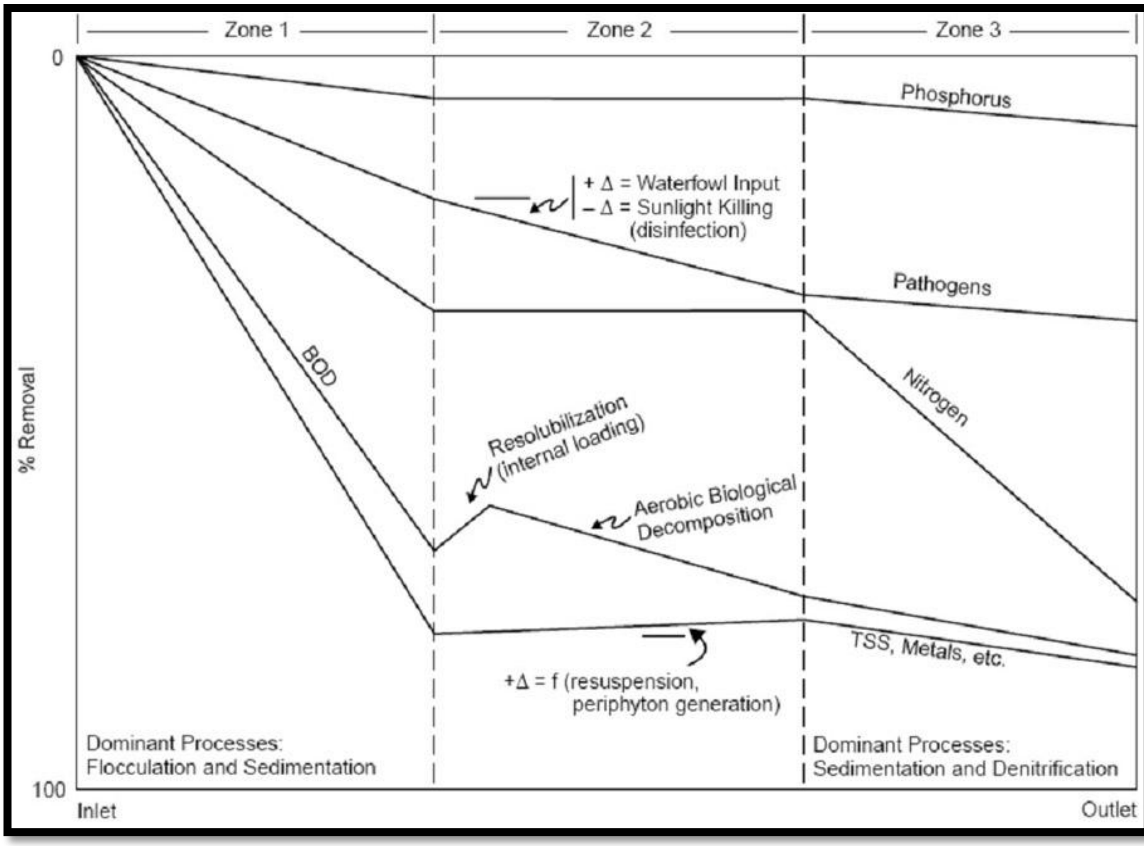



Figure 76. Generic pollution removal in a 3-zone FWS wetland (Newton, 2006).

Figure 77 shows the characteristics of plants used in constructed wetlands. Some factors to consider when planting vegetation in FWS wetlands are covered are covered in Figure 78.

Some advantages and disadvantages of FWS constructed wetlands are included in Table 9.

Table 9 Advantages and disadvantages of FWS constructed wetlands (Northern Arizona University, 2002; Newton, 2006).

| Advantages | Disadvantages |
|---|---|
| **Inexpensive to build and maintain** | Require more land area that other treatment options |
| **Require little to no energy to operate** | Surface flow can attract pests |
| **Can provide tertiary treatment** | Not affective at phosphorus removal |
| **Can provide additional wildlife habitat** | Treatment varies with different climates conditions |
| **Aesthetically pleasing additions to homes and neighborhoods** | Prolonged period before vegetation is established |
| **Self-sustaining system** | Odorous |
| **Effective BOD, TSS, pathogen and nutrient removal** | May expose humans and animals to pathogens |

| General Types of Plants | General Characteristics and Common Examples | Function or Importance to Treatment Process | Function or Importance for Habitat | Design & Operational Considerations |
|---|---|---|---|---|
| Free-Floating Aquatic | Roots or root-like structures suspended from floating leaves. Will move about with water currents. Will not stand erect out of the water. Common duckweed (Lemna), Big duckweed (Spirodela). | Primary purposes are nutrient uptake and shading to retard algal growth. Dense floating mats limit oxygen diffusion from the atmosphere. Duckweed will be present as an invasive species. | Dense floating mats limit oxygen diffusion from the atmosphere and block sunlight from submerged plants. Plants provide shelter and food for animals. | Duckwood is a natural invasive species in North America. No specific design is required. |
| Rooted Floating Aquatic | Usually with floating leaves, but may have submerged leaves. Rooted to bottom. Will not stand erect out of the water. Water lily (Nymphea), Pennywort (Hydrocotyle). | Primary purposes are providing structure for microbial attachment and releasing oxygen to the water column during daylight hours. Dense floating mats limit oxygen diffusion from the atmosphere. | Dense floating mats limit oxygen diffusion from the atmosphere and block sunlight from submerged plants. Plants provide shelter and food for animals. | Water depth must be designed to promote the type of plant (i.e. floating, submerged, emergent) desired while hindering other types of plants. |
| Submerged Aquatic | Usually totally submerged; may have floating leaves. Rooted to bottom. Will not stand erect in air. Pondweed (Potamogeton), Water weed (Elodea). | Primary purposes are providing structure for microbial attachment and providing oxygen to the water column during daylight hours. | Plants provide shelter and food for animals (especially fish). | Retention time in open water zone should be less than necessary to promote algal growth which can destroy these plants through sunlight blockage. |
| Emergent Aquatic | Herbaceous (i.e. non-woody). Rooted to the bottom. Stand erect out of the water. Tolerate flooded or saturated conditions. Cattail (Typha), Bulrush (Scirpus), Common Reed (Phragmites). | Primary purpose is providing structure to induce enhanced flocculation and sedimentation. Secondary purposes are shading to retard algal growth, windbreak to promote quiescent conditions for settling, and insulation during winter months. | Plants provide shelter and food for animals. Plants provide aesthetic beauty for humans. | Water depths must be in the range that is optimum for the specific species chosen (planted). |
| Shrubs | Woody, less than 6 m tall. Tolerate flooded or saturated soil conditions. Dogwood (Cornus), Holly (Ilex). | Treatment function is not defined: it is not known if treatment data from unsaturated or occasionally saturated phytoremediation sites in upland areas is applicable to continuously saturated wetland sites. | Plants provide shelter and food for animals (especially birds). Plants provide aesthetic beauty for humans. | Possible perforation of liners by roots. |
| Trees | Woody, greater than 6 m tall. Tolerate flooded or saturated soil conditions. Maple (Acer). Willow (Salix). | (same as for shrubs) | (same as for shrubs) | (same as for shrubs) |

Figure 77. Characteristics of plants used in constructed wetlands (Newton, 2006).

Based on nitrate values (Figure 37), the greatest variability in the current study area was at CHIL 5. CHIL 5 did not demonstrate outstanding variability for Phosphate, E. coli, Total Coliform, or BOD. TSS values at CHIL 5 were dominant above the median. The application of the FWS system at CHIL 5 is contingent on the criteria standards for phosphate, E.coli, Total Coliforms and TSS for the Chilibre River. For TSS, the warning limits for surface waters is 440 $\frac{mg}{L}$ (Envirocon, 2006). CHIL 5 was adjacent to the Chilibre CHIL 5 was dominated by pastureland between 100 and 200 meters from the water monitoring station; this would be an ideal location for the FWS wetland.

Phosphate values were most variable was at CHIL 3. CHIL 3 did not display major variability for nitrate, E. coli, TSS, or BOD. Total coliform values at CHIL 3 were mostly above the median. CHIL 3 was dominated by pastureland 100 to 200 meters from the water monitoring station; however, the FWS wetland is not ideal for phosphorus removal. The application of the FWS wetland would most likely be for the abatement of Total Coliforms. There are various factors to consider when applying FWS wetlands (see Figure 78).

BOD values were most variable was at CHIL 1. CHIL 1 show little variability for nitrate, E.coli, Total coliform, TSS, or phosphate. TSS values at CHIL 1 were most prevalent above the median. This site was dominated by shrubs and bushes 200 to 300 meters from the water monitoring station. The application of the FWS wetland here would most likely be for the reduction of BOD.

TSS values were most variable was TM3. However, TM3 did not demonstrate great variability for BOD, nitrate, phosphate or Total coliform. E. coli values at TM3 were mostly above the median. TM3 was dominant by shrubs and bushes 200 to 300 meters from the water monitoring station. The application of the FWS wetland here would most likely be for the reduction of TSS.

E. coli values were most variable was CHIL 8, but Total coliform, BOD, nitrate, phosphate or TSS did not display much variability from other sites. E. coli values at CHIL 8 were mostly above the median. CHIL 8 was dominant by pastureland 100 to 200 meters from the water monitoring station. The application of the FWS wetland here would most likely be for the reduction of E.coli.

Total coliform values (see appendix) were most variable was CHIL 3. Little variability, however, was noted E. coli, nitrate, or TSS. Phosphate and BOD values at CHIL 3 were above the median. CHIL 3 was dominant by pastureland 100 to 200 meters from the water monitoring station. The application of the FWS wetland here would most likely be for the reduction of BOD, Total coliforms, and phosphate.

| Factors | Comments |
|---|---|
| Consult local experts | The number of professional wetland scientists, practitioners, and plant nurseries has increased dramatically in the past 10 years. Help from an experienced, local person should be available from a variety of sources, including government agencies and private companies. |
| Native species | Using plants that grow locally increases the likelihood of plant survival and acceptance by local officials. |
| Invasive or aggressive species | Plants that have extremely rapid growth, lack natural competitors, or are allelopathic* can crowd out all other species and destroy species diversity. State or local agencies may ban the use of some species. |
| Tolerant of high nutrient load | Unlike natural wetlands, constructed wetlands will receive a continuous inflow of wastewater with high nutrient concentrations. Plants that can not tolerate this condition will not survive. |
| Tolerant of continuous flooding | Unlike natural wetlands, which may experience periodic or occasional dry periods, constructed wetlands will receive a continuous inflow of wastewater. Plants that require periodic or occasional drying as part of their reproductive cycle will not survive. |
| Growth characteristics | Perennial plants are generally preferred over annual plants because plants will continue growing in the same area and there is no concern about seeds being washed or carried away. For emergent species, persistent plants are generally preferred over semi- or non-persistent plants because the standing plant material provides added shelter and insulation during the winter season.† |
| Available form for planting | Costs of obtaining and planting the plants will vary depending on the form of planting material, which may be available in a variety of forms depending on the plant species. Entire plant forms (e.g. bare root plants or plugs) wi usually cost more than partial plant material (e.g. seeds or rootstock), but the plant supplier may guarantee a higher survival rate.‡ |
| Rate of growth | Slower growing plants will require a greater number of plants, planted closer together, at start-up to obtain the same density of plant coverage in the initial growing season. |
| Wildlife benefits | If the wetland is to be used for habitat, plants that provide food, shelter/cover and nesting/nursery for the desired animals should be chosen. |
| Plant diversity | Mono-cultures of plants are more susceptible to decimation by insect or disease infestations; catastrophic infestations will temporarily affect treatment performance. Greater plant diversity will also tend to encourage a greater diversity of animals. |

* Allelopathic - plants that have harmful effects on other plants by secreting toxic chemicals
† Perennial - aboveground portion dies, but below-ground portion remains dormant and sprouts in the next growing season.
Annual - entire plant dies and reproduction is only by seed produced before the plant dies.
Persistent - aboveground dead portions remain upright through the dormant season.
Semi-persistent - aboveground dead portions may remain standing for some part of the dormant season before falling into clumps.
Non-persistent - aboveground dead portions decay and wash away at the end of the growing season.
‡ Bare root plant - seedling with soil washed from roots. Plug - seedling with soil still on roots. Rootstock - piece of underground stem (rhizome).

Figure 78. Factors to consider in plant selection for FWS Wetlands (Newton, 2006).

SSF wetlands (also referred to as *reed beds* and *vegetated submerged beds*) use gravel as the medium for aquatic vegetation (Fuchs, 2009). The gravel functions as a permeable medium for the influent water to flow through (Newton, 2006). Flow can be vertical or horizontal though the latter is typical for continuous, gravity-fed systems (Fuchs, 2009). Figure 79 depicts the zones in the SSF wetland which function and are designed similarly to FWS wetland (Newton, 2006).

Some advantages and disadvantages of SSF constructed wetlands are included in Table 10.

