University Of Puerto Rico
Rio Piedras Campus
College Of Natural Sciences
Department Of Environmental Sciences
Graduate Program

A Comprehensive Stormwater Management Plan: Opportunities to Incorporate Stormwater Wetlands into The University of Puerto Rico Stormwater Management Program

By

Tamaris Jordan Gomez

A thesis submitted to the Department of Environmental Sciences, College of Natural Sciences, University of Puerto Rico, Rio Piedras Campus

In partial fulfillment of the requirements for the degree of

MASTERS IN ENVIRONMENTAL SCIENCES

February 25, 2022

Rio Piedras, Puerto Rico

University Of Puerto Rico
Rio Piedras Campus
College Of Natural Sciences
Department Of Environmental Sciences
Graduate Program

I certify that the thesis entitled “A Comprehensive Stormwater Management Plan: Opportunities to Incorporate Stormwater Wetlands into The University of Puerto Rico Stormwater Management Program” by Tamaris Jordan Gomez and presented in this document meets all the requirements of the Department of Environmental Sciences.

____

Rafael A. Rios Dávila, PhD

Principal Advisor

____

Rosana Grafals, PhD

Committe Member

____

Jorge Ortiz, PhD

Committe Member

Approved:

____

Jess K. Zimmerman

Director, Department of Environmental Sciences

Date: ______________________________

ACKNOWLEDGMENTS

This process has been a long journey filled with a lot of personal and academic challenges and triumphs. Throughout the writing of this thesis, I have received a great deal of support and assistance. First, I would like to thank my professor and advisor Dr. Rafael A. Rios, whose expertise was invaluable during this process, thank you! Your perceptive feedback pushed me to sharpen my thinking and brought my work to a higher level. You have truly been a patient mentor and a sympathetic ear, seeing me through tears and laughter alike. I would like to thank my committee members: Dr. Rosana Grafals and Dr. Jorge Ortiz for your support during this process. I would like to acknowledge my colleagues Dr. Angelica Erazo and Abelardo Colon for their friendship, support, and good wishes during this journey. Thanks to the University of Puerto Rico and OPASO for the information provided. Thanks again to Dr. Rafael A. Rios for giving me with the opportunity to work in the "Programa de Experiencias Academicas Formativas" (PEAF) providing me with financial assistance. Last but not least, thanks to my parents Octavio Jordan Stuart and Maria Gomez Mata for all your love, support, and encouragement during these years.

Abstract

The environment is continuously deteriorating due to the presence of human activity and the permanent landscape alterations that compromise the ecosystem. One of these practices is the discharge of large volumes of untreated stormwater into receiving natural bodies of water. In addition to questionable stormwater discharge practices, rainwater that is not redirected and cannot infiltrate through the impervious surfaces then accumulates and produces floods that threaten the environment and humans as well. Conventional methods of stormwater management exist that are widely used around the world; however, new eco-friendly alternative methods mainly in the form of green infrastructure have been used for the same purpose, namely, constructed wetlands that are being proposed in this thesis. The objective of this study is the design of a constructed wetland system to manage stormwater originating from the UPRRP campus that can host 13,000 students as well as 4,000 faculty and staff. The idea is that the stormwater flow would be redirected into strategically placed constructed wetlands within the UPRRP campus to provide pre-treatment and flow control. The runoff that is not retained in these stormwater wetland cells is then discharged into the conventional stormwater management infrastructure the UPRRP uses. Last, but not least, an evaluation was conducted to determine the cost a project of this magnitude would amount to.

INDEX

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND DEFINITIONS

For clarification purposes, the following acronyms/definitions are used throughout this document:

BMPs - Best Management Practices

EPA - The United States Environmental Protection Agency

FWS - Free Water Surface Wetland

Green Infrastructure - is any interconnected system or network of green space that slows and/or reduces the flow of stormwater into a sewer system, conserves natural ecosystem values and functions, and provides associated benefits to human populations.

Illicit Connection - A physical connection to the drainage system that conveys illicit discharges into the drainage system or is not authorized or permitted by the local authority (where a local authority requires such authorization or permit).

Illicit Discharge - Any discharge or seepage that is not composed entirely of storm water into the drainage system. Illicit discharges include dumping of motor vehicle fluids, hazardous wastes, grass clippings, leaf litter, domestic animal wastes, litter or unauthorized discharges of sewage, industrial waste, food services wastes, or any other non-storm water waste into the drainage system.

MS4 - General Permit for Discharges from small Municipal Separate Storm Sewer

NFHL - National Flood Hazard Layer

NPDES - National Pollutant Discharge Elimination System

OPASO - UPRRP Rio Piedras Campus Environmental Protection and Occupational Safety

Permit - The NPDES PRR040013 issued by the EPA to the UPR Rio Piedras Campus under the General Permit PRRO4000F, effective July 1, 2016.

SSF - Subsurface Flow Wetland

UPRRP - University of Puerto Rico Rio Piedras Campus

INTRODUCTION

Every stormwater management plan is unique and has its own operating environment and sets of technical requirements. As a result, the execution of a stormwater management program is subject to numerous constraints that limit the efficiency over time of the best management practices (BMPs) in place, which invariably have significant impact on the overall performance of the system. By definition, constraints refer to any condition, such as temporal/spatial limitations and safety/quality concerns, which may prevent a project to achieve its goals. Successful execution and control of a stormwater management practice relies on effective identification and management of constraints through comprehensive planning.

Taking a look at stormwater management around the world provides insight into the overall success of current and new stormwater management practices. The landscapes of countries all over the world are experiencing rapid population growth and urbanization which puts pressure on both natural and man-made environments. In addition to population growth and urbanization, climate change is pressuring city infrastructure and carrying capacity. With the hope of achieving sustainable development many cities are promoting better management practices (BMPs) for public health, transportation, sanitation, water supply, energy supply, and employment but often face several challenges toward achieving their goals. In this sense, sustainable development can be defined as an organizing concept for reaching human development goals within an urban setting while simultaneously sustaining the ability of natural systems to provide the natural resources and ecosystem services on which society relies on.

In developing countries, cities are facing several challenges regarding water management (floods, water shortages, waste of water, and sanitation), thus requiring effective approaches to promote sustainable water management (Rabêlo et al., 2019). These challenges for sustainable urban planning require new approaches and initiatives to increase the resiliency of cities (Morison and Brown, 2011). Therefore, understanding water sensitive management practices can promote sustainability in urban areas and increase cities' resiliency to climate change. This study presents water sensitive management practices designed for urban landscapes and the approach into a university as a case study.

The literature indicates that governments and social agents like universities must invest in new approaches to promote sustainable development in cities to improve water management and avoid potential crises (Rabêlo et al., 2019). Therefore, university campuses serve as role models for their city and surrounding communities by providing an ideal environment for innovation, experimentation, and learning. As complex institutions, universities resemble town-like organizations that maintain several facilities and carry thousands of students.

These institutions also concentrate a wide variety of knowledge, capacity, experts, and resources to promote learning, innovation, and transformation (Klein-Banai and Theis, 2011). University campuses are consequently complex environments and cornerstones to promote sustainable development by offering an environment to stimulate creativity and enhance open-innovation initiatives by operating living labs (Klein-Banai and Theis, 2011). Promoting sustainability in university operations requires adopting practices that facilitate energy efficiency and sustainable energy generation, sustainable transportation, waste management, sustainable buildings, management of water resources, health, and safety.

Sustainable water management in universities is a key component to promote education for sustainable development however, most of the literature on sustainable development in university institutions focuses on water management based on awareness on water use, efficient piping systems, and managements of effluents (Rabêlo et al., 2019). Improving water efficiency in pipelines, water consumption, water collection, stormwater storage, managing sewage, water effluents, and managing natural water sources on university campuses and the surrounding areas are all methods of implementing sustainable management of water resources. Such water management practices can be better developed and tested in university campuses and therefore contribute to the promotion of comprehensive programs for sustainable development. These water management practices include the implementation of various forms of infrastructure, most notably green infrastructure.

Often when people think of infrastructure, they picture roads, sewers, and utility lines. These are known as gray infrastructure. Other times people think of infrastructure as hospitals, schools, and prisons. These are also known as social infrastructure. Together, these may be referred to as constructed infrastructure. However, Webster's New World Dictionary defines infrastructure as the substructure or underlying foundation, especially the basic installations and facilities on which the continuance and growth of a community depends (Benedict and McMahon, 2002). Today, the public and various organizations are acknowledging another type of infrastructure critical to the growth and resilience of a community, green infrastructure. While it means different things to different people, depending on the context in which it is used, for the purposes of this paper, green infrastructure is any interconnected system or network of green space that slows and/or reduces the flow of stormwater into a sewer system, conserves natural ecosystem values and functions, and provides benefits to human populations.

Non-structural and Structural Best Management Practices (BMPs)

Non-structural stormwater BMPs are preventative practices that involve management and source controls. Non-structural BMPs are implemented at a facility and incorporated into day-to-day activities for the operation of the facility or into maintenance schedules within the UPRRP main campus. Examples of issues that are covered in non-structural BMPs within the UPRRP Stormwater Management Program used on campus include the following:

- Buffers along sensitive water bodies
- Education programs for developers on minimizing water quality/quantity impacts
- Education programs for the public on minimizing water quality/quantity impacts
- Minimum disturbance of soils and vegetation
- Restrictions on directly connected impervious areas
- Preservation of the natural environment
- Minimization of impervious surfaces
- Use of vegetated swales and natural storage.

Structural BMPs are physical controls and practices that involve storage practices, which improve water quality. Structural BMPs related to storm water detention and retention basins are subject to scheduled maintenance inspections in accordance with the UPRRP Stormwater Management Program. Examples of issues covered in structural BMPs within the UPRRP Stormwater Management Program that can be used on campus include but are not limited to the following:

- Wet ponds and extended detention outlet structures
- Filtration practices such as grassed swales, sand filters, and filter strips
- Infiltration practices such as infiltration basins and infiltration trenches.

The office of OPASO and the University Planning Office review all construction and renovation plans for use of structural and non-structural BMPs to prevent receiving water quality to be impacted and limit the rate at which surface water runoff discharges from any specific site. The surface water runoff discharge should not exceed the pre-development hydrologic regime. The number of sites implementing non-structural and structural BMPs is tracked for subsequent reporting. Meanwhile, non-scheduled activities are completed as they arise. Each area has operation and maintenance BMPs with the ultimate goal of reducing pollutant runoff from the university.

Green Infrastructure

Stormwater runoff is a major cause of water pollution carrying trash, bacteria, heavy metals, and other pollutants in urban areas through storm sewers into local waterways. In addition, heavy rainstorms can cause flooding that damages property and infrastructure. Communities all over the world have used gray infrastructure consisting of systems of gutters, pipes, and tunnels to move stormwater away from residences to treatment plants or local water bodies. However, gray infrastructure in many areas is deteriorating, and its capacity to manage large volumes of stormwater is decreasing. To meet this challenge, new management practices are being implemented many of which consist of green infrastructure systems.

Green infrastructure filters and absorbs stormwater. In many cases green infrastructure is designed to conduct these processes where the rainwater falls. In 2019, Congress enacted the Water Infrastructure Improvement Act, which defines green infrastructure as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters" (EPA,2021).

Green infrastructure is still considered a relatively new term, but its roots in planning and conservation efforts actually began over 150 years ago. The concept evolved from two important precedents: (1) the linking of parks and other green spaces for the benefit of people, and (2) the linking of natural areas to benefit biodiversity and counter habitat fragmentation (Benedict and McMahon, 2002). Planning utilizing green infrastructure differs from conventional open space planning because it looks at conservation values in concert with land development, growth management and built infrastructure planning (Benedict and McMahon, 2002). This paper introduces green infrastructure as a strategic approach to stormwater management that addresses the ecological and social impacts of urban sprawl and the accelerated consumption and fragmentation of the ecosystem.

Green infrastructure features can be integrated into a community at several scales. Examples of commonly used green infrastructure stormwater management practices of all sizes can be seen in Table 1. According to the EPA, when green infrastructure systems are installed throughout a community, city or across a regional watershed, they can provide cleaner air and water. Green Infrastructure may also add significant value for the community by providing flood protection, habitat diversification, and esthetically improving green spaces.

Table 1. Commonly Used Green Infrastructure Systems According to the EPA

Green Infrastructure	**Description**
Bioswales	Bioswales are essentially vegetated areas similar to rain gardens placed in long narrow spaces such as the space found along curbs and in parking lots. They use vegetation or mulch to slow and filter stormwater flows.
Constructed Wetlands	Constructed wetlands are man-made wetland systems designed to remove pollutants from stormwater runoff through wetland vegetation uptake, retention and settling. These wetlands temporarily store runoff in shallow pools that support the growth of wetland vegetation.

Downspout Disconnection	This practice reroutes rainwater from rooftop drainage pipes into rain barrels, cisterns, or permeable areas rather than a conventional storm sewer. Downspout disconnection facilitates stormwater storage and/or infiltration into the soil. It could be especially beneficial to cities with combined sewer systems.
Green Parking	Green parking infrastructure integrates permeable pavements, rain gardens, and bioswales along the parking lot perimeter. When combined into a parking lot, these practices reduce the heat island effect and improve walkability.
Green Roofs	This system covers roofs with vegetation that facilitates rainfall infiltration and evapotranspiration of stored water. They may be cost-effective in urban areas where land values are high, on large industrial areas, or office buildings where stormwater management costs are high.
Green Streets and Alleys	Green streets and alleys are created by weaving multiple green infrastructure practices together into their design to store and filter stormwater. These include permeable pavements, bioswales, planter boxes, and trees.
Land Conservation	The water quality and flooding impacts of urban stormwater also can be addressed through land conservation by protecting open spaces and sensitive natural areas within and adjacent to a city. These natural areas include riparian areas, wetlands, and steep hillsides.
Permeable Pavements	Permeable pavements are designed to infiltrate, treat, and/or store rainwater. This practice is cost effective where land values are high, and flooding is a problem. They capture water where it falls and are made of pervious concrete, permeable interlocking pavers, or porous asphalt.
Planter Boxes	These systems are made up of urban rain gardens with vertical walls and either open or closed bottoms. Planter boxes are found in urban downtown areas, where they collect and absorb runoff from streets, sidewalks, and parking lots. They are esthetically pleasing and are ideal for areas with limited space.
Rain Gardens	Rain gardens are small, shallow, sunken planted areas that collect stormwater runoff from roofs, streets, and sidewalks. These systems are designed to mimic the way water flows over and absorbs into land to reduce stormwater pollution. Also known as bioretention cells.
Rainwater Harvesting	These systems reduce stormwater pollution by slowing rainwater runoff and collecting rainfall for later use. Rainwater harvesting systems include backyard rain barrels, commercial building cisterns, ground level pits, aquifers, and even nets that capture dew and fog.

Urban Tree Canopy	Urban Trees capture stormwater on their leaves and branches. Some cities have set tree canopy goals to restore the benefits lost when the areas were developed.

(Source: EPA, https://www.epa.gov/green-infrastructure/what-green-infrastructure)

The purpose of this study is to examine various stormwater management plans and projects on university campuses. The ultimate goal is to help the University of Puerto Rico Rio Piedras Campus (UPRRP) develop a new comprehensive stormwater management plan incorporating the use of green infrastructure in combination with existing gray infrastructure. This study will examine the historic context of UPRRP's sewer system, and the environmental, social, and financial challenges presented by stormwater runoff. The study will then examine conventional methods used by other universities to control stormwater runoff and the UPRRP's efforts, which rely heavily on gray infrastructure. With this background, the paper then finds common elements between them and makes recommendations to the UPRRP for a stormwater management plan including descriptions of the innovative practices at other universities that should be emulated.

As a town-like organization, there is an opportunity for the UPRRP to become a model institution for stormwater management. Sporadic green infrastructure projects will have some effect but for truly efficient stormwater management it is necessary to direct green infrastructure projects through a stormwater management plan. This study presents water sensitive management practices designed for urban landscapes and the approach into a university as a case study. The UPRRP has various green spaces large enough to accommodate sizable green infrastructure systems. In the hopes of maximizing the use of these open green spaces this study is proposing the implementation of constructed wetlands as the green infrastructure system of preference to build within the UPRRP and integrate into the university stormwater management program.

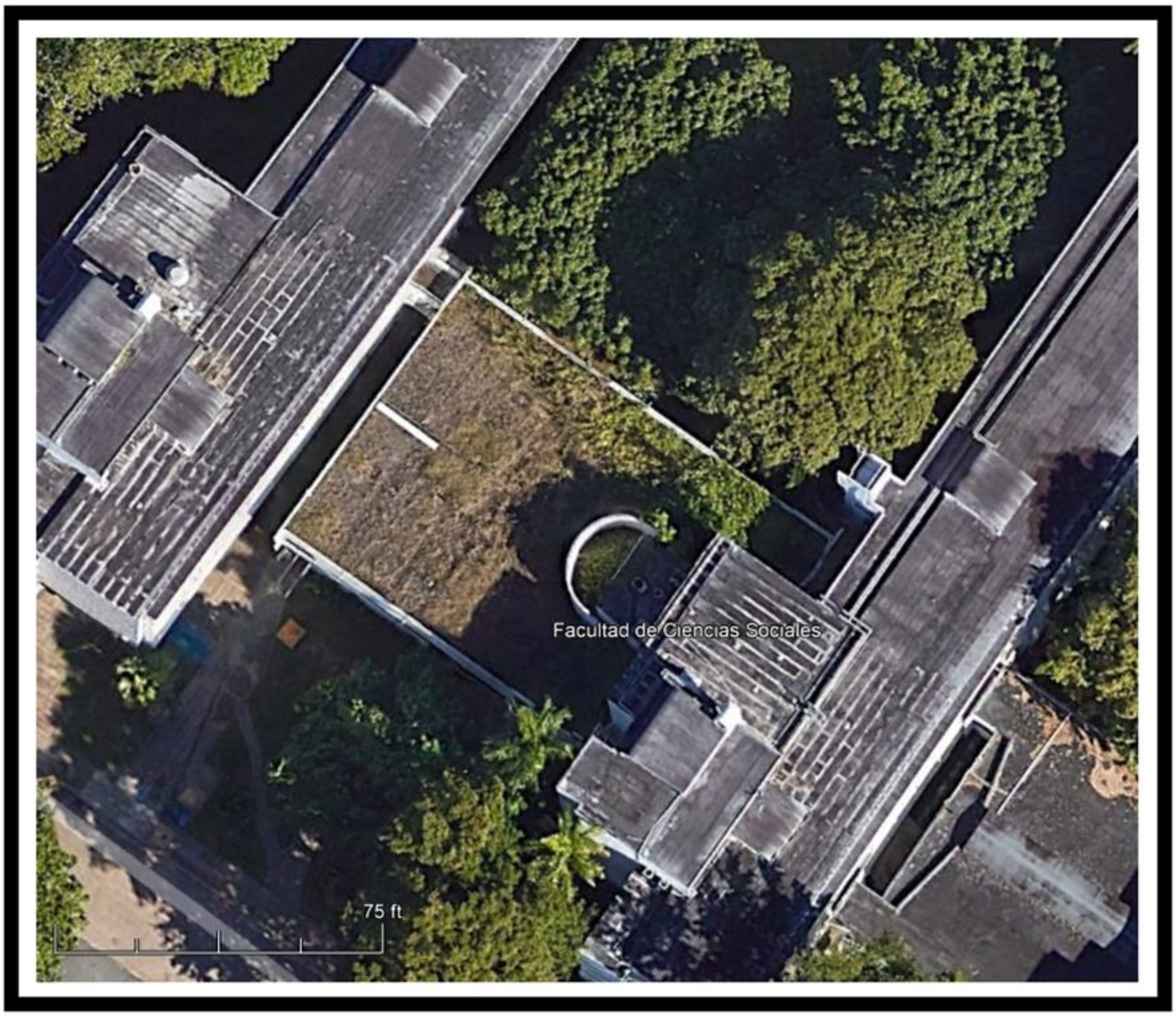
Green Infrastructure Within the UPRRP Campus

In addition to the university's storm sewer system, attempts have been made to incorporate green infrastructure into the UPRRP Campus. Unfortunately, these additions are often overlooked and are not included within the UPRRP Stormwater Management Program. The green infrastructure in question consists of green roofs and rain gardens. Only one green roof is found within the UPRRP main campus, the rest are located above the International Institute of Tropical Forestry (IITF) facilities located in the Botanical Garden of the UPRRP within the San Juan City.

