EPA/600/R-15/268
October 2015
www2.epa.gov/water-research

United States
Environmental Protection
Agency

Demonstration of a Graywater Management Project at a Community-Level on the Island of Puerto Rico

Office of Research and Development
Water Supply and Water Resources Division

Demonstration of a Graywater Management Project
at a Community Level on the Island of Puerto Rico

by

Evelyn Huertas[1], Exel Colón[2], Thomas P. O'Connor[3]

[1]United States Environmental Protection Agency (USEPA), Region 2
San Juan, Puerto Rico 00968

[2]Integrated Global Solutions LLC
Guaynabo, Puerto Rico 00968

[3]United States Environmental Protection Agency (USEPA)
Office of Research and Development
Urban Watershed Management Branch
Edison, New Jersey 08837

Contract No. EP-11-C-000217

Project Officer
Thomas P. O'Connor

REGIONAL APPLIED RESEARCH EFFORT
OFFICE OF RESEARCH AND DEVELOPMENT
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
EDISON, NEW JERSEY 08837

Notice

The United States of America Environmental Protection Agency (USEPA), through its Office of Research and Development (ORD), funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the authors and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Abstract

On-site sewage disposal for residents of many rural Puerto Rican communities were typically undersized due to small lot sizes and have other operational difficulties. To reduce hydraulic loadings to on-site systems residents release graywater to the nearest stormwater system or receiving stream. Graywater gardens are a low-cost/-maintenance alternative to conventional sewer projects. A community graywater garden was constructed and monitored in the María Jiménez community of the municipality of Gurabo. The garden infiltrated and evapotranspirated graywater from four households.

Water quality analysis during an 18-month monitoring period showed no statistically consistent removal across the graywater garden system. Some parameters had events indicative of removal as effluent concentrations were lower than influent concentrations; however, there were also events when influent concentrations were lower than effluent concentrations, potentially indicating a lagging response (e.g., total Kjeldahl nitrogen and chemical oxygen demand). Some parameters had no lagging response (e.g. magnesium, potassium and total coliform). A statistical increase in effluent iron most likely indicated the system was anaerobic and iron leached from the soil. Treatment within the graywater garden was greatly influenced by system maintenance and periods of high precipitation and humidity which limited evapotranspiration, infiltration and evaporation. Pretreatment through two 200-L tanks to control oil and grease was insufficient. A larger (1000L) tank, installed six months before the end of the project, resulted in lower concentrations of oil and grease in the garden.

Water quality monitoring indicated that the graywater garden behaved like an anaerobic drainage field for a septic system. Despite limited pollutant reduction within the graywater garden system, graywater discharges from these households were effectively eliminated or dramatically reduced. Recommendations for improving the graywater garden system and other design modifications were made.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Cynthia Sonich-Mullin, Director
National Risk Management Research Laboratory

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
COD	Chemical oxygen demand
CV	Coefficient of variance
E. coli	*Escherichia coli*
FAO	Food and Agriculture Organization
IBC	Intermediate bulk container
HDPE	High-density polyethylene
LOD	Limit of detection
MBAS	Methylene blue active substance
MPN	Most probable number
NA	Not applicable.
NH3	Ammonia
NOAA	National Oceanic and Atmospheric Administration
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
PRASA	Puerto Rico Aqueduct and Sewer Authority
PRDNER	Puerto Rico Department of Natural and Environmental Resources
PRDOH	Puerto Rico Department of Health
PREQB	Puerto Rico Environmental Quality Board
QAPP	Quality Assurance Project Plan
PDCA	Phosphate Detergents Control Act
PVC	Polyvinyl chloride
RARE	Regional Applied Research Effort
SAP	Sampling and Analysis Plan
SC	Specific Conductivity
SE	Standard Error
SM	Standard Methods
TKN	Total Kjeldahl nitrogen
USCS	Universal Soil Classification System
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WSP	Watershed Stewardship Program

Acknowledgements

A project of this type requires the dedication and cooperation of a team. The technical direction and coordination for this project was provided by the technical project team of the Urban Watershed Management Branch (UWMB), under the direction of Thomas P. O'Connor, Project Officer and Evelyn Huertas, Technical Lead for Region 2 and member of Puerto Rico's Watershed Stewardship Program. Jim Ferretti and staff performed water quality analysis on the samples at EPA's Region 2 Laboratory in Edison, New Jersey. We also want to acknowledge the help of Ramón García-Caraballo, former Mayor of Gurabo and resident of the María Jiménez community, for his continuous help to complete this project; Ms. María García for providing access to her property for constructing the graywater garden; and the neighbors of María Jiménez community who have agreed to participate in the project. Personnel from the Municipality of Gurabo Department of Public Works should also be acknowledged for their assistance in the project, specifically Concepción Cruz, Dennys Torres, and Juan Calderón. Robert Goo of the EPA's Office of Water and Daniel Murray of ORD provided peer reviews. Josephine Gardiner of the UWMB provided a technical edit.

Executive Summary

Past construction practices have created a legacy of communities in rural areas of Puerto Rico that were constructed without properly planned residential sewage disposal infrastructure. Many of these communities were built with on-site wastewater disposal systems even though the conditions were often not conducive to the proper operation of these systems due to a variety of conditions. In an effort to reduce overflows from these onsite systems, homeowners have generally adopted the practice of discharging graywater to the property surrounding the house or when available, to a storm drain, street gutter or a nearby water body or course. This discharge practice has elevated pathogenic indicator microorganisms in the local streams and lakes, and has increased phosphorous and other pollutant concentrations in downstream reservoirs.

The Puerto Rico Watershed Stewardship Program (WSP), a collaborative effort comprised of federal and local agencies, has sought various ways to improve receiving water quality and protect reservoirs. This EPA Regional Applied Research Effort (RARE) project funded the design, construction and monitoring of a community graywater garden system in the rural community of María Jiménez in the municipality of Gurabo, a small town 35 km south of San Juan. The graywater garden system received graywater from four residences comprised of 13 persons in all. The period of monitoring was from May 2013 to September 2014 during which samples were collected for standard water quality parameters (e.g. solids, organics, nutrients, metals and indictor microorganisms) for eight monitoring events.

The original design assumed there would not be graywater from the kitchen sink. Initially, a simple 400 L pretreatment system was designed to capture oil and grease from kitchen water but this was later replaced with a larger 1000 L pretreatment system which captured oil and grease better and provided more storage which reduced surges. Other operational changes were made during the demonstration project including construction of a French drain, addition of material to surface and plant harvesting in an effort to eliminate observed surface ponding during the rainy season.

Influent concentrations were similar to literature values of septic system discharges to drainage fields. While differences were observed between influent and effluent concentrations within the graywater system for individual events, the long term analysis showed no statistical difference, except for an increase in iron.

Effluent concentrations for several parameters changed during the course of the project and this was due to operational and maintenance changes. There was an increase in sulfide concentration which correlated with a drop in pH; this change potentially indicated that the 1000 L tank led to more stable anaerobic conditions. A quick look through the figures in Appendix A indicated that many of the lowest concentrations for both the influent and effluent came during the last two sampling events. This also points to better operation and maintenance by the larger pretreatment system; oil and grease capture was crucial to reducing all pollutant concentrations in the graywater garden. Phosphorous effluent concentration increased after plant harvesting, indicating that the plants had been effective in reducing nutrient concentrations.

Recommendations for improved design were made, and many of these design recommendations were derived from recommended practices for septic system drainage fields.

Overall, the graywater garden demonstration project reduced flows of graywater that would have alternatively discharged directly to storm drains and receiving water. The effluent sampling point was a submerged sampling point; most of the pollutant discharge from the graywater garden was to the soils surrounding the garden. As such, the use of

graywater gardens if practiced elsewhere on Puerto Rico and in sufficient numbers may reduce discharges to receiving streams and downstream reservoirs.

Chapter 1 Introduction

This report discusses the findings and results of a project investigating graywater management through the use of a small-scale graywater garden as a way to improve water resource management and reduce waste streams in rural areas of Puerto Rico. The chemical analysis conducted, including measurements of metals and bacterial levels, provides an assessment of the influent/effluent characteristics of the graywater in the garden system.

Overview

Throughout Puerto Rico, housing development practices in the past have often not been closely monitored by regulatory agencies. Past construction practices have often created a legacy of rural communities constructed without properly planned sewage disposal infrastructure. Many of these communities were built with on-site wastewater disposal systems though the conditions in these rural areas of Puerto Rico are often not conducive to the proper operation of these systems due to a variety of conditions such as high groundwater, steep slopes, clay soils and small lot sizes with improperly sized drainage fields. The combination of these factors with a less-than-required regulatory presence has resulted in a situation where homeowners often find it difficult or impossible to properly dispose of all of the wastewater emanating from their residence. In an effort to reduce overflows from the septic systems, homeowners have generally adopted the practice of discharging graywater to property surrounding the house or when available, a storm drain, street gutter or a nearby receiving water (WSP, 2011). Figure 1-1 is an example of the typical PVC piping used to collect and discharge household graywater.

The graywater being released, which includes laundry, sinks, kitchen/cooking and bathing water, can eventually end up in the drinking water reservoirs of Puerto Rico (Tetra Tech Inc., 2011). For example, in Puerto Rico's Río Grande de Loíza and La Plata watersheds, where 57% of the population is unsewered (PREQB, 2007), eutrophication has been identified as a major water quality problem that impacts its reservoir (Quiñones, 1980). Figure 1-2 shows development of green bio-mat in a storm drain as a result of the nutrient rich graywater discharge, while Figure 1-3 shows foaming agents in a pool of graywater ponding in the stormwater conveyance system.

Figure 1-1 Example of graywater collection for discharge (white PVC piping) for a typical residence

Figure 1-2 Typical graywater discharge to stormwater drainage system (street gutter).

Figure 1-3 Graywater discharge causing foam in stormwater drainage system.

The streams and lakes that discharge to Puerto Rico's reservoirs are known to contain high levels of pathogenic bacterial indicator microorganisms and phosphorous (Caspe, 2008). The U.S. Environmental Protection Agency (EPA), Puerto Rico Department of Health (PRDOH), Puerto Rico Environmental Quality Board (PREQB), Puerto Rico Aqueduct and Sewer Authority (PRASA) and Puerto Rico Department of Natural and Environmental Resources (PRDNER) created the Watershed Stewardship Program (WSP); this collaborative effort seeks to develop and implement replicable and affordable pollution control strategies to protect the watersheds that drain to the reservoirs. These strategies included elimination of phosphate detergents (Puerto Rico Environmental Quality Board, 1983; Puerto Rico Environmental Quality Board, 2007; Quiñones, 1980), extension of sewers and provision of affordable septic system cleanout services. This program has also targeted the rural mountain communities in the Río Grande de Loíza and La Plata watersheds because the drainage from these areas lead to the island's drinking water reservoirs for approximately 40% of the population of Puerto Rico.

The Puerto Rico Phosphate Detergents Control Act (PDCA), which was adopted in 2009 and became effective on January 1, 2010, has successfully reduced nutrient enrichment in the reservoirs (WSP, 2011). However, despite these pollution control strategies like the PDCA, residential graywater discharge will most likely continue to be practiced in the watersheds. Graywater gardens are potentially a way to reduce the impact of these discharges. Graywater gardens should be effective in Puerto Rico's tropical climate as the absence of freezing temperatures and corresponding plant dormancy should increase annual effectiveness of these planted systems. Infiltration, evaporation and evapotranspirative losses are effective mechanisms for planted systems to manage and treat water. The treatment of household graywater composed of the nutrient-rich effluent from showers, washing machines and sinks (not used for disposal of hazardous, toxic materials, food preparation, or food disposal) (McGovern, 2010) has been shown to reduce energy and costs needed for wastewater transport, treatment and disposal.

This report describes the design, construction, and monitoring of a small-scale, community graywater garden system. Influent/effluent water samples were analyzed for temperature, pH, specific conductivity (SC), metals, chemical oxygen demand (COD), ammonia (NH_3), chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-) and nitrite (NO_2^-), total Kjeldahl nitrogen (TKN), oil and grease, organic carbon, phosphorus (P^-), sulfide (S_2^-), filterable residue, non-filterable residue, fecal coliforms, total coliforms, and *Escherichia coli* (*E. coli*). These water quality parameters were collected quarterly in order to evaluate the overall efficiency of the graywater garden treatment system over time, as well as to characterize incoming water from the connected residences.

Chapter 2 Background

In 1983, the Commonwealth of Puerto Rico enacted the Underground Injection Control Rules (PREQB Resolution No. R-83-23-1) to protect surface and ground water resources throughout the island, as well as help prevent the pollution of potable water sources. The enacted regulation required owners of subsurface wastewater discharge structures to meet rigorous operational compliance criteria; however, single-family dwellings were excluded from the promulgated rules. This exclusion has contributed to communities with inappropriate onsite wastewater disposal systems throughout the island.

As noted, Puerto Rico's WSP collaborative effort is developing and implementing pollution control strategies (e.g. elimination of phosphate detergents, sewer construction and affordable septic system cleanout services) to protect receiving water quality of watersheds that drain to the drinking water reservoirs, focusing particularly on the rural, unsewered, mountain communities that have inadequate on–site treatment systems. In lieu of the traditional, expensive and disruptive sewershed build-out to rectify Puerto Rico's poorly-serviced sewershed areas, developing and demonstrating ways to treat graywater separately from residential blackwater could also help to decrease downstream impact to the reservoirs. As such, graywater garden treatment systems could support the proper operation and performance of existing onsite wastewater disposal systems by helping to maintain appropriate inflow and wastewater effluent characteristics.

USEPA's Office of Research Development (ORD) Urban Watershed Management Branch (UWMB) develops innovative urban technologies to assist municipalities and utilities in the selection of watershed approaches to control polluted urban discharges. Research by the UWMB on "graywater gardens" will help identify if this approach is a potential means of supplemental treatment in rural Puerto Rico to remedy the current practice of discharging graywater to the nearest water body or drainage system. Funding for this project was provided through the Regional Applied Research Effort (RARE) in which Region 2 works with the ORD to prioritize research project needs. The RARE Program is administered by the ORD's Regional Science Program.

Objective

This Region 2 RARE project demonstrated a graywater management system in a rural area of Puerto Rico. Household graywater was treated in a community graywater garden that was designed, constructed and monitored for this project. This goals of this project were to determine whether such gardens could improve water resource management and reduce wastewater streams, and to ascertain whether the technology could be adopted elsewhere on the island.

Location

This project was located in the María Jiménez community (18.266575 N, 65.937861 W) within the municipality of Gurabo (Figure 2-1). The residents of this small rural community were discharging graywater to property surroundings, nearby water bodies or storm drains. The municipality of Gurabo is located at the central-eastern part of Puerto Rico (Figure 2-2). It has a land area of 72.4 km^2 and is comprised of nine rural neighborhoods and one urban zone. Gurabo borders with Trujillo Alto to the north, San Lorenzo to the south, Carolina to the north-east, Juncos to the east and Caguas to the west. The population of Gurabo, based on the 2010 census, was 45,373 inhabitants. Although population across Puerto Rico has declined in recent years, Gurabo is one of several municipalities with population growth as it has become a satellite suburb of the metropolitan area of San Juan due in part to highway access. Although most of the population lives in the rural area and works outside the municipality, the main economic activities of Gurabo include the manufacturing of metals, paper, plastics, chemicals, pharmaceutical products, textiles, machinery and electrical equipment. There is also some minor livestock and fruit crops activity (Fundación Puertorriqueña de las Humanidades, 2009).

Figure 2-1 Aerial photograph of the María Jiménez community and project site (PRPB, 2010)

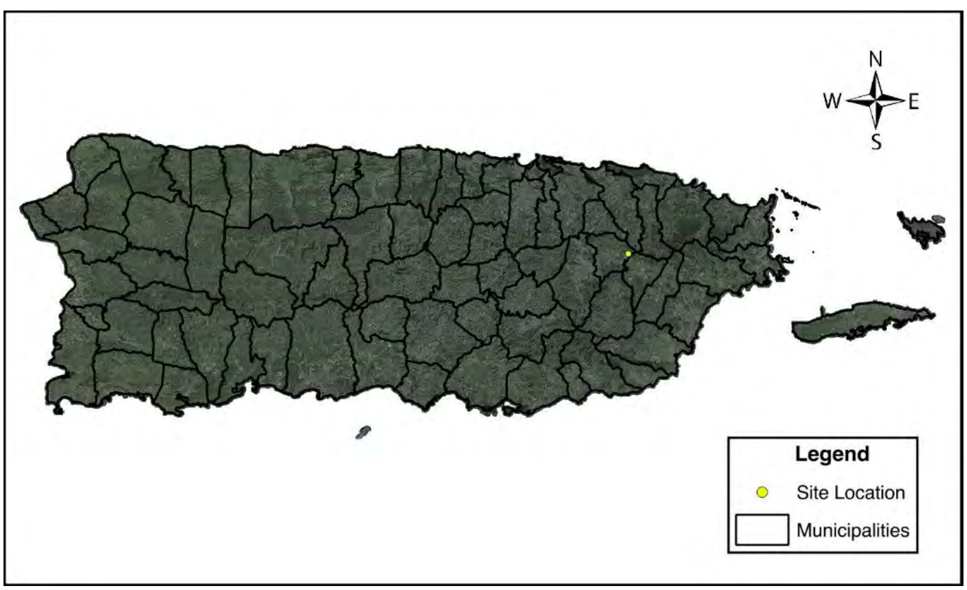


Figure 2-2 Location of the site within Puerto Rico (PRPB, 2010)

Gurabo is comprised of three different geological regions: the southern section of Gurabo belongs to Puerto Rico's eastern mountainous zone, the north is part of the Puerto Rico northern wet, and the central section belongs to the Caguas Valley. The municipality's surface is composed of alluvial deposits and volcanic and plutonic rocks. Specifically, the soils are mainly composed of the Múcara and Caguabo series which are respectively identified as a shallow, well-drained soil, formed from gravelly residuum from basic volcanic rocks and a moderately deep, slightly acid, well-drained soil, formed from weathered residual material from volcanic rock. Both of these series are characterized as moderately permeable soils (Boccheciamp, 1978). Gurabo is located within the Río Grande de Loíza watershed and is crossed by the Gurabo River, the Valenciano River, and some minor creeks. A topographical representation of the site location is provided in Figure 2-3

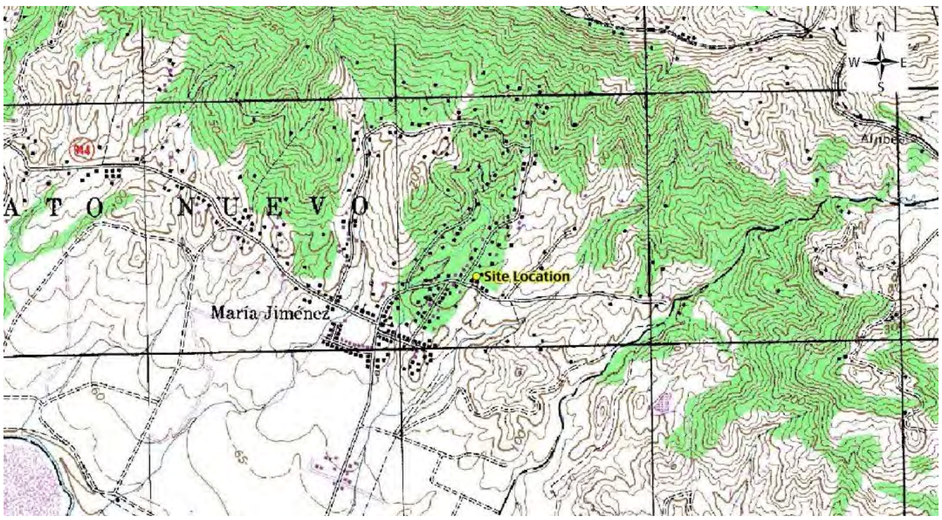


Figure 2-3 Topographic map of site and surrounding area (USGS, 1982)

The climate of Gurabo is classified as semi-tropical (Grupo Editorial EPR, 2009) with two temperature zones, a tropical zone in the plains and temperate zone in the mountains. The average temperature is approximately 25 ˚C though the average maximum daily temperatures increases to over 32 ˚C from July to September. Precipitation is abundant, with an annual average of 1700 mm of rain (NOAA, 2015); the mean monthly rainfall is provided in Figure 2-4. During hurricane season (June 1 – October 31) winds blow from east to west.

Figure 2-4 Temperature and precipitation averages in the Gurabo substation, 1981-2010 (NOAA-NWS, 2015)

Chapter 3 Materials and Methods

This section describes criteria for garden design, construction details and monitoring procedures.

Gray Garden Design and Construction

Soils for the site were characterized (Table 3-1) by standard testing methods (ASTM methods D 3282 and D 2487) based on the American Association of State Highway and Transportation Officials (AASHTO) Soil Classification System and Universal Soil Classification System (USCS), respectively. Soil percolation tests results yielded a rate of 8.4 cm/h for the María Jiménez community soil using a procedure of digging a 0.6 m x 0.6 m x 0.6 m hole into the ground which was then filled with water; water depth was measured every 15 minutes until all the water infiltrated (Integrated Global Solutions, 2012).

Table 3-1 Soil characteristics at the site

Test Method	Classification System	Sample Depth (cm)	Gravel (%)	Sand (%)	Fines (%)	Plastic Limit	Liquid Limit	Classification	Description
ASTM D3282	AASHTO	20	26	23.1	50.9	31	47	A-7-5(6)	Clayey Soil
ASTM D2487	USCS	20	26	23.1	50.9	31	47	ML	Gravelly Silt with Sand
ASTM D3282	AASHTO	41	15.2	25.8	59	30	43	A-7-5 (6)	Clayey Soil
ASTM D2487	USCS	41	15.2	25.8	59	30	43	ML	Sandy Silt with Gravel
ASTM D3282	AASHTO	61	8.5	30.5	61	25	42	A-7-6 (9)	Clayey Soil
ASTM D2487	USCS	61	8.5	30.5	61	25	42	CL	Sandy Lean Clay

Based on field observations and interviews, it was anticipated there would be graywater from 13 residents among the four households to be connected to the garden. Daily graywater input to the graywater garden was determined using calculations presented in the Quality Assurance Project Plan (QAPP) (Integrated Global Solutions, 2012), which assumed 1 m^2 of garden area could manage graywater from three residents assuming 110 L/d per capita. This 110 L/d per capita estimate was based on typical washing machine, shower and a fraction of sink usage (Mayer et al. 1999), resulting in projected graywater flows for all 13 residents of 1430 L/day. Peak direct rainfall infiltration requirements in the (Integrated Global Solutions, 2012) were 500 mm of rainfall in a period of 24 h, which is 21 mm/hr. Adding a safety factor, the gray garden's surface area was increased to 11 m^2. This resulted in a required 0.54 cm/hr infiltration rate with peak infiltration of 2.6 cm/hr to handle peak rainfall conditions as well, both of which were well below the 8.4 cm/hr measured rate.

Water level and sampling wells were placed at three different locations within the garden. These wells had depths of 250 cm, 175 cm and 50 cm measured from the existing elevation prior to excavation. Sampling wells were placed and angled in a manner that allowed sampler to stay out of the garden while taking a sample. Although it was recommended to perform excavation, construction and fill of the garden with hand instruments (e.g., shovels, pickaxes or wheelbarrows) to avoid compaction (which could negatively affect exfiltration from the rain garden), excavation and construction was performed with heavy machinery with the assistance of the Gurabo municipality. The site was excavated to a depth of 130 cm and a filter fabric was placed at the bottom to prevent fill migration. Over the filter fabric, a 10-cm gravel layer was added for improved percolation at the bottom of the garden. The greywater distribution pipes were designed to manage the discharge flows and spread the graywater throughout the planted area of the garden. These pipes had a 3% slope, producing an approximate velocity of 70 cm/s. Perforated 5-cm diameter PVC pipes were also installed to act as system drains and improve flow. Cleanouts were placed at various locations to provide access for maintenance in case of clogging.

The pre-project design assumed that kitchen sink water would not be treated in the graywater garden. With the inclusion of kitchen water, the expected per capita discharge volume would increase. Based on Mayer et al. (1999) per capita usage rates for washing machine (57 L/d), shower (44 L/d), faucet (41 L/d) and dishwasher (4 L/d), the discharge of graywater was estimated to be 144 L/d/capita. The addition of kitchen water to the graywater stream only increased the infiltration rates to 0.71 cm/hr and of 2.8 cm/hr for peak rate, both rates still well below design capacity. As long as the system did not clog, there appeared to be adequate infiltration capacity.

The four households were connected to the graywater garden with the assistance of the municipality of Gurabo, through a series of 5-cm and 10-cm diameter PVC pipes. Graywater was collected in the two 200-L pretreatment tanks. The pipe from the residences discharged to the bottom of the first tank allowing the grease to float and remain in the drum while the rest of the water continued to the second tank. In the second, screening tank, graywater passed through a 19-L plastic perforated bucket; water then discharged from the bottom of the screen tank into the graywater garden. At this point, flow was controlled through a pair of battery-powered timer valves to modulate graywater input to the garden. The screen tank also had an overflow pipe located approximately 30 cm above the bottom pipe of the tank. Water entering the garden passed through the 5-cm diameter PVC perforated irrigation pipes to diffuse into the soil. These perforations were the same diameter as in the bucket in the screen tank, so that anything passing through the screen tank, would also pass through the irrigation pipe holes without clogging them. There was also a bypass for both tanks to allow for maintenance. The grease trap and screen tank were designed for ease of construction to allow graywater gardens to be installed in other rural communities without need of extensive technical expertise.