Table 10. Advantages and Disadvantages of SSF constructed wetlands (Newton, 2006).

| **Advantages** | **Disadvantages** |
|---|---|
| **Quick start up** | Requires complicated operation to achieve nitrogen removal (compared to FWS systems) |
| **Limited human contact with primary effluent** | Higher costs of media |
| **Few Mosquito and Vector problems** | Less aesthetic and wildlife value than FWS wetlands |

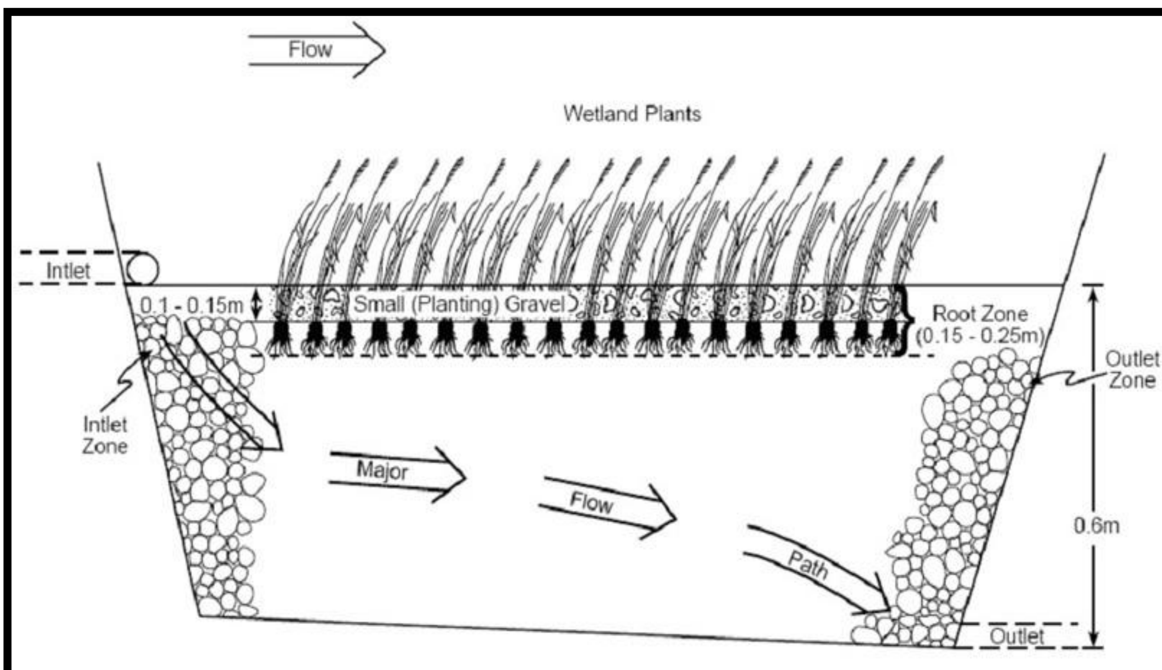



Figure 79. Zonation of SSF wetland (Newton, 2006).

SSF wetlands would be most suitable at CHIL 3 because this treatment technology is better than FWS at phosphorus removal. At CHIL 3, there is also an added benefit of BOD reduction with the application of SSF wetlands.

The application of either technology is ideal for small communities that have plentiful land and small budgets (Newton, 2006). The required space for constructed wetlands is dependent on the design and the hydraulic loading rates of influent wastewater (Newton, 2006).

**Mechanical wastewater treatment systems**

Mechanical treatment technologies utilize biological and chemical processes as well as mechanical components (i.e. pumps, blowers, screens, etc.) to treat wastewaters (Perez, 2005). There are three major types of mechanical systems (see Figure 80): filtrations systems, vertical biological reactors, and activated sludge systems that are subdivided as either attached growth or suspended growth systems.

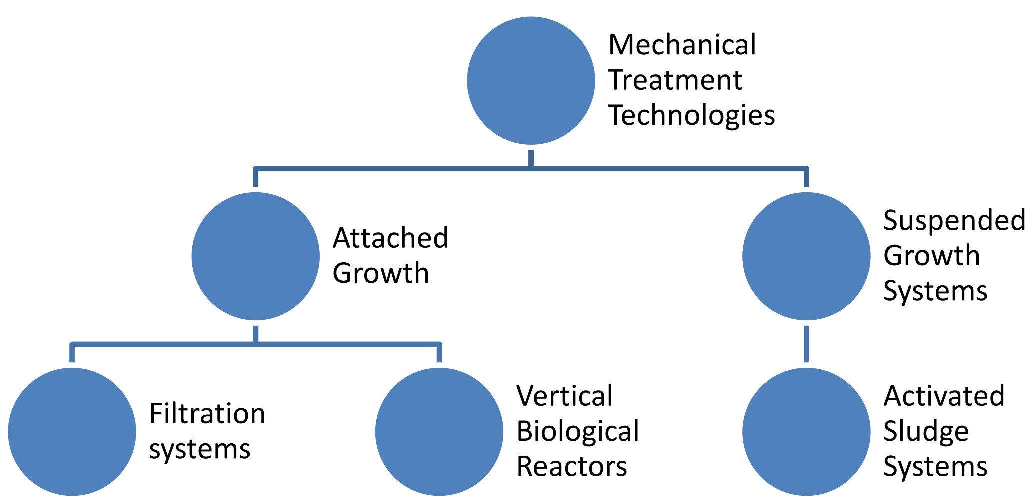



Figure 80. Mechanical treatment technology types (Adapted from the Water Environment Federation).

Suspended growth systems allow microorganisms to float freely in water. These microorganisms break down organic material and other constituents in the wastewater into secondary products that can be incorporated into the microorganism cell mass, or removed through physical processes such as settling, gaseous stripping, and other physical means (Water Environment Federation, 2009). Suspended growth systems are primarily aerobic processes typically referred to as activated sludge; however, there are also strictly anaerobic suspended growth processes for liquid-phase treatment.

Attached growth (or fixed film) systems, unlike the waste-consuming bacteria in the activated sludge process, cling to a natural or manmade surfaces comprised of media such as gravel, sand, specially woven fabric or plastic to perform water treatment (National Small Flows Clearinghouse, 2004). The dissolved organic material that is produced by the microorganisms adheres to a film that develops on the media surface. The microorganisms in attached growth media systems are primarily aerobic (National Small Flows Clearinghouse, 2004).

The main advantages of attached growth processes over suspended growth processes are they require less energy, have simpler operation, have no bulking issues, require less maintenance, and recover better from shock loads (National Small Flows Clearinghouse, 2004). Some disadvantages of attached growth systems compared to suspended growth systems are that they require a larger land area, operate less efficiently in cold weather, and are more odorous (National Small Flows Clearinghouse, 2004).

Trickling filters provide low-costs and low maintenance biological wastewater treatment in areas where large tracts of land are not available.  The influent wastewater is pumped upward through distribution arms where the liquid is trickled over the filter media. The filter media is comprised of the afore mentioned material and biofilms which form when groups of bacteria secrete a protective matrix (or biofilms) which enable the community of bacteria to adhere to almost any surface. In the trickling filter system, these biofilms are where bacteria break down organic matter. Once the biofilm reaches a certain thickness it sloughs off or can be removed manually. The treated liquid that passes through the biofilm is collected and pumped (as effluent) to sedimentation tanks (see Figure 81). In these tanks solids are separated from the treated wastewater with filters.

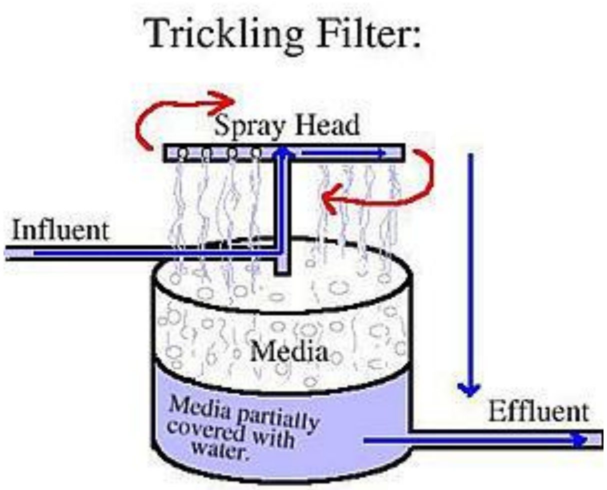



Figure 81. Trickling filter wastewater treatment process (Mountain Empire Community College, 2003).

In most wastewater treatment systems, trickling filters follow primary treatment (screens, grit chambers, and primary sedimentation of sludge). These systems are used primarily to remove BOD and suspended solids.

The application of the trickling filter would be most suitable for land areas around TM3, TM4, CHIL 1, CHIL 6, and CHIL 9 which all had the majority of their measurements above the median value for total suspended solids (TSS). Among these stations, CHIL 1 had BOD values that were dominant above the median. In the interest of minimizing costs and focusing on sites in most need of a best management practice, CHIL 1 was characterized predominantly by 35.71 hectares of shrubs and bushes that were 300 to 500 meters from the water quality monitoring station. This land cover was most closely associated with human activity and domestic waste water streams. The application of tricking filter systems in the 300 to 500 meter buffer distance from CHIL 1 might be effective at removing suspended materials and BOD, but will be less effective at removing soluble organics.

Vertical biological reactors (or Vertical loop reactors (VLRs) for biological treatment) are effective for BOD, ammonia and phosphorus removal. Ammonia and phosphorus were not reported in this study; however, industrial applications of the VLRs may help to abate excessive storm water loads during peak flow periods.

VLR are oxidation ditches that are oriented vertically characterized by a horizontal baffle which compartmentalize mixed liquor and improve aeration (see Figure 82). Oxidation ditches are circular basins through which wastewater flows (Mountain Empire Community College, 2003). Activated sludge are added to oxidation ditches to allow microorganisms to digest the BOD in wastewater (Mountain Empire Community College, 2003). The mixture of activated sludge and wastewater is known as mixed liquor.

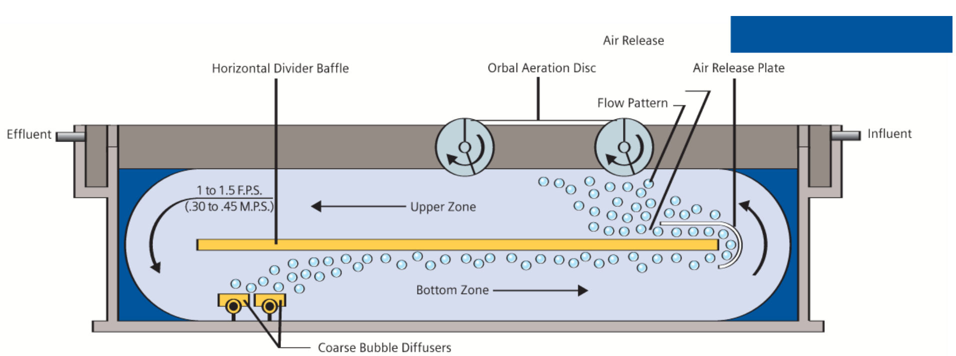



Figure 82. Vertical loop reactor (VLR) process (Siemens Water Technologies, 2006).

Oxygen is added to the mixed liquor by rotating biological contactors (RBCs) (Siemens Water Technologies, 2006). RBCs create wave action and movements in the mixed liquor which increase the DO and enhances the degredation of BOD by microorganisms (Siemens Water Technologies, 2006). When the BOD is removed, the mixed liquor flows out of the oxidation ditch, sludge is transported to aerobic digesters where it is thickened by aerator pumps (Siemens Water Technologies, 2006). Aerating sludge greatly reduces the amount of sludge produced (Siemens Water Technologies, 2006). The process continues where some of the sludge is returned to the oxidation ditch and some is sent to waste (see Figure 83).

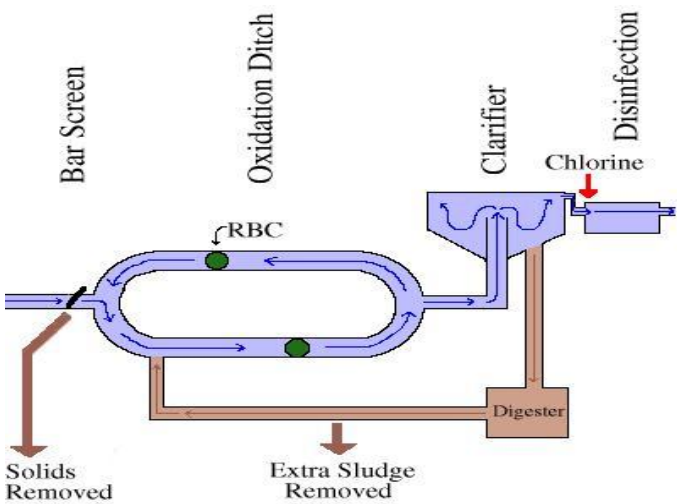



Figure 83. Oxidation Ditch Process (Mountain Empire Community College, 2003).