The green roof within the main campus stands above the Social Sciences Faculty's building and is more than 20 years old (Grullón et al., 2020). The structure does not receive any maintenance; this influences the composition of its vegetation. This roof contained some of the common species such as Cyperacea kyllinga, Bidens alba, and

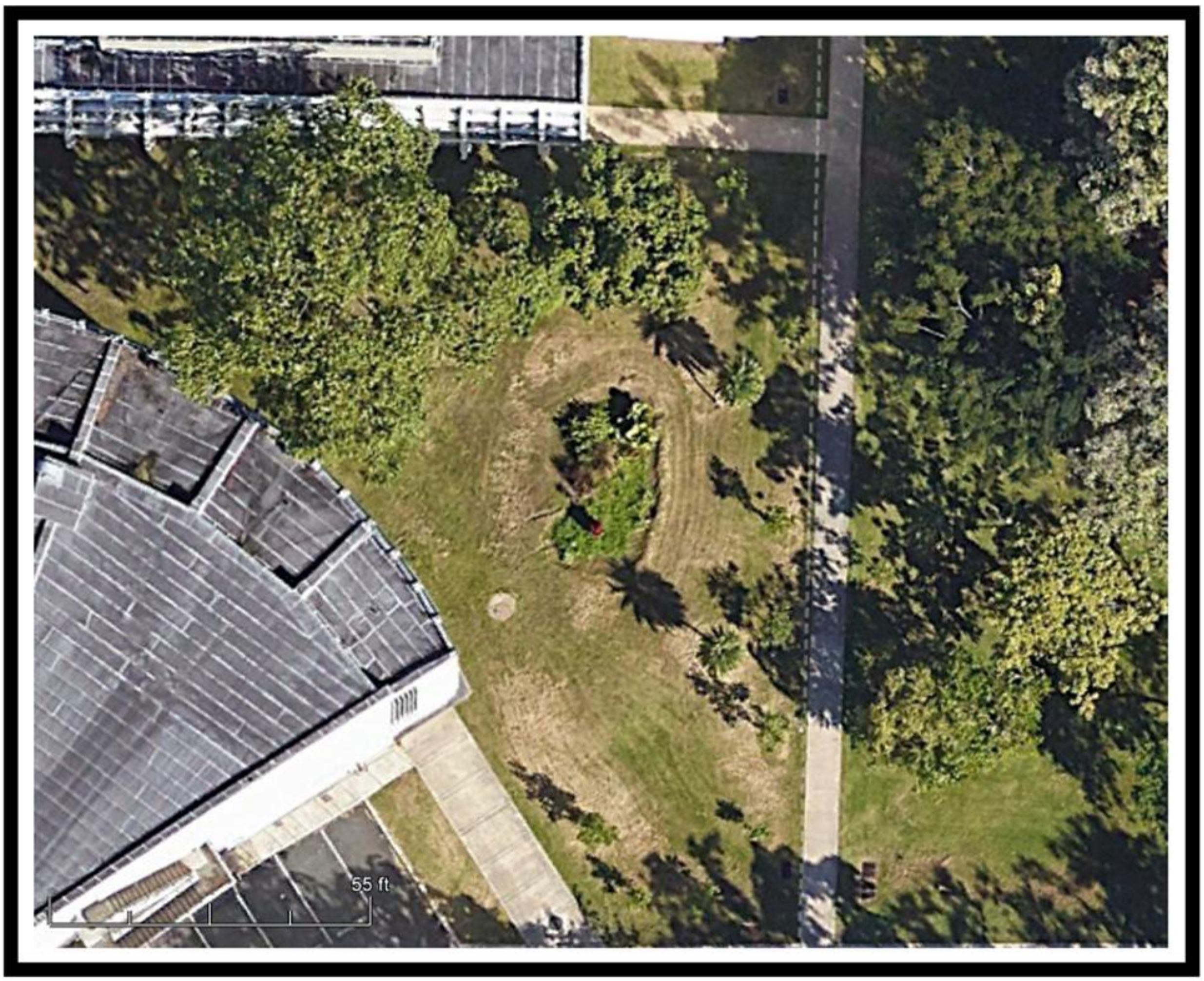
Emilia sonchifolia. It also contained species such as Cymbopogon ambiguus (the most dominant) and Kalanchoes x hoightonii (one of the originally planted species) (Grullón et al., 2020). At one point, there was interest in constructing another green roof above the Natural Sciences Faculty Library. However, complications due to structural requirements dissipated this interest and the idea was abandoned. The Figure below shows an image of the green roof above the Social Sciences faculty building. Although some vegetation can be appreciated, it is clear that the structure is in need of maintenance to restore functionality.

Figure 1. Satellite Image of the Green Roof Above the Social Sciences Faculty Building



The idea for the rain garden was born as part of the Conservation Course (CIBI-3007), in which students at the UPRRP Campus were tasked with establishing a project within the campus with the objective of helping the environment by promoting natural resource conservation. With the assistance of the USDA Natural Resources Conservation Service (NRCS) Caguas Field Office, the students decided on a rain garden, worked with the planning process, project proposal, coordination, and volunteered to assist with rain garden installation (NRCS, 2014). The UPRRP provided all of the construction materials, heavy equipment, permits and laborers for the construction of the rain garden. Agronomist Edwin Más, NRCS Plant Materials Specialist, provided the class with recommendations on the plants to be used in the rain garden, and reviewed UPR's proposed planting plan (NRCS, 2014). The Figure below shows a satellite image of the rain garden located next to the General Studies Faculty building. Much like the green roof above the Social Sciences faculty building, this project is also mostly overlooked.

Figure 2. Satellite Image of the Rain Garden Next to the General Studies Faculty Building



Constructed Wetlands

As mentioned above on Table 1, constructed wetlands are man-made vegetated water management systems that are designed to simulate the ecosystems of natural wetlands by using dense vegetation and other mechanisms to treat wastewater and provide simple and effective wastewater treatment. They help to treat and remove pollutants from stormwater before it enters our creeks, rivers, and oceans (Melbourne Water 2018).

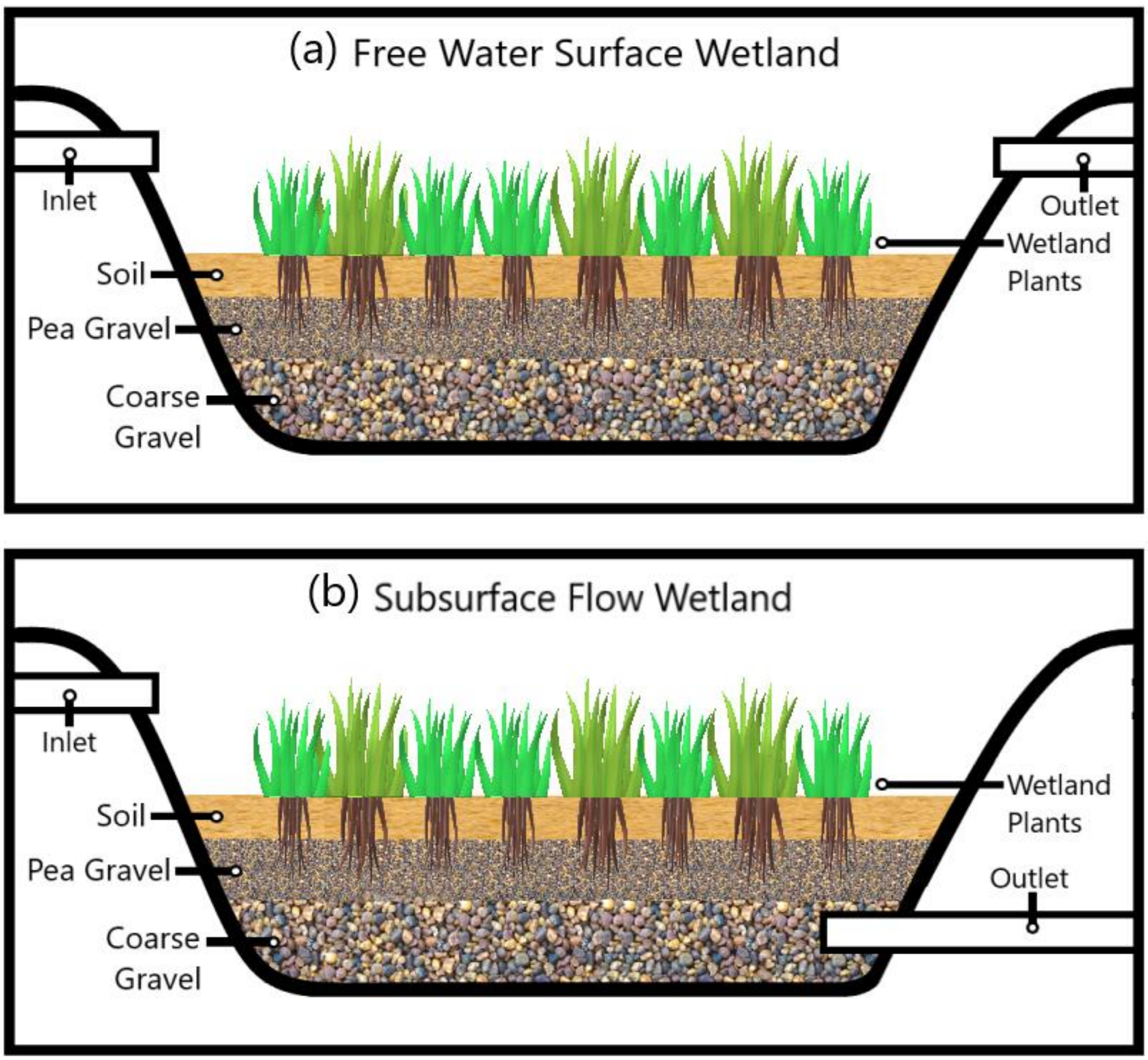
Although they vary greatly in shape and size, they usually consist of a shallow depression in the ground with a level bottom. The flow of water is controlled and allows natural processes to occur, cleaning wastewater more efficiently and spreading water evenly among the wetland plants. They can be used to treat most types of wastewaters including domestic, agricultural, industrial, and mining wastewaters (NSFC, 2004). Constructed wetlands are esthetically pleasing, attract wildlife, and provide environmental education opportunities. Their construction costs, operating costs, and maintenance costs are much less than conventional systems, often 50% to 90% lower (NSFC, 2004).

In a constructed wetland wastewater can either flow on the surface of the existing soil or through the subsurface consisting of a porous medium such as gravel. The flow of water is meant to be distributed evenly across the width of the wetland and often a waterproof liner is used on the sides and bottom of the cell to prevent leaks and provide adequate water for the wetland plants. Water level control is important for maintaining an efficient wetland in both surface and subsurface systems. In subsurface systems, the average water level is kept 1 inch below a gravel surface which improves treatment and controls mosquitoes (National Small Flows Clearinghouse, 2004). Chemical, biological, and physical processes to treat wastewater take place in the roots and stems of the plants. Such processes include the suspension of solids and settling of trace metals which are then filtered. As wastewaters flow through the system plants and organic material also absorb trace metals. Organisms that live in the wetland use these organic materials and nutrients as food and plant roots keep the rocks or soil loose so that water can flow through easily.

Constructed wetlands treatment systems based on flow format typically fall into two categories: Free Water Surface Wetlands (FWS) and Subsurface Flow Wetlands (SSF). Figure 3 shows how these types of constructed wetlands could be organized. The FWS wetland is also known as surface flow wetland. These wetlands usually consist of a basin or channels with a surface barrier of some kind to prevent seepage. They require soil suitable to support emergent wetland vegetation and water at a shallow depth flowing through the system. FWS wetlands look much like natural marshes and can provide wildlife habitat and aesthetic benefits as well as water treatment (Shutes et al., 2002). Near the surface layer conditions are aerobic and the deeper waters and substrate are usually anaerobic. The capital and operating costs of FWS wetlands are low, and their construction, operation, and maintenance are straightforward. However, FWS systems generally require a larger land area than other systems.

Stormwater wetlands are constructed wetland systems designed specifically to treat stormwater runoff. The main goal of most stormwater wetlands is to maximize the removal of pollutants from stormwater runoff through wetland vegetation uptake, retention, and settling. In addition to treating stormwater, these systems play in important role in managing stormwater runoff rate control and flood prevention. Constructed stormwater wetlands temporarily store runoff in shallow vegetated pools that are responsible for treating the water and slowly redirecting it towards the receiving water body (natural or man-made). Like other stormwater BMPs, constructed stormwater wetlands may not be located within natural wetland. According to the Massachusetts Storm Water Handbook, there are five basic types of constructed stormwater wetlands: *Shallow Marsh Systems, Basin Wetland Systems* (or Pond Wetland System), *Extended Detention Wetlands, Pocket Wetlands*, and *Gravel Wetlands.*

Figure 3. Types of Constructed Wetlands Based on Flow
(a) Free Water Surface Wetland (FWS) and (b) Subsurface Flow Wetland (SSF).



(Not Drawn to Scale)

Shallow marsh systems are usually made up of various pools 6 to 18 inches deep arranged into low and high marsh levels referred to as cells. Shallow marsh systems are designed with winding pathways to increase retention time and contact area. They require larger contributing drainage areas than other systems and therefore may not be compatible with smaller system needs. Runoff volumes are stored within the marshes, not in deeper pools where flow may be controlled over longer periods of time. On the other hand, basin wetland systems or pond wetland systems are multiple cell systems that use at least one wet basin in combination with a shallow marsh component. The first cell of this system is typically a sediment forebay that empties into a wet basin. The forebay removes particulate pollutants and reduces the velocity of the runoff entering the system. The stormwater then travels into a plunge pool that dissipates the energy of the flow. Basin wetland systems require less space than the shallow marsh systems and achieve a higher pollutant removal rate than other stormwater wetland systems.

Extended detention wetland systems provide greater temporary vertical storage, allowing these systems to require less space than shallow marsh systems while providing extra runoff detention. Water levels in these wetlands vary widely, increasing by as much as a few feet after a storm. Though water levels may increase rapidly due to storm conditions, within 24 hours they gradually return to normal. Wetlands plants selected for extended detention systems should be those best suited to tolerate dry periods followed by intermittent flooding. On the other hand, pocket wetland systems are best suited for smaller drainage areas one to ten acres. Excavating to the groundwater table is recommended to maintain adequate water levels. Pocket wetlands that are supported exclusively by stormwater runoff have difficulty maintaining marsh vegetation during dry periods. Therefore, wetland plants that tolerate dry periods are recommended. Lastly, gravel wetland systems typically consist of a sediment forebay followed by a series of treatment cells with a horizontal flow.

Stormwater Wetland Vegetation

The larger aquatic plants growing in wetlands are usually known as macrophytes, these include aquatic vascular plants (angiosperms and ferns), aquatic mosses, and some larger algae that have tissues that are easily visible (Brix, 2003). As a result of the ample light, water and nutrient supply in wetlands, the primary productivity of ecosystems dominated by wetland plants are among the highest recorded in the world (Wetzel, 2001). The presence or absence of aquatic macrophytes is one of the characteristics used to define wetlands. Although the most important removal processes in constructed wetlands are based on physical and microbial processes, macrophytes possess several functions in relation to the water treatment and are an indispensable component of wetland ecosystems (Brix, 2003). The macrophytes growing in wetlands may be classified according to their life form in the following groups (Wetzel, 2001):

1. *Emergent aquatic macrophytes* - These life forms are dominant in wetlands and marshes, growing within a water table range from 50 cm below the soil surface to

a 150 cm water depth. They generally produce aerial stems and leaves as well as large internal air spaces for transportation of oxygen and an extensive root and rhizome-system making them morphologically adapted to growing in a water-logged or submersed substrate. Among these life forms are found species like Phragmites australis (Common Reed), Glyceria spp. (Mannagrasses), Eleocharis spp. (Spikerushes), Typha spp. (Cattails), Scirpus spp. (Bulrushes), Iris spp. (Blue and Yellow Flags), and Zizania aquatica (Wild Rice).

2. *Floating-leaved aquatic macrophytes* - These macrophytes include species that are rooted in the substrate as well as species which are freely floating on the water surface. The freely floating species possess a wide range of both form and habit. They include large plants with aerial or floating leaves and complete submerged roots systems, as well as smaller surface-floating plants with few or no roots.

3. *Submerged aquatic macrophytes* - These macrophytes have their photosynthetic tissue submerged entirely below the water surface but their flowers are usually exposed to the atmosphere. Two types of submerged aquatics are usually recognised: the elodeid type and the isoetid (rosette) type.

Macrophytes growing in constructed treatment wetlands are home to several treatment processes, making them an essential component of the wetland design. The most important effects macrophytes have over wastewater treatment processes include physical processes such as erosion control, filtration effect, and providing surface area for microorganisms (Brix, 2003). The metabolism of macrophyte species may affects the treatment processes to differently depending on design. Table 2 provides a summary of macrophytes properties and their roles in treatment processes within constructed treatment wetlands. The presence of vegetation provides effective erosion control in stormwater wetlands by distributing and reducing the current velocities of the water (Pettecrew and Kalff, 1992). This in turn creates better conditions for sedimentation of suspended solids and reduces the risk of re-suspension. In vertical flow systems the presence of macrophytes, together with an intermittent loading regime, helps to prevent clogging of the medium (Bahlo and Wach, 1990).

Table 2. Summary of the major roles of macrophytes in constructed treatment wetlands

Macrophyte property	Role in treatment process
Aerial plant tissue	• Light attenuation → reduced growth of phytoplankton • Influence on microclimate → insulation during winter • Reduced wind velocity → reduced risk of resuspension • Aesthetic pleasing appearance of system • Storage of nutrients

Plant tissue in water	• Filtering effect → filter out large debris • Reduce current velocity → increase rate of sedimentation, reduces risk of resuspension • Provide surface area for attached biofilms • Excretion of photosynthetic oxygen → increases aerobic degradation • Uptake of nutrients
Roots and rhizomes in the sediment	• Stabilising the sediment surface → less erosion • Prevents the medium from clogging in vertical flow systems • Release of oxygen increase degradation (and nitrification) • Uptake of nutrients • Release of antibiotics

(Source: Brix, 1997)

The vegetation cover in a wetland can be regarded as a thick biofilm located between the atmosphere and the wetland soil or water surface in which significant gradients in different environmental parameters occur (Wetzel, 2001). Wind velocities are reduced near the soil or water surface, which reduces re-suspension of settled material and as a result improves the removal of suspended solids in water. Constructed wetlands with subsurface horizontal water flow possess channels created by the living and dead roots, rhizomes, and soil pores through which water travels. As the roots and rhizomes grow, they loosen the soil and create these channels. When these roots and rhizomes die and decay, they may leave behind tubular pores or macropores, which are thought by some to increase and stabilise the hydraulic conductivity of the soil (Brix, 1994). The structure of the macropore system is largely dependent on the plant species and can be very effective in channelling water through a soil bed (Beven and Germann, 1982). However, estimating the hydraulic conductivity of a constructed wetlands with subsurface flow should not be based on the assumption that conductivity will increase as a consequence of root and rhizome growth.

Successfully establishing and maintaining wetland vegetation is important when constructing a stormwater wetland. The Massachusetts Storm Water Handbook recommends the following considerations when selecting wetland vegetation for constructed stormwater wetlands:

- When selecting plants for wetland vegetation, consider the chances for success over pollutant removal capabilities and plant species growing in nearby natural wetlands. The most versatile genera for pollutant removal are *Carex, Scirpus, Juncus,* and *Lemna*.
- It is recommended you select native plant species and avoid those that are considered invasive. diversification within the stormwater wetland will occur naturally therefore, use a minimum number of species adaptable to the various elevation zones.

- Priority should be given to perennial species that establish themselves rapidly, as well as plant species that have already been used successfully in constructed stormwater wetlands, and that are commercially available.
- The species you select should be adaptable to a broad range of depths of water, frequency inundation, and duration of inundation.
- It is important to match the site conditions to the requirements of wetland plant selections.
- Different species have different levels of shade tolerance, therefore, consider the light conditions the wetland vegetation will be subjected to.
- Plants develop best when soils are enriched with plant roots and rhizomes, therefore establishing woody species after herbaceous species increases the likelihood of success.
- Consider adding vegetation that will achieve objectives other than pollution control. Plants that promote water infiltration into soils and plants that are aesthetically pleasing in combination with plants that provide pollutant control give an added value to the constructed wetland.

For higher chances of establishing the wetland vegetation it is recommended you use a mixture of wetlands mulch and wetland soils to enhance the diversity of the plant community. Wetland plants and soils are commercially available through wetland plant nurseries. Table 3 provides a list of recommended emergent plant species for constructed wetlands.

Table 3. Recommended Emergent Plant Species for Constructed Wetlands

Recommended Species	Image	Species Characteristics	Maximum Water Depth
Arrow arum *Peltandra virginica*	 (Image Source: Chesapeake Bay Program)	This species prefers light conditions from full sun to partial shade. They provide high wildlife value and are slow growers.	12 inches
Arrowhead/duck potato *Saggitaria latifolia*	 (Image Source: The Lady Bird Johnson Wildflower Center)	These plants are aggressive colonizers. Loses much water through transpiration.	12 inches

Common three-square bulrush *Scirpus pungens*	 (Image Source: www.illinoiswildflowers.info/grasses/plants)	This species is a fast colonizer, can tolerate periods of dryness, and provides high metal removal.	6 inches
Softstem bulrush *Scirpus validus*	 (Image Source: USDA Fire Effects Information System)	This species is an aggressive colonizer, tolerates full sun, and has high pollutant removal abilities. Provides food/cover for many species.	12 inches
Blue flag iris *Iris versicolor*	 (Image Source: The Lady Bird Johnson Wildflower Center)	This plant produces attractive flowers, can tolerate partial shade, but requires full sun to flower. They prefer acidic soil and tolerate high nutrient levels.	3 - 6 inches
Broad-leaved cattail *Typha latifolia*	 (Image Source: The Lady Bird Johnson Wildflower Center)	This species is an aggressive colonizer. They are capable of high pollutant treatment.	12-18 inches
Narrow-leaved cattail *Typha angustifolio*	 (Image Source: https://plants.ces.ncsu.edu/plants/)	This plant is an aggressive colonizer and tolerates brackish water.	12 inches
Reed canary grass *Phalaris arundinocea*	 (Image Source: Minnesota Department of Natural Resources)	This species grows on exposed areas and in shallow water. Good ground cover for berms.	6 inches
Lizard's tail *Saururus cernuus*	 (Image Source: The Lady Bird Johnson Wildflower Center)	These plants are rapid growers, shade tolerant, but provide low wildlife value.	6 inches

Pickerelweed *Pontedaria cordata*	 (Image Source: The Lady Bird Johnson Wildflower Center)	This plant tolerates full sun to partial shade. They provide moderate wildlife value, most notably nectar for butterflies.	12 inches
Common reed *Phragmites australis*	 (Image Source: USDA National Invasive Species Information Center)	This species is highly invasive; considered a pest species in many states. They add poor wildlife value.	3 inches
Soft rush Juncus effusus	 (Image Source: The Lady Bird Johnson Wildflower Center)	These plants tolerate wet or dry conditions, provide food for birds, and often grows in tussocks or hummocks.	3 inches
Spikerush Eleocharis palustris	 (Image Source: www.wetland-plants.co.uk/shop/british-native/)	This species is known for tolerating partial shade.	3 inches
Sedges Carex spp.	 (Image Source: www.plantdelights.com/collections/sedge-carex-grass)	These plants are made up of several wetland and upland species. High wildlife value for waterfowl and songbirds.	3 inches
Spatterdock Nuphar luteum	 (Image Source: The Lady Bird Johnson Wildflower Center)	These species are tolerant of fluctuating water levels. Moderate food value for wildlife, high cover value.	5 ft 2 ft minimum
Sweet flag Acorus calamus	 (Image Source: www.missouribotanicalgarden.org/PlantFinder/)	These plants produce attractive flowers. They are not rapid colonizers and tolerate acidic conditions, dry periods, and partial shade. Low wildlife value.	3 inches

Wild rice Zizania aquatica	 (Image Source: Lady Bird Johnson Wildflower Center)	Requires full sun and has high wildlife value. Annual, nonpersistent. Does not reproduce vegetatively.	12 inches

(Source of Data: Brix, 2003)

UPRRP Regulatory Background, Legal Authority, and Enforcement

Compared to a municipality, the UPRRP does not maintain a city code to regulate storm water discharges therefore it bears a close resemblance to a private industry. However, the UPRRP storm water system is equipped with infrastructure and management practices representative of similar systems owned by municipalities. The UPRRP operates and maintains a separate storm water system responsible for collecting storm water runoff from areas involved in a variety of mixed uses including student housing, institutional/research activities, science laboratories, and recreational facilities.