As a safety factor, a graywater garden overflow pipe was designed to manage any excess water coming either from heavy rainfall or excessive graywater influent. Figure 3-1 shows the plan and cross section of the piping incorporated into the graywater garden system design. The complete as-built drawings with legends are located in Appendix B.

The graywater garden was initially planted with plantains (Musa sp.) and arrowleaf elephant ear (*Xanthosoma sagittifolium*), locally known as malanga. These species provided large vapor exchange area in their leaves and, in the case of plantains, their stems could store considerable amounts of water (Carr, 2009).

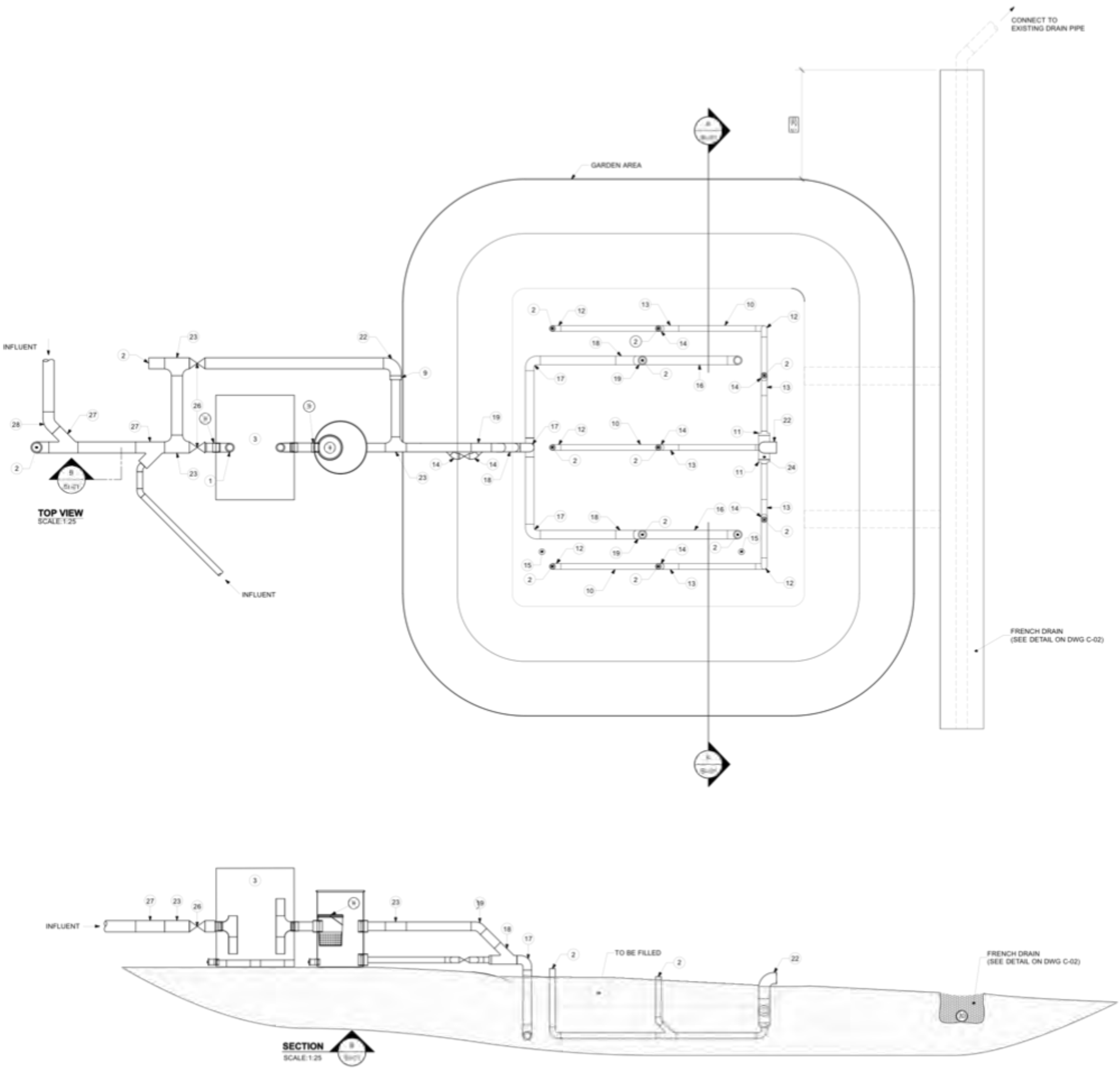


Figure 3-1 Plan and cross-section view of piping

A trapezoidal freeboard with an approximate height of 15 cm and an approximate width of 30 cm surrounded the garden as presented in Figure 3-2 which also presents an alternative cross sectional view of the graywater garden design. A berm was also placed upstream of the garden to prevent stormwater run-on. The berm and freeboard were constructed after the excavation was filled. Dimensions of the berm changed with heavy rainfalls; a few months after construction, dimensions for the freeboard were less than 10 cm in height and 40 cm in width.

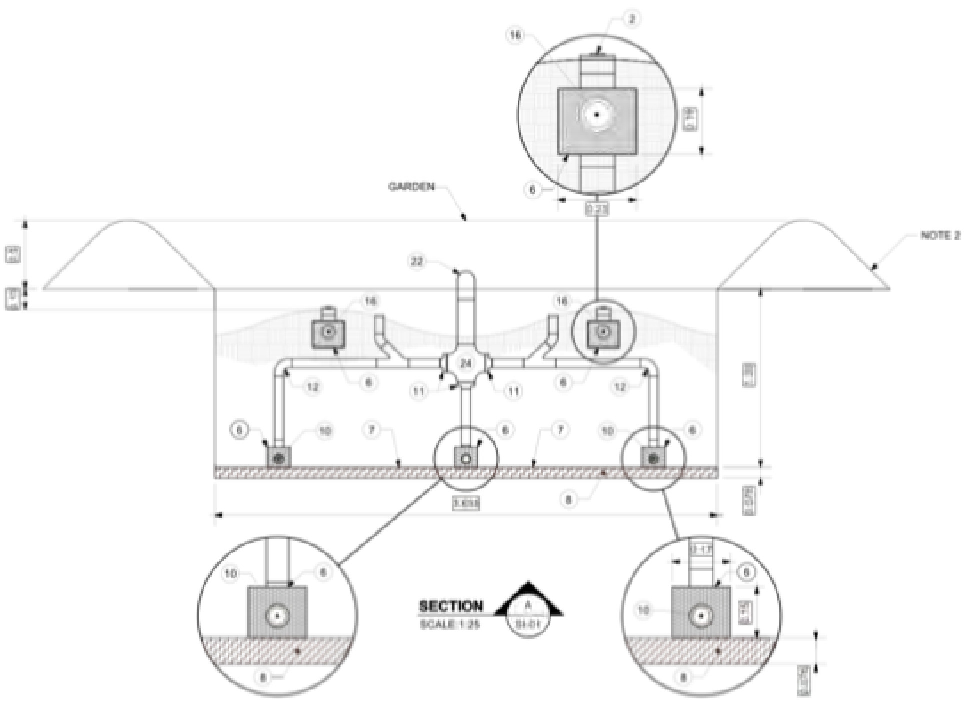


Figure 3-2 Alternative cross section view showing piping with freeboard

Grease trap cleaning was scheduled every two or three weeks with the collaboration of the Public Works Department personnel of Gurabo. Landscaping maintenance was also performed every two to four weeks, i.e., cutting grass and keeping the garden as clean as possible (refer to Appendix C for pictures). Frequency of the landscaping depended on recent precipitation and inspection of the growth of grass.

Changes after Construction and Implementation

Surface ponding started to occur in the graywater garden coinciding with the start of rainy (hurricane) season around August or September 2013. Neighbors were concerned by strong odors coming from the garden and believed mosquito breeding could present a health risk to anyone nearby. Several corrective actions to eliminate surface ponding were performed: the construction of a French drain (refer to figure Appendix B-5 and Appendix C-23 and -24 for details); reduction of the number of the plants inside the garden; scarification of the garden's surface; topping of the garden with approximately 5 cm of crushed stone; and later, providing an additional 5-cm of sand to the garden surface. These measures were effective in eliminating the surface ponding. While it was thought that this situation was caused by clogging of the pipes, flow through the pipes was verified twice by flushing with water and no clogs were detected.

Due to the nearby location of two tall mango trees which kept the garden shaded (demonstrated by numerous photographs in Appendix C), many of the initial plantings were removed so that air and sunlight could directly enhance evapotranspiration and evaporation. Even though there was wind (not quantified), shading limited the phenomenon of evapotranspiration and evaporation, which accounts for part of the removal of water in these systems (Maidment et al. , 1988). Excess rain along with high humidity during the hurricane season of 2013 caused surface ponding in the graywater garden. Some plantains were left in the garden as their leaves provided large surface area for evapotranspiration and also stored water in their stems and trunks (FAO, 2013). As a replacement to the initial plantings, a species of small shrub, brisselet (*Erythroxylum brevipes*) (Francis, 2004), was planted in various parts of the graywater garden, however, the brisselet grew very slowly. During the remainder study, a number of the brisselet were cut along with grass during landscaping maintenance.

Finally, the initial pretreatment configuration comprised of two 200-L plastic drums to trap grease and screen influent was replaced with a 1000-L intermediate bulk container (IBC) to facilitate maintenance and increase storage capacity to reduce impacts due to surges of graywater. The timer valves installed at the lower exit of the screening 200-L plastic drum to regulate the entrance of graywater to the garden were not well coordinated with the times and duration of the influent water, therefore, the screen tank operated most of the time in overflow mode and the desired control of the valves was overridden. Table 3-2 shows the timeline of construction and all modifications as well as the dates of the sampling events.

Table 3-2 Timeline of construction, modifications and sampling events

Task Number	Task	Date
1	Percolation test was performed	December 13, 2011
2	Excavation was performed and pipe system was installed	September 6, 2012
3	Pretreatment grease trap and screen tank (200 L) tanks were installed	September 8, 2012
4	Construction completed and houses connected	February 22, 2013
5	Plantains and malanga were planted	April 13, 2013
6	First quarterly sampling event	May 15, 2013
7	Second quarterly sampling event	August 13, 2013
8	Water ponding on the garden was observed	September 12, 2013
9	Third quarterly sampling event	December 3, 2013
10	French drain was installed	December 21, 2013
11	All malanga and some plantains plantings were removed from the garden and alternative plantings, brisselet, incorporated	January 21, 2014
12	Fourth quarterly sampling event	February 11, 2014
13	Larger pretreatment (IBC 1000 L) tank was installed	March 12, 2014
14	Fifth quarterly sampling event	June 3, 2014
15	Sixth sampling event	August 5, 2014
16	Seventh sampling event	August 26, 2014
17	Eighth (final) sampling event	September 23, 2014

Monitoring and Analyses

Quarterly sampling was initiated on May 15, 2013. The sampling portion of the project was terminated in October 2014, due to a request by the property owners who were looking to sell the property. Until June 2014, quarterly samples ran as scheduled, then the last three were performed at an accelerated rate resulting in eight sampling events overall (Table 3-2).

Prior to the scheduled sampling event, documentation and notification for the sampling events were prepared (normally two weeks in advance). An Analysis Request Form for the USEPA Region 2 laboratory identified which tests would be performed on the samples. Respective chains of custody were also completed. The Sampling and Analysis Plan (SAP) presented an overview of the sampling event, type of analyses to be performed on the samples and all information specifying quantity, collection and preservation of the samples. A copy of the SAP was sent to the local laboratory as well so that they could prepare the bottle order, which was usually picked up the previous afternoon. All bottles contained the preservatives for their respective contents, Region 2 having provided bottles at the onset of the sampling portion of the project. Appendix D provides example documentation from the third sampling event.

The day before a sampling event, all equipment was checked. Materials for the sampling event included: sample bottles, nitrile gloves, a 19-L bucket, two manual pumps, two 45-L coolers, six bags of ice, a marker, a pen, a pH and temperature meter, resealable plastic bags, bubble wrap, a 500-mL plastic cup and tape. Several resealable plastic bags were filled with ice the day before and stored in a freezer to increase efficiency during sampling. Approximately 15 L of sample were collected using a dedicated manual pump from the sampling point S2, located at the exit end of the garden. Each sampling bottle was carefully filled and put into one of the coolers with the ice bags. Similarly, a 15-L sample was manually pumped at the S-1 located at the grease trap.

Holding times for the parameters are provided in Table 3-3. Sample bottles with parameters that had short holding times, i.e., mainly bacteriological and some sanitary, were loaded into one cooler and were transported to a local laboratory. A second cooler was filled with sample bottles with longer holding times; this cooler was shipped to EPA's Region 2 laboratory in Edison New Jersey for analysis of the remainder of the parameters. Similarly preserved parameters were shipped in the same bottle, so there were only five bottles per influent and effluent. However, there was increased preparation time to prevent spillage during shipping as exemplified by the glass bottles in this second cooler which were also bubble-wrapped and placed in a plastic resealable bags. Sampling was usually scheduled for the morning hours, between 08:00 and 10:00, so that the cooler going to EPA Region 2's laboratory could be sent out later that afternoon.

Table 3-3 Parameter Testing method, sample volume, preservation and holding time

Parameter	Method	Container (volume)	Preservative	Holding Time
Total suspended solid	SM[1] 2540D	1 L HDPE (400 ml)	Ice, 4 ºC	7 d
Total dissolved solids	SM 2540C		Ice, 4 ºC	
Flouride	EPA 300.0	1 L HDPE (100 ml)	Not required	28 d
Chloride	EPA 300.0	1 L HDPE (50 ml)	Not required	28 d
Conductivity	SM 2510 A	1 L HDPE (100 ml)	Not required	
Oil and grease	EPA 1664A	1 L Amber glass (3 L)	HCl	28 d
Sulfide	SM 4500 S2 D	250 mL HDPE	ZN acetate +NAOH pH>9	
Chemical oxygen demand	EPA 410.4	500 mL HDPE (50 mL)	pH < 2 H_2SO_4	28 d
Total organic carbon	SM 5310	500 mL HDPE (50 mL)	pH < 2 H_2SO_4	
Nitrate + Nitrite [as N]	EPA 353.2	500 mL HDPE (100 mL)	pH < 2 H2SO4	28 d
Nitrogen, Total Kjeldahl	EPA 351.2	500 mL HDPE (100 mL)	pH < 2 H2SO4	28 d
Ammonia [as N]	EPA 350.1	500 mL HDPE (100 mL)	pH < 2 H2SO4	28 d
Phosphorous	EPA 365.4	500 mL HDPE (50 mL)	pH < 2 H2SO4	28 d
Metals	EPA 200.7	250 mL HDPE	HNO_3	6 m
pH	EPA 150.1	Field measurement	Field measurement	0 h
Fecal Coliform	SM 9221E	125 mL HDPE	0.008% Na_2S_3, 4^0C	6 h
Total Coliform	SM 9221C	125 mL HDPE	0.008% Na_2S_3, 4^0C	6 h
Escherichia coli	SM 9221F	125 mL HDPE	0.008% Na_2S_3, 4 ºC	6 h
Surfactants	SM 5540C	500 mL HDPE	Not required	48 h

[1] Standards Methods (1998).
[2] HDPE – High-density polyethylene

Statistical Analysis

Rudimentary statistical analyses were performed on the influent and effluent concentrations of the graywater garden sampling results. These analyses, i.e., median, normality, mean, standard of deviation and coefficient of variance (CV) along with t-statistic or Mann-Whitney U test are presented in Table 4-1 (metals), Table 4-2 (nutrients), Table 4-3 (organics and solids) and Table 4-4 (other parameters). Normality of data was tested the Shapiro-Wilk W test (StatSoft, 2011).

When samples were not detected, one-half the detection limit was used for calculation of statistics for a frequency of detection at or above 85%; from 85% to 50% detection, statistics were calculated using Aitchison's method (EPA, 2000). These calculations were made with Microsoft Office Excel (2013). For less than 50% detection, only frequency of detections, if any were reported.

Change in operational procedures and effect on effluent concentrations was tested by t-statistic or Mann-Whitney U test, as applicable. Correlation analyses were performed on effluent concentrations by the Spearman rank R correlation test (StatSoft, Inc., 2011). A high correlation between specific parameters for all sampling dates may imply that there were similar cause and effect for concentration changes, especially if these results increase and decrease in tandem. Where applicable, only values above the one-half detection limit were used for the normality and non-parametric correlation analysis.

Standard error (SE) was used for error bars and box plots.

Chapter 4 Analysis of Results

Weather Observations

Annual evapotranspiration in Puerto Rico is 1140 mm/yr (45 in/yr) (Hanson, 1991). Evapotranspiration rates are dependent on several variables, such as the surface area of the leaves, air temperature and the relative humidity. A high relative humidity corresponds to a high water content in the air which would reduce the gradient that allows the transfer of water from plants to the surrounding atmosphere.

An analysis of the data provided for precipitation in the area showed that precipitation was higher than normal from July to December 2013 (which leads to high humidity conditions) and corresponded with observations of surface ponding during this period of the project. Figure 4-1 shows a comparative plot of how different precipitation behaved from the historic average during the period of the study where surface ponding started, approximately August or September 2013. Figure 2-4 indicates that this is also the warmest period of the year.

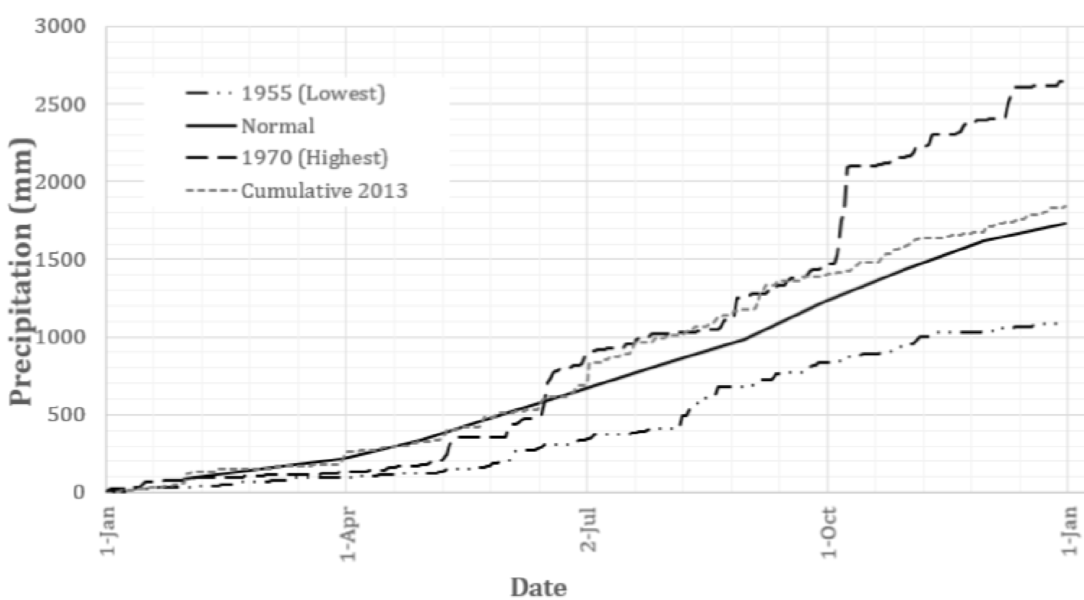


Figure 4-1 Historical precipitation maximum, minimum and average accumulation behavior for Gurabo compared to that of 2013.

Sampling Results and Statistical Analysis

Time series plots (Appendix A) were produced for parameters that had sufficient quantities of data so that statistical analysis could be performed. Due to the small sampling size (8 events maximum), at least 50% detection (along with normality, as tested by the Shapiro-Wilk W test) was required to calculate a mean concentration for the influent or effluent. Several metals, i.e., antimony, beryllium, cobalt, selenium and thallium, were not detected during sampling; arsenic, cadmium, mercury, and nickel, had only one detection while lead and vanadium had several detections but insufficient numbers of detections of either the influent or effluent to perform any rudimentary statistics. Data for parameters, as previously explained, are presented in Table 4-1 (metals), Table 4-2 (nutrients), Table 4-3 (organics and solids) and Table 4-4 (other parameters).

A general observation of the behavior of all parameters was the near absence of sustained trend of removal as a function of time, especially in the metals. Observation of the plots in Appendix A show that some parameters have some events which indicate removal as effluent concentrations are lower than influent concentrations removals; however, there are also sampling events when influent concentrations are lower than effluent concentrations, indicating a lagging in response (e.g., TKN and COD). Some parameters have no lagging response (e.g. magnesium, potassium and total coliform).

Table 4-1 Sampling results and statistics for metals

Parameter	Location	Limit of detection (ug/L)	Median (ug/L)	Lower quartile (ug/L)	Upper quartile (ug/L)	Normality (detections /events)	Mean (ug/L)	Standard of deviation (ug/L)	Coefficient of variation	Statistical difference
Aluminum	Influent	100	430	150	3400	No (7/7)	--	--	--	No
	Effluent	100	2150	370	7800	Yes (6/6)	3700	4000	1.07	
Barium	Effluent	100	100	100	230	Yes (3/6)	<LOD[1]	--	--	NA[2]
Calcium	Influent	500	37000	22000	65000	No (7/7)	--	--	--	No
	Effluent	500	33500	21000	43000	No (6/6)	--	--	--	
Chromium	Effluent	5	11	5	27	No (4/6)	--	--	--	NA
Copper	Influent	10	90	72	420	No (7/7)	--	--	--	No
	Effluent	10	140	76	180	No (6/6)	--	--	--	
Iron	Influent	50	570	380	1900	No (7/7)	--	--	--	Yes
	Effluent	50	2500	1100	4300	No (6/6)	--	--	--	
Magnesium	Influent	500	12000	7300	13000	Yes (7/7)	10600	2900	0.27	No
	Effluent	500	10200	7500	15000	Yes (6/6)	11000	3800	0.35	
Manganese	Influent	5	53	46	320	No (7/7)	--	--	--	No
	Effluent	5	235	140	430	Yes (6/6)	303	230	0.76	
Silver	Effluent	5	5	5	18	Yes (3/6)	6[1]	5	0.8	NA
Zinc	Influent	20	180	120	1400	Yes (7/7)	650	690	1.1	No
	Effluent	20	455	170	690	No (6/6)	--	--	--	

[1] Due to non-detects, mean and other normal parameters calculated using Atchison's method.
[2] NA – not applicable.

Table 4-2 Sampling results and statistics for nutrients

Parameter	Location	Limit of detection (mg/L)	Median (mg/L)	Lower quartile (mg/L)	Upper quartile (mg/L)	Normality (detections /events)	Mean (mg/L)	Standard of deviation (mg/L)	Coefficient of variation	Statistical difference
Ammonia	Influent	0.5[1]	4.2	3.1	5.7	Yes (8/8)	4.7	3.1	0.65	No
	Effluent	0.5[1]	5.7	4.0	9.2	No (8/8)	--	--	--	
Nitrate and Nitrite	Influent	0.05	0.06	0.05	0.21	Yes (5/8)	0.12[2]	0.15	1.2	No
	Effluent	0.05	0.06	0.05	0.08	No (5/8)	--	--	--	
Total Kjeldalh Nitrogen	Influent	1[1]	12	11	18	No (7/7)	--	--	--	No
	Effluent	1[1]	17	13	27	No (7/7)	--	--	--	
Phosphorous	Influent	0.5[1]	3.6	2.8	5.3	Yes (8/8)	4.0	1.6	0.39	No
	Effluent	0.5[1]	4.6	2.1	5.4	Yes (8/8)	4.1	1.9	0.45	
Potassium	Influent	0.5	9.4	8.2	12.0	Yes (7/7)	9.7	1.9	0.2	No
	Effluent	0.5	8.9	7.8	13.0	Yes (6/6)	9.8	2.6	0.3	

[1] Multiple detection limits; this is maximum detection limit.
[2] Due to non-detects, mean and other normal parameters calculated using Atchison's method.