Oxidation ditches provide one of the most thorough process for treating sewage (Mountain Empire Community College, n.d., para 17). The major advantages of the oxidation ditch high quality effluent of BOD, TSS and ammonia (National Small Flows Clearinghouse, 2003), the process is unaffected by weather. In an oxidation ditch, approximately 15% of the incoming sludge ends up as BOD (Mountain Empire Community College, n.d.). Vertical biological reactors are suited to operate when land is limited and when BOD rates fluctuate widely (up to five times the design flow) (Mountain Empire Community College, n.d.).

A major disadvantage of oxidation ditches is that it is unable to treat toxic waste streams, has high energy requirements,  and has high monetary costs associated with BOD removal (up to US $350 per metric ton BOD removed) (National Small Flows Clearinghouse, 2003; Mountain Empire Community College, 2003). However, the VBR process is most economically attractive at BOD loading rates in the range of 9.07 to 18.14  kg BOD per 28.32 cubic meter per day (Siemens Water Technologies, 2006). Above 7.26  lb BOD per 28.32 cubic meters per day, aeration requirements are reduced when tanks are at least 12.2 meters long and 3.6 meters deep (Siemens Water Technologies, 2006). Another drawback is the fact that contaminants such as sulfur dioxide are released into the atmosphere from coal-burning plants used to generate electricity for the process (Mountain Empire Community College, 2003).

A suitable application of the VLRs would be at CHIL 1, CHIL3, and CHIL 6 had the most variable BOD values. The most prevalent land cover designation at CHIL 1  were shrubs and bushes from 300 meters to 500 meters from the water qualiy monitoring station. At CHIL 3, pastureland was most prevalent between 100 to 200 meters from the sampling station. Pastureland was also the most prevalent land cover at CHIL 6 between 100 to 200 meters.

Activated sludge systems are biological treatment processes that use suspended growth of microorganisms to remove BOD and suspended solids (Mountain Empire Community College, n.d.).    All activated sludge systems include an aeration tank followed by a settling tank. From the settling tank, the mass of aerated precipitated sewage is returned to the the aeration tank where it is brought into contact with untreated sludge. The contact of plant influent and returned activated sludge (RAS) for mix liquor  hasten decomposition by microorganisms (see Figure 84).

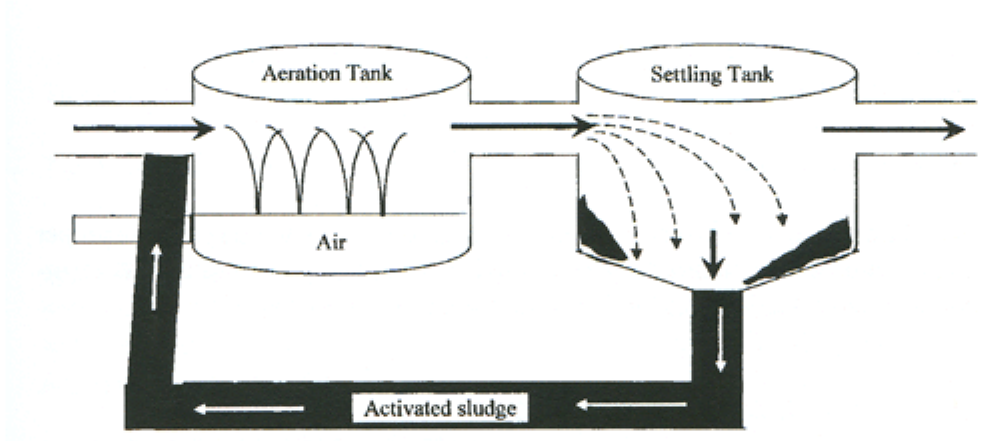



Figure 84. Primary components of activated sludge systems (Completely Mixed Activated Sludge Process) (Mountain Empire Community College, 2008).

The mixed liquor is aerated and the activated sludge organisms use available organic matter as food to produce more stable solids and more activated sludge microorganisms. Solids are seperated from the wastewater in the settling tank. Periodically excess solids and activated sludge organisms are removed from the system as waste activated sludge (WAS). If the WAS is not removed the activated sludge system will perform its intended function less efficiently and suspended solids will be loss over the settling tank solid barricade (or weir). Performance in activated sludge systems is also dependent on (Mountain Empire Community College, n.d.) :

- Temperature
- Return Rates
- Amount of oxygen available
- Amount of organic matter available
- pH
- Waste rates
- Aeration time

- Wastewater toxicity (i.e. Residential: harsh cleaning solutions, detergents, beauty products, prescriptions medications; Industrial: mercury, lead, acids, heavy metals, carcinogens)

There are various modifications to the activated sludge process, but two that do not require primary treatment are Contact Stabilization (see Figure 85) and Extended Aeration Activiated Sludge (see Figure 86).

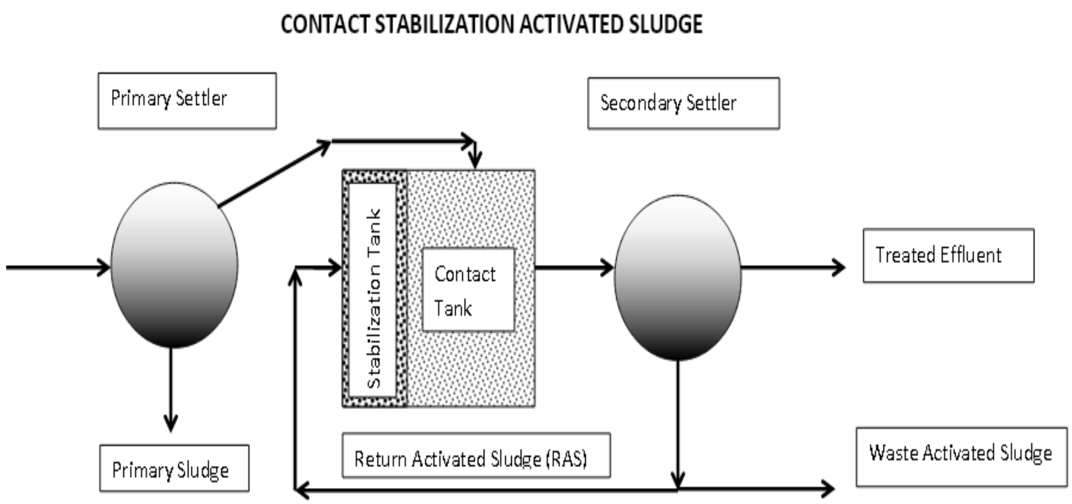



Figure 85. Contact Stablization Activated Sludge Process Process (University of Colorado, 2010).

In the Contact Stablization process, activated sludge is mixed with  influent in the contact tank where organic material is absorbed by microorganisms (Mountain Empire Community College, 2008). The mixed-liquor suspended solids (MLSS) is settled in the clarifier (secondary settler shown in Figure 85). The reaeration basin (or stabilization tank) to stablize (or deactivate) organics (Mountain Empire Community College, 2008).

The major advantages of the contact stablization process are that is requires less aeration with a short contact tank residence time and precipitates sludge better than the completely mixed activated sludge process (University of Colorado, 2010). The major disadvantage of this process is the operation is complex, there may be reduced treatment of soluble organics (i.e. urea, carbohydrates, amino acids, glycerol, etc.) in the the contact tank (University of Colorado, 2010).

In the Extended Aeration (Oxidation Ditch) Activated Sludge Process, a large circular aeration basin is utilized where a high population of microorganisms is maintained (see Figure 86) (Mountain Empire Community College, 2008). Rotors are used to supply oxygen to the systems and maintain circulation. This process is used from small flows (less than 2 MGD (National Small Flows Clearinghouse, 2003); 10,000 to 250,000 gallons per day (University of Colorado, 2010)) from subdivisions, highway rest areas, hospitals, prisons, schools, and other small communities that may have limited financial resources (National Small Flows Clearinghouse, 2003; University of Colorado, 2010).

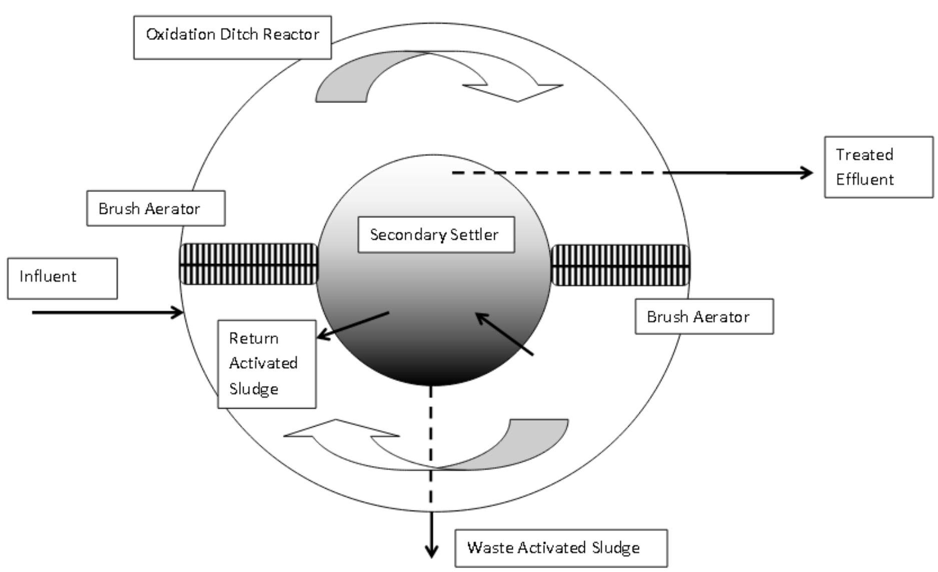



Figure 86. Extended Aeration (Oxidation Ditch) Activated Sludge Process (University of Colorado, 2010).

The major advantages associated with Extended Aeration are its easy to install, easy to operate, odor free, the relative ease of handling sludge because no primary clarifier is necessary, good settling characteristics of sludge, and low sludge yield (National Small Flows Clearinghouse, 2003; Mountain Empire Community College, 2003).

The major disadvantages associated with Extended Aeration are its long aeration time (Hydraulic retention time (flow rate ÷ tank volume) > 24), higher aeration times due to long surface loading rate (gpd ÷ square ft of a rectangular clarifier), there are high energy requirements to operate the system, unable to achieve denitrification or phosphorus removal, and the process can create zones of high oxygen and add to maintenance costs (National Small Flows Clearinghouse, 2004; University of Colorado, 2010).

Based on the available land use information, the water parameter box and whisker plots, and removal capabilities of the Extended Aeration Activated Sludge process, the land contained within the 500 meter buffers of CHIL1, CHIL 3 and CHIL 6 would be the most suitable for the placement of this wastewater treatment system. Based on the maps generated with ArcGIS 10.1 the buffer zone surrounding CHIL 3 contain a populated area with 290 to 999 persons (see Figure 97); this small community may be characterized by waste flows that are desirable for Extended Aeration systems. Based on the 2003 land cover information, CHIL 6 (with its 6.17 hectares of populated area between 400 to 500 meters from the water monitoring station) would be most suitable for the placement of the wastewater treatment system.

The question of how can a program be designed to improve sanitation and water quality of the PCW watershed has many socio-economic and political ramifications, but the following discussion will describe a program that could be implemented on the household level and scaled up to the regional level to help improve sanitation.

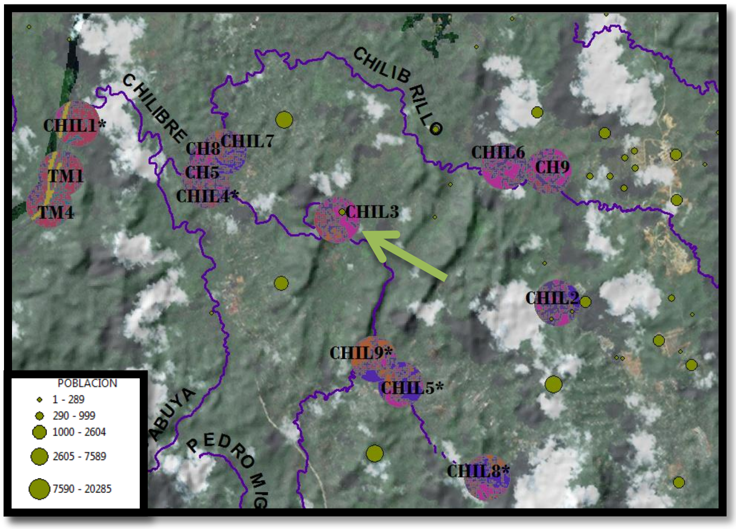



Figure 87. Land cover around water monitoring stations and population centers (Image generated by Christopher Weekes and David Eilers).