The UPRRP has the authority to implement storm water management programs on the campus as well as control, regulate, and enforce any discharges to the storm water system thanks to Puerto Rico Article Num. 1 of Commonwealth of Puerto Rico Law Num. 1 of 1966. The UPR has a Board of Trustees in charge of general supervision of its institution and the control and direction of all expenditures from the institution's funds. Article 3(g) (1) of the Law allows the Board of Trustees of the UPRRP to have general supervision of its institution and the control and direction of all expenditures and therefore has the power to promulgate policies for the operation, management, and maintenance of the storm water system. This includes the power to control illicit discharges, spills, and dumping.

The UPR releases documents describing the Storm Water Management Program for each individual campus. These comprehensive Stormwater Management Program documents identified a variety of goals and projects related to campus systems, administrative systems, earth systems, education, and engagement that enhance the University’s commitment to maintaining the campus. Each Storm Water Management Program is prepared taking under consideration requirements set by the United States Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) General Permit Number PRRO4000F for Discharges from small Municipal Separate Storm Sewer (MS4).

In 1990 the EPA announced guidelines establishing Phase I of the National Pollutant Discharge Elimination System Stormwater Program. The Phase I program established stormwater management requirements for medium and large operators of municipal separate storm sewer systems. These systems generally serve populations of 100,000 or greater. The Storm Water Phase II guideline extended coverage of the NPDES storm water program to certain "small" MS4s. However, the program took a slightly different approach to how the storm water management program will be developed and implemented for the small MS4s. The NPDES General Permit for Discharges from Small Municipal Separate Storm Sewers Systems Permit No. is PRR040013.

This study will focus on the UPRRP, its resources, and surrounding areas. The UPRRP operates a small MS4 system which is located within the San Juan urbanized area as defined by the EPA. The Phase II Rule defines a small MS4 Stormwater Management Program as a program comprising six elements that, when properly implemented, are expected to result in significant reductions of potential pollutants discharged into receiving water bodies. The EPA granted coverage under the general permit to the UPRRP campus and in accordance with Part 2.0 section 2.1.1 of the General Permit the Stormwater Management Program addresses the six program components described in the permit as minimum control measures through the development of:

- Public education and outreach program on stormwater impacts
- Public involvement/participation program
- Illicit discharge detection and elimination program
- Construction site stormwater runoff control program
- Post-construction Stormwater Management Program for new developments and redevelopment
- Pollution prevention and good housekeeping program

In addition to the campus Stormwater Management Program goals there exists a desire to move the university beyond traditional NPDES permit compliance standards and push toward more proactive and environmentally responsible management. One aspect of the University's focus on reducing its environmental impact is to reduce the impact of stormwater runoff from the campus and the UPR's properties. This study proposes a university-wide stormwater discharge reduction goal through the incorporation of green infrastructure, specifically stormwater wetlands, into the UPRRP campus Stormwater Management Program to mitigate excess stormwater runoff. For such a goal to be accomplished a series of campus stormwater runoff assessments of must be done by characterizing watershed surface conditions and features that lead to flow characteristics (such as pavement, rooftop, grass, garden, etc.).

As a result of the inclusion of stormwater wetlands and rain gardens in the University's Stormwater Management Plan there should be an increase in stormwater retention time thereby decreasing the likelihood of excess stormwater runoff accumulating, causing flooding, and all that entails. Such management practices may serve as the first step toward a campus that comprehensively manages stormwater using green infrastructure. Specifically included in this definition are both engineered vegetated landscape systems that temporarily store, treat, and/or infiltrate stormwater into the ground as well as more structural techniques. The Stormwater Management Program presents a central vision for campus design and operations but allows room for the integration of strategies that position the university to address proactively growing environmental and public health issues.

UPRRP Illicit Discharge Detection and Elimination Program

The UPRRP has an ongoing program dedicated to the identification, correction, or removal of illicit discharges. The Illicit Discharge Detection and Elimination Program described is used to determine the existence, location, and extent of possible illicit connections and discharges to the stormwater drainage system. The UPRRP and OPASO encourage the public to report any water quality problems or possible illicit connections and discharges to the stormwater system. The identification of illicit discharges come from either public reports or from OPASO staff members identifying problems during routine activities around the University. OPASO is responsible for receiving reports of water quality problems or illicit connections, perform follow-up investigations, and take action to remedy the issue where appropriate. This system is vital for the health and performance of the constructed stormwater wetland system proposed in this study. Although constructed wetlands have the potential to treat waste waters, they do not have the same capabilities as traditional treatment plants. Introducing harsh chemicals could heavily impact the vegetation within the wetland, affecting their ability to filter runoff and uptake pollutants. Plant mortality may result from illicit discharges which may ultimately find their way into other systems like that of the Juan Mendez Creek if the wetland exceeds its storage capacity and must discharge into the storm sewer system. If illicit discharges find their way into the constructed wetlands and become contained within the system, the University may take steps to restore the health of the system.

Correcting an illicit discharge usually involves modifying an unwanted behavior. In the case an individual or unit responsible for an illicit discharge is identified, the activities of said individual or unit are reviewed to determine the appropriate disposal method to use. The discharge is also reviewed to determine the appropriate reporting requirements under environmental regulations. The individual or unit is directed to stop discharging and change operations to an appropriate disposal method. OPASO responds to the area for cleanup and determines if the discharge can be removed from the system, sometimes employing and outside contractor with vacuum truck capabilities to remove the material. OPASO then performs appropriate follow-up with the supervisor of the individual or unit to ensure future discharges do not occur and a review of similar operations that could have similar implications is performed. If appropriate, education efforts are made with individuals or units associated with the similar activities to ensure no future illicit discharges take place.

Constructed Wetland Dry Weather Screening

The purpose of dry weather field screening within the UPRRP is to determine the existence, location, and extent of possible illicit discharges into the stormwater drainage system. According to the UPRRP Stormwater Management Program, the screening program was designed to target points within the stormwater system that help identify non-stormwater flow. To this program may be added dry weather screening of the constructed stormwater wetland systems being proposed here. These wetlands may be expected to undergo periods of dry weather that may extend beyond the tolerance limits of the vegetation within the systems. Therefore, dry weather screening may be crucial to maintaining wetland health and functionality beyond these dry periods. In the case of extended periods of dry weather or droughts vegetation within the wetlands may die out and require replacing. The procedure for dry weather screening is updated periodically, and the most current copy is always available for review in the OPASO office.

UPRRP Retention of Records and Management Requirements

As part of the Stormwater Management Program, the UPRRP maintains records of all monitoring information, namely a description of the program required by the General Permit. All calibration and maintenance records, original recordings for continuous monitoring instrumentation, copies of Discharge Monitoring, copies of the NPDES permit, and all the data used to complete the application of permits are stored for a period of at least three years. These records are retained in files by OPASO. The UPRRP must be able to submit their records to the EPA when asked to do so. They must also make them available to the public if requested to do so in writing. The UPRRP is required to notify the EPA Caribbean Division of any planned changes as well as any activity which may result in noncompliance with the General Permit. Meaning that any plans to build constructed stormwater wetlands must be recorded by OPASO and notify the EPA Caribbean Division.

The management requirements include proper operation and maintenance of the stormwater management system, provide containment facilities, recording results, reporting additional results, minimizing adverse impacts, and proper handling and disposal of removed substances. The UPRRP must do an annual review of the Stormwater Management Program along with the preparations for the annual report. The Stormwater Management Program may be changed during the life of the permit provided the following conditions are met:

- Adding components, controls, or requirements to the Stormwater Management Program is allowed after notifying the proper authorities. Changes meant to subtract or replace any existing components are not permitted.

- Replacing an ineffective BMP in the Stormwater Management Program with an alternate BMP may be requested at any time. The changes shall be deemed approved unless specifically denied by the EPA.

The EPA may require the UPRRP to modify the Storm Water Management Program to address any impacts on receiving water quality caused by discharges from the storm sewer. They may also include stricter requirements in order to comply with any new state or federal statutory or regulatory requirements deemed necessary to comply with the goals of the Federal Clean Water Act.

Storm Water Management Program Resources in the UPRRP

The management, maintenance, and operation of the stormwater system in the UPRRP is performed by several UPRRP departments. The Chancellor's Office and Facilities Management Department oversee all the primary responsibilities. Meanwhile, the Environmental Protection and Safety Office (OPASO) is the unit responsible for day-to-day management of environmental issues, compliance with environmental regulations, and interaction with regulatory agencies. OPASO is responsible for the development and oversight of the Stormwater Management Program and interacts with all other UPRRP departments ensuring that the requirements of the permit are met. The OPASO office also maintains trained personnel to address and handle hazardous material responses and clean-ups, routine management of hazardous materials, and disposal of hazardous materials. OPASO is open to public comments, complaints, or other information regarding stormwater runoff leading into the stormwater drainage system. All calls are investigated, and any corrective actions or notifications are handled by OPASO.

Public Education, Outreach, and Stormwater Education in the UPRRP

The UPRRP already recognizes the need for public involvement in the effort to reduce stormwater pollutants and has developed a stormwater education and outreach program. This program is connected to the UPRRP's pollution prevention BMPs and initiatives. The stormwater education curriculum is designed to promote, publicize, and facilitate watershed education while encouraging the BMP practices developed under the university's stewardship. All persons associated with the university who could potentially affect the quality of stormwater discharges are qualified to participate, including campus residents, University faculty, staff, students, visitors to the campus, contractors, vendors working on the campus, and commercial operations on campus. Below is a description of each of the program's components and accomplishments:

- Educate the public of hazards associated with illicit or improper discharges.
- Educate the public on the acceptable application and disposal of pesticides and fertilizers.
- Educate the public on discharge points and potential impacts of pollutants.

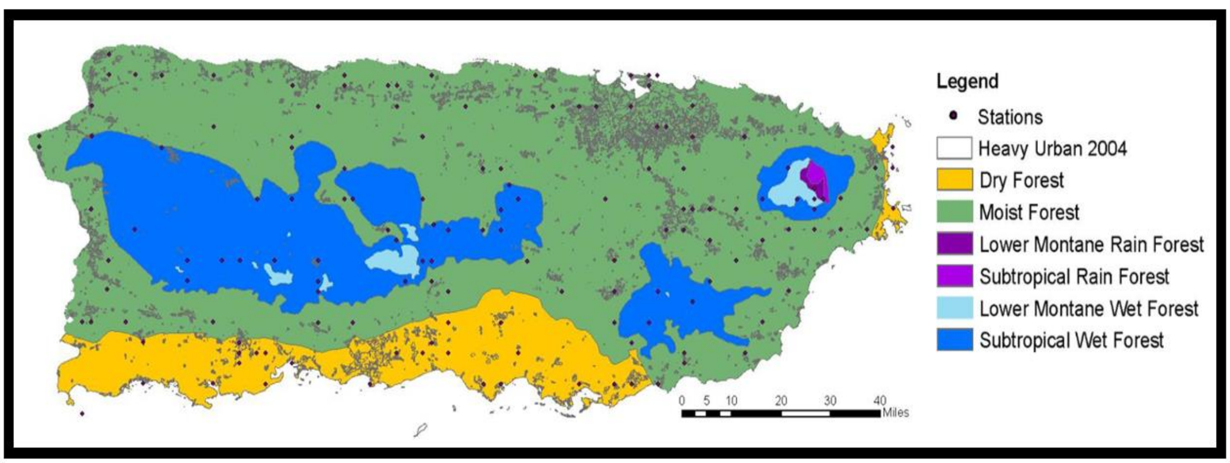
- Educate the public about their responsibilities and stewardship of their watershed.
- Educate commercial and institutional entities likely to have significant stormwater impacts.

STUDY SITE DESCRIPTION

Topography and Climate

Puerto Rico is the smallest archipelago of the Greater Antilles located in the eastern part of the Caribbean basin. Due to the conditions established by its climate and topography, Puerto Rico is considered one of the world's biodiversity hotspots. Puerto Rico is composed of one island 160 km long and 50 km wide surrounded by several smaller islands. The terrain in Puerto Rico is roughly 53% mountainous, 25% is plains, and 20% hills. Six distinctive Holdridge Ecological Lifezones are found in Puerto Rico (Torres-Valcárcel et al., 2014). These lifezones are defined by humidity, annual precipitation, and potential evapotranspiration. They range from Rain Forest (precipitation over 157 inches/year) to Dry Forest (precipitation below 35 inches/year). Figure 4 illustrates the Holdridge Ecological Lifezones (HELZ) distribution over a map of Puerto Rico. The UPRRP is locates within the Moist Forest lifezone along the northern coast.

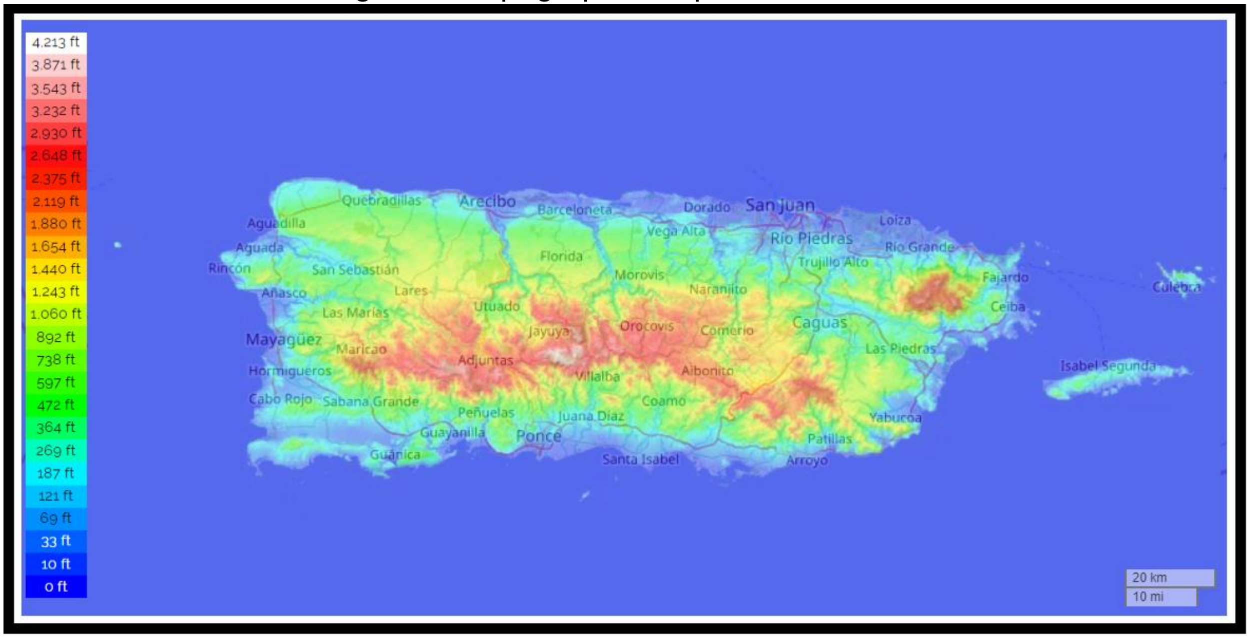
Figure 4. Holdridge Ecological Lifezones Distribution in Puerto Rico



(Source: Torres-Valcárcel et al., 2014)

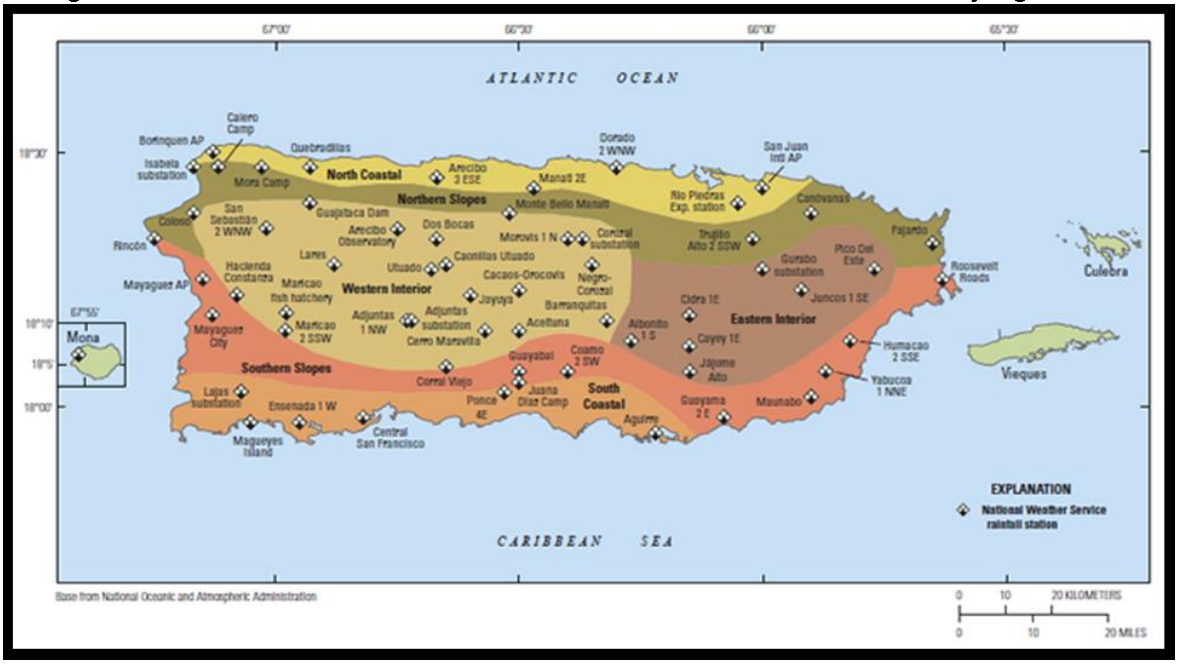
Puerto Rico is divided horizontally by the east-west trending Cordillera Central and Sierra de Cayey mountains. These mountain chains form an insular hydrologic divide that separates the island into two climatologically distinct regions consisting of the northern two-thirds of the island with a relatively humid climate and the southern one-third of the island which is semi-arid (Gomez-Gomez et al., 2014). Figure 5 provides a map illustrating the main topographic features of Puerto Rico more clearly, namely the mountain chains that clearly divide the island into northern and southern halves.

Figure 5. Topographic Map of Puerto Rico



The National Oceanic and Atmospheric Administration (1982) subdivided these climate regions even further into six climate areas and designated a seventh climate area in the outlying islands. Figure 6 identifies the seven climate areas around the island. These climate sub-divisions include the north coastal region, the northern slopes, the eastern interior, the western interior, the southern slopes, the south coastal region, and a seventh climate area in the outlying islands. The topographic relief in Puerto Rico and the effect of the prevailing trade winds heavily influence local climate within each subdivision and in the outlying islands. As a result of the combination of these two components, the distribution of precipitation throughout the islands varies greatly, resulting in the six different HELZ illustrated in Figure 4 and the climatic sub-divisions in Figure 6.