Table 4-3 Sampling results and statistics organics, solids, salts, flouride and sulfide

Parameter	Location	Limit of detection (mg/L)	Median (mg/L)	Lower quartile (mg/L)	Upper quartile (mg/L)	Normality (detections /events)	Mean (mg/L)	Standard of deviation (mg/L)	Coefficient of variation	Statistical Difference
Chemical oxygen demand	Influent	1000[1]	750	620	1900	No (8/8)	--	--	--	No
	Effluent	400[1]	870	550	1900	Yes (8/8)	1290	1040	0.81	
Oil and grease	Influent	5	70	50	180	No (8/8)	--	--	--	No
	Effluent	5	54	35	150	No (8/8)	--	--	--	
Total organic carbon	Influent	10[1]	150	130	220	No (7/7)	--	--	--	No
	Effluent	10[1]	160	130	290	Yes (7/7)	190	95	0.49	
Total dissolved solids	Influent	10	480	430	580	No (7/7)	--	--	--	No
	Effluent	10	480	440	630	No (7/7)	--	--	--	
Total suspended solids	Influent	10	110	60	350	No (8/8)	--	--	--	No
	Effluent	10	260	50	390	No (7/7)	--	--	--	
Chloride	Influent	10[1]	59	45	140	Yes (7/7)	100	84	0.83	No
	Effluent	5[1]	58	53	86	Yes (7/7)	66	17	0.26	
Sodium	Influent	1	54	43	73	No (8/8)	--	--	--	No
	Effluent	1	58	53	77	Yes (7/7)	67	16	0.24	
Flouride	Influent	0.05	0.08	0.03	0.09	Yes (7/7)	0.07	0.04	0.54	No
	Effluent	0.05	0.10	0.03	0.14	Yes (7/7)	0.09	0.04	0.38	
Sulfide	Influent	0.1[1]	3.4	0.03	4.3	Yes (7/7)	2.5	2.3	0.95	No
	Effluent	0.1[1]	1.6	0.05	4.6	Yes (6/7)	2.2[2]	2.2	1.0	

[1] Multiple detection limits; this is maximum detection limit.

[2] Due to non-detect, mean and other normal parameters calculated using substitution of ½ detection limit.

Table 4-4 Sampling results and statistics pathogenic indicators and other water quality parameters

Parameter (units)	Location	Limit of detection	Median	Lower quartile	Upper quartile	Normality (detections /events)	Mean	Standard of deviation	Coefficient of variation	Statistical Difference
Fecal coliform (MPN per 100/ml)	Influent	1.8	$2.2x10^6$	$7.2x10^5$	$4.4x10^6$	No (8/8)	--	--	--	No
	Effluent	1.8	$5.9x10^5$	$5.9x10^4$	$4.5x10^6$	No (8/8)	--	--	--	
Total coliform (MPN per 100/ml)	Influent	1.8	$1.6x10^7$	$3.6x10^6$	$1.6x10^{7A}$	No (8/8)	--	--	--	No
	Effluent	1.8	$1.3x10^7$	$1.7x10^6$	$1.6x10^7$	No (8/8)	--	--	--	
E. coli (MPN per 100/ml)	Influent	2.0	$2.2x10^6$	$7.2x10^5$	$3.9X10^6$	No (8/8)	--	--	--	No
	Effluent	2.0	160	130	4.5x106	No (8/8)	--	--	--	
pH	Influent	0.1	6.4	5.4	7.0	Yes (7/7)	6.3	0.7	0.11	No
	Effluent	0.1	6.3	5.7	6.7	Yes (7/7)	6.4	0.7	0.11	
Conductivity (µS/cm)	Influent	0.1	600	450	720	No (6/6)	--	--	--	No
	Effluent	0.1	545	500	600	Yes (6/6)	547	84	0.15	
Surfactant (mg/L as LAS, MW 320)	Influent	1.25^B	19	13	30	Yes (8/8)	22	9	0.43	No
	Effluent	2.5^B	20	13	29	Yes (8/8)	22	13	0.55	

[A] Maximum count, values recorder as > $1.6x10^7$.

[B] Multiple detection limits; this is maximum detection limit.

T-test (when data was normal) or Mann-Whitney U test (when data was not normal) indicated there was no consistent statistical differences from the influent sampling point to the effluent sampling point, except for an increase in iron in the effluent as demonstrated in Figure 4-2. There was more manganese as well, but this is considered to not be statistically different although the calculated p-values, i.e., $p = 0.063$, was very close to $p < 0.05$. High levels of organic waste can lead to higher concentrations of iron and manganese in groundwater, especially under anaerobic conditions (Sawyer and McCarthy, 1978).

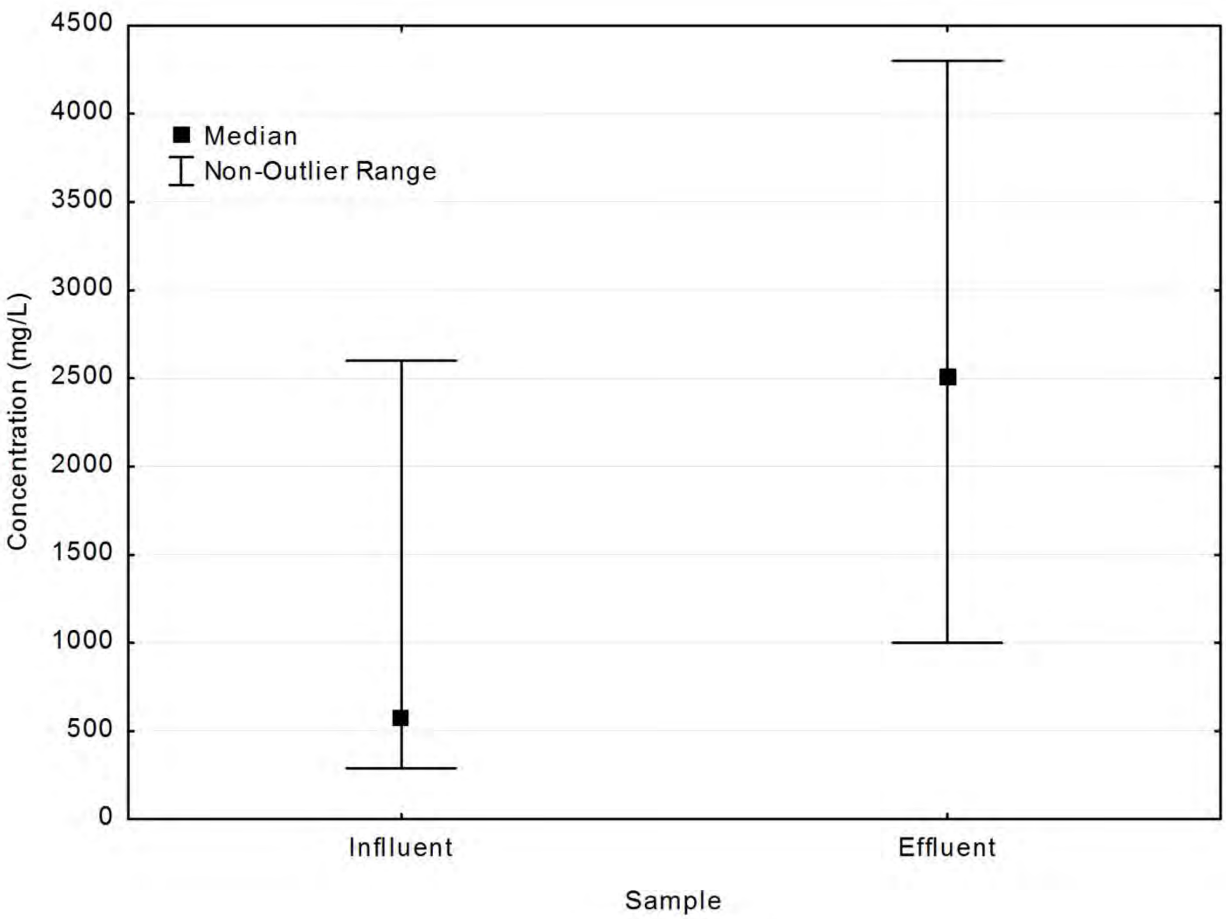


Figure 4-2 Median iron concentration and non-outlier range for influent and effluent sampling locations

Several operational changes during the course of the study were identified in Table 3-2. Probably the most important change was the increase in the size of the pretreatment system to capture oil and grease, facilitate maintenance and reduce impacts due to surges. A testing of the observed effluent concentrations before and after the installation of the 1000-L IBC resulted in three statistically relevant t-test results, i.e. reduced chloride and sodium concentration and increased sulfide concentration. Figure 4-3 is a box plot of the sulfide. Similar changes in the sulfide concentration were noted in the influent concentration as well which are indicative of the larger pretreatment system driving the water to anaerobic conditions before being discharged to the graywater garden.

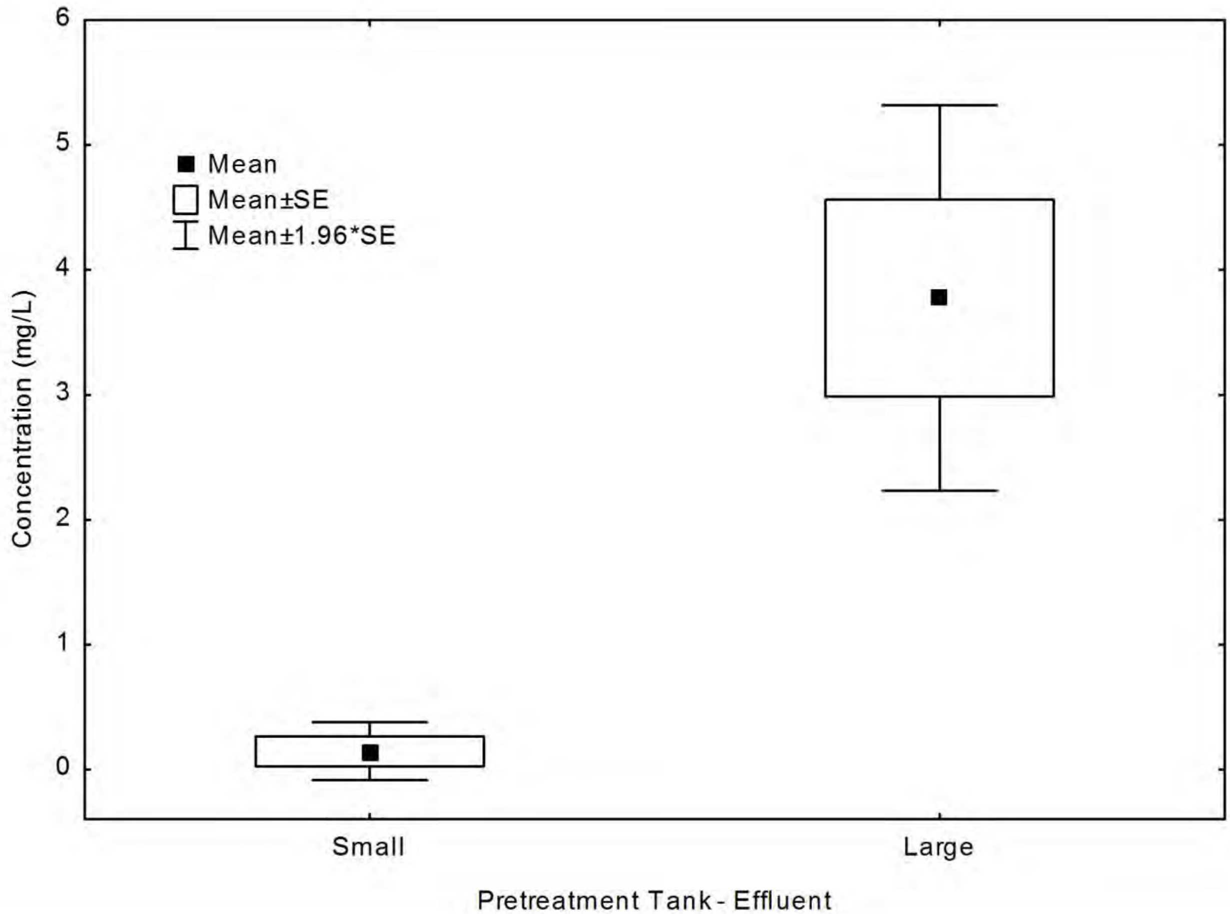


Figure 4-3 Box plot of sulfide concentration before and after change in pretreatment system

The phophorous had an unusually large effluent concentration for the first event (see Figure A-154). It was speculated that the plating of the garden just a month before may have contributed to this large effluent concentration particularly since the influent concentration was much lower in comparison. It is suspected that the general backfill soils contained nutrients. The plantains and malangas were purchased as bare roots from nearby garden store.

A retesting of the observed nutrient concentrations excluding first effluent event did not affect normality except for NH_3. A subsequent t-test did result in a statistical difference for phosphorous effluent before and after the change in the pretreatment (p-values < 0.05) as depicted in Figure 4-4. As noted in Table 3-2, many of the original plantings were removed from the garden and replaced with brisselets. The brisselets were provided by the PRDNER in pots and soil from the pots was incorporated into the garden. Additionally, more fill material was incorporated into the garden to reduce surface ponding. This addition of soil and fill along with replacement of original plantings with slow growing brisselet would appear to have negatively affected the phosphorous concentration in the effluent samples.

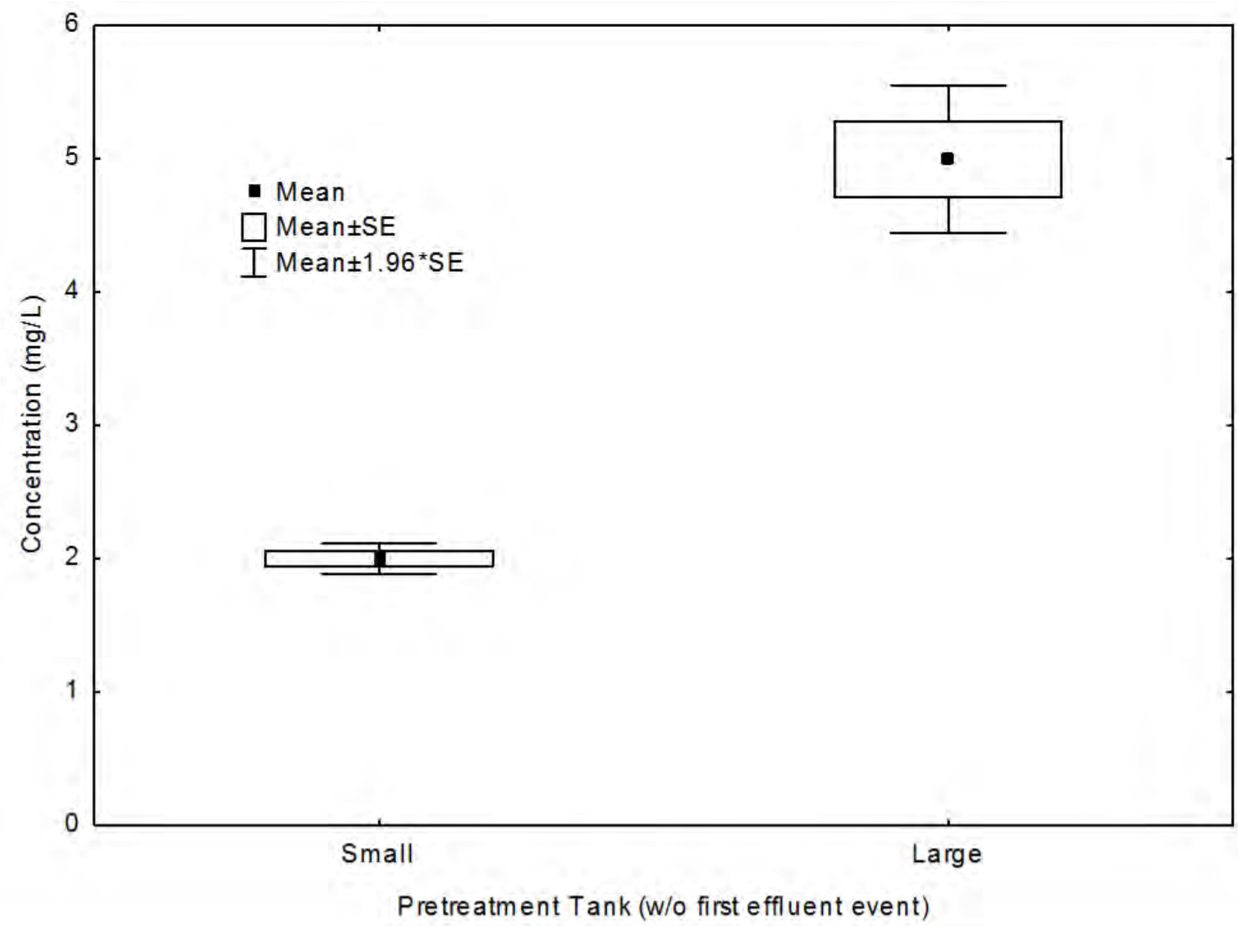


Figure 4-4 Box plot of phosphorous concentration before and after change in pretreatment system

A nonparametric Spearman Rank Order Correlation analyses was performed on the observed effluent concentrations only and is presented in Appendix E (StatSoft 2011). Correlations values in red are considered significant at p-value <0.05. Many of the observed significant correlations were an expected result. For example, sodium correlates with chloride and specific conductance; iron, aluminum and manganese correlate with each other; ammonia and TKN correlate; sulfide negatively correlates with pH (see Figure 4-5); and COD, TOC and oil and grease all correlate. Additionally, TDS correlated with calcium, magnesium and conductance; the water supply for this area of Puerto Rico has hardness between 160-180 mg/l Ca/Mg.

There are other correlations that demonstrate the impact of the high organic loading to graywater garden. COD correlates with aluminum, copper, calcium, magnesium and zinc. Similarly, so does oil and grease; however oil and grease also correlated with pH.

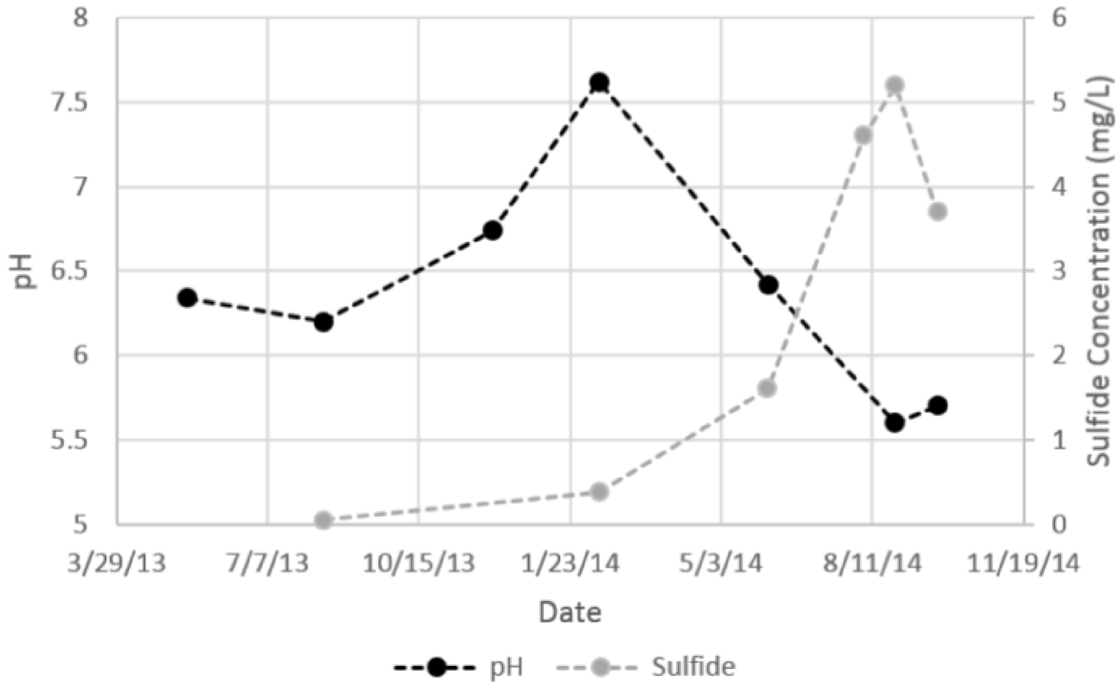


Figure 4-5 Effluent pH and sulfide concentration

Chapter 5 Discussion and Recommendations

Overall observed concentrations to the influent tank ware similar to literature values for septic tank effluent. TDS and chloride influent concentrations were similar to septic tank effluent (EPA, 2000), with TDS median of 480 mg/L compared to a mean of 497 mg/L, and chloride median of 59 compared to mean of 70, respectively. Fecal coliform was an order of magnitude larger, while nutrients, as observed for TKN and phosphorous were slightly lower in the graywater garden influent, with median of TKN at 12 mg/l and a mean of phosphorous of 3.6 mg/l as compared to mean of 44.2 and 8.6 mg/l, respectively. However, organic loadings were much higher, with graywater influent median TOC and COD concentrations of 150 mg/L and 750 mg/L, respectively, compared to septic tank mean TOC and biochemical oxygen demand (BOD) effluent of 47.4 and 93.5 mg/L, respectively. The BOD to COD ratio for sanitary loading typically is 0.4 to 0.8 (Tchobanoglous and Burton, 1991) which indicates the observed COD in the influent is much higher than the comparative literature value. This larger organic loading in the observed graywater influent concentration appears to be driven by the addition of kitchen water as literature values for kitchen sink water can be as high as 880 mg/L for TOC and 1460 mg/l for BOD (EPA, 1992).

Observed concentrations for February 2014 showed a sharp increase in many of the parameters (only phosphorous had a statistical increase in effluent concentration). This followed several operational changes including construction of French drain, removal of plants and change to larger pretreatment system, with these latter two being the most important actions influencing observed changes in concentrations. The May 2014 data points showed a marked decrease in fecal coliform and *E. coli* populations, which potentially signals that the system was entering a new operational phase. A look through the parameters in Appendix A indicate that many of the lowest concentrations for both the influent and effluent came during the last two sampling events. While this potentially indicates that the plantings were providing more benefit than originally anticipated, the decrease in both influent and effluent concentration for the final two sampling events points to better operation and maintenance of the pretreatment and oil and grease capture as being crucial to reducing concentrations in the graywater garden. Potassium is one of the principal requirements for bacterial growth, therefore decreases in potassium concentrations for the influent and effluent may also indicate reduced opportunity for bacteriological growth (Leslie Grady Jr et al., 2011). Sulfide levels increased for the same period (a statistical increase in effluent concentration), confirming anaerobic or septic conditions. The pH range which was 6 - 7 at the start of the study decreased to slightly acidic conditions between 5.5 and 6 nearing the end of the sampling period.

There was statistically more iron in the effluent from graywater garden than the observed influent concentration. Continuous discharge leads to an anaerobic environment (Tchobanoglous and Burton, 1991), and soluble forms of iron and manganese appear during anaerobic conditions (Sawyer and McCarty, 1978). The high values of the iron and manganese (Smol, 2008) indicate a reducing environment, as both metals are insoluble in an oxidizing environment. Iron, magnesium and manganese levels may be explained by the natural content of these minerals in the soil of the area, and generally, soils in the Río Grande de Loíza watershed which are hydrothermally-altered rocks (Seiders, 1971). Iron, aluminum, mangesium and calcium silicates comprise a significant portion of the common rock forming minerals of the earth's crust (Klein and Hurlbut, 1985). The decrease in iron and manganese effluent, especially during the last two sampling events, corresponds to increased sulfide production and most likely indicates that iron and manganese oxides are potentially precipitating as ferrous and manganese sulfide. In a subsurface drainage field, mineral precipitates, i.e. ferrous sulfide, aluminum, iron and calcium phosphate complexes can form and then be observed in leachate (Laak 1986). None of these metals are identified as limiting nutrients needed for bacterial growth in considerable quantities (Leslie Grady Jr et al., 2011).

Levels of organic and inorganic content in the influent and effluent sampling points may have been influenced by the fact that initial pretreatment tanks were not cleaned out consistently. An extended accumulation of oil and grease in the tanks, with the addition of surges flows, transferred these pollutants to the graywater garden. Significant oil and grease content were observed in the screen tank of the original pre-treatment configuration, and as previously noted, there was prolonged use of the overflow pipe in the screen tank. Valve use and timing were not efficiently coordinated with peak flows from the households, which may have caused the graywater garden to receive graywater directly as it came into the system. Accumulation of oil and grease inside the graywater garden piping may have also occurred, contributing to periods of surface ponding and the upwelling by the influent discharge into the graywater garden. This may have created short circuiting routing for water to traverse through the graywater garden and, as a consequence, distributing unevenly throughout the piped sections. As such, assuming that the specific point for the effluent sampling was representative of the entire graywater garden system performance may not be entirely accurate. It is believed that the influence of factors such as system maintenance, surges, rainfall run-on and the heterogeneity of conditions inside the garden contributed to the observations of high effluent concentration within the graywater garden system.

During the course of the study and following strong periods of rain, surface ponding occurred due to surges in the graywater influent, rainfall run-on from surrounding area or poor percolation of the water into the surrounding soils as rainfall induced saturation occurs. Water sources other than graywater, i.e. water from rain gutters, basement sump pump discharges or surface runoff, should be routed away from any onsite wastewater treatment system (EPA, 2002). Measures to prevent rainfall runoff (Laak, 1986) from entering the graywater garden should be performed due to the potential to overload the infiltration capacity of the system and lead to failure.