**Household waste management**

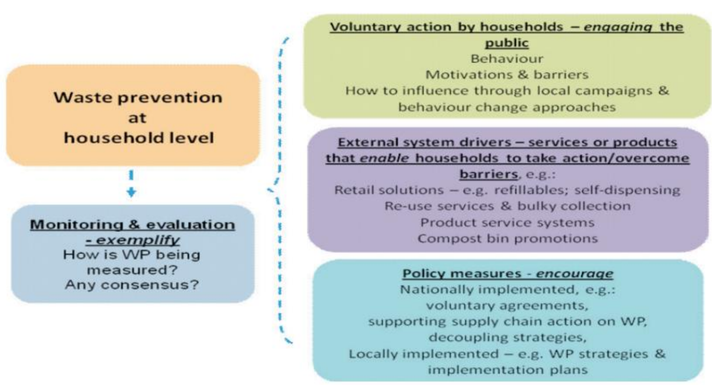



Figure 88. Analytic framework for household waste prevention (Cox et.al., 2009).

Waste prevention at the household level involves processes adapted from the 4E model. Public engagement involves behavioral changes, identifying motivations and barriers to waste prevention, and development of local campaigns designed to facilitate waste prevention. Once barriers in the waste prevention program are identified, external system drivers (products and/or services) may enable households to overcome behavioral or infrastructural barriers that preclude the implementation of waste prevention programs (Cox et.al., 2009). The development of policy measures encourages communities on the household level to participate in waste prevention programs and behaviors (see Figure 88).

It was estimated in 1995 that average waste generation per capita in Latin America at the household level was 0.3 to 0.8 kilograms per capita per day with averages nearer to 0.8 kilograms per capita per day in large cities (Moreno et al., 1999). Other estimates place waste generation at 0.9 kilograms per capita per day with potential for a 0.24 kilogram per capita per day increase in areas with high tourist flow (Savino, 2013). The managed solid wastes (MSW) (typically collected at households) are primary organic in middle-income countries like Panama (see Figure 89)

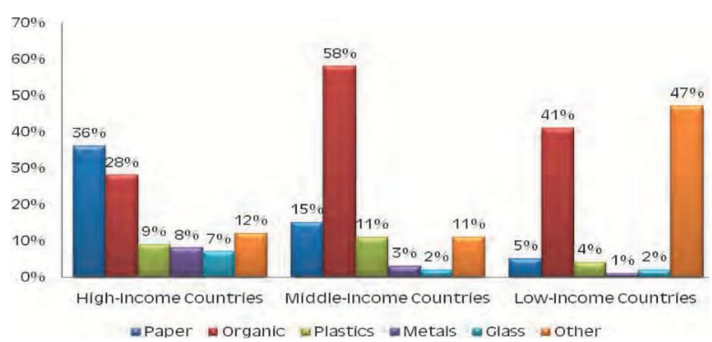



Figure 89. Characteristic of MSW streams depending on income (Khatib, 2012).

The following BMPs (Table 11) were recommended for implementation on the household level in Chilibre based on household waste generation averages in the district, traditional wastes generated at the household level, and waste composition estimates for middle-income countries. The boxes highlighted in green will be discussed based on its benefits and applicability to Chilibre Panama.

Table 11. Household wastewater management technology.

| Technology | Application(s) | Benefit(s) | Drawback(s)/difficulty(ies) |
|---|---|---|---|
| Composting Toilet (i.e. Tiger toilet) | Septic system upgrade or retrofit | Resource recovery; source control; low costs; low energy requirements; low water requirement; estimated lifetime of Tiger Toilet is > 10 years (Sanitation Ventures, 2012); estimated cost to the user per day (without revenue) is 0.005 cents (Sanitation Ventures, 2012) | Requires handling of wastes at the household level, which may be taboo in some instances; estimated capital costs for a family of 10 is US $200 (Sanitation Ventures, 2012) |
| Dry sanitation technology | Septic system | Fertilization of crops; resource recovery; source control | If dehydrated conditions are not controlled properly, organic material can contain pathogens |
| Behavioral Best Management Practices | Kitchen, trash sites, shower, bath, and septic systems | Facilitate behavior change; relatively easy incorporation into daily activities/behavior; reduction percentages with ‘soft interventions’ were 39% for $BOD_5$, 21% for TKN and 34% for $PO_4 - P$(Tsuzuki, Koottatep, Jiawkok, & Saengpeng, 2010) | Lack of motivation and support; inconsistency of sanitation practices |

At the *Reinvent the Toilet Fair* in 2012, the Bill and Melinda Gates foundation compiled an exhibitor technology guide which showcased toilets that were developed around the world which could help to improve sanitation and public health. The London School of Hygiene and

Tropical Medicine developed a Tiger Toilet which was designed to function on the household level and meet people's needs- especially in conditions of unplanned urban development in developing countries (Sanitation Ventures, 2012). Several features of the toilet make it feasible in terms of application on the household level and reduce its environmental and human health impacts.  The tank is one meter in diameter and 1.2 meters high which make it smaller than a standard pit latrine (Sanitation Ventures, 2012). The relatively small size of the toilet reduces space, digging costs, and risks associated with the collapse of heavier structures.

Another feature of the toilet is that it is easy to access which enables the public to empty the toilet hygienically and affordably. Costs associated with emptying traditional latrines and septic systems can be prohibitive to regular maintenance. Additionally, high waste removal costs can cause anti-social or illegal behavior such as constructing makeshift facilities or flooding full latrines which could have deleterious ecosystem and health effects (Sanitation Ventures, 2012). Tiger Toilets provide a sustainable and cost-effective alternative to traditional pit latrines which could help to free income that could be used for familiar support.

Inside the tank are two circular open baskets that receive wastes by a delivery pipe from the toilets above. On the top of these baskets are worm beds (usually comprised of coconut coir) which rests on mesh wire that function as bio-filters to degrade human wastes through contact with organisms such as tiger worms (Eisenia fetida) and aerobic bacteria in the collection systems. Liquid wastes drains from the filters where aerobic bacteria produce high quality effluent. Simultaneously, the Tiger Worms digest solids and collectively the solid and liquid wastes deposit in the semi-circular wastebasket.

Once a basket is full, the delivery pipe that conveys wastes from the toilet to the basket can be switch to the adjacent semi-circular basket. The worms will follow the food source to continue digesting freshly flushed material though digestion and decomposition will continue in the semi-circular tank that is no longer receiving wastes. After one year (or six months per tank) the basket (s) will be ready to empty. The material contained in the basket(s) at this time will be safe to handle as it will be non-pathogenic, dry, and have no offensive smell; this is accomplished by lifting out the basket in the semi-circular tanks and discharging or reusing the treated waste material.

Overall, the application of the tiger toilets in Chilibre Panama would be feasible because there are no electrical costs to operating the system, no wastes need processing off-site, it can serve a family of 10 people, and there is a potential for revenue generation through the energy and material recovery. Some other considerations according to Walter Gibson (one of the co-creators of Tiger Toilets) are:

- the availability of the right worm type (*Eisenia fetida*)
- water table height (though this can be worked around)
- water availability (it is designed to be linked to a pour flush toilet)
- and choice of materials for construction (dependent on locally availability)

**Community waste management**

'Water-supply systems not only have to be well-designed, constructed, and operated, but they must be used as well… continuous and correct use will be more likely when all the villagers, or at least members of all sections of the community, have been able to express their needs and their points of view during local planning and have been actively involved in decision-making and in putting the scheme into practice' (Kerr, 1990). Essentially, community level interventions in Chilibre should involve the local citizens, should include a public education campaign that emphasizes the ecosystem values and public health, should involve investment from sources external to the borough in the initial phases of the intervention to enable self-sufficiency as the intervention progresses.

In 1972 and 1976, USAID funded a rural health program in Panama designed to deliver piped water to villages with 250 to 500 residents (Donaldson, 1983). The program was relatively successful and was characterized by trained community personnel who collected monthly fees from local residents. Moreover, the program was reported to have been successful because it encouraged self-reliance and the emergence of local leadership. Reports from the study indicated that the maintenance of water systems was made more effective when communities assumed responsibilities for routine maintenance and repairs.

Some of the most important features of community managed programs is if there is equal access to a resource or service; this motivates community members to sustain their participation since they feel that there is an equal benefit to participation (Donaldson, Overview of rural water and sanitation programs for Latin America, 1983). Community participants and trained personnel should be updated regularly and the divisions of labor between engineers and/or community members should be reviewed.

The communities under investigation in Panama were assumed to occupy low- and middle-income levels whose average waste generation was 0.6 to 1.0 kg per capita per day and 0.8 to 1.5 kilograms per capita per day, respectively (World Bank,n.d.). Calculations for community waste generation start at the household level. An average of 3.7 residents per household computed during the 2010 National Census was multiplied by 0.8 kilograms per capita per day that was multiplied by 365 days per year yielded 1080.4 kilograms per household per year. The following technologies are believed the reduce communal burden of wastes (Table 12):

Table 12. Community wastewater management technology.

| Technology | Application | Benefit | Drawback/difficulty |
|---|---|---|---|
| EcocycIET systems; Wastewater Gardens | Rural communities; urban areas such as parks and open spaces; animal rearing sheds | Zero- discharge; water and nutrients are used to grow plants; used in areas where soil and soil absorption systems cannot absorb and disperse the liquid fraction of wastes; impervious bed liner; harvested willow species have economic value depending on the scale of production; the installation kit includes alarms | Some installations may require heated greenhouses; uptake varies based on humidity and precipitation; kit components might not be available locally to improve cost effectiveness. |
| Lagoon Systems | Most commonly used for community waste water treatment (Philippine Sanitation Alliance, 2008) | Relatively inexpensive to construct, operate and maintain; may be designed to operate with electricity or mechanical equipment; may be expanded | If not properly maintained may emit offensive odors, may attract nuisances, and/or contribute to groundwater and surface water pollution; must be applied on level surfaces |

Lagoons consist of in-ground earthen basins in which waste is detained for a specified time (detention time) then discharged (Hurtado, 1998). Although these lagoons, or ponds as sometimes called, are very simple in design, there are complex chemical, biological and physical processes taking place (Hurtado, 1998). Due to mechanical simplicity and low maintenance requirement, lagoons are well suited for the developing world (Hurtado, 1998). For the most part, the more air and mixing supplied to the system, the better the effluent quality of the lagoon.

**Watershed waste management**

Watersheds consist of land areas where wastewater drain downstream to water catchments or treatment facilities. At the watershed level, planning is scaled to improve (RJN Group, 2013):

- Sources of infiltration and inflow that cause sanitary sewer overflows (SSO; typical in urban areas with underlying septage pipes)
- Capacity improvements to handle the present and future flow of wastewater
- Wastewater pipes and conveyance systems

Watershed Improvement Plans (WIPs) incorporate three environmental principles which include (RJN Group, 2013):

- Prevent damage from erosion, floodwater, and sediment
- Further the conservation, development, utilization, and disposal of water
- Maximize the conservation and proper utilization of land

Vegetation is often removed or altered to make room as a result of urbanization (Silk & Ciruna, 2005). In Panama, the pro-business national government has sponsored development that has threatened wetlands and mangrove forest in Panama Bay. These ecosystems have functioned as migratory bird habitats and also protect bay residents from powerful storm surges and flooding (CBS, 2012). Wetland systems directly and indirectly support people by providing goods and services to them (Ramachandra, 2001). The direct benefits of wetlands are the components/products such as recharging groundwater water supply sources, nutrient uptake and recreation. Indirect benefits of wetlands are flood control and storm protection, and cultural value for some indigenous peoples (Ramachandra, 2001). Government representatives have argued that the Panamanian government is committed to protecting the bay, but simultaneously that development can help to accommodate population growth and urbanization (CBS, 2012).

Constructed wetland and buffers have been used to improve surface flow hydrology and water quality,  enhance wildlife habitats, treat wastewater and mine drainage, and for storm- water retention and control  (Silk & Ciruna, 2005). Choosing the buffer width depends on the planning goals and financial limitations of the restoration program; however, the larger the wetland buffer the greater the benefit (see Figure 90) (U.S. Fish and Wildlife Service, 2001).

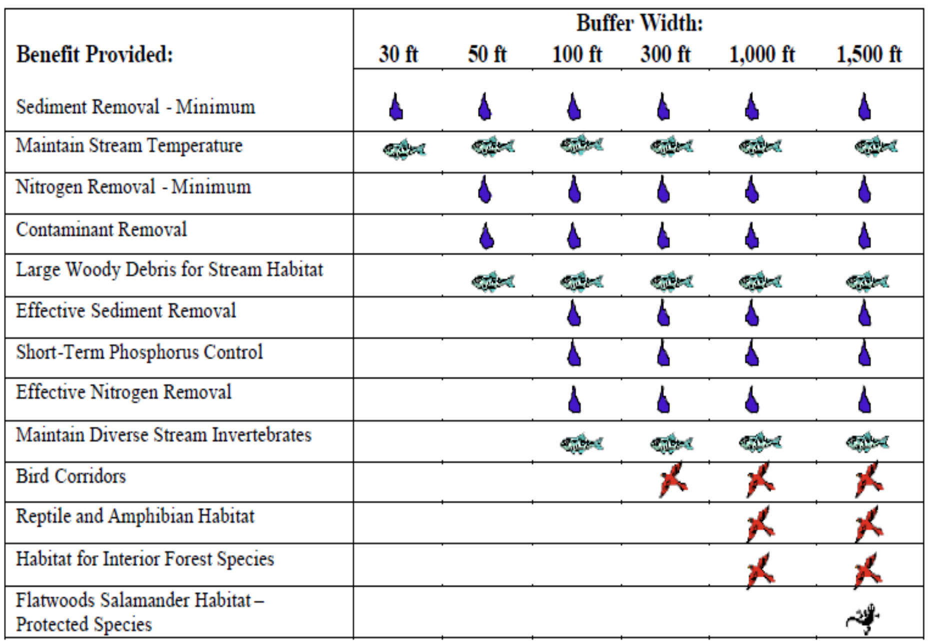



Figure 90. Watershed benefits provided by wetlands by size (U.S. Fish and Wildlife Service, 2001).