Figure 6. Climatic Subdivision Distribution of Puerto Rico and Outlying Islands

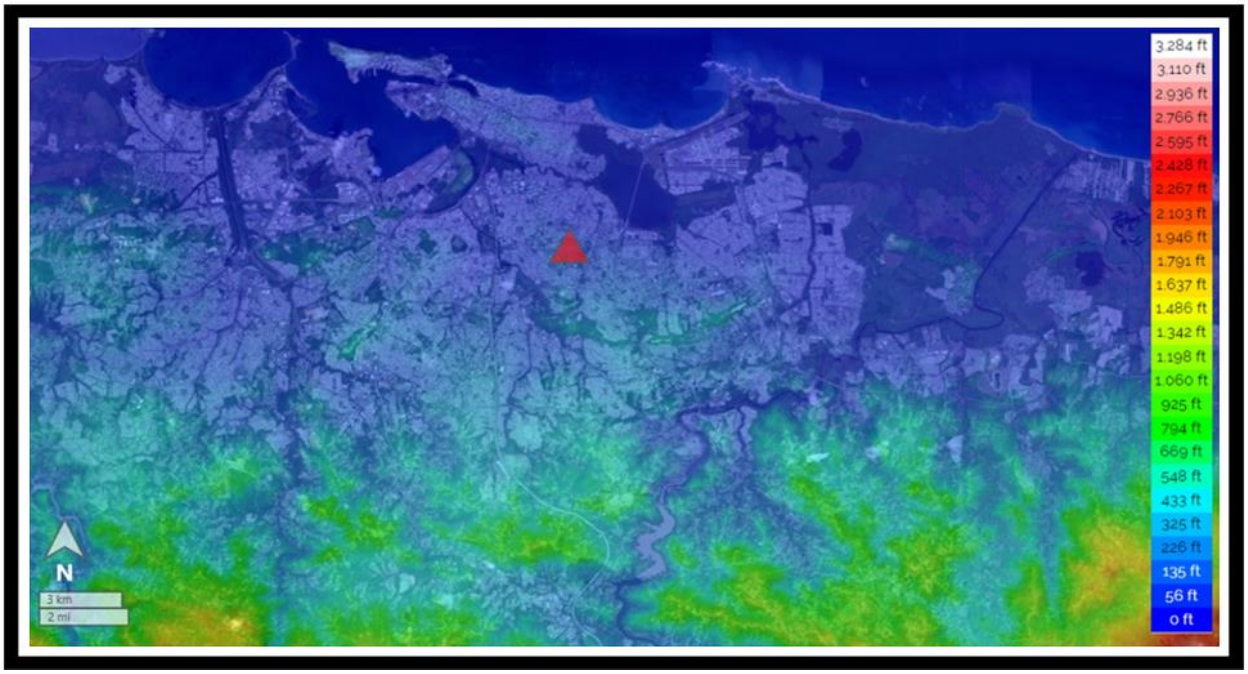


(Source: Gomez-Gomez et al., 2014)

Figure 7 presents a satellite image with color grading that illustrates topographic features of the north coastal San Juan Metropolitan Area where the UPRRP campus is located. The red triangle on the figure indicates the location of the UPRRP campus. In this figure the image is layered with a color gradient representing the changes in elevation. Specifically, the figure demonstrates changes of color from yellow to green to blue, representing a decline in elevation from south to north. Yellow represents the higher elevation and blue represents the lowest elevation. It can therefore be inferred that the flow of all natural water bodies and rainwater runoff generally flows towards from the south to the north.

The north coastal landscape in general possesses this decline in elevation towards the north. Due to this trend in topography all the rivers and rainwater runoff that fall in this climate region flow in this direction as well (with the exceptions caused by microtopographic variations throughout the landscape), emptying into the Atlantic Ocean. On the right side of Figure 7 is a legend consisting of a vertical bar of blocks of colors with numbers representing their respective elevations. The elevations represented by the color grading from yellow to blue present over the satellite image range roughly between 1600 to 0 feet above sea level. The UPRRP campus possesses elevations somewhere between 200 and 0 feet above sea level, according to the figure.

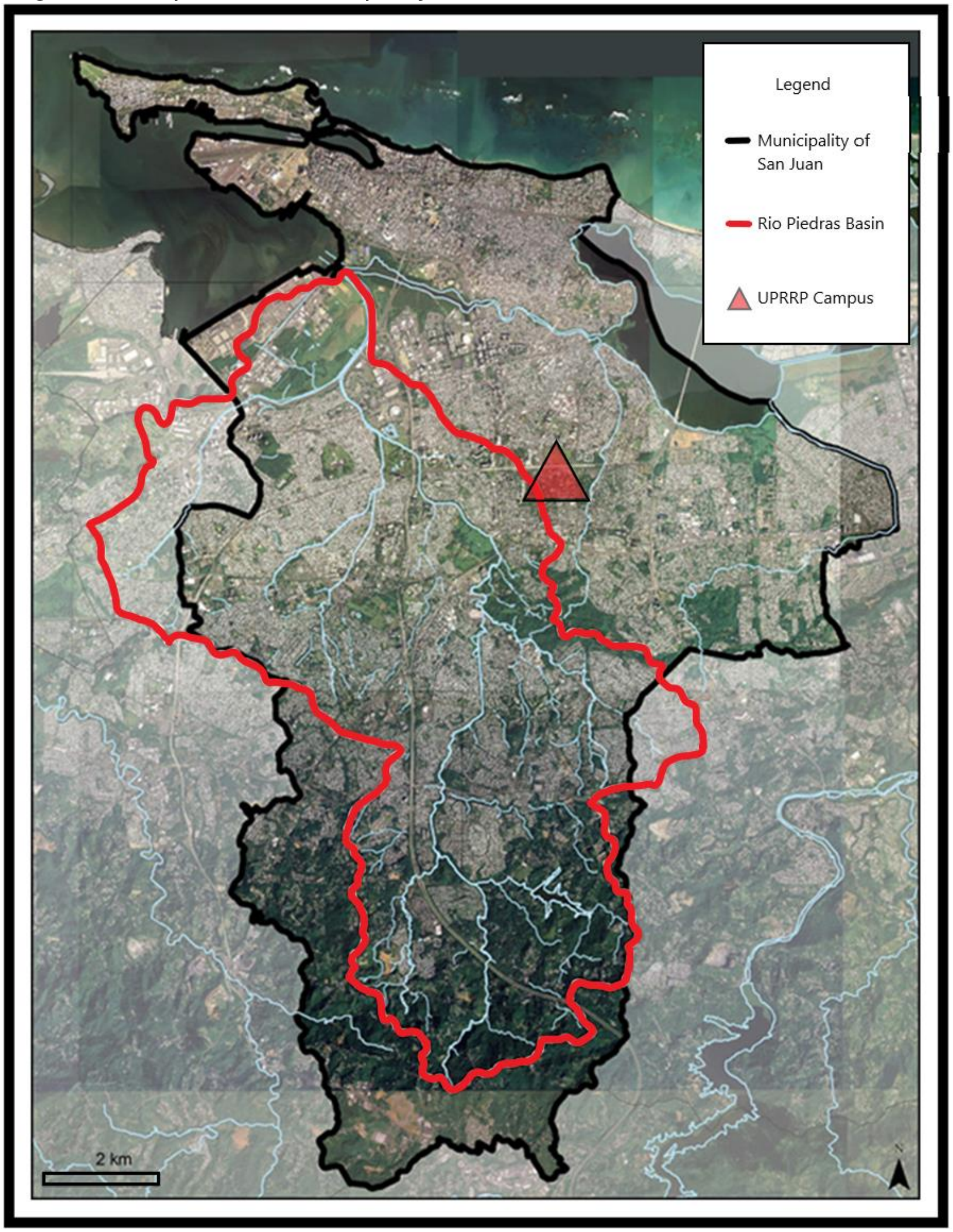
Figure 7. Topographic Satellite Image of the San Juan Metropolitan Area within the North Coastal Region



Río Piedras was once an independent municipality until it was incorporated into the municipality of San Juan and became a sector of the city. The UPRRP campus is in the municipality of San Juan in the North Coastal region as shown in Figure 8. The satellite image in this Figure shows the location of the UPRRP campus (red triangle), the limits of the Rio Piedras basin (white line), and the borders of the San Juan municipality (black line). This region along with the outlying islands are all exposed to prevailing trade winds from the northeast, meanwhile the wind patterns in the southern coast of Puerto Rico are affected by the east-west trending mountains. Prevailing winds along the western end of Puerto Rico are from the west, which is nearly opposite to the prevailing northeast trade winds (Gomez-Gomez et al., 2014). Prevailing west winds are infrequent in other areas of the island.

The National Oceanic and Atmospheric Administration (1982) found that the San Juan area receives west prevailing winds less than 3% of the time and they are generally associated with the passing of cold fronts across the island. Due to pronounced orographic effects from the Cordillera Central and the Sierra de Cayey mountains in Puerto Rico, high amounts of rainfall occur on the windward side of the mountains, north of the insular hydrologic divide (Gomez-Gomez et al., 2014). South of the divide the opposite occurs resulting in lower amounts of rainfall. This puts the UPRRP campus on the side receiving greater amounts of rain and therefore requires special attention to stormwater management.

Figure 8. Map of the Municipality of San Juan and the Rio Piedras Basin



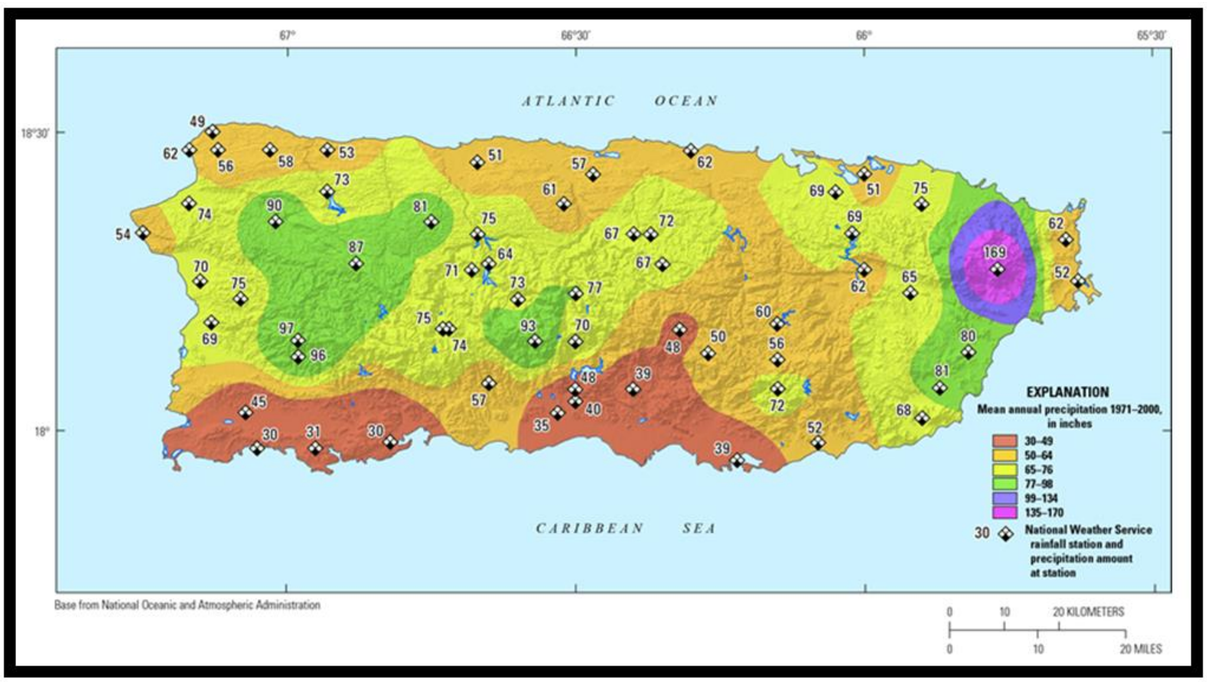
(Source: Muñoz-Erickson & Lugo)

Constant insolation and seawater temperatures cause air temperatures to fluctuate little throughout the year. The rate of solar radiation delivered to Puerto Rico is nearly constant because the number of hours of daylight varies little during the year (e.g., there is only a two-hour difference between the longest day of the year and the shortest day of the year) (Gomez-Gomez et al., 2014). On the other hand, the spatial distribution of rainfall in Puerto Rico is variable. Figure 9 shows the mean annual precipitation distributed throughout Puerto Rico.

According to Figure 9, the UPRRP receives a mean annual total rainfall of 69 inches of rain. Precipitation is greatest in the Sierra de Luquillo rainforest in the eastern part of Puerto Rico where the mean annual total rainfall is 169.0 inches per year. The least amount of rainfall occurs in the southwestern region of Puerto Rico where the mean annual total rainfall is 30.0 inches per year. Climate data has been very important to mapping potential vegetation or ecological zones, and such mapping has become more sophisticated or increased in spatial resolution recently (Daly et al., 2003). Puerto Rico is an especially complex Caribbean Island whose ecological zones change rapidly over small areas due to complex topography, climate, and soils (Beard, 1949).

Two climate mechanisms cause significant rainfall events producing substantial volumes of rain in Puerto Rico: (1) the passage of an easterly wave or (2) the passage of a cold front (Gomez-Gomez et al., 2014). Easterly waves occur from May to November causing tropical storms and hurricanes. From November to April cold fronts occur and can produce enough precipitation to cause flooding even during what is considered the dry season from December to April. May has a secondary wet period.

Figure 9. Distribution of Mean Annual Precipitation in Puerto Rico

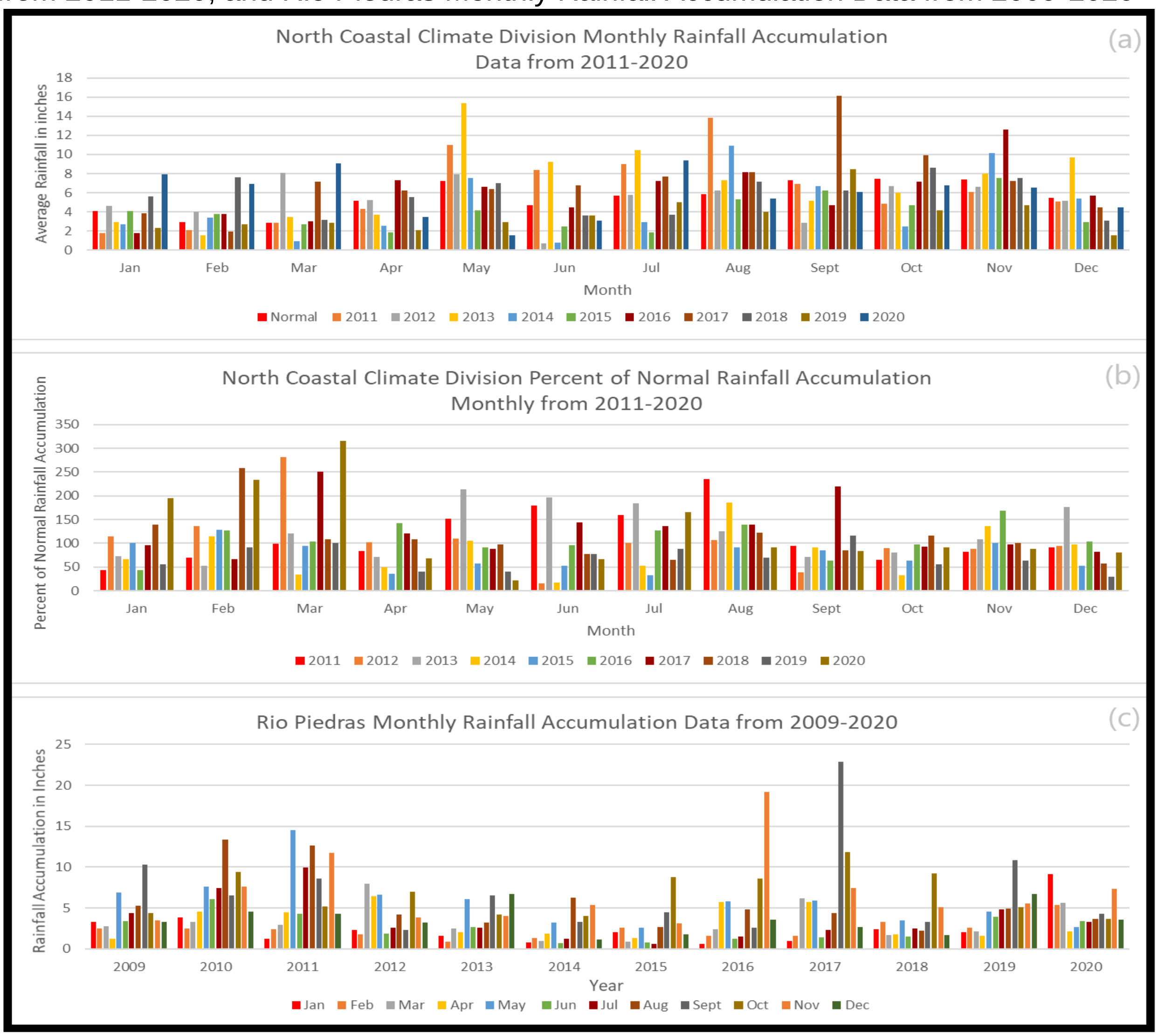


(Source: Gomez et al., 2014)

Figure 10 reflects these climate trends in the north coastal climate region through monthly rainfall data from 2011 to 2020. Rio Piedras is in Holdridge's subtropical moist forest life zone. In Figure 10c Rio Piedras monthly rainfall accumulation data from 2009-2020 reflects these trends as well. The mean annual rainfall in the Rio Piedras basin increases from the coast to the uplands. However, historical trends for the monthly precipitation in each HELZ in Puerto Rico has decreased. Studies suggest that although smaller precipitation periods or events have decreased, the frequency of larger precipitation periods or events have increased (Comarazamy et al., 2013).

Figure 10b presents the north coastal climate division percent of normal rainfall accumulation from 2011-2020. Here we see the number of times rainfall reached the normal values and how many times normal values were exceeded. Certain climatic events, like hurricanes, may be identified in this figure. Picó (1969) reports six hurricanes and tropical storms significantly affected Puerto Rico between 1893 and 1956. Several other hurricane events have affected the island since then, including hurricanes Hugo and Georges, which were considered the most severe in terms of wind effects and most recently hurricanes Irma and Maria devastated Puerto Rico in 2017.

Figure 10. North Coastal Climate Division Monthly Rainfall Accumulation Data from 2011-2020, North Coastal Climate Division Percent of Normal Rainfall Accumulation Monthly from 2011-2020, and Rio Piedras Monthly Rainfall Accumulation Data from 2009-2020



(Source of Data: The National Weather Service)

Despite the dominant decreasing trend in precipitation combined with an increase of heavy precipitation periods in recent years matches projections for the Caribbean Basin under climate change scenarios (Comarazamy et al., 2013). Although from the data analyzed the magnitude and intensity of precipitation events is not evident, periods of larger precipitation may occur by either low frequency of large precipitation events or high frequency of small precipitation events both yielding large amounts of total accumulations for a given period (months or years) (Torres-Valcárcel et al., 2014). Climate change projections for the Caribbean point at higher frequency of dry periods combined with a lower frequency of high precipitation periods (Comarazamy et al., 2013).

Flooding Areas and Storm Sewer Systems

Floods are the most common type of disaster and cause the most humanitarian need than any other natural disasters (Torres et al., 2018). Flash floods are often linked to urban heat island effects as a consequence of the increase of the impervious areas. Almost 90% of all-natural disasters in the United States lead to flooding and 20% of all flooding claims happen in low to moderate flood risk areas (Consumer Reports, 2018). This information is important when judging where to live. Home insurance doesn't cover anything that isn't attached to the house therefore, cars are often the most affected by flooding. Puerto Rico has an area of about 13800 km², of these 1488 km² are prone to flooding with a recurrence period of 100 years, making about 11% of the total area of Puerto Rico susceptible to major flooding (Torres et al., 2018).

Unfortunately, the worst flood disasters in Puerto Rico have not been due to major climatic events. Many of the events that have caused significant flood disasters hardly reach a recurrence period of 5 years. Unplanned growth, poor drainage, or deficient storm sewer systems within urban centers can cause people financial loses, such as people who lose vehicles due to flash floods in parking lots. On September 19, 2011, in a parking lot located in the western Puerto Rico area a precipitation of 110 minutes caused great damage to many vehicles and floods in a significant number of storehouses in Mayaguez city. During this brief event, it was thought that the precipitation had an average recurrence interval of 100 years, but rain gauges located in the area, display the event magnitude, where the maximum precipitation was of 2.65 inches. According to Hydrometeorological Design Studies Center NOAA's National Weather Service this precipitation behavior belongs to that of an event with an average recurrence interval of 5 years. This demonstrates a lack of planning when urban centers become so widespread, turning many rural areas into predominantly impervious surfaces, and rendering the drainages deficient.

The UPRRP is in a position to influence projects that affect the communities of San Juan and all of Puerto Rico. Stormwater management projects like the channelization of the Rio Piedras often cause controversy metaphorically flooding the media with supporters and opposers alike. In this case the affected communities demand other alternatives to address the flood problem and warn about the adverse effects that the project would have. Neighbors of the communities bordering the Rio Piedras, in San Juan, denounced a lack of transparency regarding the channelization project. To them channelizing that body of water implies the elimination of green areas around the riverbed, which would have the potential to aggravate flooding in the area and sedimentation downstream. Comments on the issue range from positive to negative and often reflect distrust toward the government's ability to manage the body of water and while keeping the community's best interest in mind. Some members believe channeling rivers should always be the last resort. Instead of channelizing the rivers and streams they believe urban planning that includes these bodies of water in its design is better for the community. Countries that do so achieve harmony with the natural resource and create beautiful urban centers.

Other members of the community question the competency of the government for using, what is in their opinion, outdated methods to channel rivers and increase the use of grey infrastructure as the go-to management practice. Many believe there should be more green areas that allow the water to drain slowly and would welcome projects that develop the Rio Piedras into a linear park to stroll along, as seen in other cities. Some members of the community go as far as calling the project to channel the Rio Piedras the most horrendous crime committed to nature in Puerto Rico. Although highly urbanized there are those who recognize that the Rio Piedras is a habitat for many species, some of which could be in danger of extinction as well as serving as a green lung for the metropolitan area.

Some members of the community believe that some people mistakenly believe the US Army Corps of Engineers is without faults. They understand that more economic options must be available, and that routine maintenance such as keeping the sewers free of garbage and perhaps some dredging the river are essential to stormwater management. The channelization of the Rio Piedras represents millions of dollars in contracts and many members of the public believe corruption could be at the heart of the Corps decision to channelize the river despite the community's objection. They believe the project should have the endorsement of the residents of the area who would be regularly affected by the consequences of the project. They comment that channelizing the Rio Piedras only creates a gutter for a fixed volume of water that aesthetically is quite ugly.