Even though the initial testing of the infiltration capacity appeared to be sufficient, the graywater garden may not have been big enough due to the potential to clog when accepting higher organic loads associated with water from the kitchen sink. In septic systems, release of greases and oils to the septic disposal field can lead to reductions in infiltration capacity (Tchobanoglous and Burton, 1991). Laak (1986) recommended a large anaerobic pretreatment for graywater septic systems due to large concentrations of grease in graywater. Septic system disposal fields typically develop a biomat (Tchobanoglous and Burton, 1991 or clogging layer (Laak, 1986). Future sites should be tested more thoroughly for infiltration capacity of the disposal field as per guidance for septic disposal fields, i.e. saturated coefficient of permeability (Tchobanoglous and Burton, 1991). The initial infiltration testing performed was more appropriate for intermittent infiltration not continuous infiltration with high organic content. The long-term acceptance rate (LTAR) for onsite disposal systems is more typically 0.05 – 0.08 cm/hr (Tchobanoglous and Burton, 1991, which would have required an 8 by 8 m to 12 by 12 m field size for approximately 150 L/ day; instead of approximately 1 m^2 per capita designed for this project, approximately 10 m^2 may be required to meet the aforementioned LTAR.

As demonstrated by the hilly terrain in Figure 2-3 and potential for large rain falls as demonstrated in Figure 4-1, this site may have benefited from an upslope curtain drain (EPA, 2002) to maintain unsaturated conditions in the soils surrounding the graywater garden. Even when remedial measures were taken, i.e. French drain, water kept surfacing, although not ponding; however, despite periods of surface ponding and remedial action, the majority of the water influent to the graywater system either exfiltrated or evapotranspirated during the period of this demonstration project.

Besides maintaining the grease trap, additional design and operational changes like designing the system to have more than one garden for acceptance of graywater may help functionality. As previously noted, the surrounding soils of the graywater garden were identified to contain clay. Alternating subsurface drainage fields helps prevent clogging of on-site systems (EPA, 1996). This resting of the field allows for cracking in the biomat and reaggregation of clay particles which improves infiltration capacity (Tchobanoglous and Burton, 1991).

As previously noted, the site was subject to shading. Only a few plantain plants were left until the end of the project (see figure Appendix C-27), while the rest of the existing vegetation was removed. The replacement plants did not provide an immediate benefit to the study. Siting future graywater gardens in sunnier locations and providing long-term maintenance of plants in the garden with periods of harvesting and replanting would contribute to greater evapotranspiration and pollution removal. A graywater demonstration project performed in Colorado (EPA, 2012), had such a high period of evapotranspiration during the summer months that there was no observed effluent from this two stage wetland system. This graywater wetland was lined, due to strict water usage laws in Colorado, so that effluent concentrations were returned the sanitary sewer. The Colorado graywater system had better removals overall, but had intermittent flows and was subject to much less annual precipitation and drier, less humid conditions. During winter periods, there was a rise in the pathogen indicators of the Colorado graywater system that would have necessitated further treatment if the purpose was to reuse the graywater. Any graywater garden or wetland system will be subject to climatic conditions and the interaction of vegetation with climatic conditions. For future projects in Puerto Rico, it is recommended to use more of both Musa sp. and Xanthosoma sp. plants in sunnier locations to better evaluate the full evapotranspiration potential.

Recommendations for improved implementation are:

- Where possible, only graywater from washing machines and shower water should be applied to the garden systems.
- When kitchen/cooking water is to be included, an adequately sized (large) septic pretreatment with a grease trap is required with a maintenance agreement in place.
- A larger graywater garden is required based on a LTAR (especially if kitchen wastewater is included)
- Greater distance between influent discharge points and effluent sampling points may result in longer treatment times and lessen observed short circuiting.
- At least two gardens should be constructed so that flows can be alternated between gardens.
- Graywater garden design should take into account more features to reduce rainfall induced surcharging as direct discharge from the garden only occurred during the rainy season.
- A greater mix of plants could be tested.
- Graywater gardens should use automated valves after first determining optimal detention times and volumes for storage and later discharge.
- Use of upslope curtain drains to improve unsaturated conditions in surrounding soils around graywater gardens.

Chapter 6 Conclusions

Results from the quarterly analysis of the graywater garden constructed in the María Jiménez community of the municipality of Gurabo in Puerto Rico did not demonstrate statistically consistent removals of monitored parameters. The statistical increase in observed effluent iron was most likely an indicator of excessive organic loading to the system.

Operational changes had a statistically relevant effect on the effluent. The increased size of the pretreatment system, from two 200-L plastic drums to a 1000-L IBC, facilitated maintenance and increased surge capacity. Higher values of sulfide were observed indicating a more stable anaerobic environment; while aluminum, iron and manganese values were initially large, higher sulfide concentration observed after this change potentially indicated the formation of metal sulfide precipitates.

The plants were shown to have an effect on sampled effluent concentration as there was a statistical effect on the uptake of phosphorous by reducing effluent concentration.

Alternate designs of graywater gardens and targeting all aspects of graywater flow (e.g. larger pretreatment systems alternating discharge to parallel gardens to avoid clogging) or targeting specific graywater flows (e.g. washing machine water only to reduce nutrient discharges) should be pursued.

This project tested a community graywater garden as a potential remedy to the practice by rural residents of Puerto Rico of discharging graywater directly to storm drains or the nearest receiving water. The performed monitoring revealed some aspects of the inner workings of the graywater garden system. Surface ponding required some modifications to the system (e.g., installation of a French drain to address rainfall induced ponding and stormwater run-on, installation of larger pretreatment system); however, other than the rainy season there was no surface discharge, which implies there was a reduction in release of graywater to receiving waters by the participants in this study. As such, similarly introduced graywater gardens may have a net benefit through the reduction of direct graywater discharges to receiving waters.

Chapter 7 References

Boccheciamp, R. A. (1978). Soil Survey of San Juan Area of Puerto Rico. San Juan: United States Department of Agriculture Soil Conservation Service.

Carr, M. (2009). The Water Relations and Irrigation Requirements of Banana (Musa spp.). Expl Agric, 45, 333-371.

Caspe, R. L. (2008). An Overview of Water Quality Improvement Strategies for Puerto Rico. Dimension Ingenieria y Agrimensura, Revista del Colegio de Ingenieros y Agimensores de Puerto Rico, Ano 22, Vol. 2, pp. 7-8.

EPA (1992). Assessment of On-Site Graywater and Combined Wastewater Treatment and Recycling Systems, EPA Report No. 832R92900, http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=200046NF.txt.

EPA (1996). Wastewater Treatment: Alternatives to Septic Systems Guidance Document. U.S. Environmental Protection Agency, Region 9 Drinking water Program EPA Report No. 909-K-96-001

EPA (2000). Guidance for Data Quality Assessment: Practical Methods for Data Analysis. Office of Environmental Information, U.S. Environmental Protection Agency, Washington, DC, Report No. 600/R-96/084.

EPA (2002). Onsite Wastewater Treatment Systems Manual Revised 2002. Rep. No. EPA/625/R-00-008, pp. 369, http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30004GXI.txt.

EPA (2012). Graywater Treatment Using Constructed Wetlands. EPA, Office of Research and Development, Cincinnati, Ohio, EPA/600/R-12/684, http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100FSPJ.txt.

Food and Agriculture Organization (FAO) (2013). Crop Water information: Banana. Retrieved 12/1/2014, from FAO Water: http://www.fao.org/nr/water/cropinfo_banana.html

Francis, J. K. (2004). Wildland Shrubs of the United States and Its Territories: Thamnic Descriptions. San Juan: United States Department of Agriculture Forest Service. Retrieved from http://www.fs.fed.us/rm/pubs_other/iitf_gtr026.pdf on 10/1/2014.

Fundación Puertorriqueña de las Humanidades. (2009). Gurabo General Information. Retrieved 2/1/2012, from Encyclopedia of Puerto Rico: http://www.enciclopediapr.org/ing/article.cfm?ref=09021902

Grupo Editorial EPRL (2009). Fundación Puertorriqueña de las Humanidades. Retrieved 10/22/2009 from Encyclopedia of Puerto Rico: http://www.enciclopediapr.org/esp/print_version.cfm?ref=09021902.

Hanson, R.L., (1991). Evapotranspiration and Droughts. Retrieved from: http://geochange.er.usgs.gov/sw/changes/natural/et/

Integrated Global Solutions. (2012). Quality Assurance Project Plan for the Implementation of a Greywater Management Project at a Community Level on the Island of Puerto Rico. Office of Research and Development, USEPA.

Klein, C. and C. S. Hurlbut (1985). Manual of Mineralogy (20th Edition). John Wiley and Sons, Inc.

Laak, R. (1986) Wastewater Engineering Design for Unsewered Areas (2nd edition) Technomic Publishing Co., Lancaster, PA.

Leslie Grady Jr, C. P, G. T. Daigger, N. G. Love and C. D. Filipe (2011). Biological Wastewater Treatment (3rd edition). CRC Press, Boca Ratón, FL.

Maidment, D. R., L. W. Mays, and V. Chow (1988). Applied Hydrology (1st edition ed.). McGraw-Hill, New York,

NY.
Mayer, P., W. DeOreo, E. M. Opitz, J. C. Kiefer, W. Y. Davis, B. Dziegielewski and J. O. Nelson (1999). "Residential End-uses of Water" Published by the AWWA Research Foundation and American Water Works Association. http://www.waterrf.org/PublicReportLibrary/RFR90781_1999_241A.pdf
Microsoft® Excel®, 2013.
McGovern, C. (2010). Residential Graywater Reuse. Innovative Energy Management Workshop (p. 16). Oahu: USEPA Region 9. http://www.epa.gov/region9/waterinfrastructure/training/energy-workshop/docs/2010/ResidentialGraywaterReuseHiMauiOahuKauai.pdf
National Oceanic and Atmospheric Administration, National Weather Service (NOAA-NWS) (2015). Gurabo Normals [online image]. Retrieved from http://www.srh.noaa.gov/sju/?n=climo_gurabo#GuraboAES
Puerto Rico Environmental Quality Board (1983). Puerto Rico Underground Injection Control Rules R-83-23-1. San Juan: Puerto Rico Environmental Quality Board.
Puerto Rico Environmental Quality Board. (2007). Total Maximum Daily Loads (TMSL), Río Grande de Loíza Watershed: Fecal Coliform, Copper, Biochemical, Oxygen Demand, Ammonia. Water Quality Area. San Juan: Puerto Rico Environmental Quality Board.
Puerto Rico Planning Board (PRPB). (2010). Puerto Rico Aerial Orthophotography, October 31, 2009 through January 27, 2010 (Web Map Service). Retrieved from http://gis.otg.pr.gov/ArcGIS/services/Ortofotos/Orthophoto2009_10/mapserver/WMSServer.
Quiñones, F. (1980). Limnology of Lago Loíza: Puerto Rico (Water Resources Investigation Report No. 79-97). United States Geological Survey, Water Resources Division, San Juan.
Sawyer, C. N. and P. L. McCarty (1978). Chemistry for Environmental Engineers. MacGraw-Hill Publishing Co. 3rd Ed.
Seiders, V. M. (1971). Geologic Map of the Gurabo Quadrangle, Puerto Rico. United States Geological Survey.
SM (1998). Standard Methods for the Examination of Water and Wastewater. Edited by A. D. Eaton, L. S. Clesceri, and A. E. Greenburg. Published Jointly by American Public Health association, American Water Works Association and Water Environment Federation, 20th Edition.
StatSoft, Inc. (2011). STATISTICA (data analysis software system), version 10. www.statsoft.com.
Tchobanoglous, G. and F. Burton (1991). Wastewater Engineering: Treatment, Disposal and Reuse. McGraw-Hill, Inc., 3rd Ed.
Tetra Tech Inc. (2011). Fecal Coliform Bacteria Total Daily Maximum Loads for Assessment Units in the Commonwealth of Puerto Rico. Environmental Planning and Protection, USEPA Region 2. San Juan: Puerto Rico Environmental Quality Board.
United States Geological Survey (USGS) (1982). Gurabo Quadrangle 7.5 minute series [map]. (ca. 1:20,000.) Retrieved from http://gis.otg.pr.gov/ArcGIS/services/Geodata_services/Ambiental_Topografia/mapserver/WMSServer
Watershed Stewardship Program (WSP) (2011). Rio La Plata and Rio Grande De Loiza Watersheds Final Report, Phase III, Puerto Rico Watershed Stewardship Program, November, 2011.

Appendix A Graphs of Data

The following figures are presented in the same order of Tables 4-1 through 4-4 and show the raw data for parameters that had detected values for both the influent and effluent sampling locations. Error bars, where applicable, are derived from the standard error and are presented for data exhibiting normality. Only detected values are presented with the exception of sulfide, i.e., one non-detect which used ½ detection was used to complete the graph.