Wetland management programs involve activities designed to protect, restore, and manipulate wetland ecosystems to as to promote optimal function. The implementation of a wetland program should be driven by data to best inform the decisions about placement and design in later phases. Modeling of wetland best management practices could provide a time-sequence of water flow and contaminant mass balances that could help to better estimate the treatment efficiency of constructed wetlands (U.S. Fish and Wildlife Service, 2001).

Nevertheless, the implementation of a watershed level intervention such as a wetland must consider more than the physical and chemical characteristics of the landscape. It must also consider the suitability of the land area which encompasses social, cultural, and economic characteristics of the people occupying the landscape that could be best informed through community surveys, promoting wetland stewardship and education, and continuous monitoring scaled to the program size (Southern California Coastal Water Research Project, 2011).

Management programs should involve buffering wetlands which protect wetlands from human pressures that can affect the normal function of the wetlands. Additionally, wetland management should be an integrated approach in terms of planning, execution, monitoring, and be driven by effective knowledge in ecology, hydrology, economics, and watershed management. In order to achieve this integrative and balanced approach local expertise from residents, planners and decisions makers should be incorporated into the program process.

The following technologies are believed the reduce the burden of wastes on the watershed level (see Table 13):

Table 13. Watershed wastewater management technology.

| Technology | Application | Benefit | Drawback/difficulty |
|---|---|---|---|
| Subsurface flow constructed wetlands | Secondary wastewater treatment; phosphorus removal over large land areas | Microorganisms utilize organic nutrients from incoming waste water for growth and yield clean effluent; increased contaminate uptake in warmer climates; range of BOD loading 1.8 to 140 pounds per acre per day (Perez, 2005); media provides greater number of surfaces for biological treatment; chemical treatment can occur as organic wastewater material contact media (Northern Arizona University, 2002) | Sometimes the systems are scaled incorrectly which lead to substandard performance; blockage associated with horizontal flow systems at inlet; limited removal efficiency of phosphorus; no consensus for how much oxygen is contained in plant roots to degrade organic matter and facilitate nitrification of ammonium; selection of plants is limited by regulatory and cultural restraints (Rani, Din, Yusof, & Chelliapan, 2011) |
| Surface water flow constructed wetlands | Secondary wastewater treatment | Biological treatment tends to speed up in warmer weather; wetland plants filter water, regulate flow, and provide surface area for biological treatment; floating plants help shade water surface and prevent algae growth | The range of organic loading as BOD is between 9 to 18 pounds per acre per day (Perez, 2005). |
| Sustainable urban drainage system (SUDS) | Used for the management of surface water runoff | Source control; increase groundwater quality; storm water detention; promotes storm water infiltration; provide a habitat for wildlife | Implementation requires planning, water quality and water resource assessment, and architectural and landscape considerations (NBS, 2007) |
| Treatment ponds; Waste Stabilization Ponds | Primary treatment of wastewater; | Low costs – no need for electromechanical equipment; 90-99% removal efficiency of bacteria, viruses, protozoan cysts and helminth eggs | Man-power and muscle power are required for the removal of aquatic vegetation; high-capital costs associated with removal of aquatic vegetation; geographic, temperature, and raw-water quality conditions may inhibit the removal efficiency of the system |

It has been found that urban infrastructure creates basic constraints on best achievable wetland conditions. Studies conducted by researchers in the Southern California Coastal Water Research Project found that levels of Cu, Pb, Zn, polyaromatic hydrocarbons (PAHs) and cypermethrin were positively correlated with the percent imperviousness of catchment areas—a proxy for urbanization (Southern California Coastal Water Research Project, 2011). However, it was found that site-specific management factors such as wetland design, management, and maintenance could mitigate the constraints of the urban landscape (Southern California Coastal Water Research Project, 2011). The studies found that treatment wetlands reduced the concentrations of E. coli, enterococcus, fecal coliform, total coliforms, and nutrients but there was great variability in the effectiveness of removal (Southern California Coastal Water Research Project, 2011).

Physical characteristics of the study site such as slope, impervious surfaces, and soil type should also be considered when choosing the width of a wetland buffer (U.S. Fish and Wildlife Service, 2001). In an agricultural setting, the application of a wetland buffer would present less challenges because the infrastructure of the land requires less development on natural land. In comparison, once land is built over in urban environments only the active removal of that infrastructure will allow for the environment to be succeeded by a natural system (Silk & Ciruna, 2005). Due to this difference, urban development is 'considered a greater threat to the integrity if freshwater ecosystems' (Silk & Ciruna, 2005).

**Regional waste management**

Development pressures in Chilibre have been accompanied by an increasing demand for urban sewerage collection. The formation of peri-urban[17] settlements have put strains on the existing

[17] On the urban margins (Landon, 2006).

sewerage collection networks which have resulted in the discharge of wastes to water bodies without any form of treatment (Looker, 1998). From 1995 to 2005, the sewerage coverage was expected to grow from 5% to 60% in Latin America and the Caribbean and in 1995 regional reports reflected that 64 % of urban dwellers and 81% of rural dwellers had access to sanitation systems (Looker, 1998).

The most recent estimate of sanitation coverage suggests that only 35% of the population of Chilibre has access to sewer collection networks (Castro, 2003). There is no reporting of the sanitation status of dwellings that are not defined by land-ownership. Supposedly, these transient dwellings are not be incorporated into the existing sewerage network and present contamination risks to the PCW as is often the case in middle to low-income communities in developing countries (Looker, 1998). Regional efforts carried out by IDAAN have been focused on revamping the sewerage system in regions like Chilibre (i.e. San Miguelito and Las Cumbres), but have not been effective in controlling the growing waste dumping problem.

Transient populations can contribute to the local increases in waste generation that contributes to increased regional pollution. The following technologies can be applied regionally to reduce the burden of waste generated (Table 14):

In 2010, three Brazilian communities were investigated by Professor Peter Rogers of Harvard and Susan Leal in their book entitled *Running Out of Water* which described the successes of sanitation cooperatives in those communities (Leal, 2013). Sanitation cooperatives (or *condominials systems*) were septic systems that were designed and sometimes built by local

Table 14. Regional wastewater management technology.

| Technology | Application | Benefit | Drawback/difficulty |
| --- | --- | --- | --- |
| Sanitation co-operatives (*condominial* system) (Leal, 2013) | Urban slum settlements that lack access to sanitation services | Only maintain pipes are buried underground and smaller pipes that connect to houses are above ground | Success predicated on resident participation and government education programs (Leal, 2013) |
| Dump trucks | Regional networks | The removal of approximately 3 metric tons of wastes | Narrow and discontinuous roads may make services unfeasible; collisions; tipping |
| NERV Reactor | Existing treatment systems | Low capital costs, low running costs; low sludge disposal volumes; easy integration | Acceptance and available funding |
| Modular Reed Bed | Existing treatment system; secondary or tertiary treatment process | Low operation and maintenance costs; remote monitoring is possible; resource recovery of mixed media; phosphorus recovery | Can only be erected on flat surfaces; planning permission may be necessary to implement the enclosure system |
| The BioSelector | Existing treatment systems | Helps to correct typical problems such as high levels of COD, BOD, and suspended solids | Questionable operational capacity for sustained (long-term) overloads; conforms to EU directives not Panamanian directives; lag phase before bacteria colony formation which reduces wastewater control effectiveness; limitations on growth based nutrients |

the communities owing majorly the small sanitation pipes that connected to main sanitation pipes were closer to the surface and required less costs associated with trenching. The trenching that did take place was facilitated by the residents which helped the government to save on labor costs and also developed a sense of community (or social capital); allowing residents to build the sanitation network created a sense of ownership towards the sanitation system.

Failures in the implementation of water and sanitation projects have been attributed to both private sector and public sector deficiencies. In the case of the public sector, inefficiencies in governance, corruption and lack of cohesion between stakeholders, consultants and government have exacerbated the lack of coverage that is typical in low-income communities. Majorly centralized governance, particularly with regard to public utility services, have unraveled as local revenues do not cover the costs of water and sanitation projects[18], when government institutions lack the funds to implement the projects, projects are not reflective of national development goals, or the present infrastructure in the regions most affected cannot sustain the practices necessary to protect human health.

Alternatively, failures in the private sector have been attributable to attrition, rapid implementation of projects that have addressed underlying issues directly, or lack of community acceptance and demand (United Nations Human Settlement Programme (UN-Habitat), 2003). Owing to the shortcomings of both public sector and private programs dedicated to addressing water and sanitation issues, there has been a growing movement to integrate both public and private sector responsibilities during such projects (United Nations Human Settlement Programme (UN-Habitat), 2003). The public-private partnership (PPP) refers to situations where a public agency works with one or more private enterprises to provide goods and services

[18] These projects are often developed by committees that lack local representation; this precludes water use fees from being managed at the local level.

previously provided by the public sector (United Nations Human Settlement Programme (UN-Habitat), 2003). It is believed that PPP programs can help to achieve sustainable service delivery for sanitation and water. The PPP will require the participation of entities that participate in the pilot phases of the project, NGOs and private organizations, universities, and ministries (see Figure 91).

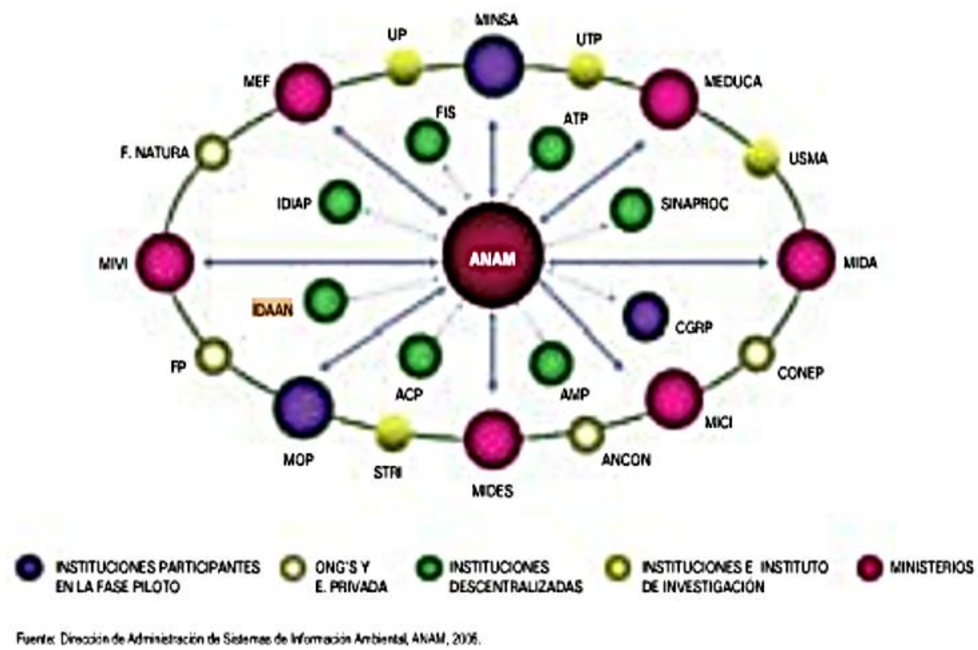



Figure 91. Entities required for the effective implementation of PPP (Ministerio de Economia y Finanzas, 2007).

MINSA has control of the treatment and the final disposition of wastewater from households and industries. The health authority reserves the right to reject applications for non-compliance to established health standards in order to preserve the interests of public health (Villareal, 2012). MINSA possesses the infrastructure to monitor water quality and has technical staff to conduct water quality analysis and control (Villareal, 2012). The entity also regularly collaborates with agencies and ministries that are charged with responsibilities related to urban development, chemical substances use, regulations and codification of environmental law, agro-ecology programs, and zoonotic disease (Villareal, 2012). The implementation of any pilot phase environmental health program in Chilibre will require collaboration with MINSA for project oversight and for facilitating necessary partnerships. Additionally, MINSA's involvement in the development of sanitation program can be sustained through its direct partnerships with local universities which have the potential to continually replenish research personnel. More central to any environmental program in Panama will be the collaboration with the National Environment Authority of Panama (ANAM).