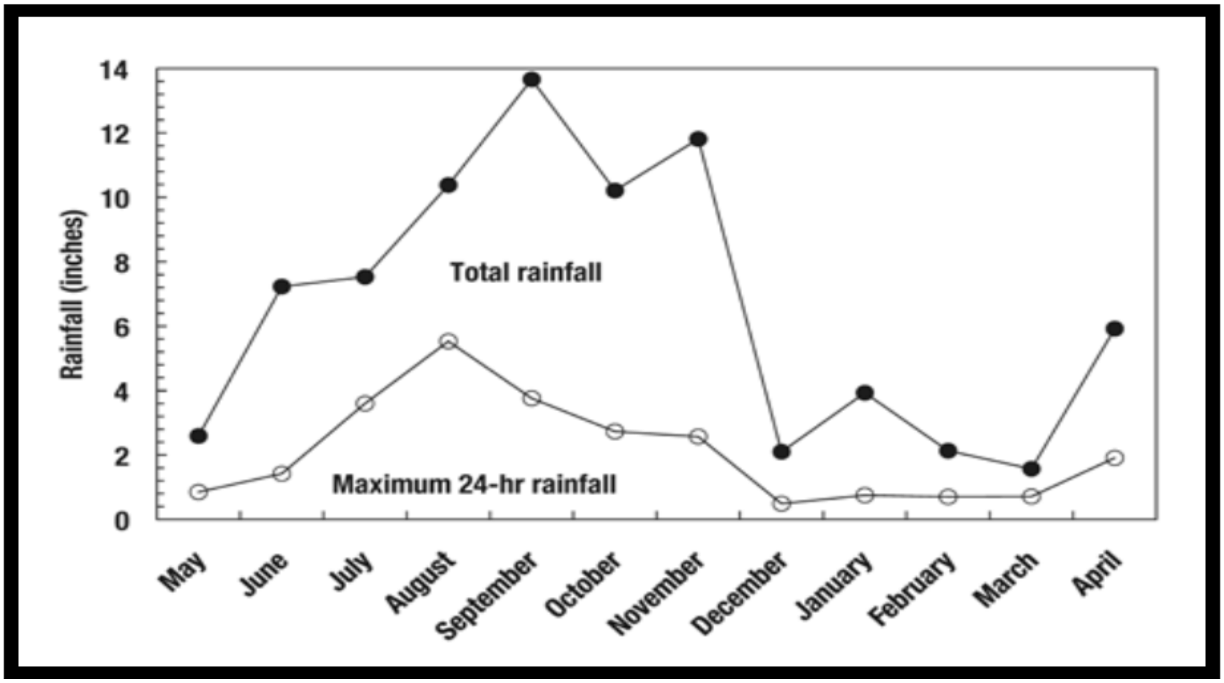
On the other hand, many members of the community are in full support of the project and place the blame on the affected residents, claiming they built in places that should not have been developed and nobody forced those people to live by the water. They believe the news sensationalizes the objections and the protests against this project. The members of the community that follow this line of thinking believe that because only a small group of people are in opposition the media goes out of its way to give the impression that no one agrees with the project. Some believe that no matter how beneficial the project is, there will always be ungrateful people in opposition, and that because the US Army Corps of Engineers oversees the project to channelize the Rio Piedras and that it's not financed by the community, there shouldn't be any complaints. The members of the community who protest these types of projects are often viewed as rebels without a cause, mockingly called environmentalists who protest for the sake of protesting.

In terms of community perception it's clear that there is ample distrust on both sides of the issue of stormwater management. In the case of the channelization of the Rio Piedras, the opposers distrust that further developing grey infrastructure to manage the river and the stormwater runoff will satisfy all the needs of the community. The supporters of this project don't believe that green infrastructure is effective for flood control. The truth is that a combination of both management practices is the best strategy for managing stormwater and protecting the quality of life the residents of these communities wish to maintain. The UPRRP can lead by example and present the community with alternative green infrastructure stormwater management practices.

The storm sewer is a system designed to carry rainfall runoff and other drainage, it does not carry sewage or hazardous wastes. Typically, runoff is carried in underground pipes or open ditches and discharges untreated into local streams, rivers, and other surface water bodies. The UPRRP storm sewer system follows this pattern. Storm drain inlets can be found along curbs, low-lying outdoor areas, and some buildings have basement floor drains that connect to a storm sewer system. The disposal of chemicals or hazardous substances into storm sewer systems are issues of great concern due to the damages they cause to the environment. Motor oil, cleaners, paints and other common items that get into storm drains can poison fish, birds, and other wildlife, and can find their way into drinking water supplies. In addition, grass clippings, leaves, litter, and organic matter can clog storm drains and cause flooding. The UPRRP storm sewer system experiences issues such as clogged sections diminishing the overall efficiency of the system and regularly monitors for contaminants such as motor oil and grease.

If the data from the Luis Muñoz Marín International Airport climate station is plotted monthly beginning from the 1950's, every month would show temperature increases. The monthly means after 1981 are higher than they were before 1981 but tend not to exceed 1981 mean values (Lugo et al., 2011). The sharp increase of temperature after 1964 might be explained by the surroundings having been heavily urbanized over the years. At the beginning of the 20th century, The United States Fish Commission Steamer Fish Hawk sponsored a group of scientists to recorded climate parameters in San Juan for a complete year between May 1899 and April 1900 (Lugo et al., 2011). Their observations are presented in the original units of measurement in Figure 11. The long-term rainfall pattern was visible that year, with dry months in February to March and peak monthly rainfall in September (Lugo et al., 2011). A 5-inch (125 mm), 24-hour rainfall event took place in August, minimum temperatures dipped in December, maximum temperatures were high in April, clear days prevailed during the dry season, and June had the greatest number of rainy days (Lugo et al., 2011).

Figure 11. Total Rainfall and Maximum 24-hour Rainfall in Old San Juan in 1900

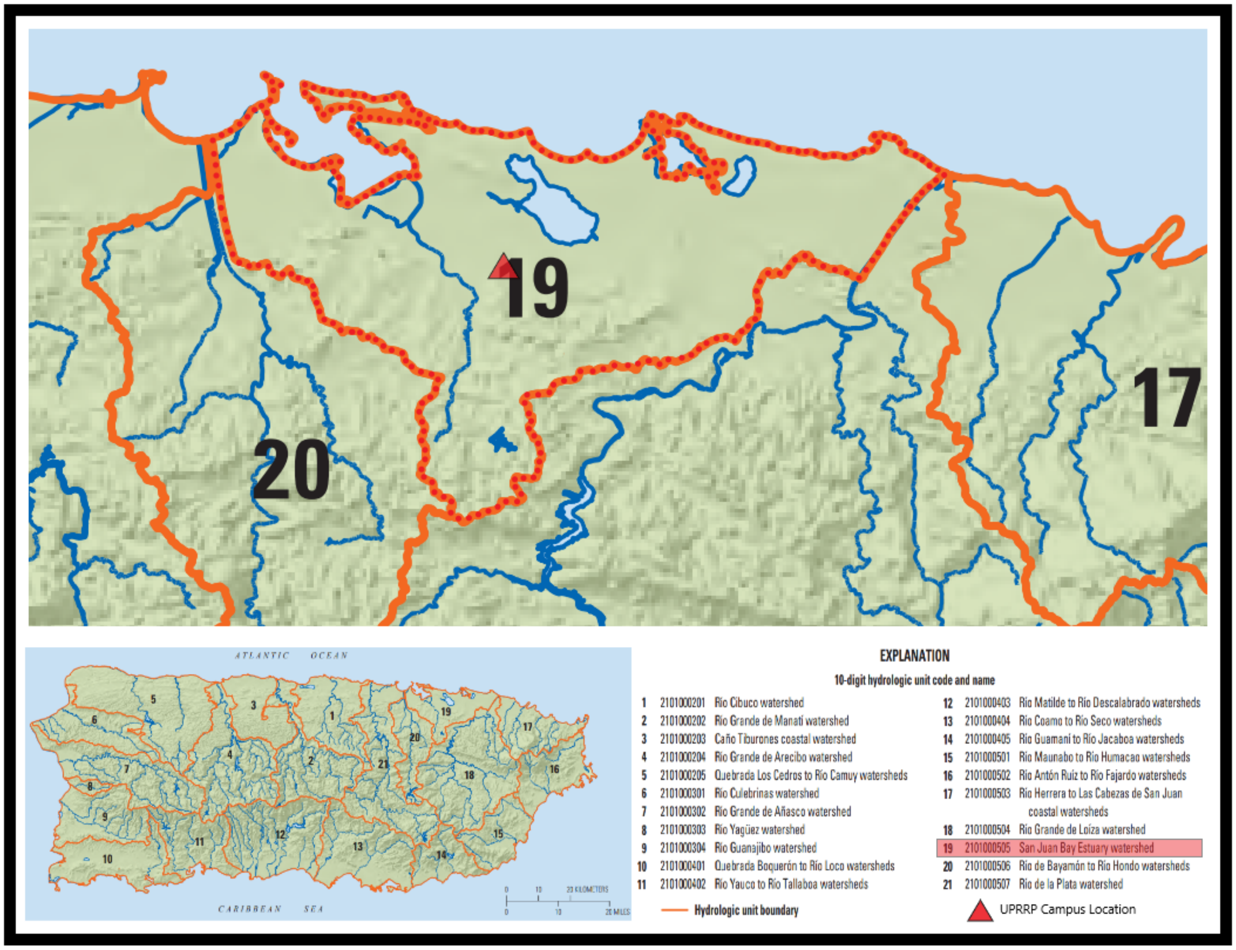


(Source: Lugo et al., 2011)

San Juan Basin and Rio Piedras Watershed

The Rio Piedras basin belongs to the municipality of San Juan, it is the only river in San Juan, and at one point it provided all the drinking water that the city needed (Lugo et al., 2011). In San Juan, coastal mangroves were filled in and built over streams to accommodate urban sprawl. The filling of wetlands and the tubing, burial, or channelling of streams contributed to the flooding of the city. The water body lost water quality, which reduced its recreational services to the population and, in some areas became a threat to public health. Loss of water quality caused the use of river water as a drinking water supply to be abandoned and created the need to import water from other river basins. The relationship between the city and the watershed of the Rio Piedras deteriorated to such a degree that citizens turned their backs on the river.

Figure 12. San Juan Bay Estuary Watershed within Puerto Rico Hydrologic Units



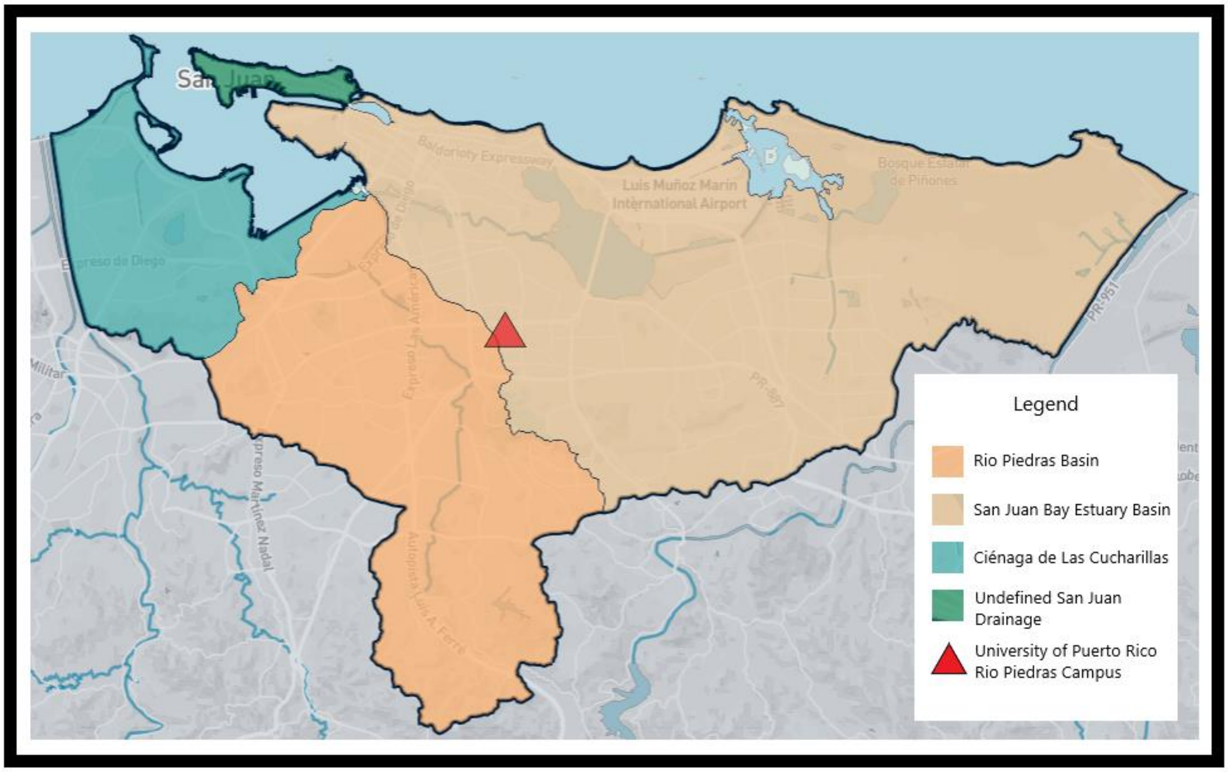
(Source: Gomez et al., 2014)

A watershed or catchment is made up of all the surface area of a zone or region where the topography generally controls runoff to a single point (Puerto Rico Water Resources Inventory, 2004). The coastal areas group together areas that discharge into the sea, many of which possess undetermined drainage (Quiñones and Torres, 2005). Figure 12 illustrates the hydrologic units or watershed delimitations that make up Puerto Rico. The UPRRP is located inside hydrologic unit 19 named the San Juan Bay Estuary watershed. A red dotted line outlines the watershed, and a red triangle identifies the location of the UPRRP campus within the hydrologic unit. The delineation of the San Juan Bay Estuary Basin groups together rivers and streams that flow from the upper area, channels, lagoons, and beaches where fresh and saltwater merge.

The map on Figure 13 presents a closer look at this hydrologic unit, which contains three sub-basins. All together these three sub-basins are comprised of 62,080 acres (Comprehensive Conservation and Management Plan, 2000). On the left you can identify the Ciénaga Las Cucharillas Coastal Area basin, to the right the Río Piedras Basin in the center, followed by the Coastal-East Area of the San Juan Bay Estuary basin. The

UPRRP campus lies between the Río Piedras Basin and the Coastal-East Area of the San Juan Bay Estuary. In Figure 13, a red triangle marks the location of the UPRRP campus on the San Juan Bay Estuary Basin on. The university is spread across two of these sub-basins of the San Juan Bay Estuary watershed: the Rio Piedras Basin and the Coastal-East Area of the San Juan Bay Estuary Basin. Below, Table 4 lists a summary of the San Juan Bay Estuary Basin's subdivisions and their perspective areas in acres. The majority of the UPRRP campus lies in the San Juan Bay Estuary Basin, the largest of the basins within the watershed.

Figure 13. San Juan Bay Estuary Watershed Divided into its Respective Sub-Basins



(Source: Programa del Estuario de la Bahía de San Juan)

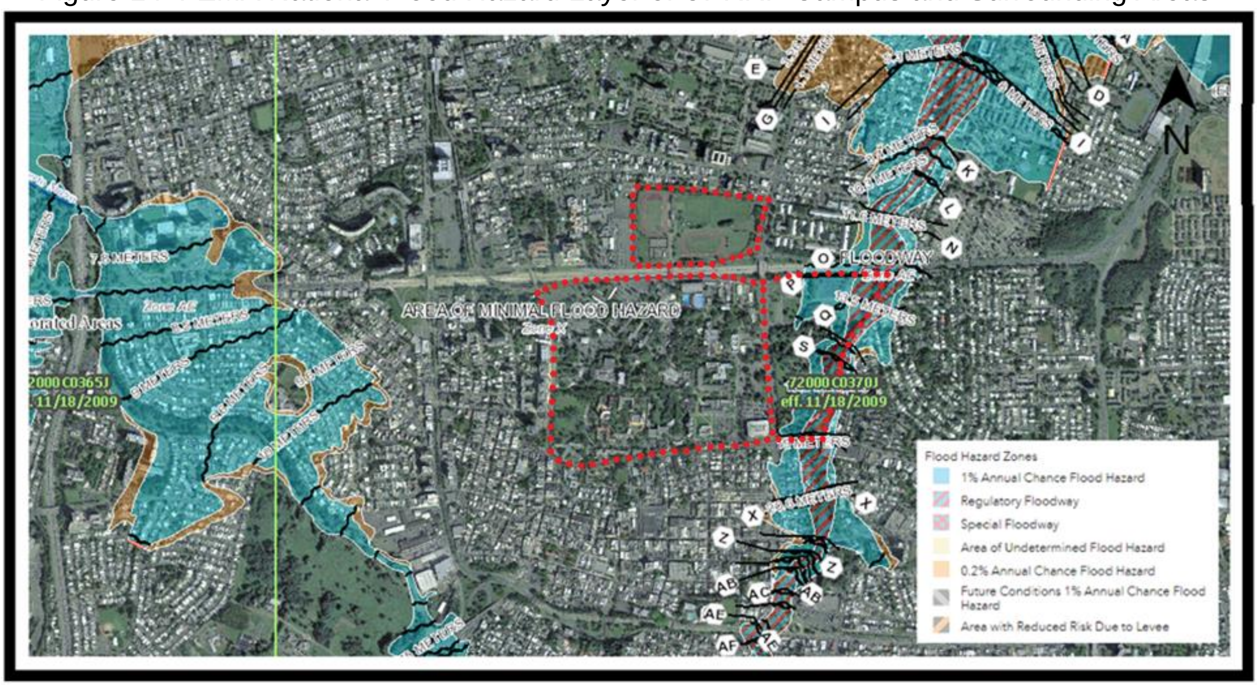
Table 4. San Juan Bay Estuary Watershed Divided into its Respective Basins

Basin	Ciénaga de Las Cucharillas Basin	Río Piedras Basin	San Juan Bay Estuary	Antique San Juan Drainage (not defined)
Percent	11.62	29.54	57.68	1.16
Area in Acres	6,739.32	17,133.17	33,453.77	670.54

(Source: Programa del Estuario de la Bahía de San Juan)

At present, flooding is not considered a significant issue on the UPRRP campus. Flood control projects are therefore not urgently needed. For permit purposes, the UPRRP Stormwater Management Program states that an evaluation of the 100-year flood event must be conducted to identify any future needs of flood control. Figure 14 presents satellite imagery of the FEMA National Flood Hazard Layer of the area of San Juan where the UPRRP campus is located and some of its surrounding communities. The National Flood Hazard Layer (NFHL) is a geospatial database that contains reliable flood hazard data provided by FEMA in support of the National Flood Insurance Program. The NFHL provides draft national flood hazard layer data, preliminary flood hazard data, and pending flood hazard data.

Figure 14. FEMA National Flood Hazard Layer of UPRRP Campus and Surrounding Areas



(Source: La Junta de Planificacion de Puerto Rico)

The purpose of this database is to provide an early look at a community's projected risk to flood hazards and possible changes to regulatory flood map information. To that end, one can observe that the UPRRP campus itself does not lie within a flood hazard area. It is however, surrounded by communities to the east and to the west that are considered at risk according to FEMA in this NFHL map. Although the UPRRP campus is not at risk of significant flooding, it does serve as the perfect place to implement alternative methods of stormwater management BMPs such as green infrastructure that may later be adopted by surrounding communities with higher flood risk of pressing flood control issues. For stormwater management systems to be truly effective a balance between gray infrastructure and green infrastructure should exist. The Environmental Protection Agency (EPA) carried out a survey in 78 municipalities in Puerto Rico after the passage of Hurricanes Irma and María in 2017. This survey revealed the extent of damage to the stormwater system in Puerto Rico.

All municipalities reported damages in at least one category. These categories are presented in Table 5 along with the number of municipalities that reported each type of damage and the percent of municipalities making the reports. This gives an idea of the type of maintenance that is most needed in the gray infrastructure around the island and what maintenance needs are the most neglected. Like all the municipalities involved in this study, the UPRRP also possesses more than one category of damages to the stormwater management system. Some of these damages reported may have been the result of the passage of Hurricanes Irma and María in 2017 while others were pre-existing damages that may or may not have been aggravated by these climatic events.