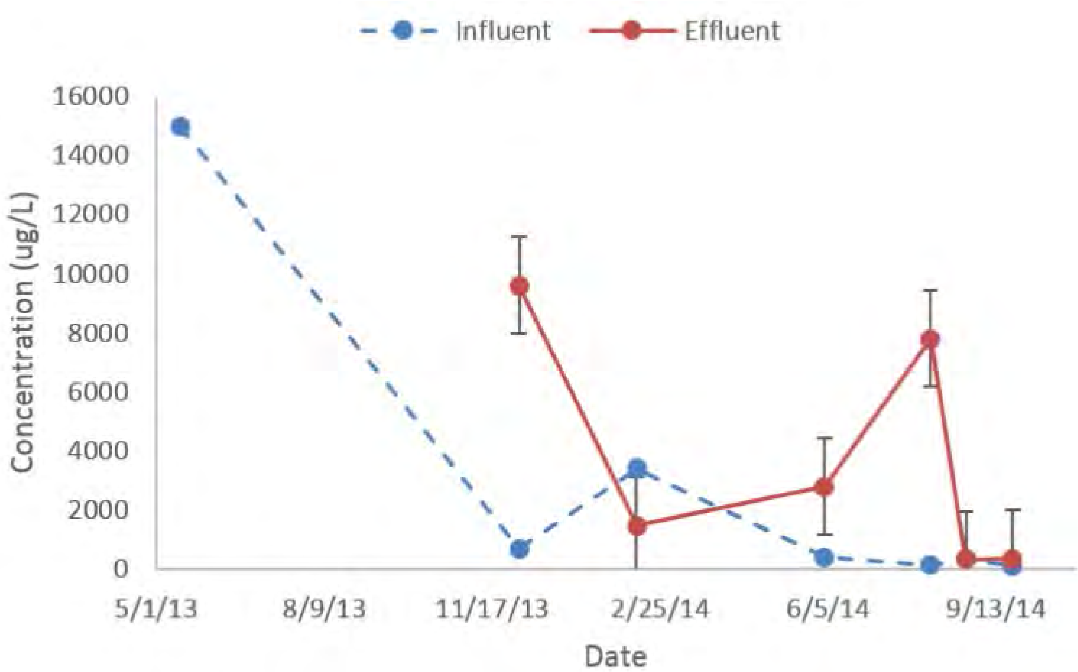


Figure A-1 Parameter concentration profiles for aluminum

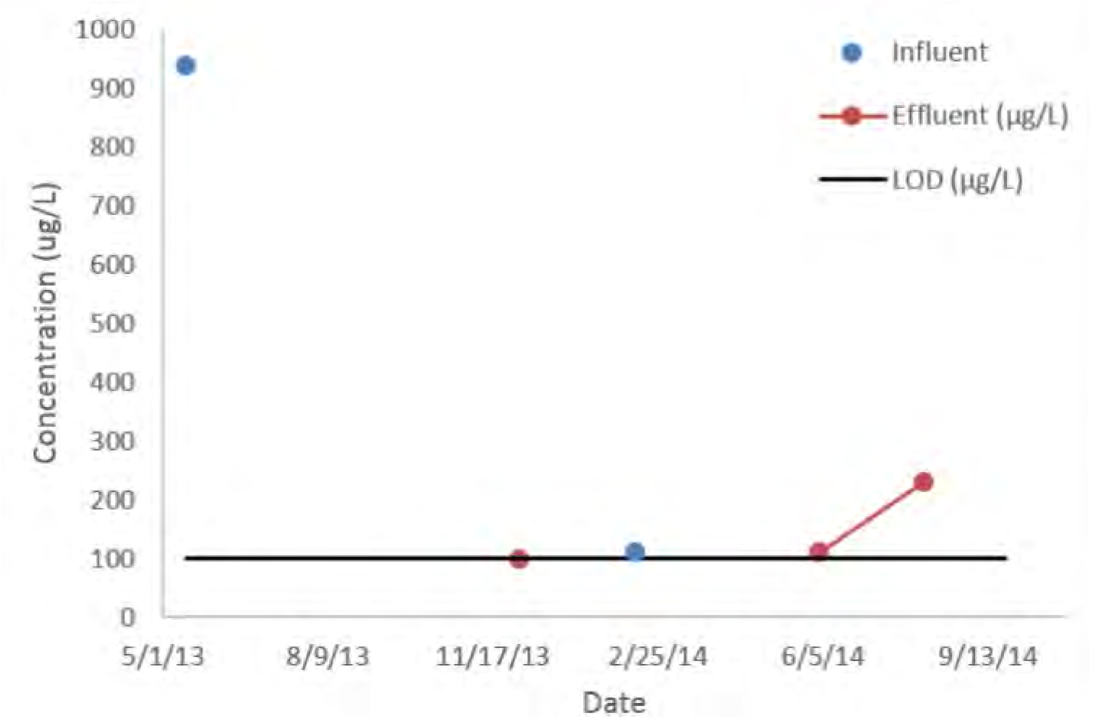


Figure A-2 Parameter concentration profiles for barium with limit of detection

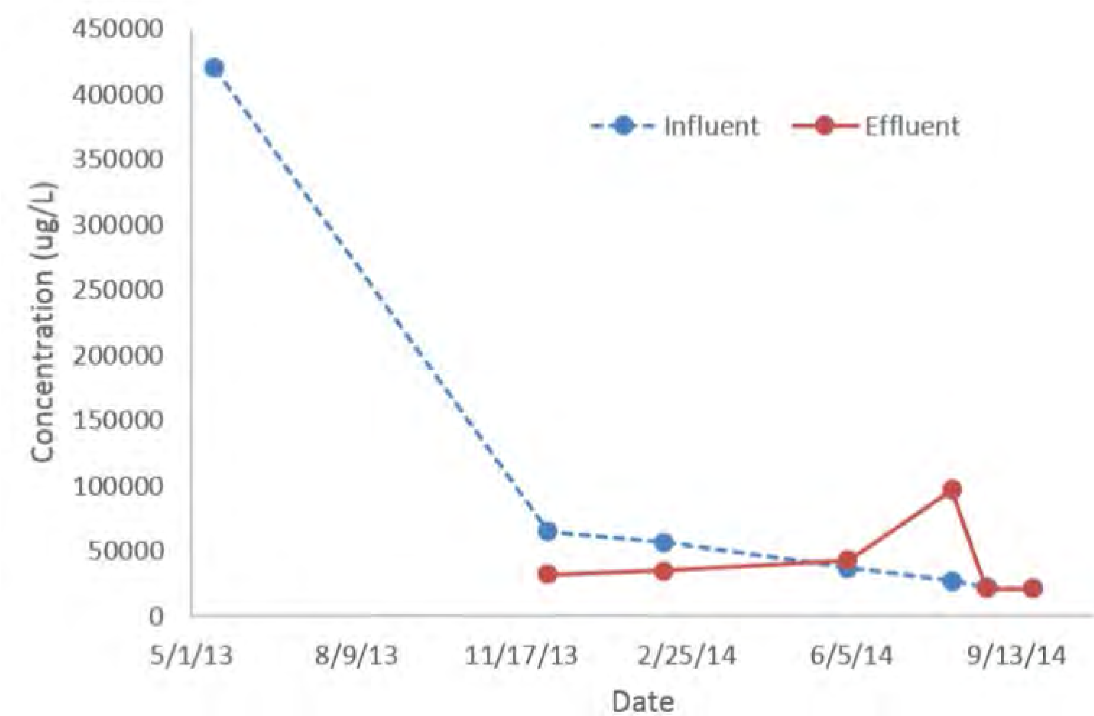


Figure A-3 Parameter concentration profiles for calcium

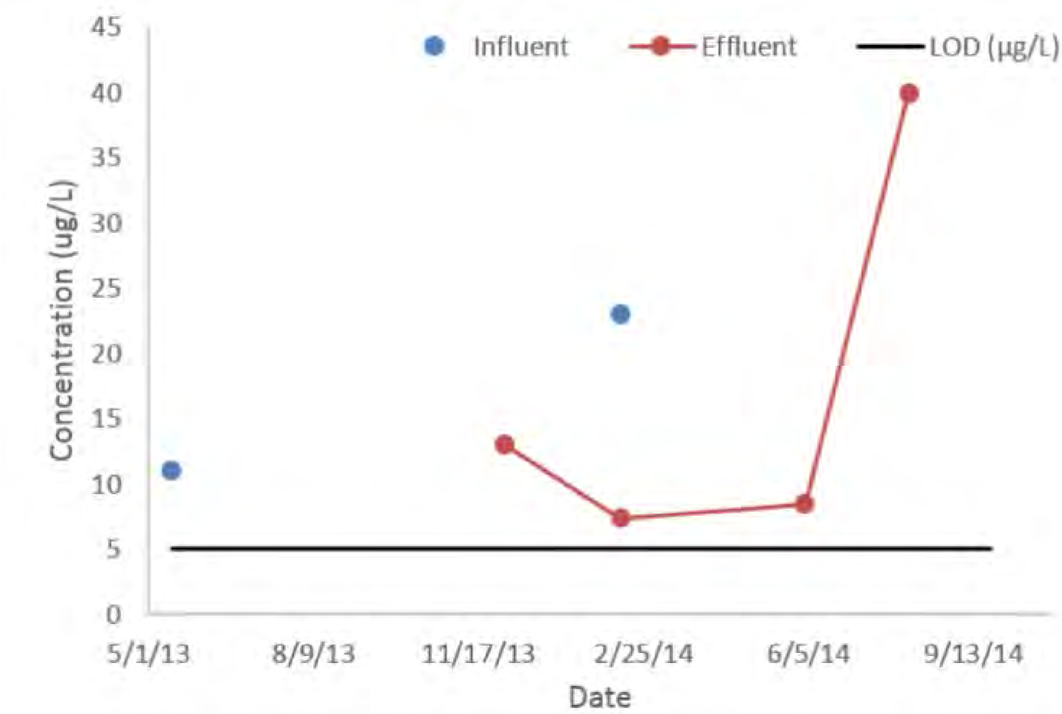


Figure A-4 Parameter concentration profiles for chromium with limit of detection

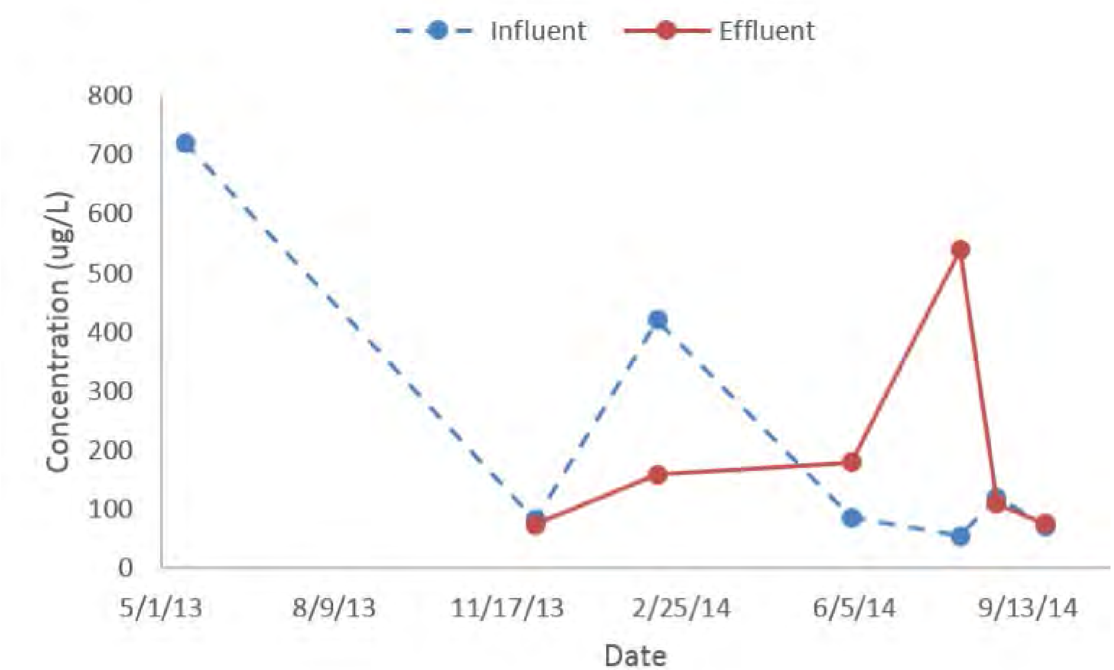


Figure A-5 Parameter concentration profiles for copper

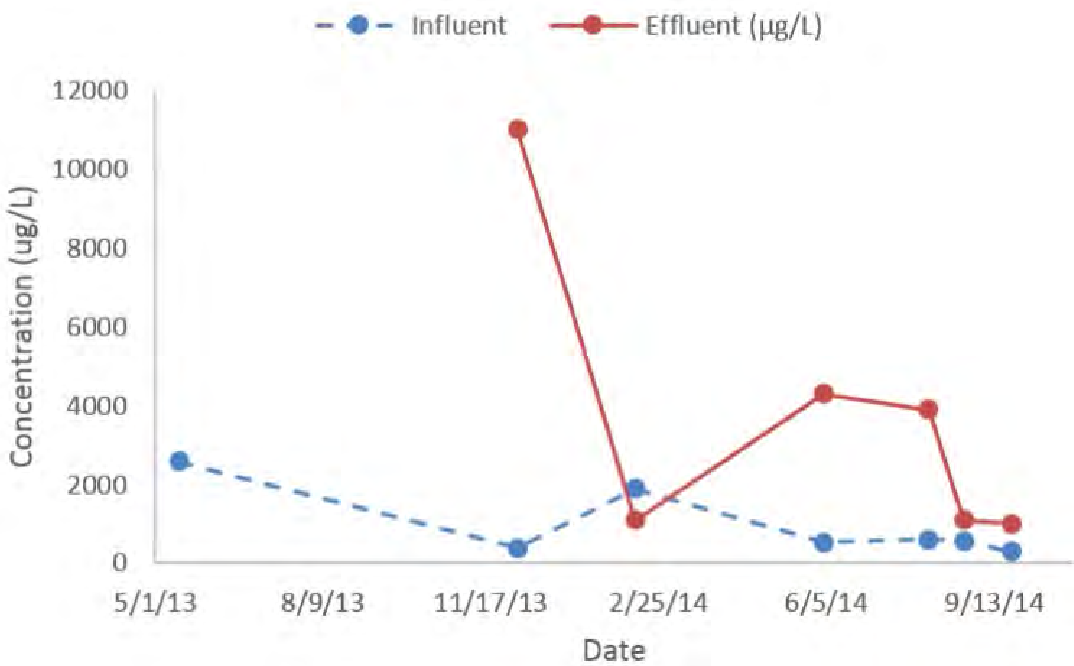


Figure A-6 Parameter concentration profiles for iron

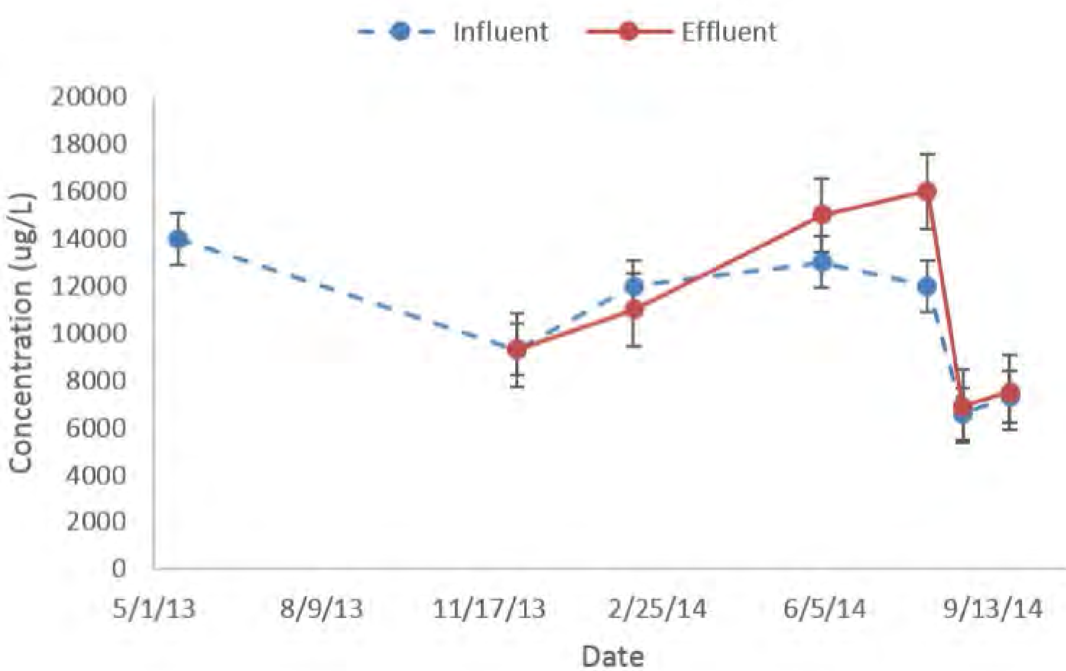


Figure A-7 Parameter concentration profiles for magnesium

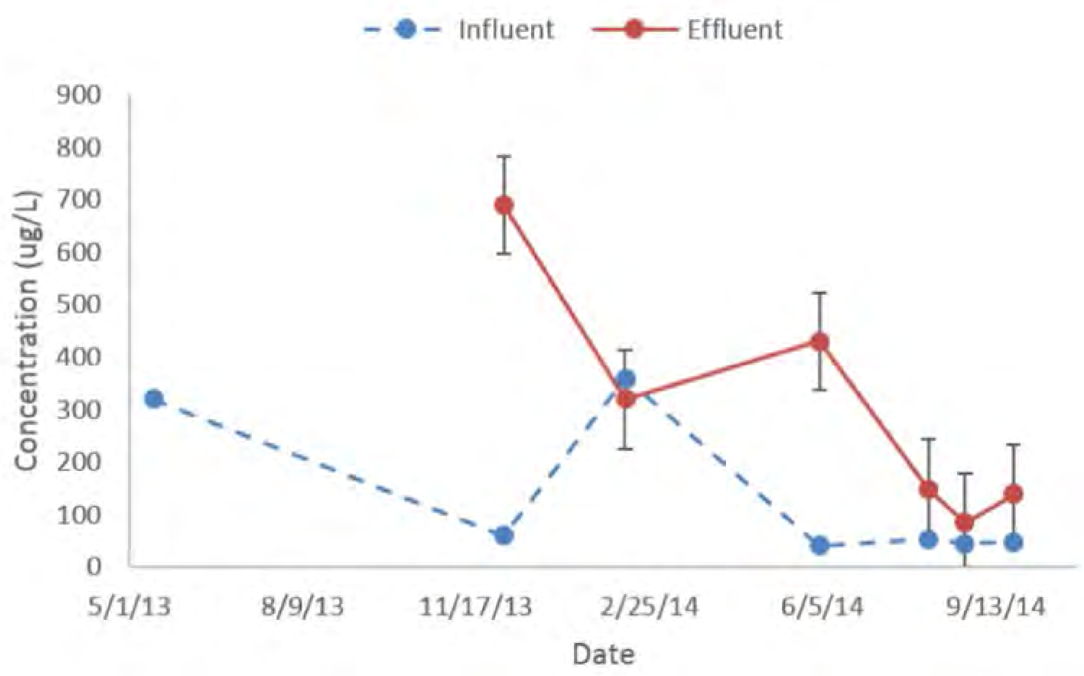


Figure A-8 Parameter concentration profiles for manganese

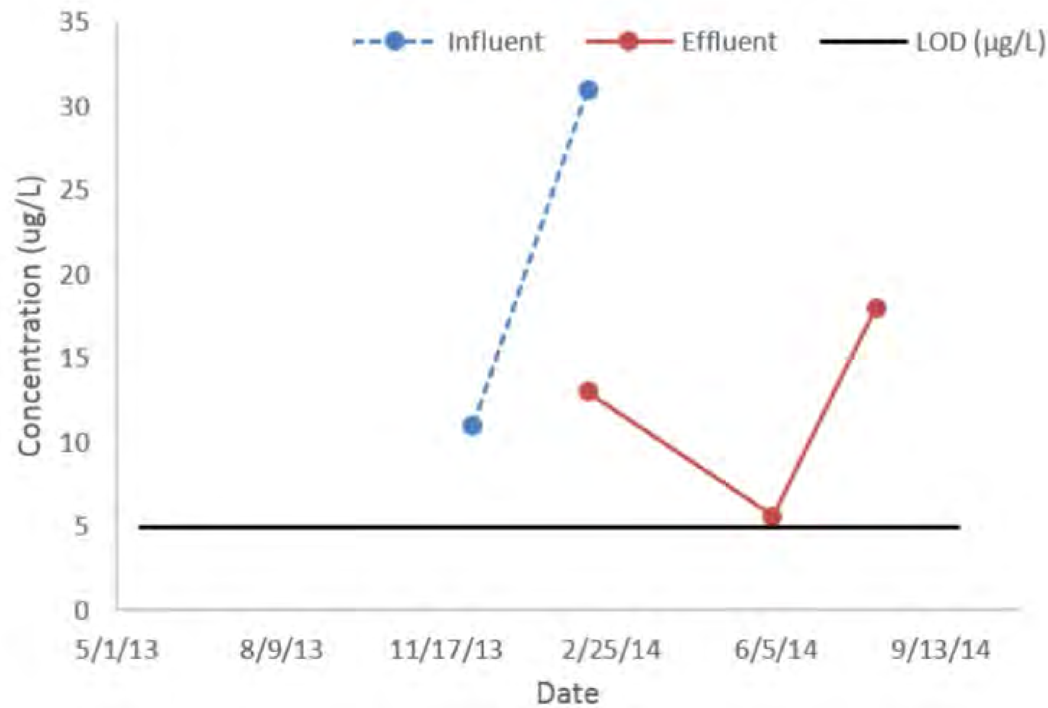


Figure A-9 Parameter concentration profiles for silver with limit of detection

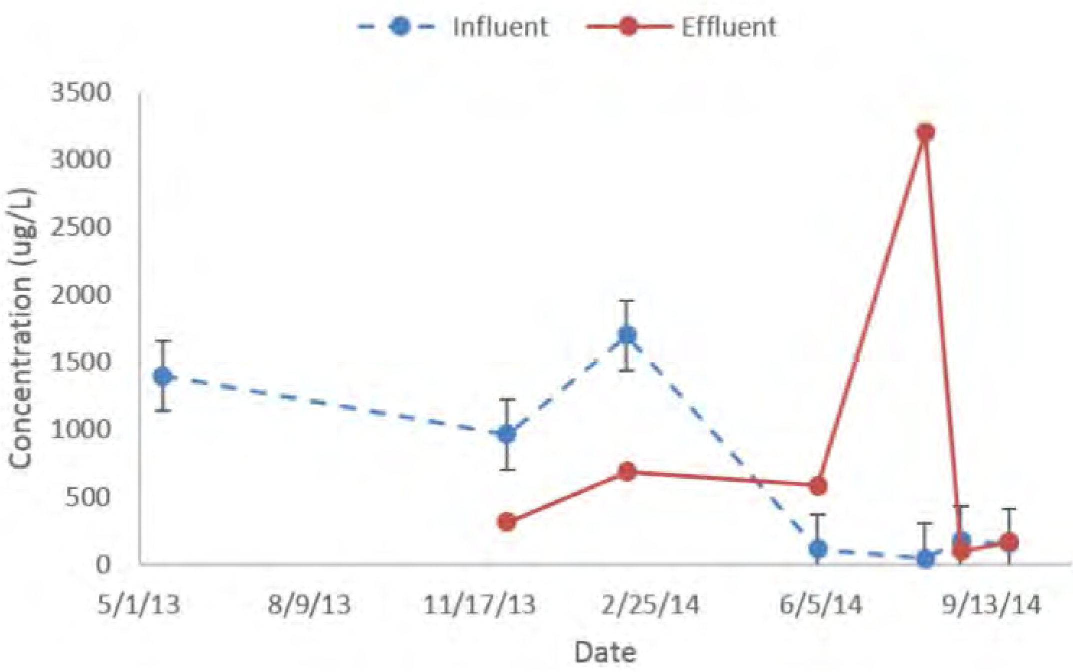


Figure A-10 Parameter concentration profiles for zinc

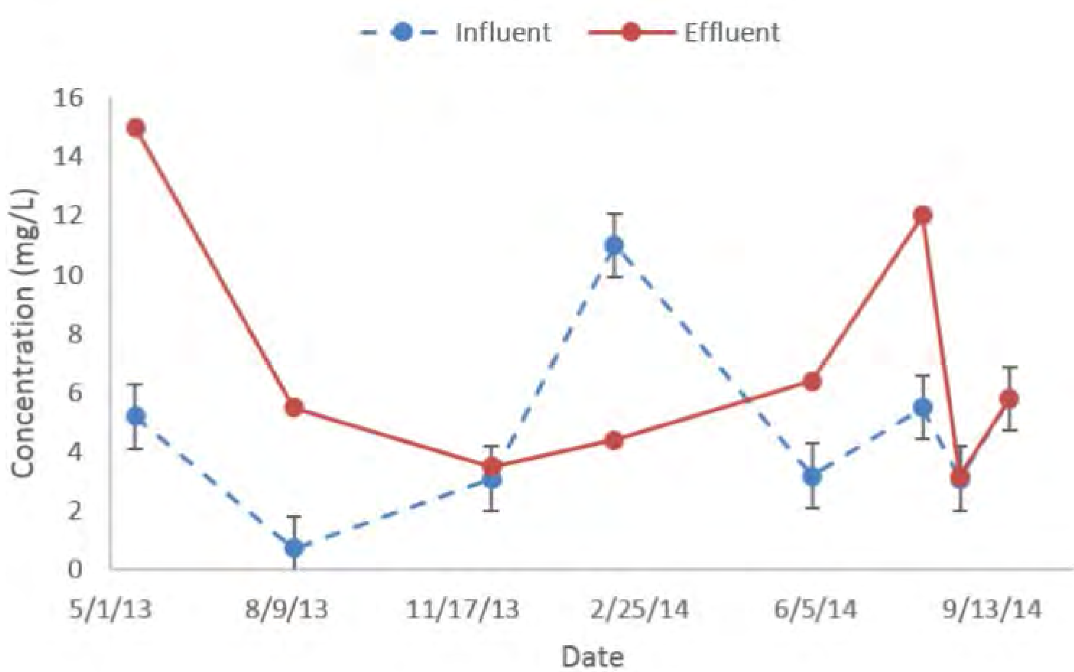


Figure A-11 Parameter concentration profiles for ammonia

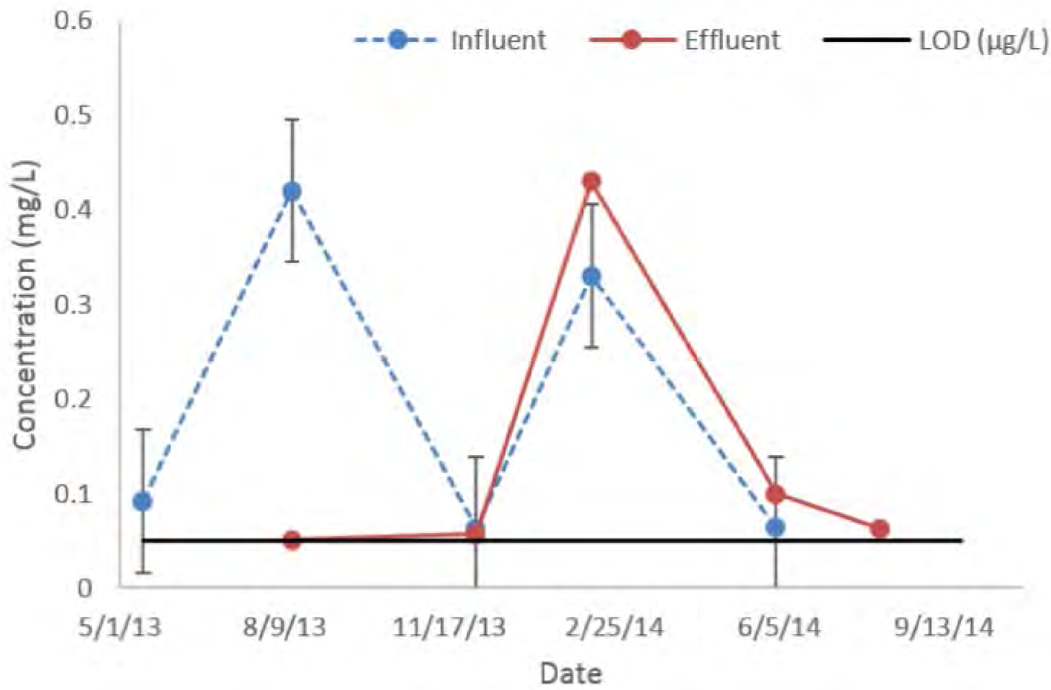


Figure A-12 Parameter concentration profiles for nitrate and nitrite with limit of detection