ANAM is entity that can facilitate sustainable delivery of environmental services. Sustainable service delivery is a process that empowers local authorities (such as ACP and IDAAN) and communities with authority and resources as well as building the capacity of these entities to manage water supplies and sanitation services. ANAM aim is to promote environmental sustainability which can be achieved through structural changes that (United Nations Human Settlements Programme (UN- HABITAT), 2003):

- strengthen institutions and governance
- correct market failures and distortions
- improve access and use of scientific and technical knowledge

ANAM plays a pivotal role in developing partnerships among the various entities in which it collaborates. However, a country level framework does not exist in Panama which enables the directed action towards environmental improvements of entities with differing priorities. Fortunately, the Health and Environmental Linkages Initiative (HELI), developed by the World Health Organization (WHO) and the United Nations Environmental Program (UNEP), provides a framework to help developing countries achieve collective actions directed to improve environmental health while promoting economic development and social development. HELI activities include country-level pilot projects and the refinement of assessment tools to support decisions making (World Health Organization; UNEP, 2012) These tools help to generate qualitative and quantitative analysis which enable comparisons between the benefits and costs of different policy choices (World Health Organization; UNEP, 2012).

Before the HELI framework can be applied, it is customary that both environmental assessments and health assessment be performed. Two such assessments that have been used to establish baselines and monitoring criteria for environmental quality and health status in developing countries coping with rapid rates of modernization and urbanization have been the Strategic Environmental Assessments (SEA) and the health Impact assessment (HIA).

**Strategic environmental assessment**

SEA is a practical and direct means of achieving environmental sustainability which calls for the integration of sustainable principles into country policies and programs. Furthermore, in accordance with the Johannesburg Plan[19] developed at the World Summit of 2002, SEA emphasizes the importance of 'strategic frameworks and balanced decision making […] for advancing the sustainable development agenda' (OECD, 2006). These frameworks utilize a family of approaches which are tailor made to the context in which it is applied (OECD, 2006).

SEA strategies were implemented in Colombia in which an inter-agency committee comprised of the Department of National Planning, the Ministry of Environment, and the Ministry of Development with the financial assistance of the World Bank quantified various negative

[19] A plan which outlined how to progress toward economic growth through cooperation and urgency based on a common quest for sustainable development with priority areas in poverty eradication, education, trade, science and technology, regional concerns, natural resources and institutional arrangements (Blue Economy Monaco 2011, 2010).

externalities such associated with the deterioration of water quality, inefficient water use, the impacts associated with construction and maintenance of public works and facilitated joint work on water and sanitation (OECD, 2006).

**Health impact assessments**

Health Impact Assessments (HIAs) are predicated on the idea that community design can help improve health status of individuals in a community. In practice, HIAs help to evaluate the potential health effects of a plan, project, or policy before it is implemented. HIAs should be applied simultaneously with the BMPs to better inform the responsible parties involved in the implementation and maintenance of the community sanitation programs. The major steps in conducting an HIA include (Centers for Disease Control and Prevention, 2012):

- Screening (identifying plans, projects or policies for which an HIA would be useful),
- Scoping (identifying which health effects to consider),
- Assessing risks and benefits (identifying which people may be affected and how they may be affected),
- Developing recommendations (suggesting changes to proposals to promote positive health effects or to minimize adverse health effects),
- Reporting (presenting the results to decision-makers), and
- Monitoring and evaluating (determining the effect of the HIA on the decision)

Despite the progressiveness of these plans, how might sanitation programs be financed in Chilibre Panama? The following discussion will address the potential benefit and application of microfinance programs.

**Spotlight: microfinance and sanitation in Chilibre Panama**

Current estimates of the unemployment rate in Chilibre hover around 16.3 % (~8,970 persons) (see Figure 92). As mentioned previously, the average income of the residents in the Chilibre sub-district is about $285 dollars per month but this is not reflective of all members of the population some of whom do not generate income (URS Holdings, 2007). Most of the working population commutes to larger cities to work and then commutes back to Chilibre for domestic purposes (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007). Residents suffer from riding on overcrowded buses, that frequently malfunction, and are unreliable (Comision Interstitucional de La Cuenca Hidrographica del Canal de Panama, 2007). Low-income people are powerless to the economic forces which drive them to endure such phenomena daily. The development of local business could restore some semblance of autonomy and create a sense of ownership for low-income people if sanitation and water management programs are staffed and maintained locally and promoted through marketing campaigns to create a regional demand for environmental services.

| *Corregimiento* | Total Inhabitants per *Corregimiento* | Annual Average Income per Person (in Balboas) | Average Monthly Income of Employed Population 10 years of age and older | Percentage of Unemployed | Percentage of Persons Engaged in Agriculture | Percentage of Persons Engaged in Fishing | Percentage of Persons Engaged in Mining Exploitation | Percentage of Persons Engaged in the Manufacturing Industry | Percentage of Persons Engaged in Electricity | Percentage of Persons Engaged in Construction | Percentage of Persons Engaged in Commercial Activities | Percentage of Persons Engaged in Hotels/Restaurants | Percentage of Persons Engaged in Transportation Activities | Percentage of Persons Engaged in Financial Activities | Percentage of Persons Engaged in Real Estate Activities | Percentage of Persons Engaged in Public Administration | Percentage of Personas Engaged in Teaching | Percentage of Persons Engaged in Social Services Activities | Percentage of Persons Engaged in Community Activities | Percentage of Persons Working in Private Homes | Percentage of Persons Working for International Organisms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BARRIO NORTE | 24,346 | 2,604.00 | 298.7 | 23.9 | 0.0 | 0.00 | 0.0 | 6.0 | 1.0 | 5.0 | 29.0 | 5.00 | 14.00 | 2.00 | 6.00 | 5.00 | 5.0 | 4.0 | 5.0 | 6.0 | 0.0 |
| BARRIO SUR | 17,787 | 2,381.00 | 921.2 | 19.1 | 0.0 | 0.00 | 0.0 | 5.0 | 1.0 | 4.0 | 30.0 | 8.00 | 15.00 | 1.00 | 6.00 | 5.00 | 5.0 | 3.0 | 5.0 | 5.0 | 0.0 |
| BUENA VISTA | 10,428 | 1,619.00 | 259.4 | 14.4 | 6.0 | 0.00 | 0.0 | 12.0 | 1.0 | 15.0 | 27.0 | 3.00 | 11.00 | 1.00 | 3.00 | 4.00 | 3.0 | 2.0 | 3.0 | 7.0 | 0.0 |
| CATIVA | 26,621 | 2,556.00 | 312.6 | 16.9 | 1.0 | 0.00 | 0.0 | 6.0 | 1.0 | 8.0 | 28.0 | 4.00 | 19.00 | 2.00 | 6.00 | 4.00 | 6.0 | 3.0 | 4.0 | 5.0 | 0.0 |
| LIMON | 4,092 | 1,467.00 | 233.8 | 19.0 | 8.0 | 1.00 | 1.0 | 6.0 | 1.0 | 14.0 | 27.0 | 3.00 | 14.00 | 0.00 | 2.00 | 5.00 | 3.0 | 1.0 | 4.0 | 8.0 | 0.0 |
| NUEVA PROVIDENCIA | 3,065 | 1,413.00 | 230.3 | 11.9 | 5.0 | 0.00 | 0.0 | 7.0 | 1.0 | 16.0 | 33.0 | 3.00 | 8.00 | 0.00 | 4.00 | 4.00 | 2.0 | 1.0 | 4.0 | 10.0 | 0.0 |
| SABANITAS | 17,073 | 2,617.00 | 313.0 | 15.3 | 1.0 | 0.00 | 0.0 | 6.0 | 1.0 | 8.0 | 34.0 | 4.00 | 16.00 | 2.00 | 5.00 | 4.00 | 6.0 | 3.0 | 5.0 | 6.0 | 0.0 |
| SAN JUAN | 13,325 | 1,628.00 | 268.3 | 13.5 | 5.0 | 0.00 | 0.0 | 12.0 | 1.0 | 17.0 | 28.0 | 4.00 | 9.00 | 1.00 | 2.00 | 3.00 | 3.0 | 2.0 | 4.0 | 6.0 | 0.0 |
| SANTA ROSA | 735 | 1,269.00 | 206.8 | 11.8 | 25.0 | 0.00 | 5.0 | 9.0 | 0.0 | 11.0 | 15.0 | 1.00 | 4.00 | 0.00 | 1.00 | 8.00 | 2.0 | 2.0 | 7.0 | 7.0 | 0.0 |
| SALAMANCA | 2,920 | 1,133.00 | 182.0 | 15.4 | 32.0 | 1.00 | 0.0 | 10.0 | 0.0 | 14.0 | 15.0 | 3.00 | 4.00 | 0.00 | 1.00 | 3.00 | 2.0 | 2.0 | 3.0 | 7.0 | 0.0 |
| CHILIBRE | 40,475 | 1,868.00 | 283.5 | 16.3 | 5.0 | 0.00 | 0.0 | 13.0 | 1.0 | 15.0 | 21.0 | 5.00 | 10.00 | 1.00 | 4.00 | 5.00 | 3.0 | 2.0 | 4.0 | 9.0 | 0.0 |

Figure 92. Density, employment, and income of Chilibre, Panama (URS Holdings, 2007).

Microfinance can enable the development of locally maintained business by empowering low-income people through small loans designed to allow people to pursue small business ideas (Yunus, 2007). In context, microfinance can be applied on the community level to support bio-enterprises which are cooperatives that provide environmental services (Bass et.al., 2005). CREER micro-finance program was applied in Menziales Colombia as a business development project designed to decrease informal employment and provide a legal framework for economic activities (Bass et.al., 2005).

The program generated 8640 new jobs between 2002 and 2004 after loaning $400,000 (USD) through 4300 micro-credits (Bass et.al.,2005). Small producers, artisans, craftsman and women, as well as traders and service providers benefited the most from the micro-lending program because the program built trust and solidarity and promoted cooperation among small businesses in the community (Bass et.al., 2005; Yunus, 2007). Local government, institutions, private sector participants, and university students helped to provide support for the development of new businesses, the identification of environmental problems, and advice for overcoming them (Bass et.al, 2005).

A micro-finance program geared towards environmental business development could be successful because of the diverse and relatively balanced divisions of labor in Chilibre. However, in order for an environmental program to succeed in Chilibre an effective marketing campaign must target the patrons in these sectors with feasible environmental employment alternatives. Employment alternatives such as local sanitation maintenance workers, sanitation outreach and community development personnel, or (but not limited to) locally led strategic sanitation development personnel require transportation, construction materials for sanitation best management practices, repair tools, and a way to transfer funds to carry out sanitation centered job assignments. One way that funds can be transported is through the use of mobile devices. In Kenya, M-pesa (M-mobile, pesa –money in Swahili) technology allow delocalized communities to transfer funds which are redeemable for the purchase of goods and services at locally endorsed vendors (Graham, 2010).

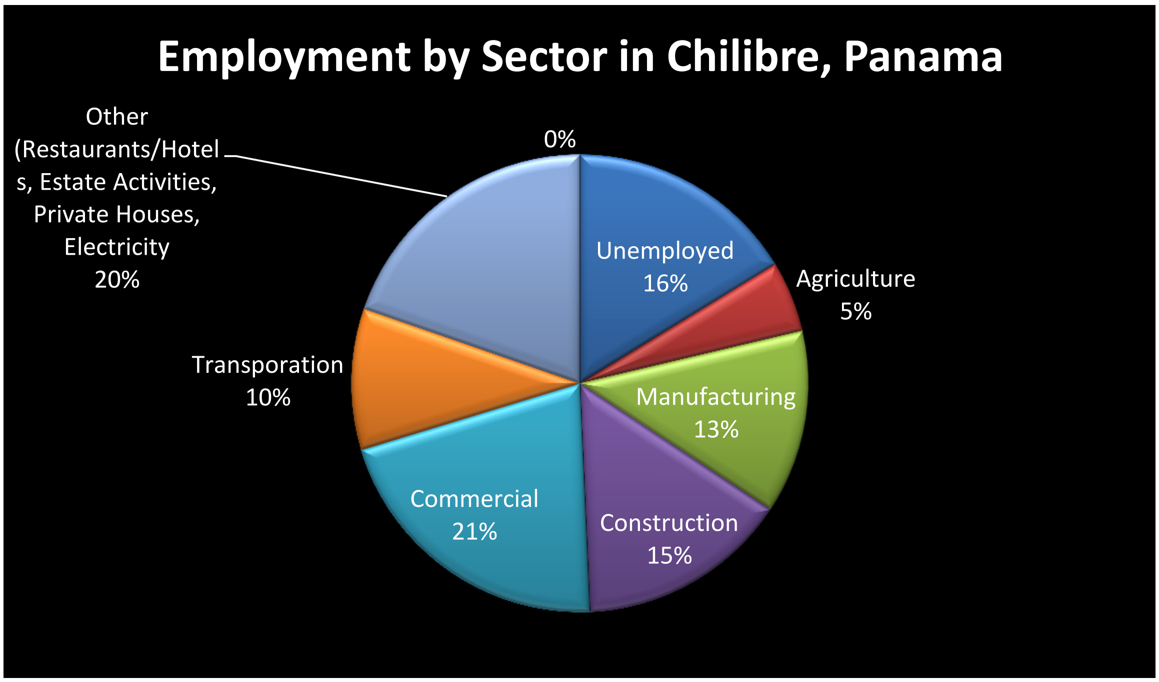



Figure 93. Employment by business sector in Chilibre Panama (Adapted from URS Holdings, 2007).