Table 5. Summary of Pluvial Infrastructure Damage Reports in Puerto Rico

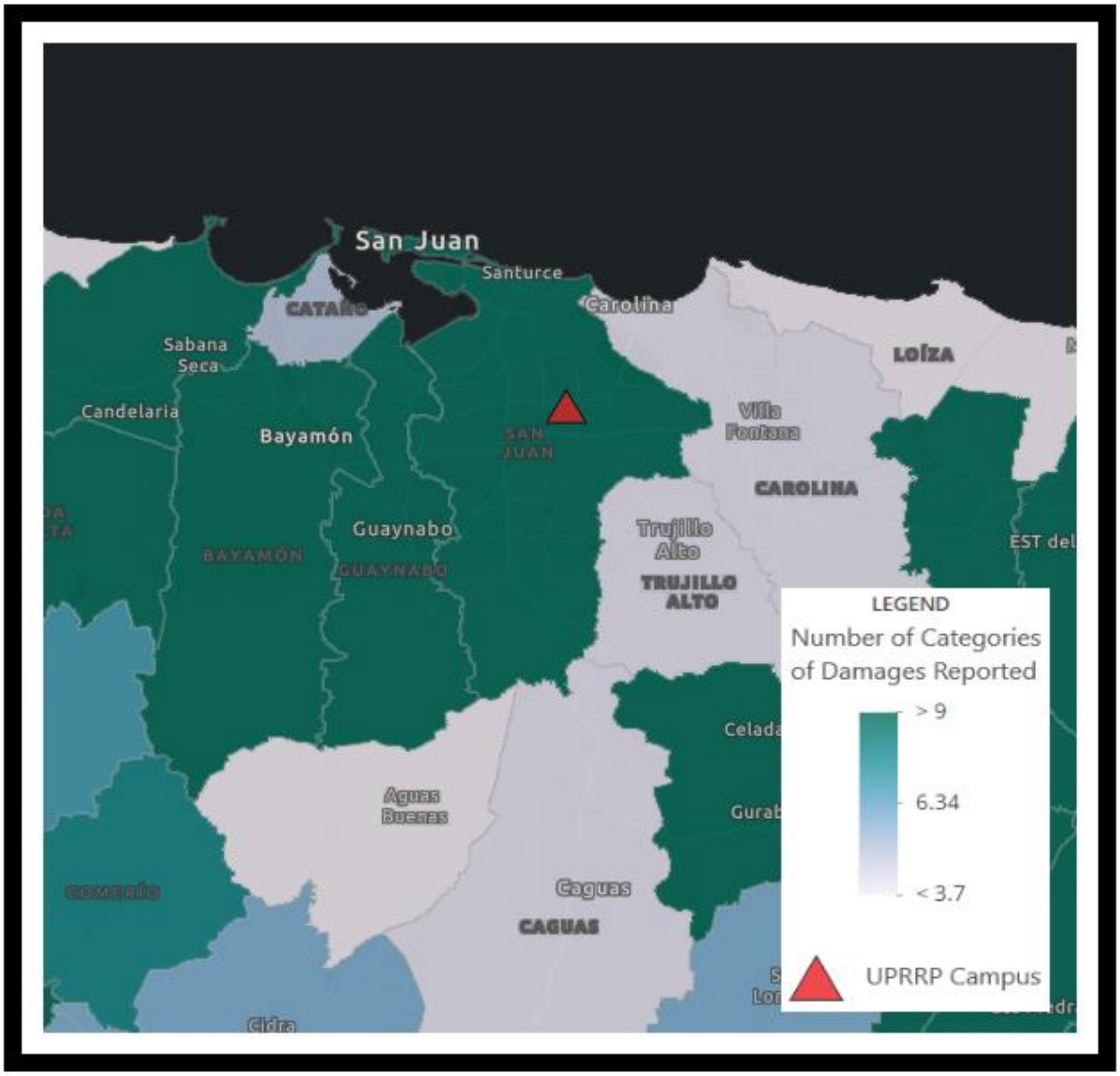
Description of Damage	Number of Municipalities Reporting Damage	Percent of Municipalities (out of 78)
Catch basins broken or missing	37	47%
Poor function of stormwater controls	43	55%
Manholes broken or missing	45	58%
Retaining walls or headwalls broken	51	65%
Open drainage ditches	51	65%
Collapsed storm sewer or drainage pipes	57	73%
Culverts missing or broken	56	72%
Grids missing or broken	62	79%
Obstructions due to debris/sediment	75	96%
Other	20	26%

(Source: Programa de Planificación Integral para la Resiliencia Comunitaria)

The illustration in Figure 15 is a section of a map of Puerto Rico showing various municipalities in and around the metropolitan area including San Juan and its surroundings. These municipalities reported damages in their gray stormwater infrastructure. Categories of damages include broken or missing catch basins, manholes, retaining walls or headwalls broken, grids, and culverts. Other damages reported are collapsed storm sewers or drainage pipes, damages open drainage ditches, and obstructions due to debris or sedimentation. The information used to develop the map comes from the survey that the EPA conducted after the passage of hurricanes Irma and

María. The color gradient presented on the map indicates the number of damage categories reported by the municipality. The greater the number of damage categories, the darker the color of the municipality. San Juan has reported 9 or more categories of damages to pluvial infrastructure. The location of the UPRRP main campus is shown on the map with a red triangle.

Figure 15. Gray Stormwater Infrastructure Damage Reports in San Juan and the Surrounding Metropolitan Area of Puerto Rico



(Source: Programa de Planificación Integral para la Resiliencia Comunitaria)

UPRRP Outfall Inventory, Receiving Waters, and Drinking Water

The UPRRP Campus spans across 280 acres and includes several buildings and housing units. The main campus, and focus of this study, is outlined in figure 11 and is comprised of roughly 240 acres. The remaining 40 acres that are located outside these 240 acres will not be taken into consideration. The stormwater management system is designed to transport runoff, untreated, to surface water bodies through pipes, ditches, and gutters.

Since the runoff does not undergo any treatment, it is important not to dump any chemicals that may be hazardous. Such hazardous chemicals may include oils, cleaners, paints, poisons, or fertilizers, among others. These can degrade and adversely affect receiving water bodies and wildlife in the area. It is important that the components of the system are not obstructed or covered by garbage, leaves or organic material, as they can cause runoff accumulation and flooding. The stormwater runoff generated from these buildings, their parking lots, and other impervious surfaces each is substantial.

The precipitation runoff that flows from the campus is important to the health of the water bodies they discharge into. Ultimately, the quality of the water going into the stormwater system and the receiving bodies, is in large part determined by the large population the UPRRP system serves. It is the goal of the UPRRP that any program to reduce the discharge of pollutants in storm water should involve public participation. According to the UPRRP Stormwater Management Program, in 2018 the UPRRP enrolled 16,000 students, employs 4,000 faculty and staff, and serves 22,000 people.

The UPRRP Stormwater Management Program documents from 2018 has identified 16 outfalls from its storm water drainage system in Attachment 1. Out of 16 outfalls only one of the outfalls discharges directly into the surrounding surface waters of the state. This outfall empties into the receiving waters of the Juan Mendez Creek which runs behind the ROTC and Faculty Residence facilities. Only one outfall discharges directly into this creek however, the drainage area of the UPRRP that leads to this outfall is comprised of approximately two thirds of the entire campus drainage area.

The stormwater runoff that is not destined for the Juan Mendez Creek outfall discharges into the storm sewer system owned and operated by the City of San Juan. Figure 16 provides a closer look at the where the boundary between the Rio Piedras Basin and the Coastal-East Area of the San Juan Bay Estuary Basin is located across the UPRRP campus. The red dotted line in Figure 16 outlines the limits of the UPRRP main campus of which this study is focused on. The blue line running along the eastern border of the UPRRP campus, to the right of the map, is the Juan Mendez Creek.

Figure 16. UPRRP Campus Divided into Hydrologic Sub-Units

(Source of Map: Programa del Estuario de la Bahía de San Juan)

All outfall locations can be viewed in the campus Storm Sewer System map included in Attachment 1. On the map there are some brief descriptions of the condition of the storm sewer system throughout the campus (i.e., “Full of water and obstructed with tree roots”). Although the stormwater discharged from the UPRRP Storm Sewer System is within the standards imposed by the NPDES Permit, but there is always cause for vigilance regarding certain pollutant concerns. According to the UPRRP SWMP there are no known pollutant discharges produced within the UPRRP MS4’s coverage area. However, there is always a chance for situations to develop in which any pollutant discharge could initiate, including oil & grease from vehicles/machinery, sanitary sewer system overflows/breakages, and dirt/debris accumulation from flash flooding resulting from heavy precipitation.

There is always room for experimentation and improvement and as a prestigious University, the UPR has an opportunity to set the example by incorporating more green infrastructure stormwater management practices into the program. None of the existing

Rio Piedras Campus Storm Sewer System outfalls impacts any drinking water source however, they do affect an already heavily impaired natural flowing body of water like the Juan Mendez Creek. Table 6 gives a summary of the receiving water classification and the number of discharging outfalls from the campus to the receiving waterbody segment. Table 7 summarizes the location of the 15 outlets discharging into the city of San Juan MS4 receiving waterbody segments and the impairments or pollutants of concern. Both tables were obtained from the UPRRP Storm Water Management Program documents and reflect current conditions.

Table 6. Receiving Water Data Summary Table of the UPRRP Stormwater Management Program

Receiving Waterbody Segments	Juan Mendez Creek	City of San Juan MS4
Water Quality Standard Classification	Impaired	N/A
Impairment/ Pollutant of Concern	Oil & Grease, Enterococci, and Turbidity	Oil & Grease
TMDL's	N/A	N/A
Applicable WLA's	N/A	N/A
Number of Discharging Outfalls	1	15

(Source of Data: UPRRP Stormwater Management Program)

Table 7. City of San Juan MS4 Receiving Water Data Summary Table

Receiving Waterbody Segments	Pinero Ave.	Ponce de Leon Ave.	Gandara Ave.	Barbosa Ave.
Water Quality Standard Classification	N/A	N/A	N/A	N/A
Impairment/ Pollutant of Concern	Oil & Grease	Oil & Grease	Oil & Grease	Oil & Grease
TMDL's	N/A	N/A	N/A	N/A
Applicable WLA's	N/A	N/A	N/A	N/A
Number of Discharging Outfalls	3	4	1	7

(Source of Data: UPRRP Stormwater Management Program)

UPRRP Endangered Species, Critical Habitats, and Historic Properties

According to the UPRRP Storm Water Management Program and the NPDES Permit there are no endangered or threatened flora or fauna species on the campus. There are no critical habitats identified to exist within the UPRRP MS4 area either nor should any endangered or threatened flora and fauna be affected by any of the changes in landscape proposed by this paper. Having been founded in the year 1903, naturally the Rio Piedras campus has a significant number of historic sites and structures. The green infrastructure BMP's being proposed to control stormwater rate and pollutant discharges will not affect these any of these sites. The National Historic Properties List contains the following:

1. Roman Baldorioty de Castro (La Torre)
2. Felipe Janer
3. Anexo Economia Domestica
4. Registrador
5. Eugenio Maria de Hostos
6. Teatro UPR
7. Luis Palés Matos
8. Anfiteatro Julia de Burgos
9. Sebastian Gonzalez Garcia
10. Antonio S. Pedreira
11. Agustin Stahl
12. Julio Garcia Diaz

CASE STUDIES AND LITERATURE REVIEW

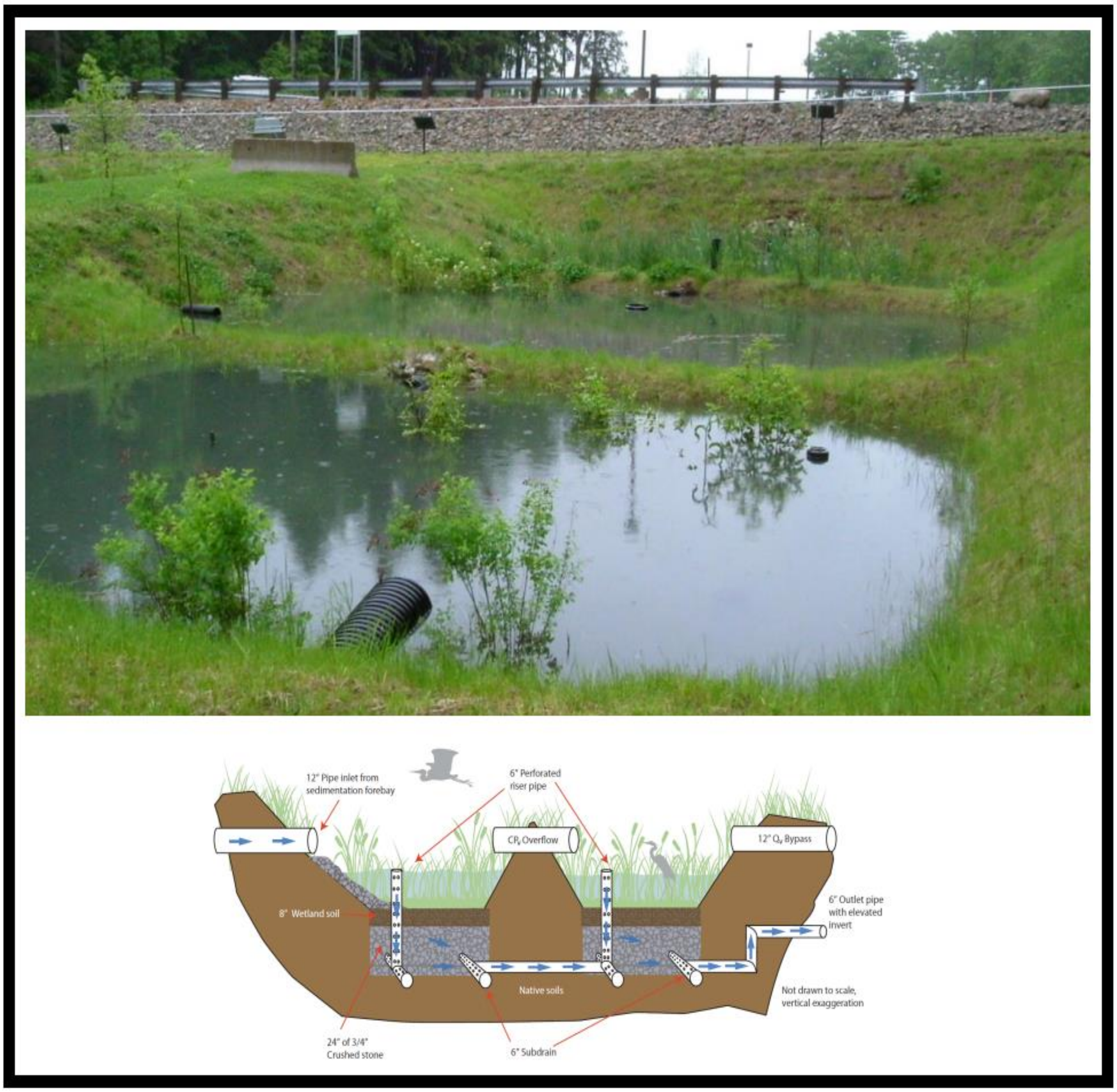
The University of New Hampshire Stormwater Center Subsurface Gravel Wetland

The University of New Hampshire subsurface gravel wetland is designed as a series of cells characterized by horizontal flow-through treatment and preceded by a sedimentation basin or forebay (Ballestero et al., 2016). The University of New Hampshire Stormwater Center (UNHSC) subsurface gravel wetland system was designed to treat stormwater runoff and to temporarily retain 10% of the water quality volume in the forebay and 45% of the water quality volume above each treatment cell (Ballestero et al., 2016). Other systems have been subsequently designed and tested at the UNHSC and still achieve exceptional water quality performance. The inclusion of a pretreatment forebay may increase maintenance activities and reduce nitrogen reduction performance if it is not well drained. The UNHSC recommended that if forebays cannot be installed to drain between storms then concrete inlet structures such as off-line deep sump catch basins may be used for pre-treatment as opposed to a forebay structure. Figure 17 presents a photograph of a subsurface gravel wetland located in the University of New Hampshire followed by a cross section diagram of the wetland system.

The subsurface gravel wetland is designed as an underground flow through treatment system where the stormwater travels horizontally through a saturated gravel substrate with a microbe rich environment. By design, the water quality volume is temporarily retained in the basin above the wetland soil and subsequently treated through the subsurface gravel wetland before draining to receiving waters. All surface basin side slopes should be 3H:1V or flatter for maintenance (Ballestero et al., 2016).

Standing water of significant depth is not expected other than during large rainfall events. According to Ballestero et al., the gravel substrate within the wetland's cells is intended to be continuously saturated below a depth of four to eight inches from subsurface gravel wetland surface grade to promote water quality treatment conditions and support wetland vegetation. The design of the UNHSC wetland allows the ponded water to slowly drain down into the gravel layer below and where it is filtered before to leaving the system. Events producing precipitation greater than the design volume will redirect overflows to receiving waters through an emergency spillway.

Figure 17. University of New Hampshire Subsurface Gravel Wetland and Cross Section Diagram



(Source of Image: Ballestero et al., 2016)

System functionality within the subsurface gravel wetland has multiple components. The wetland plants and their root systems perform water quality treatment, but to what extent is undocumented by the UNHSC. The gravel layer performs processes such as filtration, sorption, uptake and storage, and microbially mediated transformation. Meanwhile, the conversion and removal of nitrogen is dependent on an aerobic sedimentation forebay followed by subsurface anaerobic treatment cells. The subsurface gravel wetland material layers and their specifications are as follows (Ballestero et al., 2016):

- The top layer is an 8-inch-thick layer of a wetland soil built with a surface slope of zero.
- The middle layer is a 3-inch-thick layer of a graded aggregate filter or pea gravel to prevent the wetland soil from moving down into the gravel sub-layer.
- The bottom layer should be a 24-inch-thick layer of ¾-inch crushed-stone. This is the active zone where treatment occurs made of crushed stones needed to maintain system longevity.
- If the native soil does not have a naturally low hydraulic conductivity below the bottom gravel layer, a low permeability liner should be used to minimize infiltration, preserve horizontal flow in the gravel, and maintain the wetland plants.

The University of Yale's Constructed Wetlands and Other Green Infrastructure

Yale University's 1,046-acre campus is home to a wide range of land uses including academic buildings, residential buildings, administration buildings, laboratories, green spaces, and sports fields (Yale Office of Facilities, Utilities & Engineering, 2013). The impervious surface cover throughout the campus makes up 55% of the total property (Yale Office of Facilities, Utilities & Engineering, 2013). When rain falls onto these roofs, roads, walkways, and parking lots, the surfaces create an impervious barrier that prevents rainfall from infiltrating into the ground. This water instead transforms it into runoff that flows off these surfaces and into the city of New Haven's sewer system. The campus is spread across the city of New Haven and the stormwater runoff from the campus drain into two different sewer systems.

The Yale University property lies within four watersheds: Mill River, West River, Beaver Pond, and New Haven Harbor. The stormwater runoff from the University's property discharges directly into one of the four waterways without treatment. The stormwater runoff draining to the combined sewer system in New Haven will generally drain to the Greater New Haven Water Pollution Control Authority (GNHWPCA)'s East Shore Water Pollution Abatement Facility (Yale Office of Facilities, Utilities & Engineering, 2013). Storm events that create greater stormwater volumes overload the GNHWPCA's system, causing the combined sewage to overflow into one of the waterways through structures called combined sewer overflows.

The City of New Haven and the GNHWPCA own the underground network of sewers, the roadways throughout campus, and the associated catch basins, Yale University's authority for reducing its environmental impact associated with stormwater issues at this point does not include changes or upgrades to the sewer systems (Yale Office of Facilities, Utilities & Engineering, 2013). Yale has the opportunity to reduce its environmental impact through stormwater management by implementing green infrastructure systems that slow or reduce the runoff from its surfaces. Yale University is the largest landowner in New Haven, and they hope to meet their goal of reducing their environmental impact while serving as a leader in the community and assisting the City of New Haven in moving toward their goals for stormwater management. For this reason, Yale University envisions a campus where stormwater runoff is reduced sustainably through green infrastructure.

Yale has already taken steps toward managing the University's stormwater through various green infrastructure systems, including incorporating stormwater management into new building construction and landscapes. Existing green infrastructure already on campus include stormwater storage tanks, green roofs, no-mow zones, drywells, vegetated filter strips, a bioswale, a constructed wetland, a preserved wetland area referred to as the Yale Swale, and the Yale Sustainable Food Project, which is included because of its urban agriculture component (Yale Office of Facilities, Utilities & Engineering, 2013).

Figure 18. Yale University Campus Constructed Wetland Next to Kroon Hall

(Source of Image: Yale University Sustainable Stormwater Management Plan, 2013)

In addition to the structural and engineered systems that the University has in place, Yale maintains over 2,000 trees on its campus (Yale Office of Facilities, Utilities & Engineering, 2013). It is estimated that the trees found on Yale's campus help prevent over seven million gallons of stormwater from entering the sewer system each year. The constructed wetland in Figure 18 above, is located next to Kroon Hall on the Yale University campus uses aquatic plants to help filter stormwater from the building's roof and grounds for re-use for flushing toilets and irrigation.

Reclamation Pond in Duke University

In 2007, due to a serious drought the County of Durham was a few days from depleting its potable water reservoirs. Duke University is Durham County's largest potable water consumer, and as a result the University was close to experiencing a serious reduction in campus functionality (Duke Office of Sustainability, 2018). Campus buildings and labs are cooled using a chiller plant that require sufficient water to properly function. In response to this situation, Duke University decided to find a sustainable and secure way of handling the University's water needs. One project key to resolving this water supply issue was the Duke Reclamation Pond. The Reclamation Pond pictured in Figure 19, is one example of a stormwater management practice Duke University has implemented in New Haven.

Figure 19. Duke University Reclamation Pond

(Source of Image: https://sustainability.duke.edu/campus-lab-under-construction/cal-endorsed-sites/reclamation-pond)

Also known as the "Duke Pond," the project was completed in 2015 and cost $11.5 million (Duke Office of Sustainability, 2018). The pond extends over 5.5 acre and is located on a 12-acre forested lot. Duke Pond collects its water from rainfall and the runoff generated from 265 acres of campus and can hold 15.8 million gallons of water (Duke Office of Sustainability, 2018). This pond provides a Chiller Plant with 100 million gallons of water annually. The plant withdraws 100,000-400,000 gallons of water daily on average but can withdraw 1 million gallons in peak summer depending on the University's cooling needs (Duke Office of Sustainability, 2018). The pond can provide water to the Chiller Plant for two weeks during extreme drought. Overflow generated from the Pond is discharged into the Haw River.

As a result of the development of the Duke Pond project 100 million gallons that are pumped annually for the Chiller Plant no longer need to be purchased from The City of Durham. This saves the university an average of $400,000 every year and in times of drought, the university will be less of a strain on Durham's potable water needs (Duke Office of Sustainability, 2018). In addition to providing water for the Chiller Plant, the Pond is a core component of Duke's stormwater management plan. Roughly 50% of the 265 campus acres that drain into the pond is covered by impervious surfaces (Duke Office of Sustainability, 2018). The pond acts as a central drainage spot that keeps the rain from collecting in places of low elevation and small streams which could cause flooding and habitat destruction. The Pond is an attractive site that adds aesthetic and functional value to the campus. Recreational spaces around the pond include a walking path, a pavilion, a bridge, a boardwalk, and an amphitheater. Cities need to find ways to implement stormwater management infrastructure capable of handling increased amount of runoff with less space.