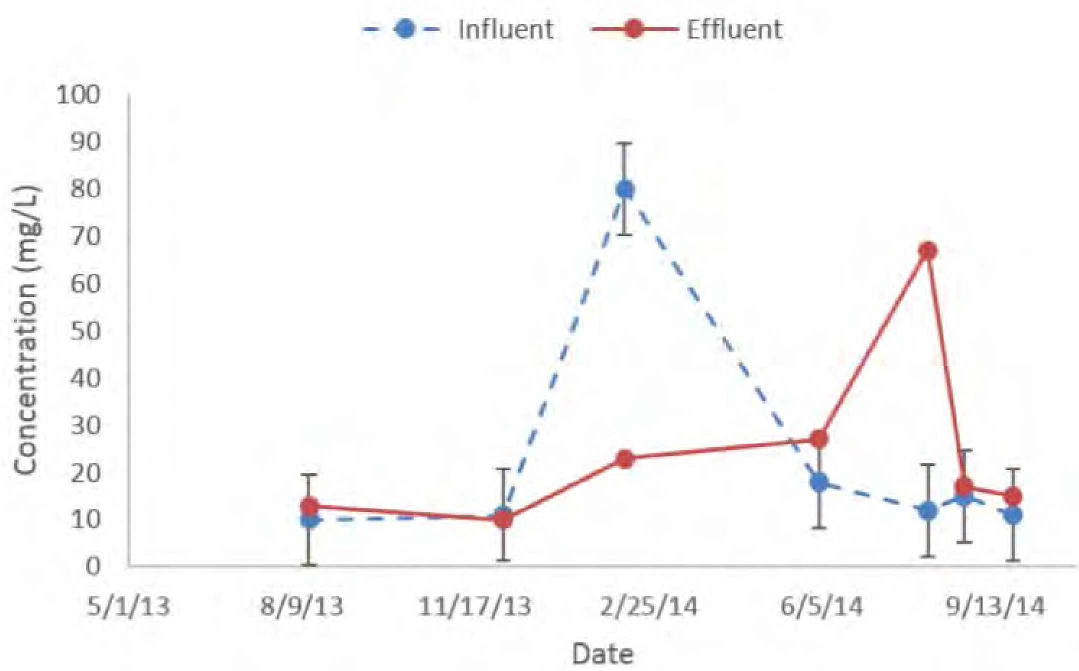


Figure A-13 Parameter concentration profiles for total Kjeldahl nitrogen

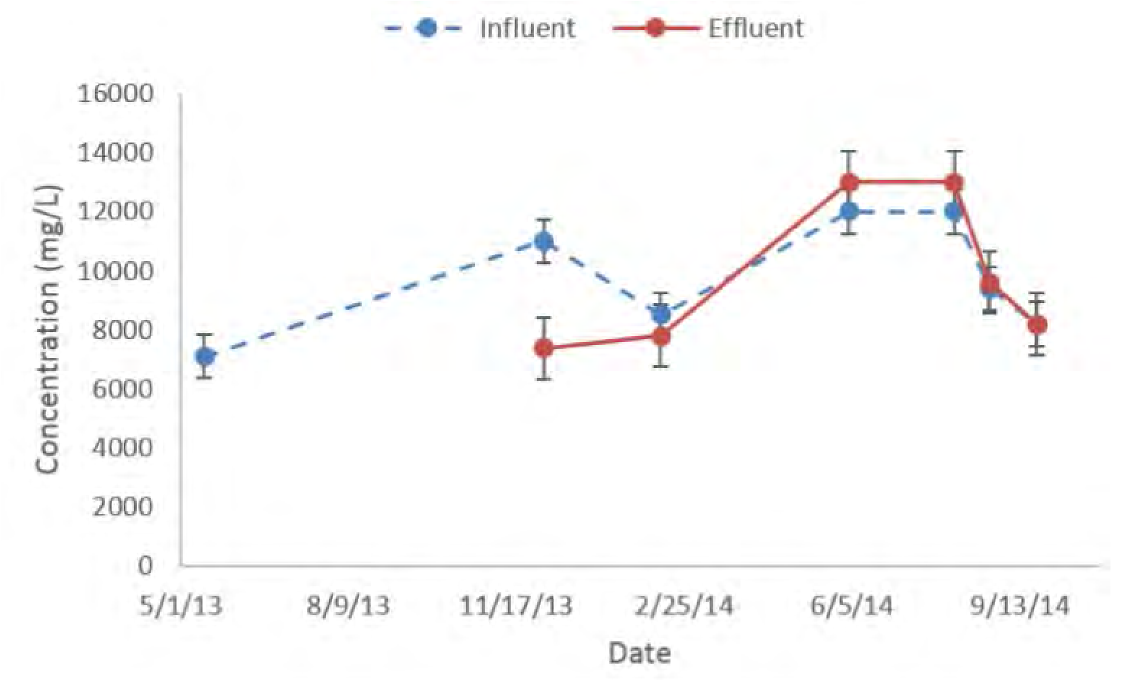


Figure A-14 Parameter concentration profiles for potassium

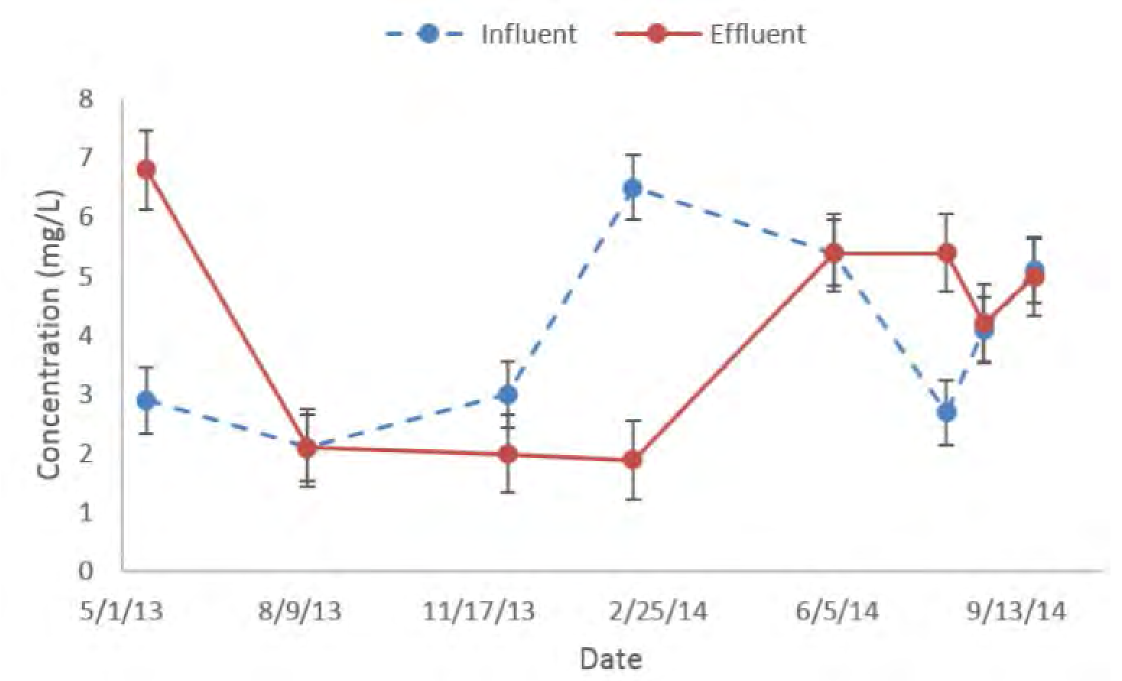


Figure A-15 Parameter concentration profiles for phosphorous

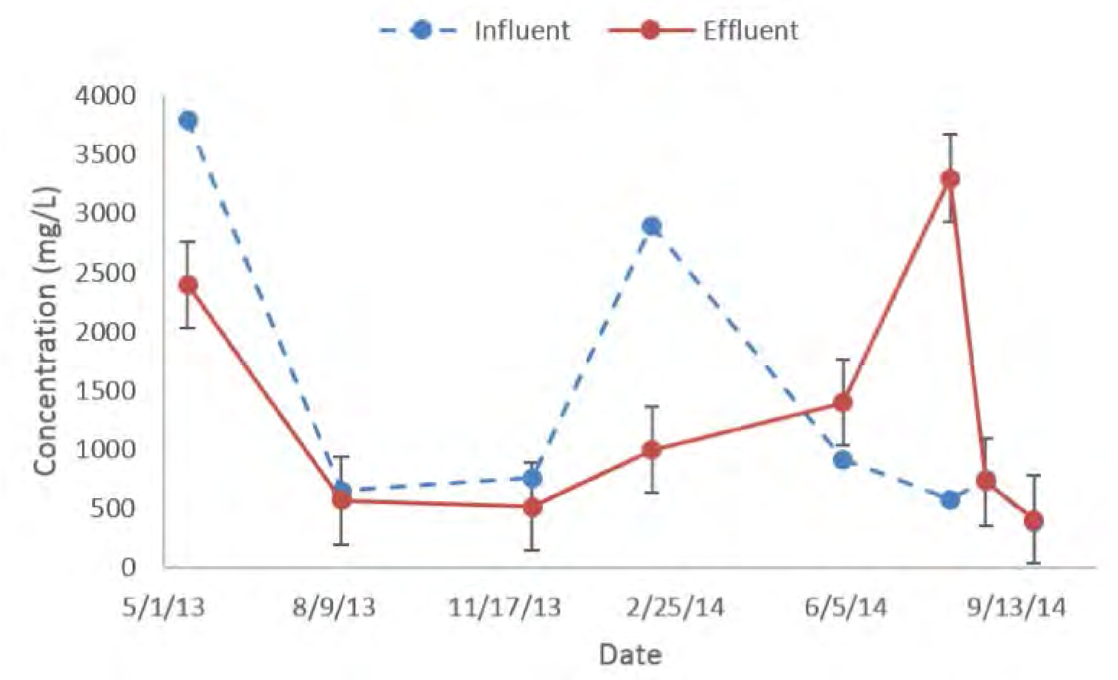


Figure A-16 Parameter concentration profiles for chemical oxygen demand

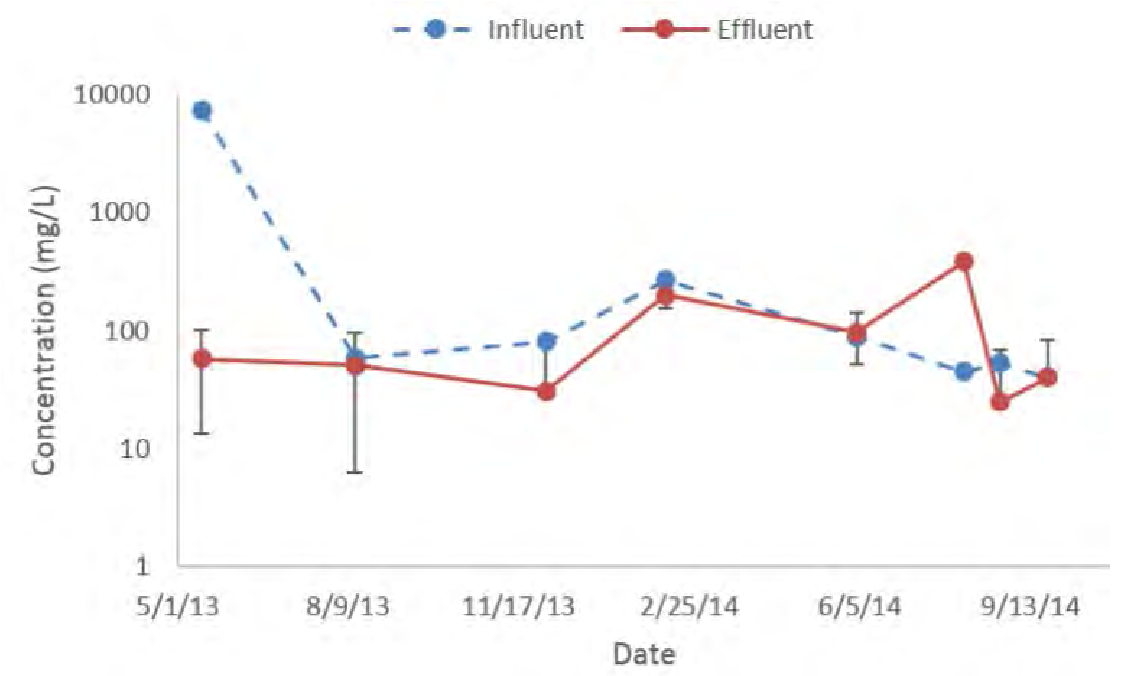


Figure A-17 Parameter concentration profiles for oil and grease in log scale (due to large initial concentration)