In order to target the unemployed it is important to characterize the skillset of the unemployed population (see Figure 93). As mentioned previously, many migrants to the Chilibre region previously worked in agriculture, the demand for agricultural goods and services need to be created before this segment of the unemployed population is targeted. It is important to identify the needs of the unemployed population and tailor environmental programs towards the people's needs. Additionally, there micro-lenders should be flexible with regard to the provisioning of loans so as not to discourage borrowing within the community and to promote environmental business innovation.

Possible barriers to the implementation of a sanitation-based microfinance program could be a lack of government interest, a lack of local representation, insecurity associated with transferring funds between vendors and consumers (for those without mobile technologies), and high interest rates associated with loans. Also, the project speed and job creation may be delayed by donors and recipients, lack of experience or technical expertise during the implementation phase of the program into design specifications, a lack of solidarity, and attrition of participants (McKenzie, 2009). Furthermore, agreement among diverse populations to cooperate in planning, installing, funding and managing sewers requires commitment to sanitation ventures which may be difficult to maintain (United Nations Human Settlements Programme (UN- HABITAT), 2003). It is also may be difficult to install water and sanitation systems in districts like Chilibre that lack clearly delineated plots, might experience delays in construction because of unfavorable weather conditions, and have limited access to roads and paths to each numerous dwellings (United Nations Human Settlements Programme (UN-HABITAT), 2003).

Some researchers have argued that directing funds to sanitation and water improvement programs deflects from the more fundamental problems that needs addressing which are the weakness sanitation providers, but effective community provisions have 'helped to change the approach of municipal authorities and on occasion has been the result of municipal authorities own support' (United Nations Human Settlements Programme (UN- HABITAT), 2003). Nevertheless, microfinance programs enable cost recovery through business development rather than relying on constant loans from external sources which may require collateral and be accompanied by high interest rates (Yunus, 2007). Implementation of microfinance programs on the community level could help to curtail these high interest rates and enable borrowing without the need for immediate collateral.

Future studies should seek to evaluate the effectiveness of community-level business programs in developing countries and identify site-specific barriers. Additionally, these studies should investigate the willingness of the national governments' and banks' to accept low-interest microfinance  loans that go directly to community based organizations geared at improving social capital and environmental health.

## Conclusion

*Table 15. Descriptive summary of the monitoring stations (Created by Christopher Weekes).*

| Station | Region | Water Quality Violation (s) | Dominant Land Cover Disturbance Designation |
|---|---|---|---|
| DCH (F) | 1 | DO; BOD | Domestic |
| DCH (S) | 1 | BOD | Domestic |
| DCI (F) | 1 | DO;BOD | Farm/Agricultural |
| DCI (S) | 1 | BOD | Farm/Agricultural |
| ERP (F) | 1 | DO; E.coli;BOD | Domestic |
| ERP (S) | 1 | BOD | Domestic |
| PNP (S) | 1 | BOD | Domestic |
| PNP (F) | 1 | DO;BOD | Domestic |
| TAG (F) | 1 | BOD | Farm/Agricultural |
| TAG (S) | 1 | BOD | Farm/Agricultural |
| CHIL 1 | 2 | DO; PO4; BOD | Domestic |
| CHIL 2 | 2 | PO4 | Domestic |
| CHIL 3 | 2 | DO; NO3; PO4; BOD | Farm/Agricultural |
| CHIL 4 | 2 | PO4 | Domestic |
| CHIL5 | 2 | PO4 | Farm/Agricultural |
| CHIL 6 | 2 | DO; BOD | Farm/Agricultural |
| CHIL 7 | 2 | PO4 | Domestic |
| CHIL 8 | 2 | E.coli | Domestic |
| CHIL 9 | 2 | Temp; E.coli | Farm/Agricultural |
| TM1 | 3 | DO; E.coli;pH | Domestic |
| TM2 | 3 | DO; E.coli | Domestic |
| TM3 | 3 | DO | Domestic |
| TM4 | 3 | DO; NO3 | Domestic |
| CHI | 3 | E.coli | Domestic |
| Represent monitoring stations that violated criteria standards 3 or more times | | | |
| Represent monitoring stations that violated criteria standards 2 times | | | |

Based on the summary data (Table 15) CHIL 3 had the most water quality violations among all the monitoring stations and was dominated by farming/agricultural land cover. Subsurface constructed wetlands would be the most suitable BMP to apply at this site based on the qualitative relationship determined by the study because the monitoring stations contains a population that ranges between 250 to 999 persons who are expect the generate 161,025 kilograms of wastes or 352, 999 pounds (at 250 persons) in the year. The area contained at the site is 196,250 $m^2$ (or 0.19625 $km^2$) and the population density of Chilibre is 58.4 persons per $km^2$; this gives the each person the waste generation potential of 0.003 (from $km^2$ of the buffer area ÷ the population density). The BMP has a BOD loading range of 846.47 grams to 502.93 grams (or 63 kg) pounds per acre per day and the waste generation for the each person in this region is 150.03 grams (2 kg) per acre per day.

More consistent water quality reporting and formatting would enable more detailed and informative spatial analysis that can help to establish benchmarks for human disturbance and landscape disturbance indices. The data reported had several inconsistencies with regard to the coordinates reported at the monitoring stations. Additionally, STRI, ANAM and ACP had different data layers in their GIS databases which often did not overlap; this might have been reflective of using different resolutions, using different coordinate systems, and interference from cloud cover which may have led to generalizations that diminished the accuracy of any data layer. Land disturbance and human disturbance indices should be established at each water monitoring station so that different activities are given different weight (or different contributions) to water parameters collected.

Some barriers implementing and maintaining environmental projects in Panama stem from a variety of constraints encompassing technical, financial, institutional, economic and social dimensions. The Panamanian government may not prioritize certain environmental programs because of a lack of human resources and/or a lack of definite roles assigned to participants in programs. Moreover, local taxation systems may not be adequately developed and there may not be sufficient funds for environmental programs from local entities or external agencies.

Lastly, the underlying low priority given to environmental programs stem from the low status given to waste management workers that may diminish work ethic and work quality for anyone assigned roles. Sometimes there are communication barriers between government entities and environmental agencies. Often jargon used by agencies with different agendas prevent actionable goals from being established at environmental conferences. Concern over hierarchies, titles, and self-promotion take precedence over finding a middle ground or achieving a common objective. One of possible solution to remedy the lack of communication, support, and awareness is to recruit interdisciplinary task forces from within and outside of Panama that do not operate under the auspices of any organization but rather function as an entity that can contribute ideas from their agencies with the purpose of developing actionable solutions. The participants must be willing to commit to the problems identified and be resilient to change. Students or independent researchers can be potential recruits for such tasks forces.

Providing safe sanitation to Chilibre and similar communities requires more than technocratic solutions. Material assistance should be accompanied with an understanding of the local context in which poor people, local businesses, and government entities operate. Sanitation science and technology should be scalable, affordable, safe, sustainable, and centered on the needs of the user. Consideration should also be made before applying sanitation improvement strategies to stimulate both demand and supply of improved sanitation facilities (Gates Foundation, 2012). Achieving a high rate of adoption for improved sanitation and sustaining it over time will require a deeper understanding of what local people want and what they will keep using (Gates Foundation, 2012)[20]. Moreover, it is essential to incorporate the policies and practices needed to support sanitation improvements at different scales.

[20] 'The emerging consensus in the field of sanitation field suggests that community-led sanitation approaches are effective at reducing unsanitary practices and achieving open-defecation-free status' (Gates Foundation, 2012 page 3).

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**Appendix**

The following graphs were constructed for descriptive purposes; however, there are no water quality standards presently to corroborate the data.

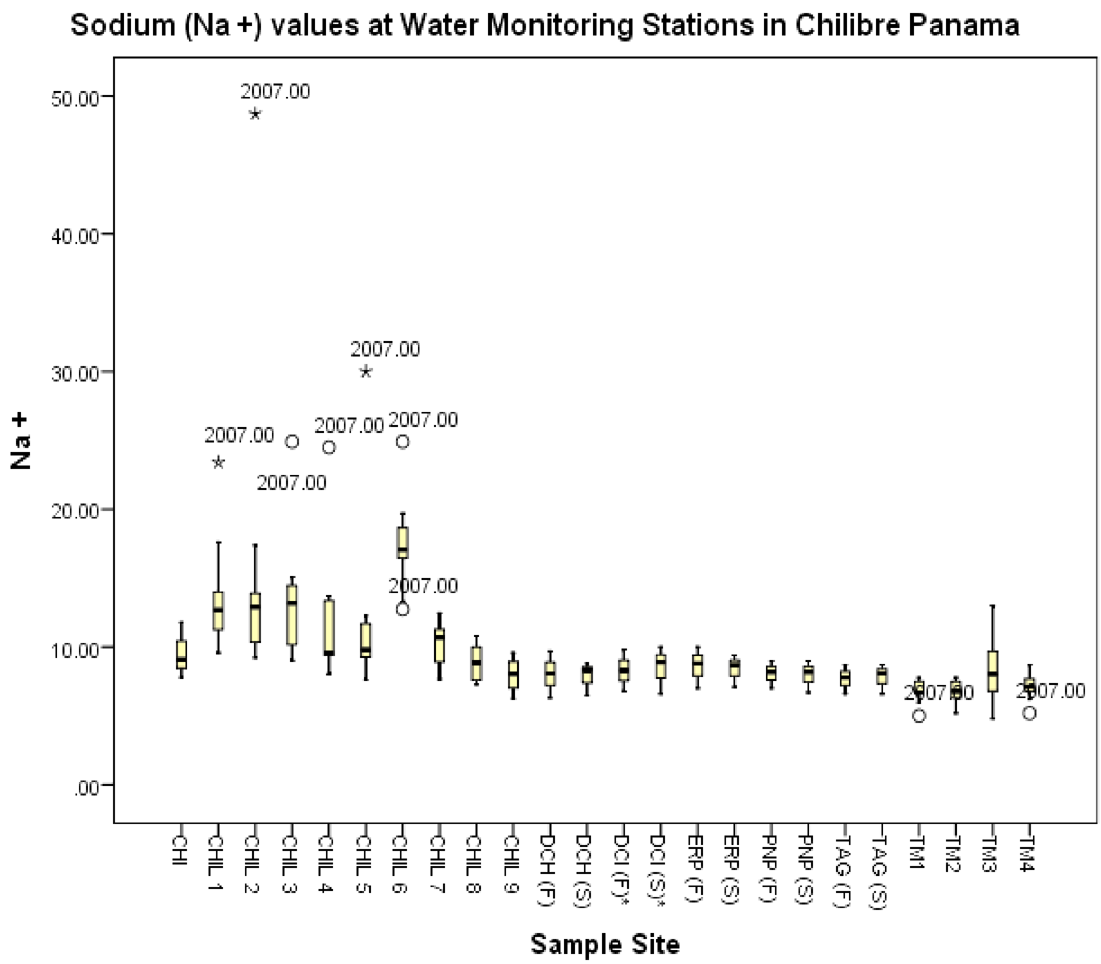


*Figure 1E. Sodium values ($\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes)*