Constructed wetlands as biofuel production systems in China

Clean biofuel production is an effective way to mitigate climate change and energy crisis. Progress has been made in reducing greenhouse gas emissions and nitrogen fertilizer consumption through biofuel production. This study advocates an alternative approach that efficiently produces cellulosic biofuel, reduces greenhouse gas emissions, and uses waste nitrogen from wastewater treatment constructed wetlands in China (Liu et al., 2019). The net life-cycle energy output of constructed wetlands is higher than that of corn, soybean, switchgrass, low-input high-diversity grassland, and algae systems (Liu et al., 2019). Constructed wetlands also have a greater greenhouse gas reduction rate than other existing biofuel production systems. This study found that constructed wetlands provide several ecosystem services in large quantities and wetlands exhibit a much higher cost-benefit ratio than other biofuel systems. In addition, constructed wetlands may also provide other ecosystem services such as biodiversity conservation and recreation, which are not offered by other biofuel production systems.

For this study five experimental constructed wetlands were established with 12 monoculture plots for biofuel production (Liu et al., 2019). Species with high biomass productivity were selected. The 7 species selected with relatively high biomass productivity include Phragmites australis, Typha latifolia, Cyperus papyrus, Canna indica, Phalaris arundinacea, Arundo donax, and Glyceria maxima (Liu et al., 2019). The structure of the constructed wetland is of an integrated vertical flow constructed wetland designed with two layers of filters: 0.5 m layer of gravel followed by a 0.4 m layer of coarse sand at the top (Liu et al., 2019). This system was fed with domestic wastewater after pre-treatment and flows evenly into the upper pool of the wetland through the distribution pipe. This kind of constructed wetland structure has no water on the surface and therefore all the vegetation is emergent. It is suitable for more plant species growth, which allows for a better treatment effect and landscape function.

Figure 20. Constructed Wetland Biofuel System in Zhoushan, Zhejiang Province, China

(Source of Image: Liu et al., 2019)

Figure 20 above, shows images of this constructed wetland biofuel system in Zhoushan, Zhejiang Province, China. Using constructed wetlands to simultaneously produce biofuels and treat wastewater takes advantage of the waste nitrogen, does not need additional nitrogen fertilization, and saves more energy input than other biofuel production systems (Liu et al., 2019). The study found that the constructed wetlands produced more renewable energy than is consumed in their production. The annual surface biomass yield of the constructed wetland in Zhoushan, Zhejiang Province, China, averaged 37,813 kg ha−1 year−1 as the by-product of treating waste N, which is about one order of magnitude larger than traditional biofuel production systems (Liu et al., 2019).

Since constructed wetland biomass can be produced on marginal lands, constructed wetland biofuels do not compete for fertile soils with food production nor do they encourage ecosystem destruction. Constructed wetlands are often scattered in space, especially in rural areas in China, which make it difficult to collect constructed wetland plant biomass (Liu et al., 2019). This study notes that the proposed strategy of using constructed wetlands for biofuel production could be enhanced by developing a centralized rural sewage treatment system in rural areas.

Constructed Wetlands in the North Carolina Agricultural and Technical Farm

This project investigates the feasibility of producing ethanol from harvested cattails from the constructed wetlands of the North Carolina A&T Farm. Using the cattails to produce renewable energy adds value to the land and reduces emissions of greenhouse gases by replacing petroleum products. Renewable transportation fuels are often developed to lower emissions of green-house gases and enhance energy security. Biodiesel and starch-based ethanol predominate, but the technology required for conversion of cellulose to ethanol is constantly improving (Suda et al., 2009). Cellulosic ethanol has a better environmental profile than starch-based ethanol, with a 90% reduction in carbon emissions over gasoline as compared to a 29% reduction using starch-based ethanol (Wang, 2005). It has the advantages of not requiring fertile agricultural land and of using non-food source vegetation to produce fuel. Figure 21 shows a view from above of the North Carolina A&T Farm used in this study.

Figure 21. Constructed Wetland Located on the North Carolina State University Farm

(Source of Image: https://projects.ncsu.edu/cals/waste_mgt/smithfield_projects/constructed%20wetland/constructedwetland.htm)

Pretreatment of the dried cattails with dilute NaOH was followed by solid-liquid separation and enzymatic hydrolysis and fermentation of the solids (Suda et al., 2009). Two trials gave an average conversion efficiency of 43.4% for the pretreated solids alone which, in conjunction with the crop yield for the cattails, would give up to 4,012 L ethanol/ha, a favorable comparison with corn stover's 1,665 L/ha at a 60% conversion rate (Suda et al., 2009). Two years of data from the A&T Farm indicate that the average yield of cattails from the constructed wetlands is 16.1 m ton/ha with a maximum of 42.7 m ton/ha (Suda et al., 2009). The harvested plants had average moisture content of 78.6% and energy content at 5.4% moisture content was found to be 17.4 MJ/kg. Cellulose, hemi-cellulose and lignin content for the dry material were determined as 28.7%, 23.4%, and 10.1%, respectively (Suda et al., 2009). The authors note that a large part of the energy in the process is used to dry the feedstock, further studies could look at the possibility of using it without drying.

The preliminary study did not address the environmental impact of harvesting cattails however, there is no need for machinery, except for the once yearly sustainable harvest in late summer, so the detrimental environmental impact should be less than for feedstocks requiring fertilization and irrigation (Suda et al., 2009). In addition, the cattails are used for phytoremediation of wastewater and the reduction in greenhouse gas emissions (Suda et al., 2009). Using a life cycle analysis, pure bioethanol emits 90% less carbon dioxide than an equivalent energy amount of gasoline (Wang, 2005).

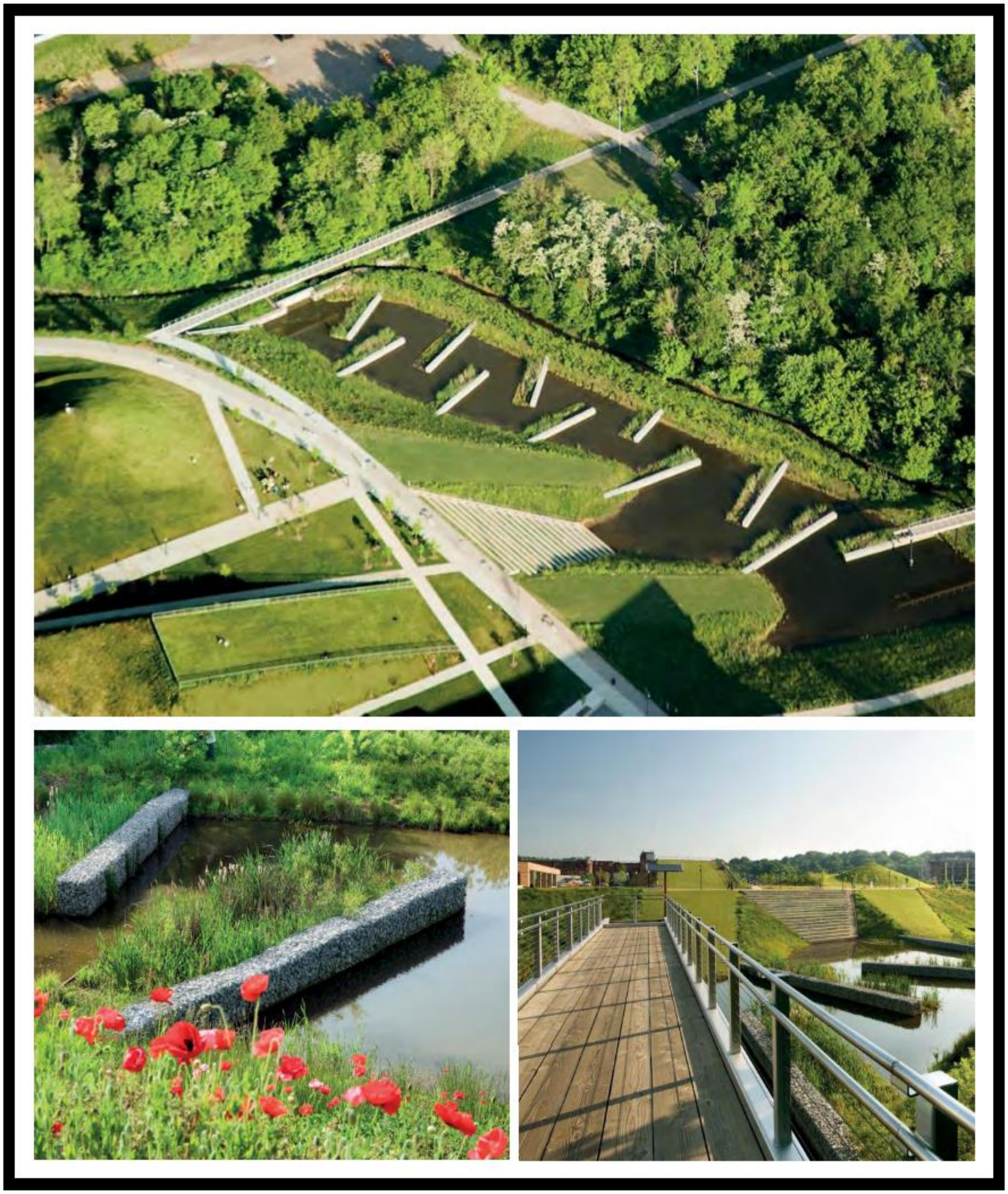
Although the initial trials in this study only achieved 43.4% conversion efficiency using cattails to make bioethanol, it is believed that further trials will obtain better results by using more advanced conversion organisms, and by combining the liquid and solid fractions (Suda et al., 2009). The low conversion rate is made up for by the high productivity of the wetlands, and by the reduction in emissions in the life cycle analysis of the fuel produced. With advances in technology, it is not unlikely that ethanol plants will soon be able to use a variety of feedstocks. Cattails from constructed wetlands could be a valuable part of an integrated system with their role as cleaning agents and clean fuel feedstock.

Renaissance Park in Chattanooga, Tennessee

Renaissance Park is a 22-acre urban brownfield redevelopment project located in Chattanooga, Tennessee (Hargreaves et al., 2009). This river park is the final phase of the 21st Century Waterfront Master Plan and was completed in 2006. The project is responsible for transforming a heavily impacted post-industrial site leaching contaminants into surface and groundwater resources into a renowned public park. This development has also sparked reinvestment into Chattanooga's Northshore neighborhood. Renaissance Park provides a platform for environmental education, strengthening ecosystem services of preserved floodplain forest, meadow plantings, a constructed wetland that treats site stormwater, and increases floodplain storage capacity.

Preservation areas and meadows reduce construction and maintenance costs, while aesthetically pleasing engineered landforms safely enclose contaminated soils. Figure 22 presents two images, the image to the left shows a view from above of the park and the image to the right shows a close-up of a portion of the wetland feature within the park.

Figure 22. Renaissance Park Located in Chattanooga, Tennessee



(Source of Images: Hargreaves et al., 2009)

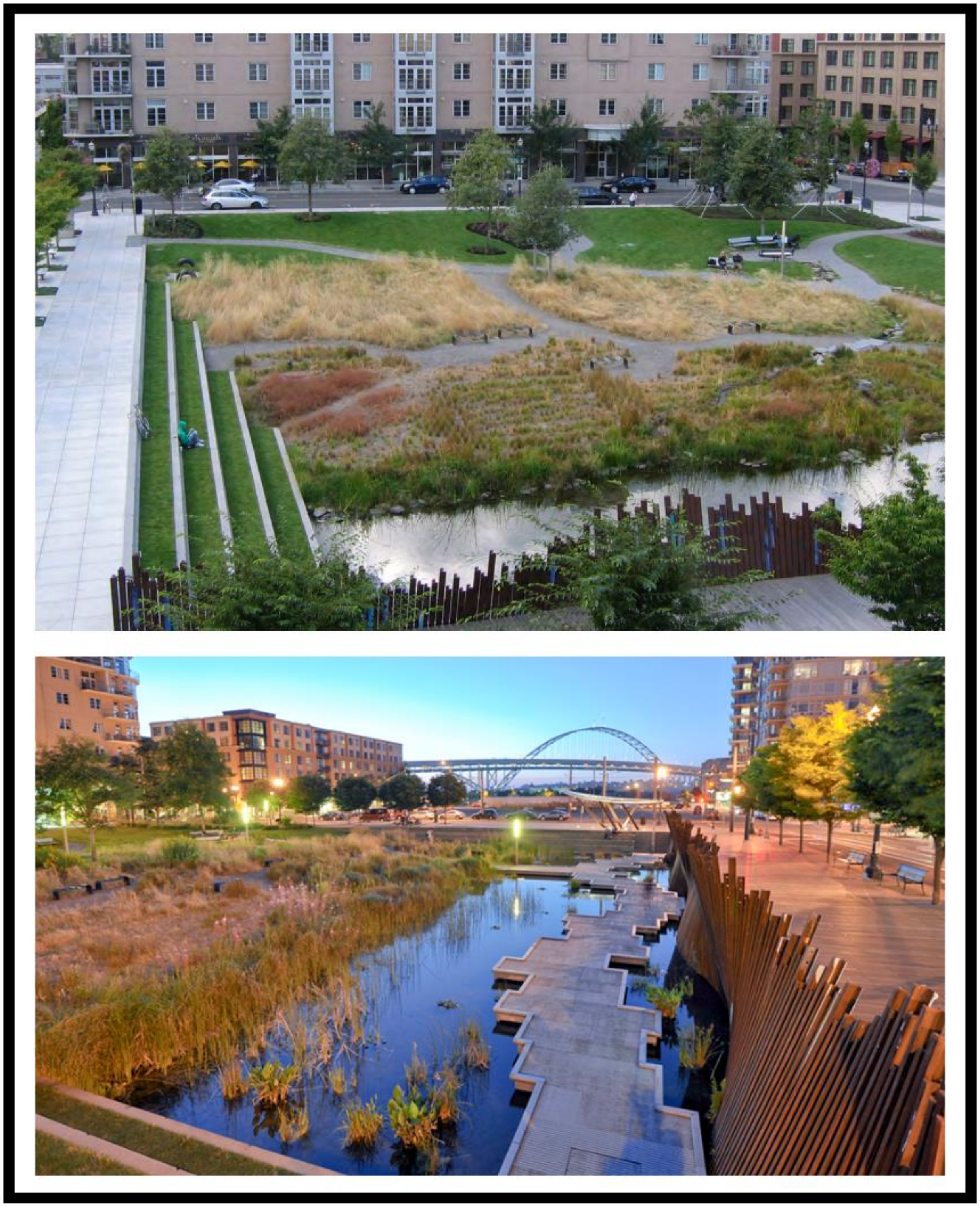
This development removed 34,000 cu yd of contaminated soil from the 100-year floodplain and sealed it within the park's landforms, including 12,000 cu yd of soil mixed with enamel frit, which was leaching contaminants into groundwater. Floodplain storage was increased by 9.32 acre feet through excavation of contaminated soil and creation of the constructed wetland. The habitat value of the North Market Branch stream improved from marginal to suboptimal. According to 85% of 85 park users surveyed, the park promotes a healthy lifestyle and 81% agree that the park increases their outdoor activity. The Park attracts roughly 145,220 visitors annually, many of whom also patronize local shops or dine within 1/2 mile of the area before or after visiting the park. This activity stimulates economic development and neighborhood reinvestment. Since 2005, over $55 million has been invested into redevelopment projects adjacent to Renaissance Park. The developers saved $1,080,000 in construction cost by salvaging 18,000 cu yd of concrete factory floor from the site and reusing it as fill.

Tanner Springs Park in Portland, Oregon

The district where the Tanner Spring Park is located was once a wetland and lake fed by streams that flowed down from the nearby hills in southwest Portland. The springs from Tanner Creek are named for the tannery built in 1845, which flowed into the shallow basin of Couch Lake (Portland Parks & Recreation). This area is now the area surrounding Tanner Springs Park. Tanner Creek was rerouted in the late 19th century through an underground system of pipes to the Willamette River as the population of Portland grew. The lake and the surrounding wetland were filled to make warehouses and rail yards which were later replaced by residences, shops, and public spaces. Today, the block known as Tanner Springs Park is located right in the center of historic Couch Lake, 20 feet above the former lake surface near the Tanner Creek channel (Portland Parks & Recreation).

Planning for this park began in early 2003 when GreenWorks, an award-winning, local landscape architecture firm, collaborated with Atelier Dreiseitl, a renowned German design firm, to design Tanner Springs Park, urban park in Portland (Portland Parks & Recreation). This one-acre park in the center of this Portland District is the second of three parks envisioned by the City and Peter Walker Partners. The Tanner Springs Park design team was responsible for incorporating water and a pedestrian boardwalk that was part of the original master plan. The urban park was designed with a wetland focus and serves the developing surrounding neighborhood and all visitors to the area. The design of the park attempts to recapture the area's past with its native wetlands and steams, the springs connect the park to Tanner Creek which once flowed openly through this area. The sustainable design features modern uses of stormwater and creates a refuge for people as well as wildlife in the midst of this urban district. The design process was very inclusive encouraging public involvement of Portland citizens through a series of public workshops. Figure 23 shows two images of the Tanner Springs Park from different angles that illustrate many of the features mentioned below.

Figure 23. Tanner Springs Park in Portland, Oregon



(Source of Image: Portland Parks & Recreation)

Tanner Springs Park was designed as a tilted plane that captures a transect of the major natural plant communities historically found in the Willamette Valley including freshwater pond plants, emergent wetland plants, wet prairie plants, and oak woodland plants. The design team described the inspiration for this design as wanting to peel back the skin of the city to discover the forgotten wetland. All of the plants in the park are native to the Willamette Valley area. A spring emerges at the top of a large grassy meadow and then drips down to a wetland pond that sinks 6 feet below street level.

The east edge of the pond is framed by an undulating wall that doubles as an art installation constructed out of reclaimed railroad rails. Some of the rails are nearly a century old. Lawn terraces run down opposite sides of the park provide space for recreational activities. Within the park pedestrian paths are crafted from recycled basalt cobblestones. These too have historical value as they were once found in the streets of the neighborhood. This place was designed to pay homage to the evolution of the district through the many historic references installed throughout the park. It is a combination of the natural creek and wetland that once existed, the industry and train yards, and today's modern city.

Menomonee Valley Community Park in Milwaukee, Wisconsin

The Menomonee River Valley in Milwaukee, Wisconsin, was once an industrial brownfield that was abandoned after becoming blighted in the early 1990s. In the early 2000s a plan was created to develop this area into a centralized park and shared stormwater treatment area in an area that had been off-limits to the public for over 50 years (Landscape Architecture Foundation, 2010). The revitalized landscape within the park offers over 60 acres of recreational space and wildlife habitat along the Menomonee River. The Park eliminates the need for irrigation by using drought-tolerant native plants and manages 100-year flood volumes for an over 100-acre basin while improving water quality (Landscape Architecture Foundation, 2010). The development of the Menomonee Valley Community Park catalyzed the use of the Menomonee River Valley as an outdoor science laboratory, receiving on average 10,000 student visits every year (Landscape Architecture Foundation, 2010). The Park added 3 pedestrian and bicycle bridges as well as 7 miles of regional bike and pedestrian trails, connecting the greater Milwaukee area and neighborhoods to the park, river, and valley.

By seeking solutions with multiple benefits, the city of Milwaukee was able to combine several large infrastructure projects and leverage costs to support projects that were mutually beneficial to the community and the environment (Landscape Architecture Foundation, 2010). As a result of this redevelopment project benefits such as environmental remediation, development site preparation, and Canal Street construction there has been a surge in parks, open spaces, and environmental restoration (Landscape Architecture Foundation, 2010). Figure 24. shows 3 images of a portion of the Menomonee Valley Redevelopment and Community Park in Milwaukee, Wisconsin. The image to the left shows the Menomonee Valley Community Park under dry weather conditions and the image to the right shows the same section of the park full of stormwater.

Figure 24. Menomonee Valley Community Park in Milwaukee, Wisconsin

(Source of Images: Landscape Architecture Foundation, 2010)

The Menomonee Valley Community Park was constructed under financially challenging circumstances with zero capital from the City Parks Department. Grants and funders responsible for coming up with the capital necessary for the project include the Wisconsin DNR, the US EPA Great Lakes Initiative, the Milwaukee Metro Sewerage District, and Menomonee Valley Business Partners. The construction budget for the park was $40 million for development sites and remediation and $9 million for the stormwater park (Landscape Architecture Foundation, 2010).

The Dell at the University of Virginia in Charlottesville, VA

The Dell was 11-acres of abandoned and unused land that was transformed into a state-of-the-art stormwater pond system that resurrects a buried stream located at the heart of the University of Virginia (Hughes and Geffel). The primary goals of the design were to restore Meadow Creek to a more ecologically productive and daylit condition, to create an effective stormwater treatment facility, and to develop a space that would become a public recreational and educational amenity in the heart of the historic campus. The system is located within a relatively narrow corridor of open space, but it is highly effective at managing smaller storm events. In addition, the park reintroduces vanishing wildlife habitat, provides multiple recreation opportunities, mediates between the campus and an adjacent neighborhood, serves as a memorable entrance for visitors arriving at the University, and functions as a demonstration landscape and Virginia-native eco-botanic garden for students and faculty.

Figure 25. The Dell at the University of Virginia

(Source of Images: Hughes and Geffel)

In order to maximize useable field space a limited stormwater capacity was determined for the site. The stream channel within the Dell was designed to accommodate 2-year storm events, and runoff from larger storm events is diverted by a flow-splitter into an existing underground pipe that carries the excess water to a larger stormwater treatment facility downstream. The development of this project faced major challenges in the form of a very modest budget with which these ambitious goals were to be achieved. In response to the modest budget, the majority of the plants were installed as plugs, small container sizes, or in seed form, but were closely spaced. This proved to be a fine, perhaps even preferable, method for installation and within a short time the plantings filled in very nicely. Figure 25 presents 2 images of the University of Virginia's stormwater wetland system, the Dell. The image to the left shows a view from above of the Dell and the other image presents the restored stream meander working with the adjacent rain gardens as an initial filter, capturing sediment and debris before water enters the detention pond forebay.