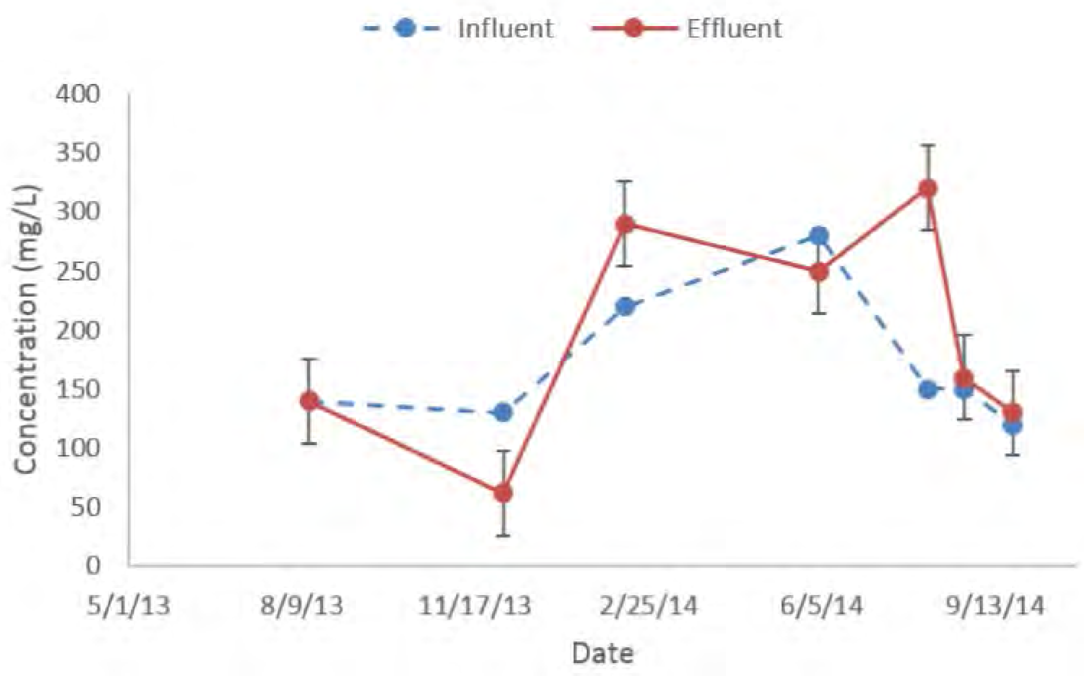


Figure A-18 Parameter concentration profiles for total organic carbon

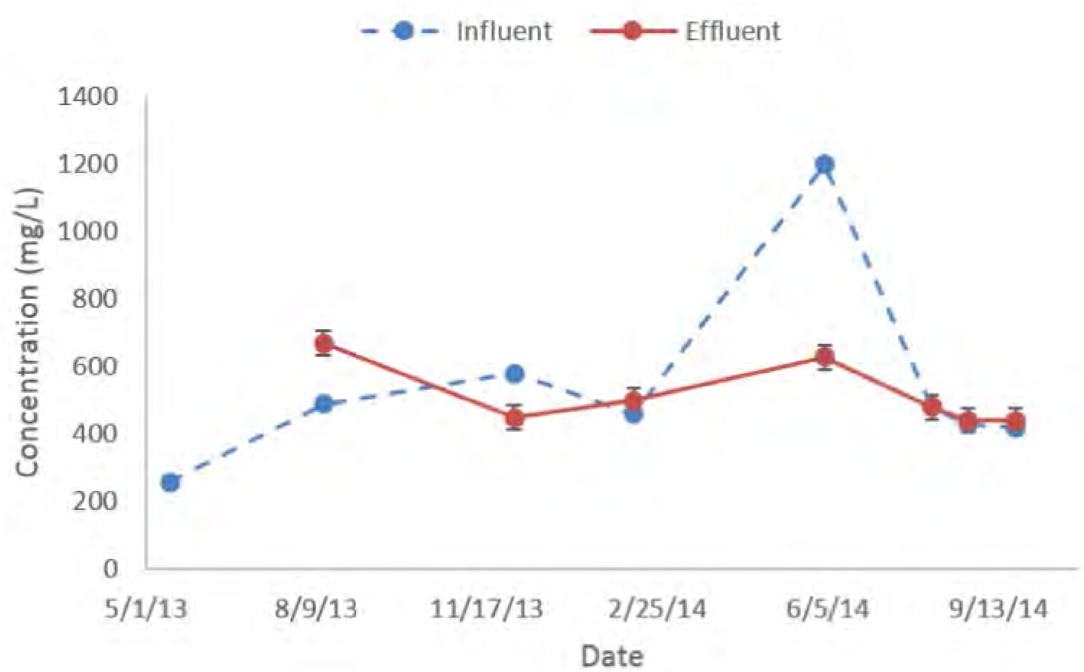


Figure A-19 Parameter concentration profiles for total dissolved solids

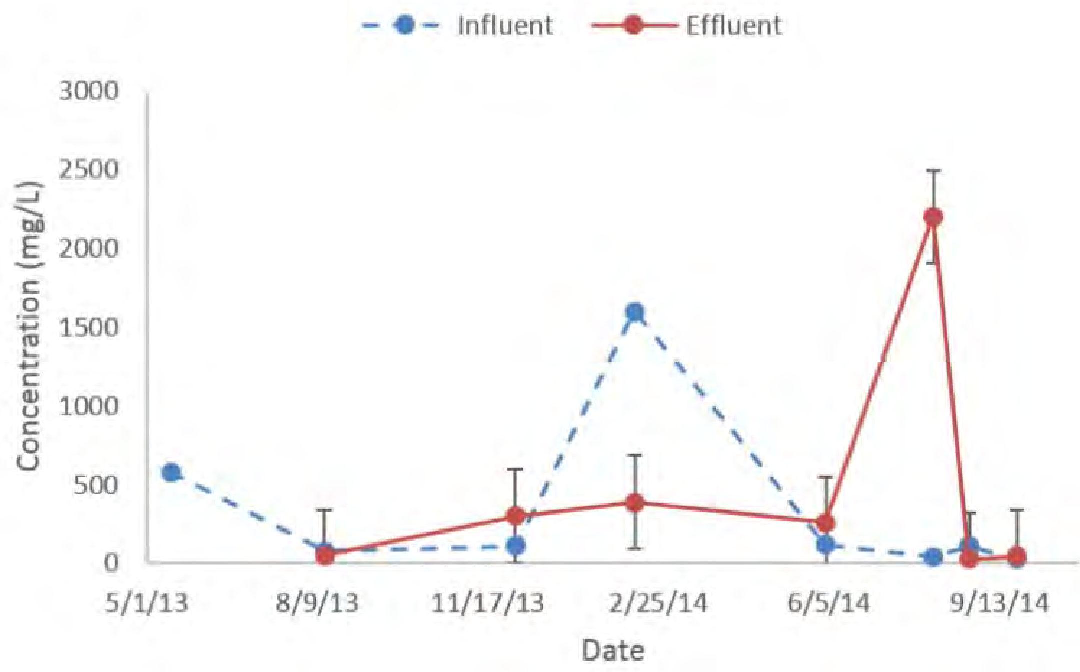


Figure A-20 Parameter concentration profiles for total suspended solids

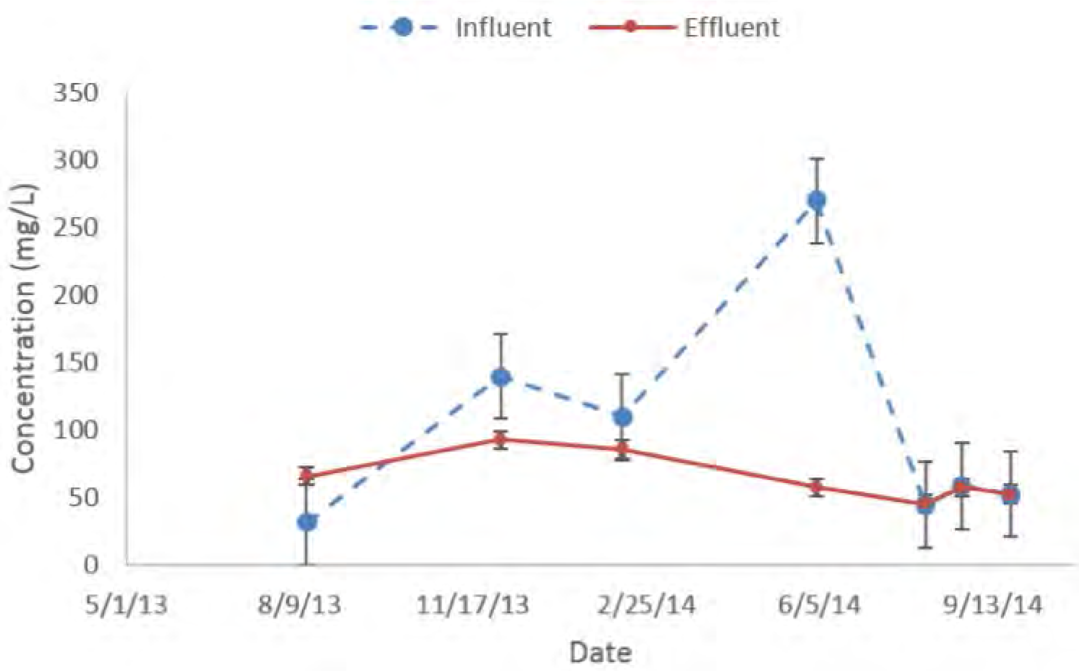


Figure A-21 Parameter concentration profiles for chloride

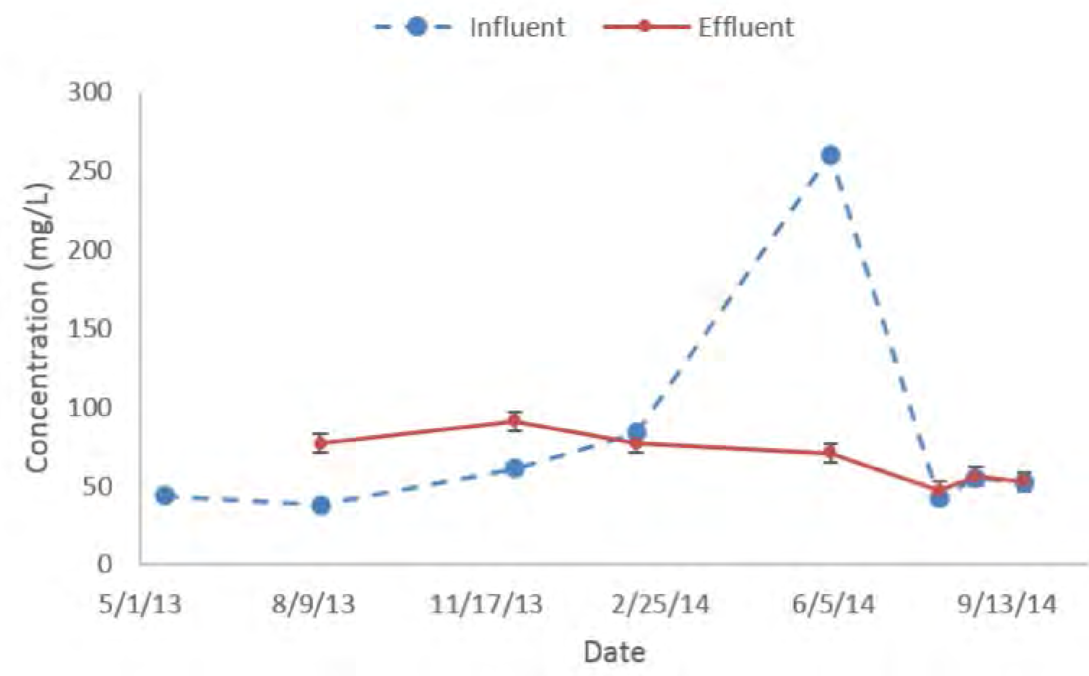


Figure A-22 Parameter concentration profiles for sodium

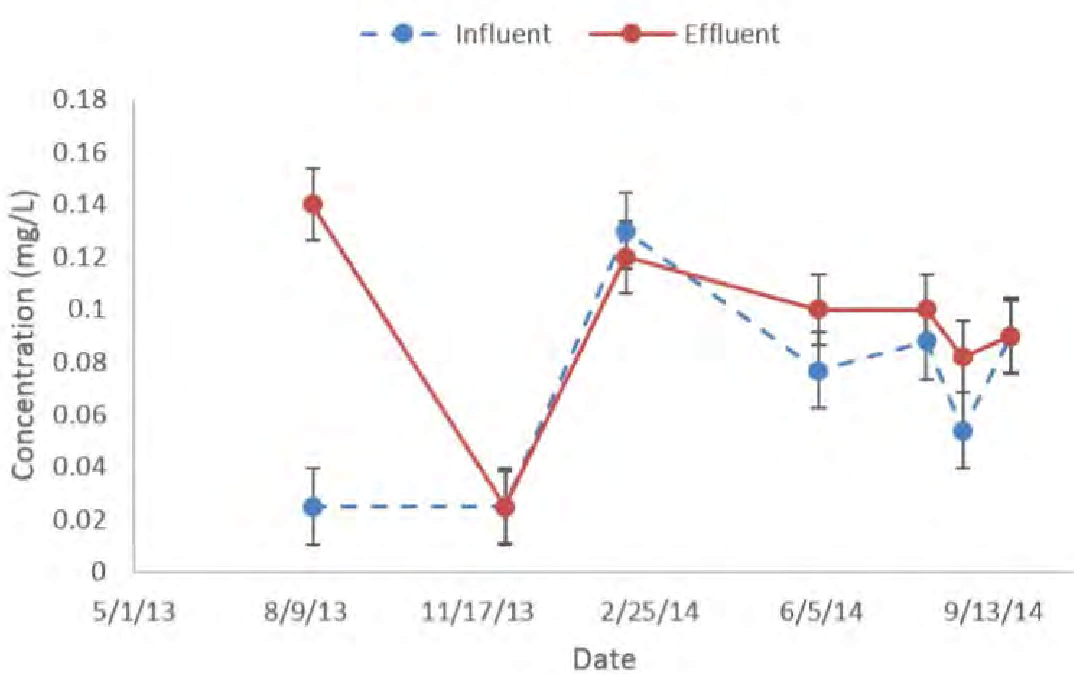


Figure A-23 Parameter concentration profiles for fluoride

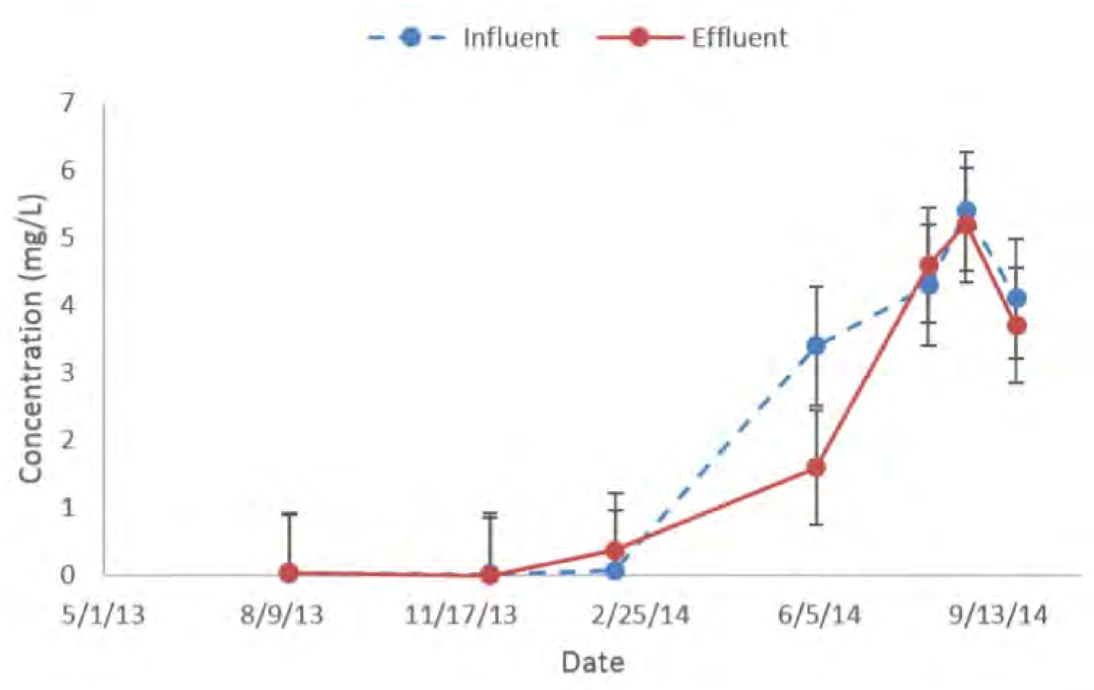


Figure A-24 Parameter concentration profiles for sulfide

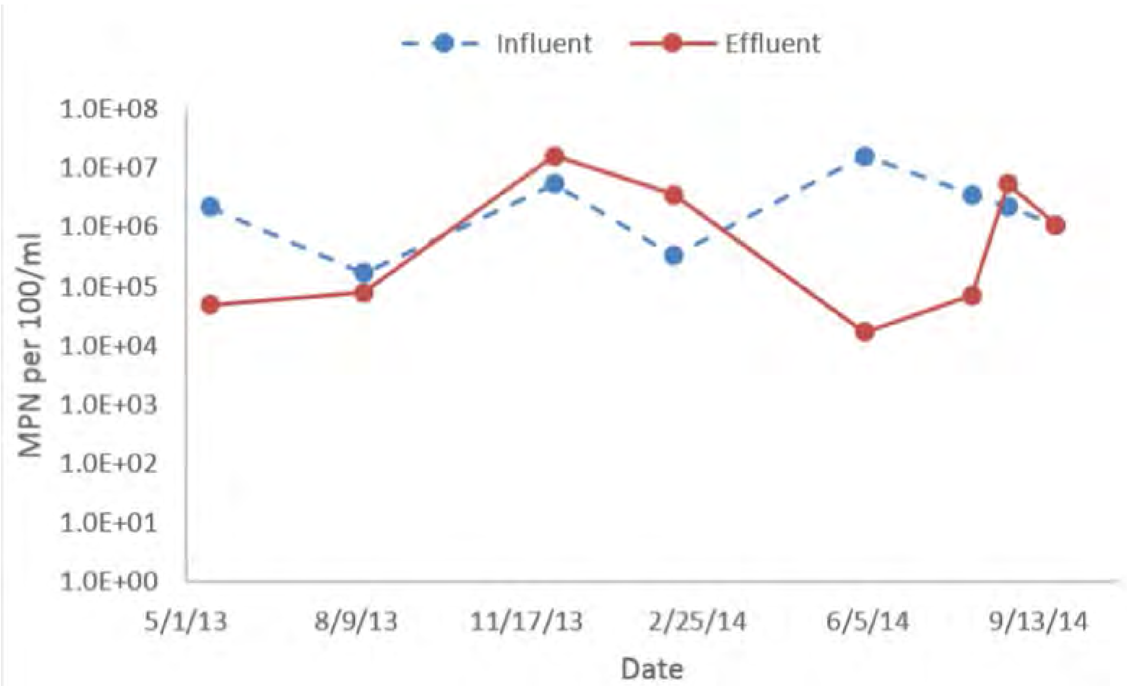


Figure A-25 Most probable number profiles for fecal coliform

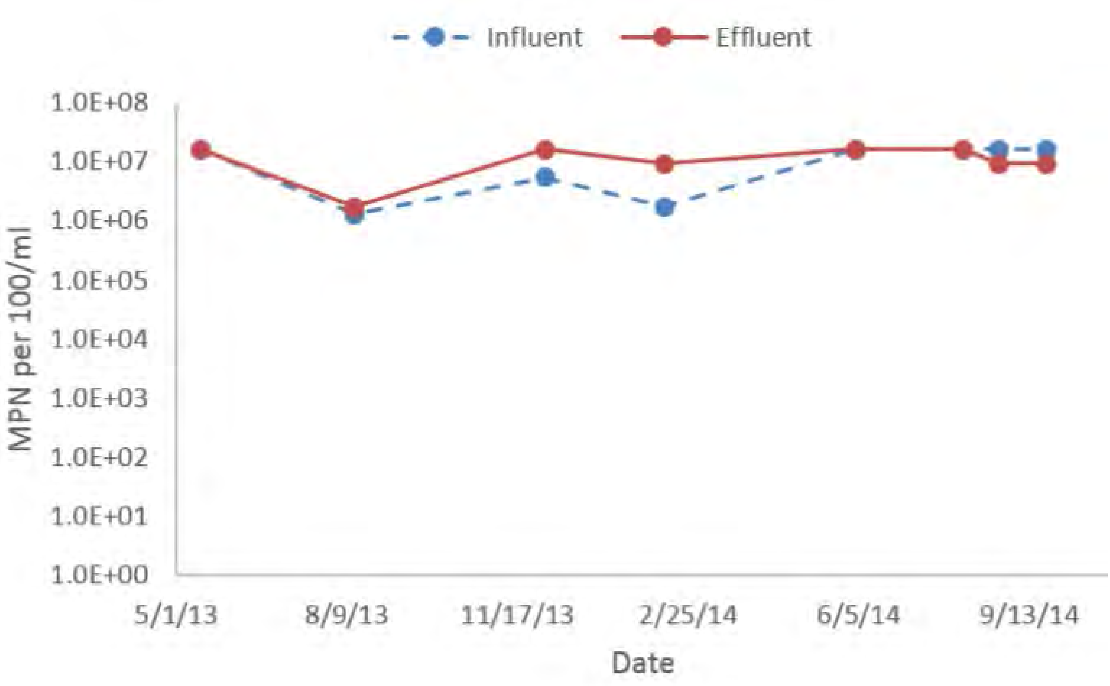


Figure A-26 Most probable number profiles for total coliform

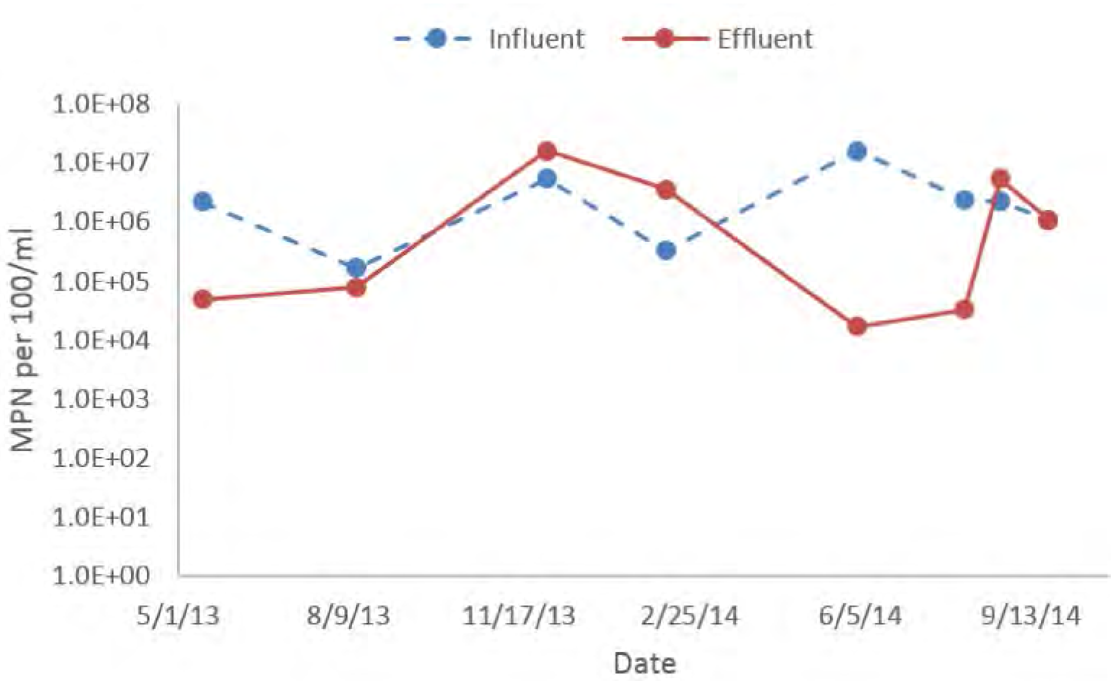


Figure A-27 Most probable number profiles for *Escherichia coli*

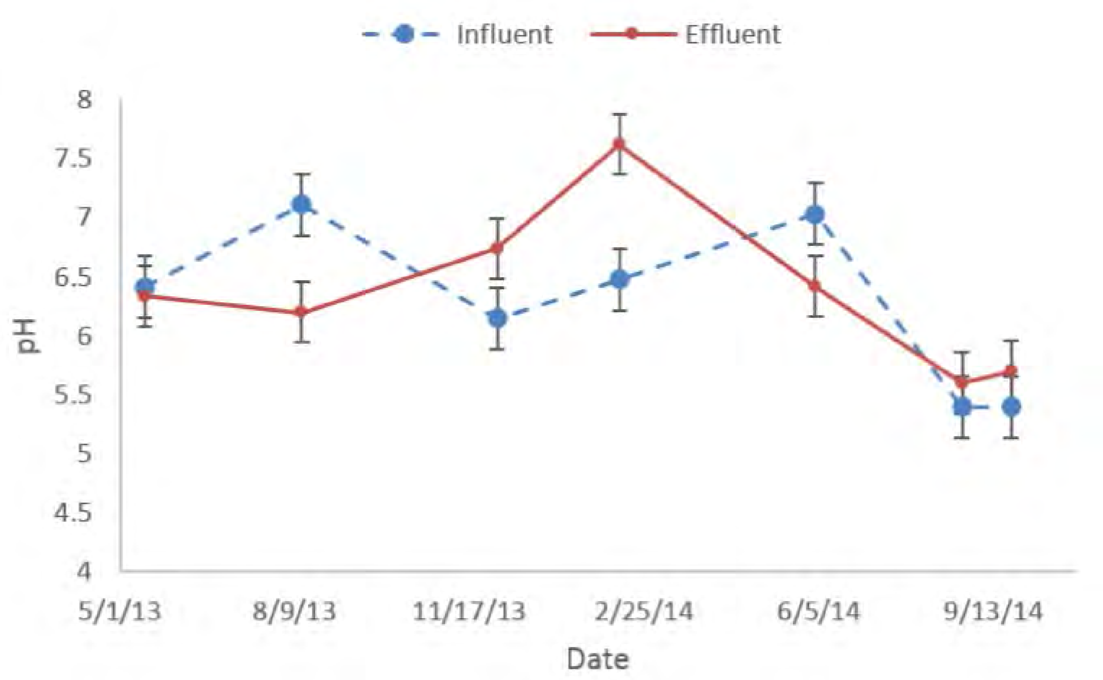


Figure A-28 Profiles for pH

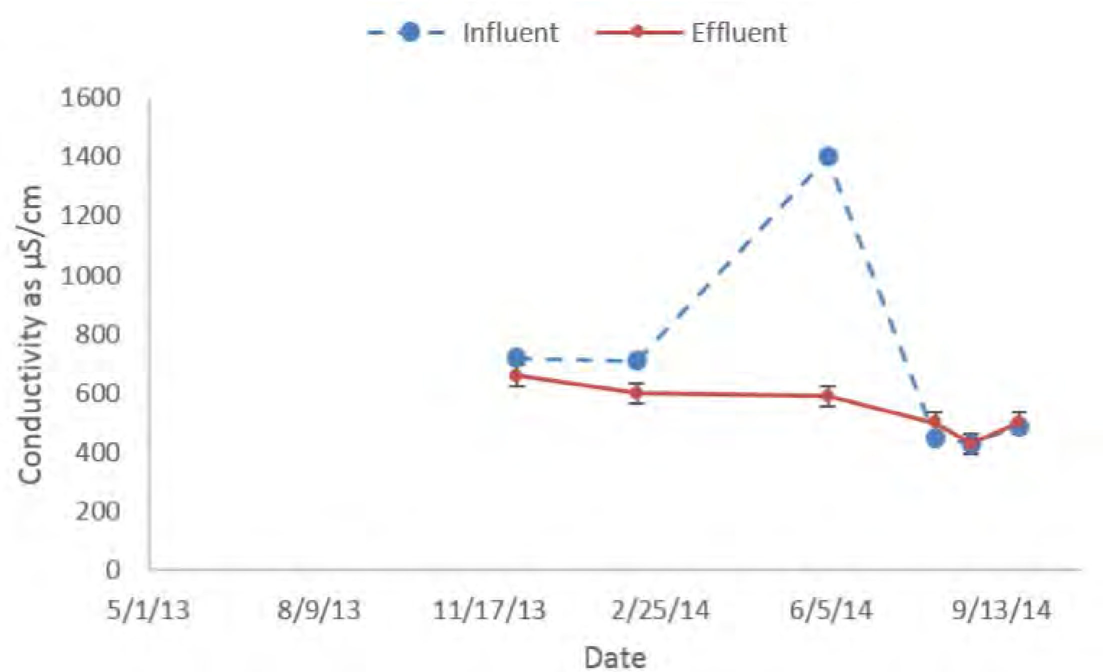


Figure A-29 Profiles for conductivity

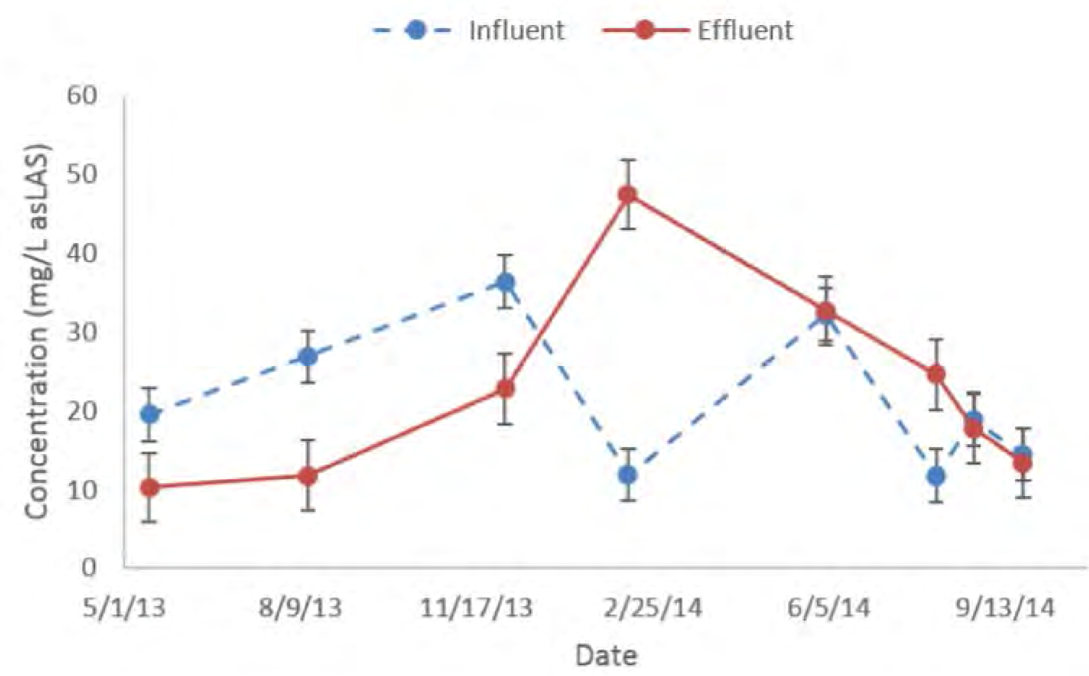


Figure A-30 Parameter concentration profiles for surfactant

Appendix B As-built Drawings

IMPLEMENTATION OF A GREYWATER MANAGEMENT PROJECT AT A COMMUNITY LEVEL IN THE ISLAND OF PUERTO RICO

AS-BUILT DRAWINGS

EP-11-C-000217

GURABO, PUERTO RICO
PRESENTED TO: U.S. ENVIRONMENTAL PROTECTION AGENCY

DATE: JUNE 2014

INDEX OF DRAWINGS

Sheet No.	Description	Drawing No.
	INFORMATIVE DRAWINGS	
T-01	TITLE AND DRAWINGS INDEX	1
G-01	FLOW DIAGRAM	2
	TOPOGRAPHIC DRAWINGS	
TS-01	TOPOGRAPHIC SURVEY	3
	SITE DRAWINGS	
C-01	SITE PIPING LAYOUT	4
C-02	SITE DETAILS	5

ECRE
ECR ENGINEERING, LLC

INTEGRATED GLOBAL SOLUTIONS

Figure B-1 As-built drawings for the graywater garden, sheet one

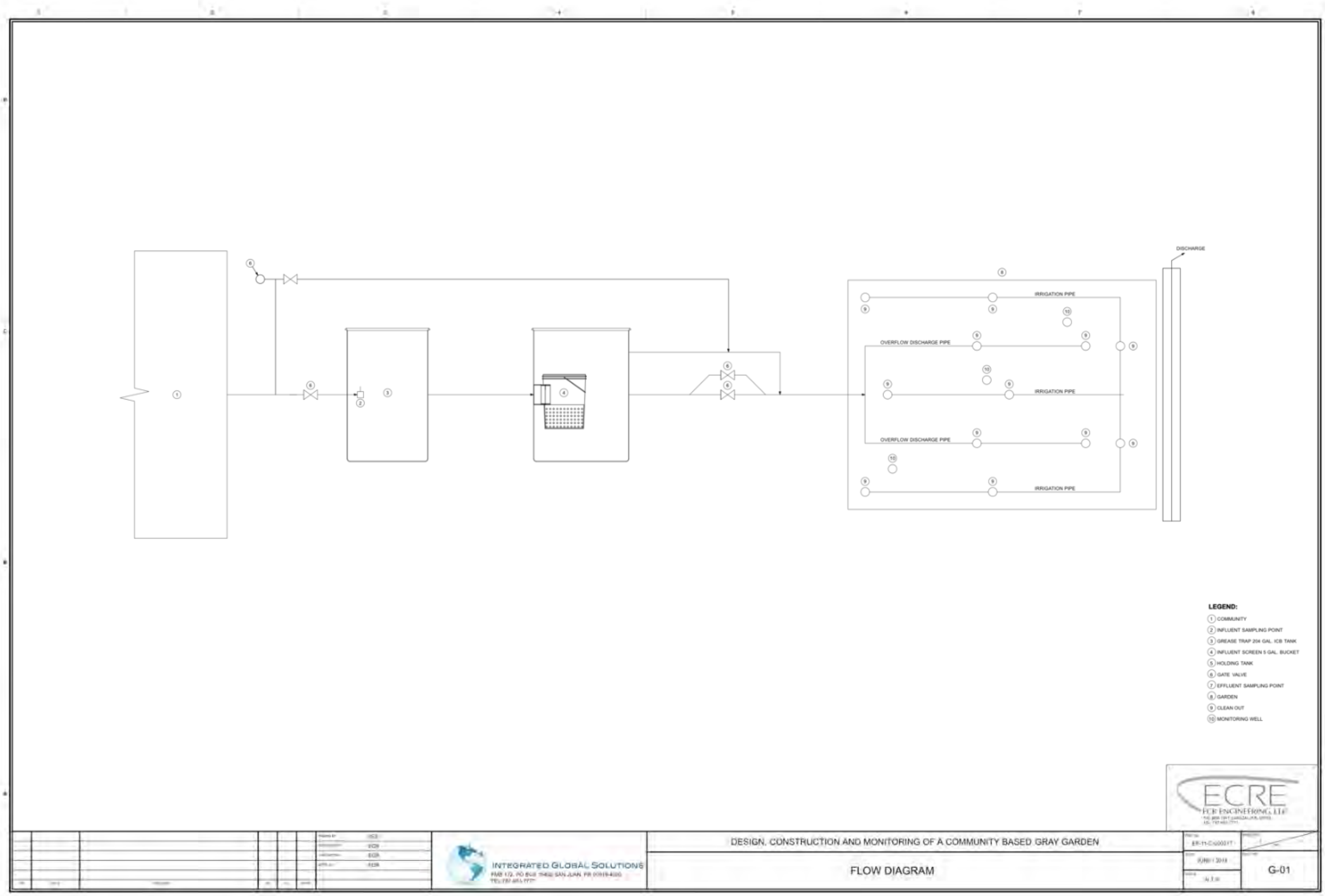


Figure B-2 As-built drawings for the graywater garden, sheet two

Figure B-3 As-built drawings for the graywater garden, sheet three

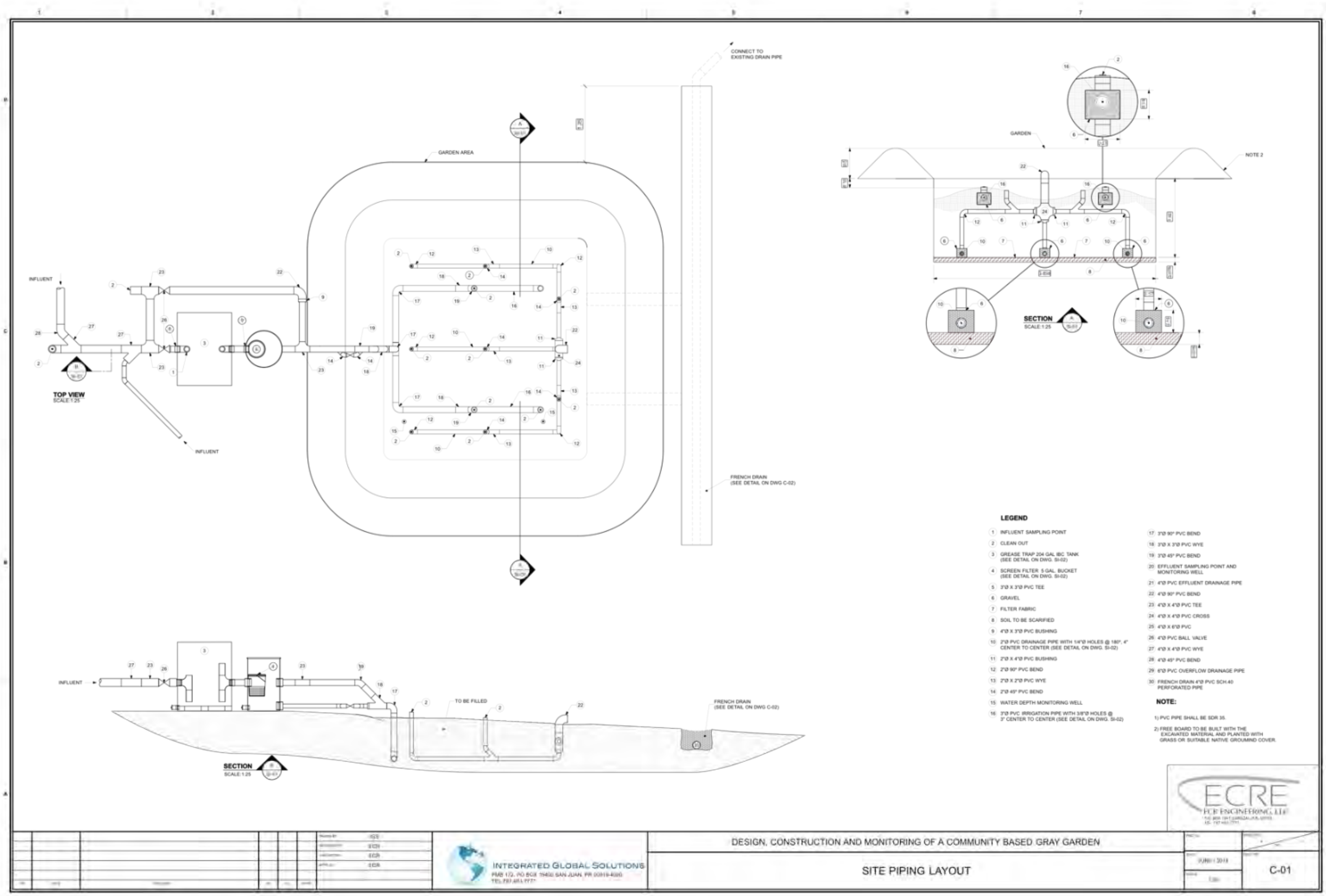


Figure B-4 As-built drawings for the graywater garden, sheet four

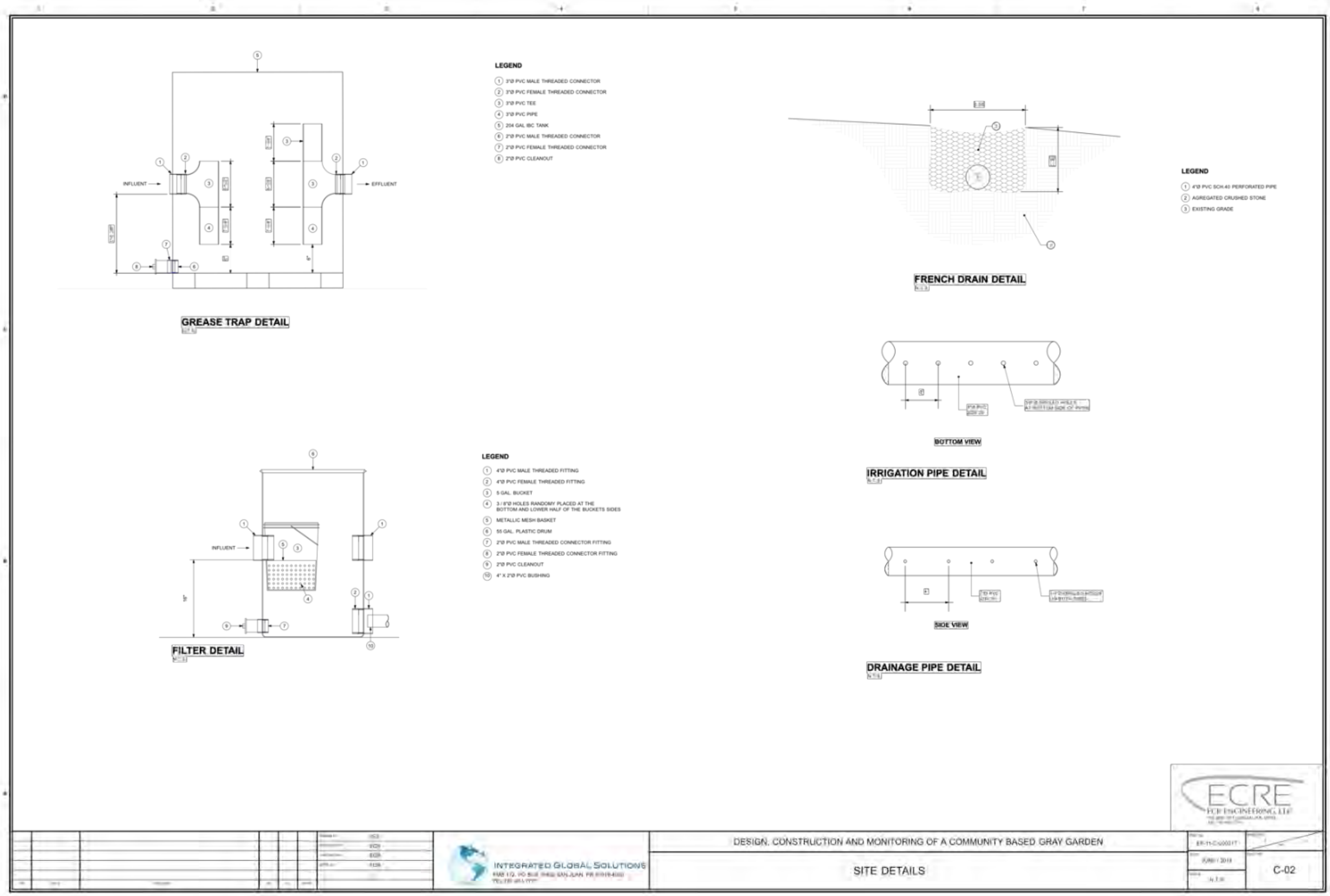


Figure B-5 As-built drawings for the graywater garden, sheet five

Appendix C Project Images

Figure C-1 Maria Jiménez graywater garden site before excavation

Figure C-2 Piping scheme in the excavation and gravel in the bottom

Figure C-3 Filling in the excavation with dirt

Figure C-4 Pipe installation of the graywater garden

Figure C-5 Back view of the recently-filled graywater garden

Figure C-6 Front view of the recently-filled graywater garden

Figure C-7 Side view of the recently-filled graywater garden with germinating plants

Figure C-8 Side view of the recently-filled graywater garden with germinating plants

Figure C-9 View of the garden from street lamp post

Figure C-10 Garden with some developed vegetation

Figure C-11 Pre-treatment units of the graywater garden

Figure C-12 Vegetation grown in the garden

Figure C-13 Vegetation grown in the garden, alternative angle

Figure C-14 Plantain trees and tannia plants growing

Figure C-15 High view of the garden with several plantain trees grown

Figure C-16 Local street view leading to the site

Figure C-17 view of the garden before cutting grass

Figure C-18 View of the garden after cutting grass

Figure C-19 Accumulation of water downstream of the system

Figure C-20 Entrance of the site and stormwater pipe under the street

Figure C-21 Surface ponding in the garden

Figure C-22 Installation of French drain

Figure C-23 Covering up French drain

Figure C24 Covering up French drain with stone

Figure C-25 View of the graywater garden with copious vegetation

Figure C-26 View of the graywater garden with grown Musa spp. and Xanthosoma sp. plants

Figure C-27 View of the graywater garden with remaining plantain (Musa spp.) plants

Appendix D Sampling Documentation

US EPA REGION 2 LABORATORY ANALYSIS REQUEST FORM

SURVEY NAME: Implementation of Greywater Management at the Community Level in PR ; DATE OF REQUEST: February 07, 2014

REQUESTOR: Evelyn Huertas AFFILIATION: CEPD PROGRAM: Water

E-MAIL ADDRESS FOR FINAL ELECTRONIC REPORT: huertas.evelyn@epa.gov

ADDRESS FOR FINAL HARD COPY REPORT: City View Plaza II – Suite 7000, 48 RD. 165 Km. 1.2, Guaynabo, P.R. 00968-8069
SAMPLING DATES: February 07, 2014 ; ARRIVAL DATES: ; ARRIVAL TIME:
METHOD OF SHIPMENT: UPS ; REQUESTED TURNAROUND TIME:

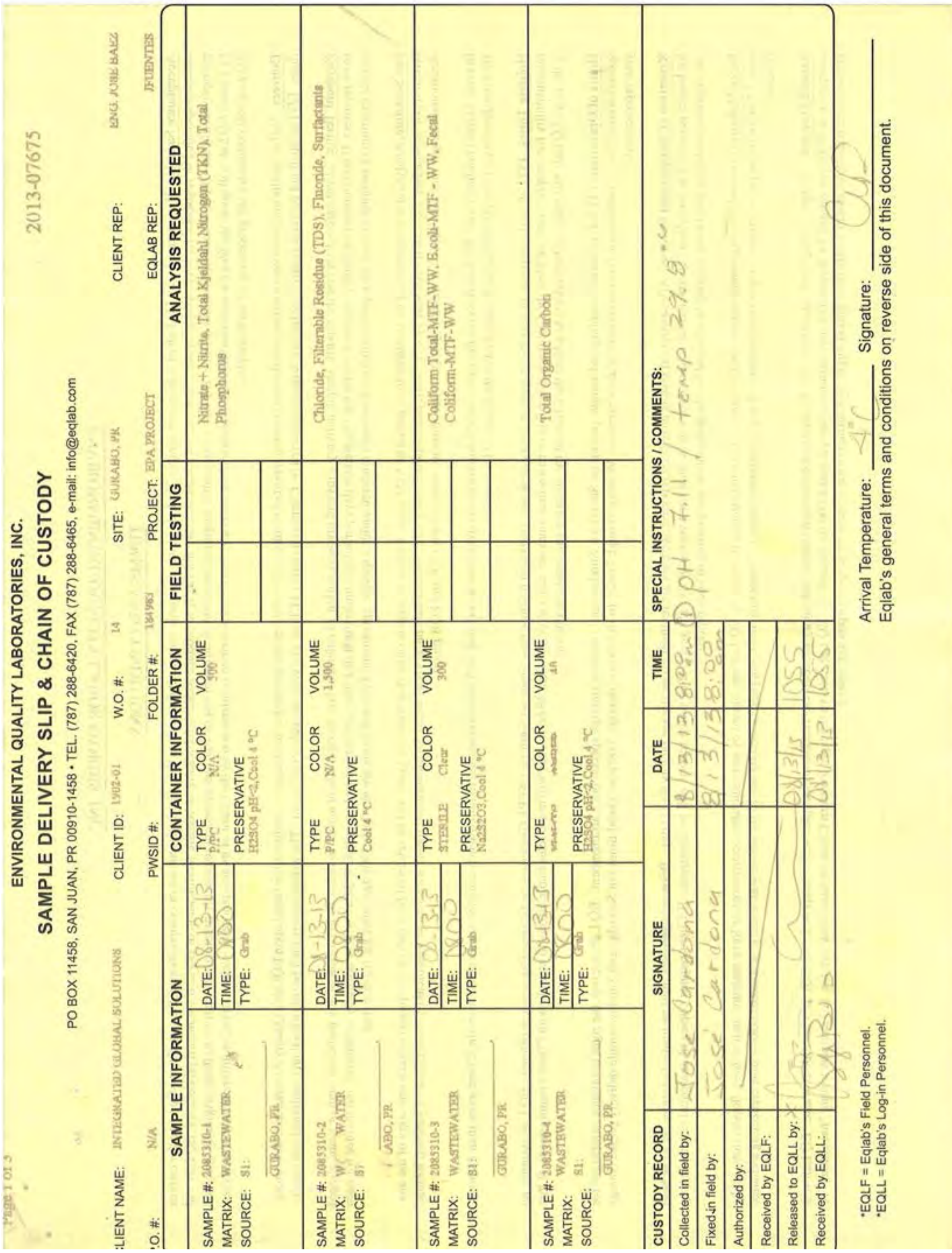
# Samp	Analyte	Matrix	# Samp	Analyte	Matrix	# Samp	Analyte	Matrix	# Samp	Analyte	Matrix
SANITARY			2	OIL& GREASE	A		*ENTERO-COCCUS, MPN			PAHs	
	ACIDITY			ORTHO-PHOSPHATE			*F-COLIFORM, MF			PCBs TCL	
	ALKALINITY, TOTAL			PETROLEUM HYDROC. TOTAL			*F-COLIF. MPN			PCBs TSCA	
2	AMMONIA	A		PHENOLICS			*HPC			PESTICIDES TCL	
	ASPHALTENES		2	PHOSPHORUS	A		*SALMONELLA			PESTICIDES TCLP	
	*BOD, 5DAY			SOLIDS, % 105degC			*T-COLIF. COLILERT			TRIHALO-METHANES	
	*CBOD, 5DAY		2	SPECIFIC CONDUCTANCE	A		*T-COLIF. MF			VOA TCL	
2	CHLORIDE	A		SULFATE			*T-COLIF. MPN			VOA TCLP	
2	COD	A	2	SULFIDE	A	**METALS**				VOA TRACE (DW levels)	
	*COLOR			SULFIDE, UNIONIZED			Specific Metals: list under Special Requests		**BIOLOGY**		
	CORROSIVITY			SULFUR			LEAD (in DW)			#EFFLUENT TOXICITY,ACUTE	
	CYANIDE		2	TDS	A		METALS – SLUDGE			#EFFLUENT TOXICITY, CHRONIC	
	CYANIDE, AMEN. TO CL		2	TKN	A		HARDNESS			#SED.TOX.FRESH WATER	
	CYANIDE, WAD [FREE]		2	TOC	A		METALS FINISHING			#SED.TOX. MARINE WATER	
	*DO (dissolved oxygen)		2	TSS	A		METALS TAL (DW levels)			GRAIN SIZE:	
2	FLUORIDE	A		*TURBIDITY		2	METALS TAL	A		PIPET METHOD (PLUMB 1981)	S
	*HEX. CHROMIUM			VISCOSITY			METALS TCLP			HYDROMETER METHOD ASTM-422D-63	S
	IGNITABILITY		**MICROBIOLOGY**			**ORGANICS**			Y/N	%TOTAL SAND?	
	*MBAS (surfactants)			*CLOSTRIDIUM PERFRINGENS			HALOACETIC ACIDS		Y/N	5 SAND FRACTIONS?	
	*NITRATE			*CRYPTO/ GIARDIA			HERBICIDES		Y/N	%TOTAL FINES? (silt+clay)	
2	NITRATE+ NITRITE	A		*E-COLI			NVOA TCL		Y/N	%TOTAL SILT?	
	*NITRITE			*ENTERO-COCCUS, MF			NVOA TCLP		Y/N	%TOTAL CLAY?	

SPECIAL REQUESTS (turnaround time, additional analytes, etc):

REPORTING REQUIREMENTS: (attach separate sheet, if more room needed):

REQUEST APPROVED BY: DATE APPROVED:

Figure D-1 Example of a Laboratory Analysis Request form used for USEPA Region 2 laboratory in Edison, New Jersey


ENVIRONMENTAL QUALITY LABORATORIES, INC.
SAMPLE DELIVERY SLIP & CHAIN OF CUSTODY
PO BOX 11458, SAN JUAN, PR 00910-1458 • TEL. (787) 288-6420, FAX (787) 288-6465, e-mail: info@eqlab.com
2013-07675

CLIENT NAME: INTEGRATED GLOBAL SOLUTIONS — CLIENT ID: 1902-01 — W.O. #: 14 — SITE: GURABO, PR — CLIENT REP: ENG. JOSE BAEZ
P.O. #: N/A — PWSID #: — FOLDER #: 184963 — PROJECT: EPA PROJECT — EQLAB REP: JFUENTES

SAMPLE INFORMATION		CONTAINER INFORMATION	FIELD TESTING	ANALYSIS REQUESTED
SAMPLE #: 2085310-1; MATRIX: WASTEWATER; SOURCE: S1: GURABO, PR	DATE: 08-13-13; TIME: 0800; TYPE: Grab	TYPE: P/PC; COLOR: N/A; VOLUME: 300; PRESERVATIVE: H2SO4 pH<2,Cool 4 °C		Nitrate + Nitrite, Total Kjeldahl Nitrogen (TKN), Total Phosphorus
SAMPLE #: 2085310-2; MATRIX: WASTEWATER; SOURCE: S1: GURABO, PR	DATE: 8-13-13; TIME: 0800; TYPE: Grab	TYPE: P/PC; COLOR: N/A; VOLUME: 1,500; PRESERVATIVE: Cool 4 °C		Chloride, Filterable Residue (TDS), Fluoride, Surfactants
SAMPLE #: 2085310-3; MATRIX: WASTEWATER; SOURCE: S1: GURABO, PR	DATE: 08-13-13; TIME: 0800; TYPE: Grab	TYPE: STERILE; COLOR: Clear; VOLUME: 300; PRESERVATIVE: Na2S2O3,Cool 4 °C		Coliform Total-MTF-WW, E.coli-MTF-WW, Fecal Coliform-MTF-WW
SAMPLE #: 2085310-4; MATRIX: WASTEWATER; SOURCE: S1: GURABO, PR	DATE: 08-13-13; TIME: 0800; TYPE: Grab	TYPE: ; COLOR: ; VOLUME: 40; PRESERVATIVE: H2SO4 pH<2,Cool 4 °C		Total Organic Carbon

CUSTODY RECORD	SIGNATURE	DATE	TIME
Collected in field by:	Jose Cardona	8/13/13	8:00 am
Fixed in field by:	Jose Cardona	8/13/13	8:00 am
Authorized by:			
Received by EQLF:			
Released to EQLL by:		08/13/13	1055
Received by EQLL:		08/13/13	1055

SPECIAL INSTRUCTIONS / COMMENTS: pH 7.11 / temp 29.8 °C

*EQLF = Eqlab's Field Personnel.
*EQLL = Eqlab's Log-in Personnel.

Arrival Temperature: 4 °C Signature:
Eqlab's general terms and conditions on reverse side of this document.

Figure D-2 Example of a Chain of Custody form used for the local laboratory

The third sampling event (SE3) for the greywater management project will be performed on Tuesday, December 03, 2013, in the María Jiménez community in Hato Nuevo, Gurabo. The SE3 will follow the sampling as established in *Addendum 1* of the Quality Assurance Project Plan (QAPP) for this project. Samples will be taken in two places, the system's influent (S1) and the effluent (S2). The influent sample is taken inside the first drum, whereas the effluent is taken from one of the garden's sampling pipes, to the end of the system. Two samples will be taken in each point, one to send to the EPA Region 2 laboratory and another one to send to a local laboratory for those parameters that have short holding times. These will be divided into five (5) bottles for certain parameters to be analyzed, as seen in the following tables.

TABLE 1 . Bottle summary for samples S1-EPA and S2-EPA to be sent to EPA's Region 2 laboratory.

NAME	PARAMETERS	SAMPLE	BOTTLE TYPE	PRESERVATIVE
Bottle 1	Total suspended solids (TSS), Filterable residue (TDS), Chloride, Fluoride, Conductivity	1000 mL	1000-mL HDPE	Ice
Bottle 2	Oil & grease	3000 mL	1000-mL Amber	Hydrochloric acid
Bottle 3	Sulfide	250 mL	250-mL HDPE	Zinc acetate / Sodium hydroxide
Bottle 4	Chemical oxygen demand (COD), Total organic carbon (TOC), Total Kjeldahl nitrogen (TKN) Nitrate+Nitrite, Ammonia Total phosphorus	500 mL	500-mL HDPE	Sulfuric acid
Bottle 5	Metals - TAL	250 mL	250-mL HDPE	Nitric acid

Following is a table with a detail of the various parameters that will be measured for the event and their respective reporting limits for EPA Region 2.

Figure D-3 Example of the second page of the Sampling and Analysis Plan presented two weeks before each sampling event

TABLE 2 . Parameters and respective reporting limits for samples S1-EPA and S2-EPA to be sent to EPA's Region 2 laboratory.

PARAMETER	PRESERVATIVE	VOLUME, mL	BOTTLE TYPE	REGION 2 LIMITS, mg/L
TSS	Ice	400	HDPE	10
TDS	Ice	-	HDPE	10
Fluoride	Ice	100	HDPE	0.1
Chloride	Ice	50	HDPE	1.0
Conductivity	Ice	100	HDPE	0.1 uS/CM
Oil & grease	Hydrochloric acid	3000	1-L amber glass	5.0
Sulfide	Zn acetate + Na hydroxide	250	HDPE	.01
COD	Sulfuric acid	50	HDPE	20.0
Nitrate + Nitrite	Sulfuric acid	100	HDPE	.05
TKN	Sulfuric acid	100	HDPE	0.1
Ammonia	Sulfuric acid	100	HDPE	.05
Total phosphorus	Sulfuric acid	50	HDPE	.05
TOC	Sulfuric acid	50	HDPE	1.0
Metals –TAL	Nitric acid	250	HDPE	Varies

Figure D-4 Example of the third page of the Sampling and Analysis Plan presented two weeks before each sampling event

TABLE 3 . Bottle summary for samples S1 and S2 to be sent to EQLab's laboratory.

NAME	PARAMETERS	SAMPLE	BOTTLE TYPE	PRESERVATIVE
Bottle 1	Filterable residue (TDS), Chloride, Fluoride, Surfactants	1500 mL	2000-mL HDPE	Ice
Bottle 2	Nitrate+Nitrite, Total phosphorus, Total Kjeldahl nitrogen (TKN)	500 mL	500-mL HDPE	Sulfuric acid
Bottle 3	Total coliform (MTF-WW), *E.coli* (MTF-WW), Fecal coliform (MTF-WW)	300 mL	300-mL HDPE	Sodium thiosulfate
Bottle 4	Total organic carbon (TOC)	40 mL	Amber vial	Sulfuric acid

TABLE 4 . Parameters and respective reporting limits for samples S1 and S2 to be sent to EQLab's laboratory.

PARAMETER	PRESERVATIVE	BOTTLE TYPE	MDL LIMITS
TDS	Ice	HDPE	5 mg/L
Fluoride	Ice	HDPE	0.01 mg/L
Chloride	Ice	HDPE	3 mg/L
Surfactants	Ice	HDPE	0.5 mg/L as LAS
Nitrate+Nitrite	Sulfuric acid	HDPE	0.01 mg/L
Total Phosphorus	Sulfuric acid	HDPE	0.25 mg/L
Total Kjeldahl Nitrogen	Sulfuric acid	HDPE	0.2 mg/L
Total Coliform	Sodium thiosulfate	HDPE	1.8 MPN/100 mL
E. coli	Sodium thiosulfate	HDPE	2.0 MPN/100 mL
Fecal Coliform	Sodium thiosulfate	HDPE	1.8 MPN/100 mL
TOC	Sulfuric acid	Amber vial	0.5 mg/L

Figure D-5 Example of the fourth and last page of the Sampling and Analysis Plan presented two weeks before each sampling event

Appendix E Results of Spearman Rank Order Correlation

A Spearman rank R correlation test was performed in Statistica 10 (StatSoft, Inc., 2011) on the effluent concentrations. A high correlation value between specific parameters for all sampling dates may imply that there were similar cause and effect for concentration changes, if positively correlated. If negative correlation are large, results may also be linked. Marked correlations or red values imply statistically significant results. Variables on the left were tested against each column (e.g. COD is significantly, positively correlated with TKN, O&G, TOC and TSS).

Spearman Rank Order Correlations (Nutrients.sta)
MD pairwise deleted
Marked correlations are significant at p <.05000

Variable	NH4	COD	Cl	F	TKN	O&G	TOC	TDS	TSS	Na	SC	S	F Col	T Col	E coli
NH4 as N	1.00	0.29	-0.18	0.77	0.58	0.21	0.28	-0.08	0.26	-0.00	-0.00	0.19	-0.65	0.27	-0.65
COD	0.29	1.00	0.28	0.28	0.78	0.87	0.85	0.42	0.80	0.07	0.38	0.07	-027	0.15	-0.27
Chloride (Cl)	-0.18	0.28	1.00	0.02	0.19	0.21	0.06	0.35	0.41	0.91	0.76	-0.41	0.51	-0.08	0.52
Floride (F)	0.77	0.28	-0.02	1.00	0.67	0.39	0.45	0.17	0.21	0.17	-0.00	0.13	-0.58	-0.15	-0.57
TKN	0.58	0.78	0.19	0.67	1.00	0.65	0.85	0.17	0.54	0.28	0.13	0.37	-0.32	0.10	-0.31
Oil&Grease (O&G)	0.21	0.87	0.21	0.39	0.65	1.00	0.73	0.52	0.81	-0.00	0.43	-0.11	-0.30	0.01	-0.31
TOC	0.28	0.85	0.06	0.45	0.85	0.73	1.00	0.39	0.54	0.14	0.14	0.37	-0.22	0.14	-0.21
TDS	-0.08	0.42	0.35	0.17	0.17	0.52	0.39	1.00	0.34	0.39	0.68	-0.48	-0.09	-0.22	-0.09
TSS	0.26	0.80	0.41	0.21	0.54	0.81	0.54	0.34	1.00	0.30	0.54	-0.29	-0.14	0.12	-0.12
Sodium (Na)	-0.00	0.07	0.91	0.17	0.28	-0.00	0.14	0.39	0.30	1.00	0.74	-0.43	0.33	-0.07	0.35
Specific conductance (SC)	-0.00	0.38	0.76	-0.00	0.13	0.43	0.14	0.68	0.54	0.74	1.00	-0.84	0.25	-0.29	0.27
Sulfide (S)	0.19	0.07	-0.41	0.13	0.37	-0.11	0.37	-0.48	-0.29	-0.43	-0.84	1.00	-0.07	0.51	-0.08
F Col	-0.65	-0.27	0.51	-0.58	-0.32	-0.30	-0.22	-0.09	-0.14	0.33	0.25	-0.07	1.00	0.08	1.00
T Col	0.27	0.15	-0.08	-0.15	0.10	0.01	0.14	-0.22	0.12	-0.07	-0.29	0.51	0.08	1.00	0.07
E coli	-0.65	-0.27	0.52	-0.57	-0.31	-0.31	-0.21	-0.09	-0.12	0.35	0.27	-0.08	1.00	0.07	1.00
Iron (Fe)	0.43	0.46	-0.08	0.36	0.42	0.29	0.28	0.14	0.67	0.13	0.07	-0.25	-0.26	0.13	-0.26
Aluminum (Al)	0.26	0.69	0.36	0.22	0.39	0.60	0.32	0.44	0.89	0.26	0.60	-0.61	-0.11	-0.02	-0.09
Calcium (Ca)	0.20	0.87	0.36	0.20	0.48	0.86	0.52	0.72	0.80	0.06	0.65	-0.44	-0.18	-0.00	-0.17
Copper (Cu)	0.28	0.92	0.17	0.56	0.88	0.81	0.78	0.29	0.77	0.03	0.14	0.05	-0.46	-0.09	-0.44
Magnesium (Mg)	0.55	0.74	-0.00	0.45	0.58	0.76	0.65	0.78	0.69	-0.02	0.50	-0.28	-0.33	0.27	-0.34
Manganese (Mn)	0.45	0.36	0.02	0.41	0.28	0.27	0.08	0.14	0.62	0.24	0.25	-0.55	-0.28	-0.17	-0.27
Phosphorous (P)	0.60	0.40	0.05	0.28	0.63	0.22	0.37	-0.08	0.14	0.11	0.17	0.39	-0.42	0.28	-0.42
Potassium (K)	0.16	0.19	-0.21	0.05	0.41	0.11	0.52	0.54	-0.07	-0.04	-0.04	0.35	-0.22	0.15	-0.24
Zinc (Z)	0.36	0.74	0.26	0.38	0.44	0.76	0.32	0.26	0.85	0.07	0.45	-0.44	-0.44	-0.24	-0.42
Ni+Ni	-0.09	0.39	-0.15	0.04	0.28	0.43	0.42	-0.09	0.23	-0.23	-0.05	0.24	-0.11	-0.25	-0.11
pH	-0.07	0.38	0.32	0.02	0.13	0.54	0.43	0.62	0.62	0.42	0.75	-0.62	0.06	-0.18	0.06
Sodium (Na)	-0.00	0.07	0.91	0.17	0.28	-0.00	0.14	0.39	0.30	1.00	0.74	-0.43	0.33	-0.07	0.35
Surfactants (Sur)	-0.47	0.25	0.29	-0.32	0.10	0.42	0.32	0.41	0.43	0.20	0.47	-0.26	0.29	-0.02	0.28

Spearman Rank Order Correlations (Nutrients.sta) MD pairwise deleted Marked correlations are significant at p <.05000

	Fe	Al	Ca	Cu	Mg	Mn	P	K	Z	Na+Ni	pH	Na	Sur
NH4 as N	0.43	0.26	0.20	0.28	0.55	0.45	0.60	0.16	0.36	-0.09	-0.07	-0.00	-0.47
COD	0.46	0.69	0.87	0.92	0.74	0.36	0.40	0.19	0.74	0.39	0.38	0.07	0.25
Chloride (Cl)	-0.08	0.36	0.36	0.17	-0.00	0.02	0.05	-0.21	0.26	-0.15	0.32	0.91	0.29
Floride (F)	0.36	0.22	0.20	0.56	0.45	0.41	0.28	0.05	0.38	0.04	0.02	0.17	-0.32
TKN	0.42	0.39	0.48	0.88	0.58	0.28	0.63	0.41	0.44	0.28	0.13	0.28	0.10
Oil&Grease (O&G)	0.29	0.60	0.86	0.81	0.76	0.27	0.22	0.11	0.76	0.43	0.54	-0.00	0.42
TOC	0.28	0.32	0.52	0.78	0.65	0.08	0.37	0.52	0.32	0.42	0.43	0.14	0.32
TDS	0.14	0.44	0.72	0.29	0.78	0.14	-0.08	0.54	0.26	-0.09	0.62	0.39	0.41
TSS	0.67	0.89	0.80	0.77	0.69	0.62	0.14	-0.07	0.85	0.23	0.62	0.30	0.43
Sodium (Na)	0.13	0.26	0.06	0.03	-0.02	0.24	0.11	-0.04	0.07	-0.23	0.42	1.00	0.20
Specific conductance (SC))	0.07	0.60	0.65	0.14	0.50	0.25	0.17	-0.04	0.45	-0.05	0.75	0.74	0.47
Sulfide (S)	-0.25	-0.61	-0.44	0.05	-0.28	-0.55	0.39	0.35	-0.44	0.24	-0.62	-0.43	-0.26
F Col	-0.26	-0.11	-0.18	-0.46	-0.33	-0.28	-0.42	-0.22	-0.44	-0.11	0.06	0.33	0.29
T Col	0.13	-0.02	-0.00	-0.09	0.27	-0.17	0.28	0.15	-0.24	-0.25	-0.18	-0.07	-0.02
E coli	-0.26	-0.09	-0.17	-0.44	-0.34	-0.27	-0.42	-0.24	-0.42	-0.11	0.06	0.35	0.28
Iron (Fe)	1.00	0.79	0.38	0.52	0.50	0.88	-0.01	-0.09	0.47	-0.23	0.45	0.13	0.14
Aluminum (Al)	0.79	1.00	0.77	0.65	0.63	0.78	-0.01	-0.22	0.78	-0.19	0.68	0.26	0.41
Calcium (Ca)	0.38	0.77	1.00	0.68	0.79	0.38	0.14	0.16	0.80	-0.04	0.48	0.06	0.47
Copper (Cu)	0.52	0.65	0.68	1.00	0.52	0.41	0.31	0.04	0.74	0.42	0.28	0.03	0.32
Magnesium (Mg)	0.50	0.63	0.79	0.52	1.00	0.38	0.29	0.37	0.48	0.17	0.70	-0.02	0.31
Manganese (Mn)	0.88	0.78	0.38	0.41	0.38	1.00	-0.09	-0.29	0.57	0.12	0.45	0.24	0.18
Phosphorous (P)	-0.01	-0.01	0.14	0.31	0.29	-0.09	1.00	0.52	0.16	0.02	-0.26	0.11	-0.25
Potassium (K)	-0.09	-0.22	0.16	0.04	0.37	-0.29	0.52	1.00	-0.11	-0.07	-0.09	-0.04	0.13
Zinc (Z)	0.47	0.78	0.80	0.74	0.48	0.57	0.16	-0.11	1.00	0.13	0.36	0.07	0.38
Ni+Ni	-0.23	-0.19	-0.04	0.42	0.17	0.12	0.02	-0.07	0.13	1.00	0.65	-0.23	0.42
pH	0.45	0.68	0.48	0.28	0.70	0.45	-0.26	-0.09	0.36	0.65	1.00	0.42	0.47
Sodium (Na)	0.13	0.26	0.06	0.03	-0.02	0.24	0.11	-0.04	0.07	-0.23	0.42	1.00	0.20
Surfactants (Sur)	0.14	0.41	0.47	0.32	0.31	0.18	-0.25	0.13	0.38	0.42	0.47	0.20	1.00