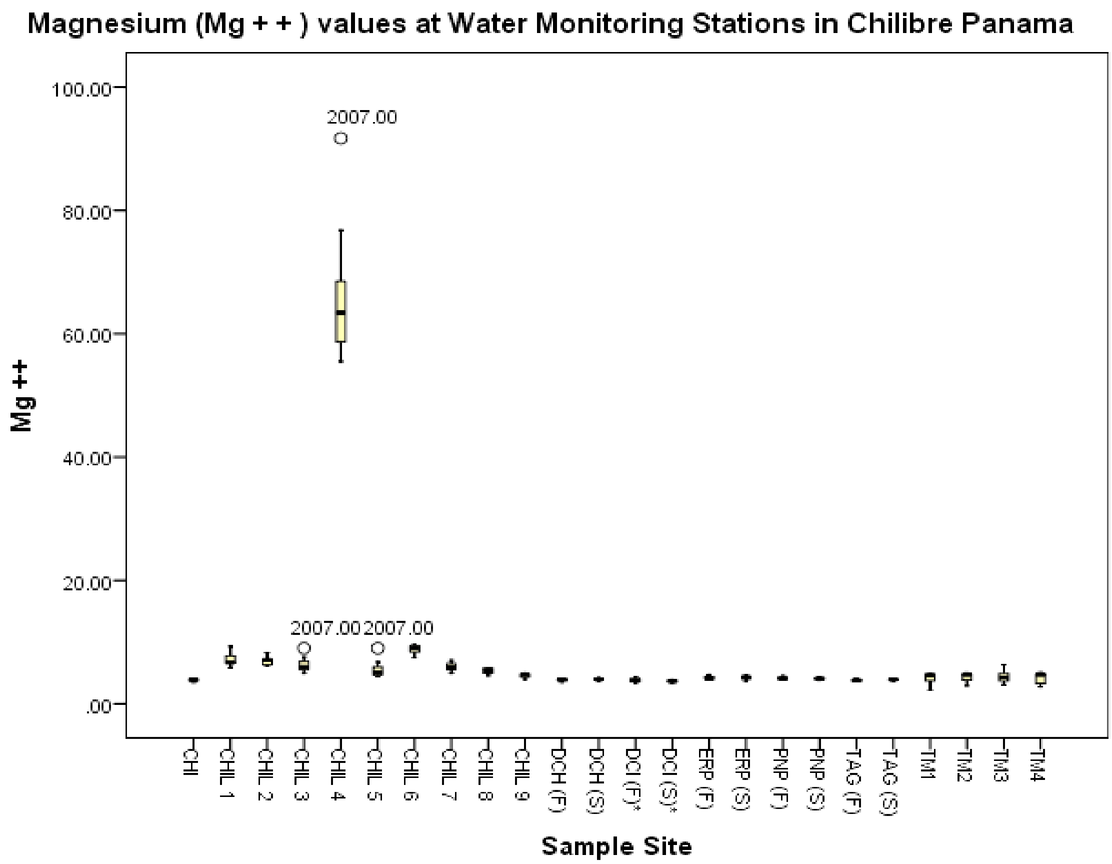


*Figure 2E. Magnesium values ($\frac{mg}{L}$) at monitoring stations in Chilibre Panama (Created by Christopher Weekes)*

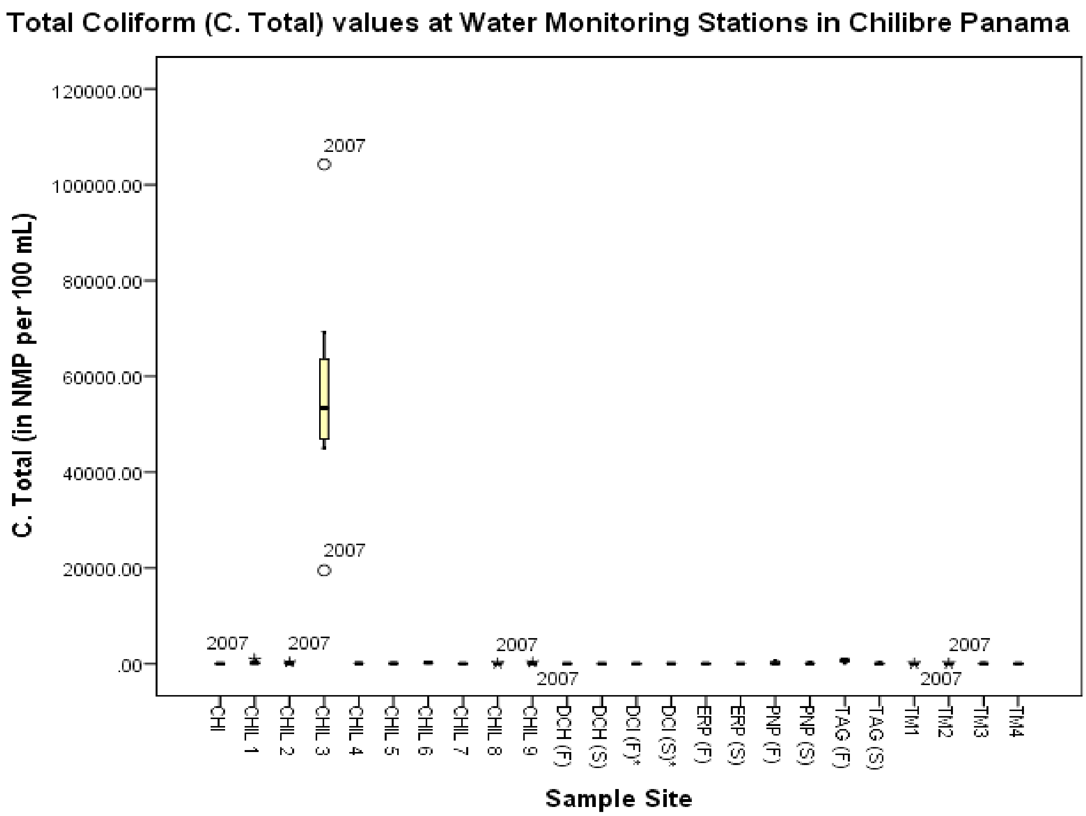


*Figure 3E. Total coliform values at monitoring stations in Chilibre Panama (Created by Christopher Weekes)*

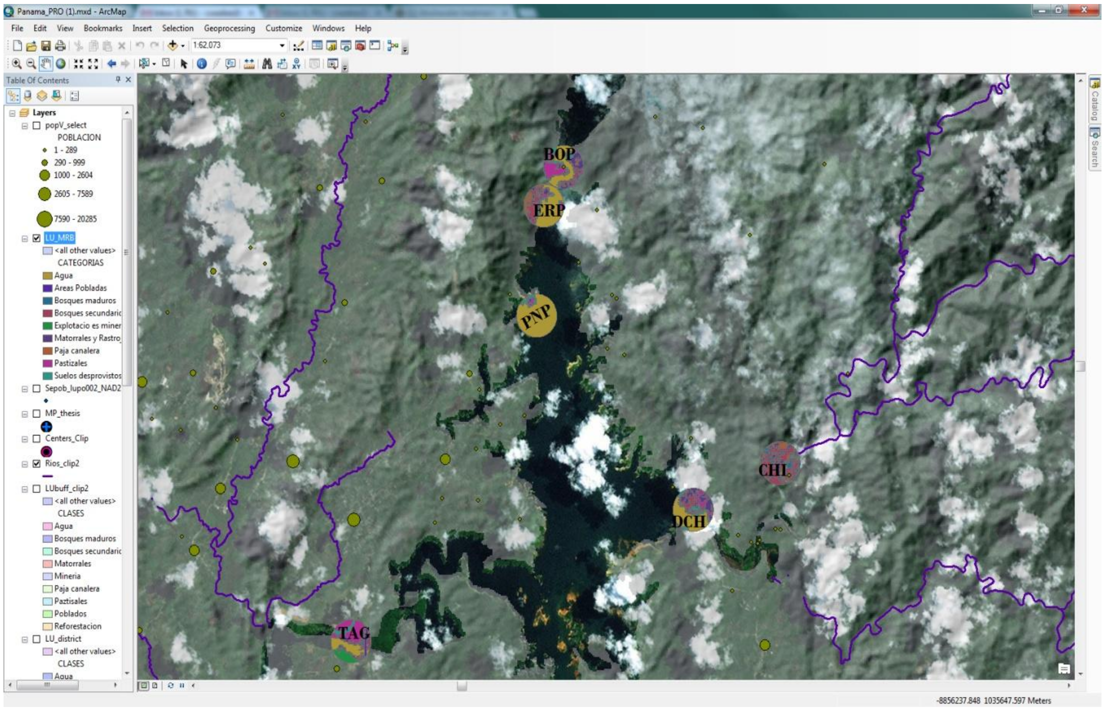


*Figure 4E. Region One monitoring  stations and land use (Created by Christopher Weekes and David Eilers).*

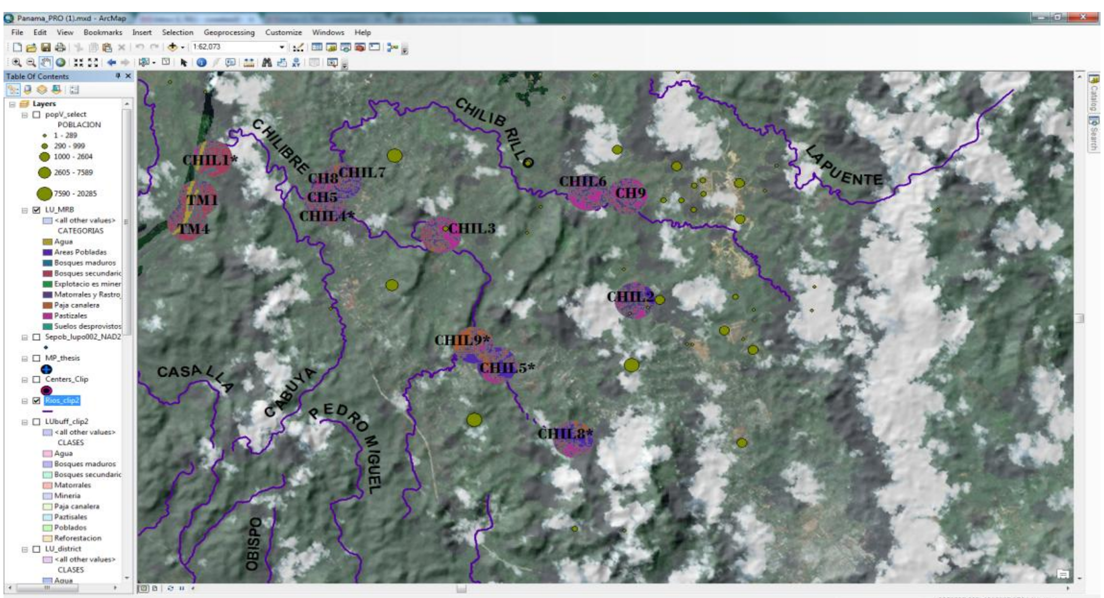


*Figure 5E. Region Two monitoring  stations and land use (Created by Christopher Weekes and David Eilers).*

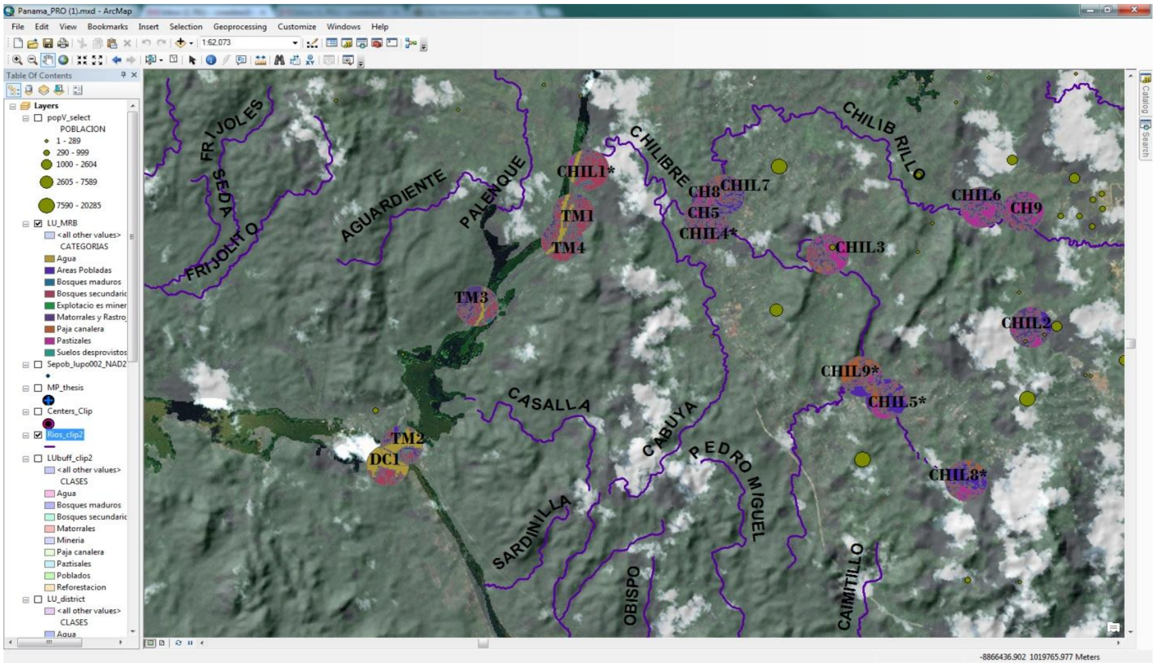


*Figure 6E. Region Three monitoring  stations and land use (Created by Christopher Weekes and David Eilers).*

## About the Author

Christopher Weekes is a MSPH student at the University of South Florida scheduled to graduate on August 10th 2013 with a degree in Environmental Health and a graduate certificate in Water,Health, and Sustainability. Future plans include finishing an MBA in Sustainable Business from Green Mountain College, obtaining a GIS certificate from the University of Southern California, completing an MLA at John Hopkins University and gaining some international work experience before pursuing a DrPH in Environmental Health Engineering. With this degree he would like to work for and eventually develop an environmental consultancy that operates in Latin America and the Caribbean.

In his spare time he likes to dance, read, play soccer and basketball, garden and tinker with the piano and guitar. He would one day like to be a part-time choir director, join an improvisation group, and coach a middle school basketball and or soccer team.