METHODOLOGY

In order to propose alternate stormwater management approaches it was important to examine the stormwater management efforts the UPRRP employs as well as those used by other well-known institutions, universities with well known stormwater management practices such as Yale University and the University of New Hampshire among others. The following research considerations guided this study:

1. The efforts the UPRRP campus is currently making to manage stormwater runoff.
2. Green infrastructure stormwater management practices for runoff rate control in existence.
3. Progress other universities made in developing new stormwater management plans that the UPRRP can emulate.
4. Stormwater management practices that can be implemented in tropical climates.

To understand comprehensively how the UPRRP campus is addressing the issue of stormwater management a copy of the UPRRP Stormwater Management Program was obtained along with a map of the campus stormwater sewer system. Then research into traditionally grey stormwater systems and best management practices along with green infrastructure management practices was conducted. In an overview of stormwater management issues and practices, Kloss and Calarusse (2006) briefly compare the stormwater management efforts happening in various major cities across the United States. They note that the use of green infrastructure to reduce the volume of runoff entering the sewer is rarely a major point of focus in the literature.

The interest in stormwater volume rate control in green infrastructure and the vast open green spaces within the UPRRP, it was then decided that the BMP of greatest interest for this paper would be constructed wetlands. Further research was then conducted on the study site, remote sensing produced elevation maps, flood risk maps were obtained, and satellite imagery outlining green/permeable surface area in the UPRRP campus were created. PDFs of construction documents of existing site conditions and proposed redevelopment were obtained. Then impervious areas of the UPRRP site conditions were identified and outlined with a polyline tool to create vector type closed polygon shapes around these areas. Pervious areas of the UPRRP site were delineated and quantified using the polyline tool as well. These were then subtracted from the overall impervious area, also delineated and quantified with the polyline tool.

To reduce stormwater runoff volume, constructed stormwater wetlands were chosen as the preferred management practices being proposed in this study. Rain gardens or pocket wetlands are also recommended for smaller areas where space is not available for a larger system or where flooding occurs due to poor ground infiltration along the borders of sidewalks or buildings. These green infrastructure best management practices were chosen because they are low-cost alternatives that maximize the use of green spaces and put no strain on pre-existing structures. Other practices such as green roofs demand extra support to handle the increased load, which can become costly.

Having chosen this type of Constructed wetlands as the green infrastructure we wish to develop, research was conducted design procedures, construction considerations, and other wetland design criteria. Using several maps and satellite images, potential green infrastructure sites were identified within the UPRRP main campus. The goal in choosing these spaces is to maximize the use of pre-existing permeable spaces, predominantly green vegetated areas, with no alternate use. Stormwater runoff was then calculated using the rational method for the entire UPRRP campus and then for each prospective stormwater wetland site, followed by the calculation of total runoff volume. The following equations were used:

$$\boldsymbol{Q = CIA}$$

Q = peak runoff rate (cubic feet per second)
C = Rational Method runoff coefficient
I = rainfall intensity (inches per hour)
A = drainage area (acres)
(ASCE, 1992)

The Rational Method uses an empirical linear equation to compute the peak runoff rate from a selected period of uniform rainfall intensity (New Jersey Department of Environmental Protection, 2004). Although it was originally developed over 100 years ago, the rational method continues to be useful in estimating runoff from simple, relatively small drainage areas. According to the New Jersey Department of Environmental

Protection (2004), the use of the Rational Method should be limited to drainage areas less than 20 acres with generally uniform surface cover and topography. This description matches the characteristics of the prospective sites identified for implementing green infrastructure management practices. It is important to note that the Rational Method can be used only to compute peak runoff rates because it is based on a period of rain that produces the peak runoff rate. The rational method cannot compute runoff volumes unless the user assumes a total storm duration (New Jersey Department of Environmental Protection, 2004).

Throughout the research and data collection stage of this study it should be noted that many papers on the topic of stormwater management focused on individual green infrastructure projects (Grehl & Kauffman, 2007), or broadly outlined the associated environmental issues (Kloss & Calarusse, 2006). These studies have value, but it is important to study how individual green infrastructure projects interact with one another (Damodaram et al., 2010). For example, university campuses typically consist of many buildings spread over a large area. Even on an urban campus such as the UPRRP, the buildings are spread across 280 acres on the main campus. A comprehensive stormwater management plan could direct green infrastructure projects on campus effectively, offering the largest overall effect possible. For this reason, when calculating the total runoff volume of the outfall discharging into the Juan Mendez creek the possible rate reduction caused by the individual proposed stormwater wetland sites was taken into consideration.

The Philadelphia Water Department implemented a program to provide incentives for the construction of green infrastructure around the city. To do so instead of basing their stormwater charge estimates on the diameter of the pipe at the water meter, the new stormwater charge is based on the amount of impervious cover on a land parcel (Philadelphia Water Departement, 2009). The values calculated for the UPRRP campus were obtained using a similar approach focusing on the amount of impervious cover versus that of vegetated pervious land cover. This is considered more accurate in indicating how much stormwater the parcel of land contributes to the sewer system. Advances in satellite imaging and Geographic Information Systems (GIS) technologies also allow water departments to maintain an updated database of the impervious cover of land parcels (Blossom, 2004).

Both Cook (2007) and the Philadelphia Water Department (2009) outlined various green infrastructure management practices, including rain gardens, green roofs, pervious pavement, flow-through planters, stormwater wetlands, and rain harvesting barrels among other strategies. In their case study, Grehl and Kauffman (2007) tried to implement a rain garden on the University of Delaware campus, and in doing so they discovered that there can be unintended consequences associated with some of the simplest projects. Grehl and Kauffman suggested placing the rain garden near an existing stormwater inlet to catch overflow and experienced issues with erosion and the rate at which water percolated into the ground. Cook (2007) stated that drainage through green infrastructure is most effective if a site's natural systems are first studied and understood. This assertion and the unintended consequences of previous projects greatly influenced the design stage of this study.

While it is true that green infrastructure will produce growing benefits at a certain scale, it is also important to understand that the combination and spatial distribution of green infrastructure projects will most likely influence the level of benefits observed (Damodaram et al., 2010). The UPRRP campus was divided into two major drainage zones that discharge stormwater into two waterways: (1) the city of San Juan storm sewer system and (2) the Juan Méndez Creek which forms part of the San Juan Bay Estuary System. One possible stormwater wetland site was identified for the drainage zone that discharges into the San Juan separated storm sewer system and four possible sites were identified for the drainage zone that discharges into the Juan Méndez Creek. The design for each stormwater wetland site was adapted from various stormwater management manuals from the United States and university campus case studies.

The available literature states that green infrastructure projects are influenced by factors that are site-specific. Therefore, each campus would need to study the hydrology and the characteristics of the impervious and pervious surfaces on campus to develop a rational stormwater management plan (Gillard, 2011). Having conducted research, collected data, evaluated the study site, and designed stormwater wetlands for the sites identified, an analysis was then conducted where the results of the study were discussed, possible further investigations are suggested, and obstacles related to this study and the implementation of said measures are reviewed.

Design Procedure and Construction Considerations

Before deciding to construct a wetland for stormwater management, it is helpful to consider the viability of using one. The Massachusetts Storm Water Handbook recommends never to use constructed stormwater wetlands to manage runoff during site grading and construction. Site conditions can limit how suitable constructed stormwater wetlands are for stormwater management. Inappropriate soil types, depth to groundwater, contributing drainage area, and available land are all factors that limit viability. Soils consisting of sands are inappropriate because they are considered unsuitable for establishing wetland vegetation. Unless the groundwater table intersects the bottom of the constructed wetland or the constructed stormwater wetland the necessary moisture cannot be maintained. In places where land area is not a limiting factor, various types of wetland design may be possible.

Places where land area is limited are better suited for pocket wetlands as the preferred stormwater management practice. The Massachusetts Storm Water Handbook also recommends not locating constructed stormwater wetlands within natural wetland areas. Constructed stormwater wetlands differ from other wetlands designed for storage, restoration, or replication purposes. They lack the full range of ecological functions of natural wetlands and are designed specifically to improve water quality. In addition, they do not create any additional wetland resource area or buffer zones. The following steps for stormwater wetland design procedure and construction considerations are adapted from the Minnesota Stormwater Manual, the New Jersey Stormwater Best Management Practices Manual, and the Massachusetts Storm Water Handbook:

Step 1: Judge whether site conditions are appropriate for wetland construction. When designing a stormwater wetland, it is important to make a preliminary judgment as to whether site conditions are appropriate for the intended use. Then it is important to identify the function of the wetland in the overall system. Although treatment is desired the primary focus of this study is flow rate control and flood prevention. Consider basic issues such as the site drainage area, soils, slopes, space required for wetland, depth to water table, and receiving waters. Then determine how the wetland will fit into the overall stormwater treatment system.

Step 2: Confirm local design criteria and check with local officials and other agencies to determine if any additional restrictions and/or surface water requirements may apply.

Step 3: Check site suitability by performing field verifications of site suitability. If evaluations indicate that a wetland would be a good BMP for the site, it is recommended that soil borings be taken and water balance calculations made to ensure wetland that conditions can be maintained after construction.

Step 4: Compute the runoff control volumes and the permanent pool volumes. If the wetland is being designed as a wet detention pond, then a permanent wetland pool volume (V_{pp}) of 1800 cubic feet of storage below the outlet pipe for each acre that drains to the wetland is recommended. If part of the overall permanent stormwater wetland pool volume is to be treated by other BMPs, subtract that portion from the V_{pp} to determine the volume that is to be treated by the stormwater wetland.

This can be calculated by:

$$V_{pp}=1800A$$

A = total watershed area in acres draining to the pool.

Step 5: Determine whether to incorporate a sediment forebay as a way to pre-treat the stormwater. In the absence of upstream treatment by other BMPs, it is recommended to add a sediment forebay at each inlet. The volume should equal to 10 percent of the computed wetland permanent pool volume. The forebay storage volume and may be subtracted from the permanent wetland pool volume for subsequent calculations.

Step 6: Determine the wetland location, its preliminary design and geometry, and distribution of wetland depth zones. This step involves laying out the wetland design and determining the distribution of wetland surface area among the various depth zones (high marsh, low marsh, and deep water). The design should provide length to width ratios and maintenance access. If trucks or machinery are required for maintenance a 10-foot width access is recommended.

Step 7: Design embankments and/or spillways for the stormwater wetland. The embankment side slopes should not be steeper than 1V:3H and should be stabilized with vegetation (no trees). All constructed stormwater wetlands must have an emergency spillway capable of detouring runoff from large storms.

Step 8: Design the stormwater wetland inlet structures. To prevent standing water in the pipe it is recommended to increase the slope to 1 percent if conditions permit.

Step 9: Design the sediment forebay for the stormwater wetland. If it is decided that a sediment forebay should be incorporated into the design (step 5), the forebay should follow the inlet structure and include a sediment marker to indicate when sediment removal is necessary. A forebay with a hard bottom will make facilitate sediment removal but will result in reduced vegetative processes that remove pollutants.

Step 10: Design the outlet structures while paying particular attention to the risk of clogging or blockages. The minimum outlet pipe diameter should be 18 percent, with a minimum 1 percent slope. Outlet pipes that traverse an embankment should be equipped with an anti-seepage collar to prevent failure.

Step 11: Incorporate maintenance access and safety features into the stormwater wetland design. Maintenance access is necessary and should reach the pond, forebay, inlet structures, and outlet structures. The maintenance access is already contemplated in step 6. Some safety features that can be incorporated into the design include obstructive planting to make access difficult, warning signs, fencing, and others as deemed appropriate. Aesthetic enhancements such as trails, benches, and other amenities should may also be included

Step 12: Prepare vegetation and landscaping plan for the stormwater wetland. The landscaping and planting should be prepared by a qualified professional for the pond and surrounding area. The plan must contain the location, quantity and propagation methods for the wetland plants as well as site preparation and maintenance. Using native vegetation wherever possible is recommended.

Step 13: Prepare an operation and maintenance plan for the stormwater wetland.

Step 14: Prepare the cost estimate for the stormwater wetland system.

Step 15: Prepare final pond-scaping and grading plans for the constructed stormwater wetland. At the same time, order wetland plant stocks from nurseries following the wetland landscape plan.

Step 16: Once the constructed stormwater wetland volume has been excavated, grade the wetland to create the major internal features and micro-topography. These features include pools, aquatic benches, deep water channels, embankments, etc.

Step 17: After excavating and grading the soil, it's time to place of the liner and deposit the medium. In this case the UPRRP stormwater wetlands shall be filled with crushed stone, pea gravel, and topsoil mixed with organic matter or wetland mulch needed to support vigorous plant growth.

Step 18: Once the Crushed stone, pea gravel, and topsoil has been added, it's time to grade the constructed stormwater wetland to its final elevations. The Massachusetts Storm Water Handbook recommends evaluating the wetland elevations during a standing period of approximately six months to assess how the constructed stormwater wetland responds to storm flows and inundation and determine if the final grade and micro-topography will persist over time.

Step 19: Aggressively apply erosion controls during the standing and planting periods. Stabilize the vegetation in all areas above the normal pool elevation during the standing period (typically by hydroseeding). Locate vegetative buffers around the perimeter of the constructed stormwater wetland to control erosion and provide additional sediment and nutrient removal for sheet flow discharging to the constructed stormwater wetland.

Step 20: Before planting, measure the constructed stormwater wetland depths and if necessary, modify the pond-scape plan to reflect altered depths or availability of plant stock. Dewatering the constructed stormwater wetland is recommended at least three days before planting, because dryer conditions make the planting process easier.

Liners for Stormwater Management

Soils with a lot of rock are not preferable when it comes to pond-building. Clay soils mixed with moderately good soils are easily manipulated and compacted with heavy machinery, and therefore preferred among pond builders. Porous soils are great for a septic tank or for a good garden, however these unforgiving soils drain too quickly to maintain hydric conditions necessary to sustain a pond BMP. Basically, if an expert describes your soils as too rocky, too sandy, or don't have enough clay to seal the pond and keep water from escaping and the cost of bringing in clay or other amendments (i.e. bentonite) is excessively high.

Before investing in liners, it is recommended that test holes are dug around the property to find out if adequate clay may be found close by. Local soil surveys may offer reliable information regarding the prospects of finding good soils that can be compacted. If it is decided a liner is required, your liner needs to be a certain thickness, a certain pliability, and the proper size to ensure there are no issues after installation. Liners are made from a small variety of plastic-type materials, but they are all susceptible to punctures.

Liners are often purchased in large rolls, machinery is used to gently lift the sections of liner and placed them strategically. The edges are then stitched together with another machine designed just for that purpose. The liner is then secured around the entire edge of the pond by digging a trench. The edges are rolled into the trench, these are then refilled with good soils ensuring the liner won't pull free as the pond fills with water. Adding a layer of soil on top of the liner after it is installed may protect the integrity of the liner, improve efficiency at preventing leaks, and provide a medium for pond vegetation to establish itself.

Figure 26. Impermeable Liners for Constructed Stormwater Wetland BMPs

(Source: Philadelphia Water (PWD) Stormwater Management Guidance Manual.)

Figure 26 shows various stages of the installation process for liners. The photograph (a) of the figure shows the liner being stretched, then overlapped into a peripheral trench followed by photograph (b) where the trench is backfilled with pulverized clay to hold the liner in place. Photograph (c) shows heavy machinery preparing the site because as seen in photograph (d) rocky soils must be smoothed so as not to puncture the liner.

Liners are designed to limit infiltration of water from a stormwater BMPs into underlying and adjacent soil. Conditions where liners are required under the Construction Stormwater General Permit of Philadelphia include systems with less than 3 feet of separation from seasonally saturated soils or from bedrock; and systems located within active karst terrain. The Minnesota Stormwater Manual also recommends that liners be used under the following conditions:

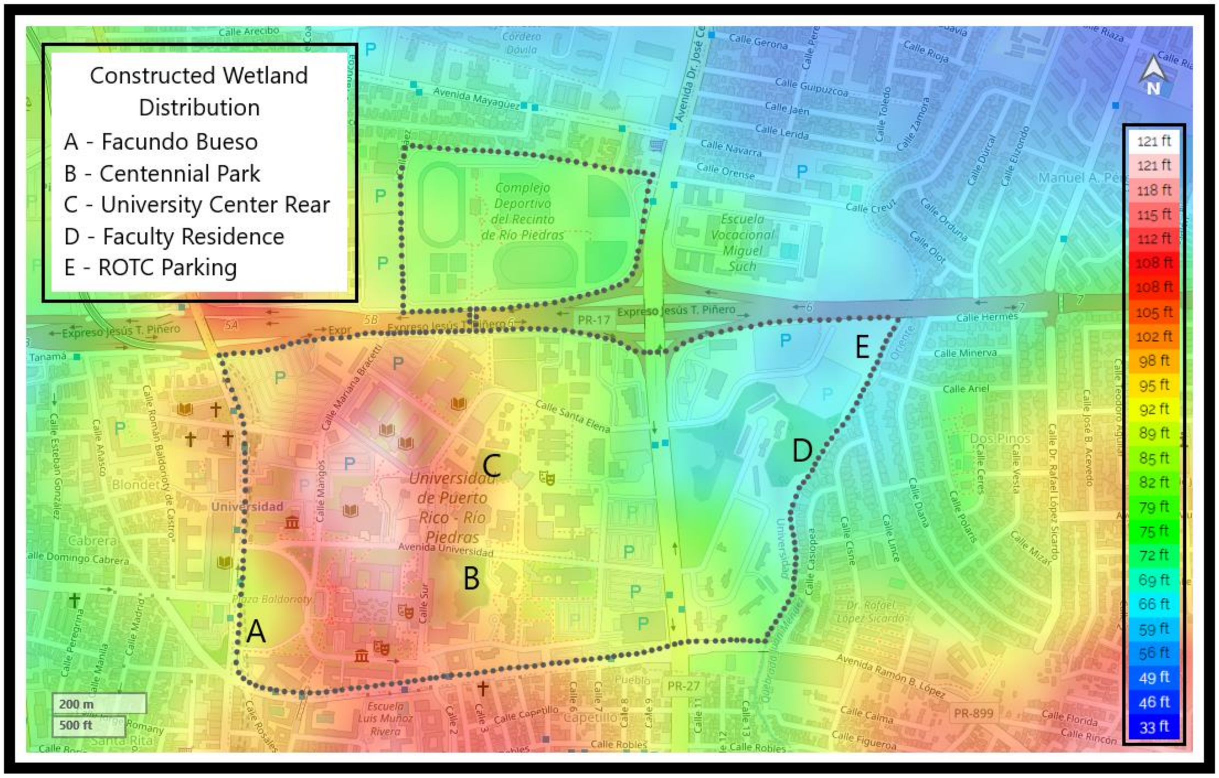
- Circumstances where a permanent pool is needed but difficult to maintain due to site conditions. In these cases, constructed wet detention ponds or constructed wetlands requiring a permanent pool and underlain by areas with Hydrologic Soil Group A soils, gravel, or fractured bedrock require liners to prevent rapid infiltration of water.
- Permeable pavement designs in compacted fill soils.
- Areas where seepage from a BMP into the groundwater would otherwise occur but should be avoided due to risk of groundwater contamination.
- Areas where infiltrating water will mobilize contaminants in soil or groundwater
- Use impermeable liner as needed to separate tree BMPs from road, parking lot, sidewalk or adjacent walls or building foundation

These areas also include those that are confirmed as stormwater hotspots where the potential for groundwater pollution is high. Groundwater pollution potential is determined based on hydrogeologic conditions, which are used to estimate the time of travel for water and conservative chemicals to pass through the soil and vadose zone and into groundwater. Liners for facilities covered by an Industrial Stormwater Permit and where ponds are allowed with a constructed liner must be lined with a synthetic liner that is chemically compatible with materials expected to enter the pond. The industrial stormwater pond liner must be Ultra Violet stable and must be capable of restricting infiltration to less than 500 gallons per acre per day. The industrial stormwater pond must be designed in accordance with accepted engineering practices.

RESULTS, DESIGN, AND SITE OBSERVATIONS

Maps of the UPRRP storm sewer system and other documents detailing site conditions were obtained in order to illustrate the constructed wetland developments proposed in this paper. Specifically, the maps obtained from the UPRRP Stormwater Management Program documents are missing certain details, but they were the only documents available at the time this paper was written and the missing details do not pose any hinderance to the project. The 5 locations that were chosen include the Facundo Bueso area close to the main entrance of the university, the Centennial Park, the space at the rear end of the University Center building, the Faculty Residence, and the ROTC Parking lot area. Figure 27 illustrates a map that presents the distribution of these constructed wetlands sites within the UPRRP campus.

Figure 27. Elevation Map of UPRRP Main Campus with Locations of Constructed Wetland Sites



The pervious areas within the UPRRP site were identified and outlined with a polyline tool to create vector type closed polygon shapes around these areas as seen in Figure 28. The impervious areas of the UPRRP site were delineated and quantified using the polyline tool as well. These were then subtracted from the overall campus area to calculate the difference in percent of land use cover as shown below:

UPRRP Main Campus Area: 240 acres
UPRRP Site Pervious Area: 100 acres
UPRRP Site Impervious Area: 140 acres
Percent Pervious Area = 100 acres/240 acres = 0.41 or 41%
Percent Impervious Area = 140 acres/240 acres = 0.59 or 59%

In Figure 28, the UPRRP campus is outlined with a solid red line and the green spaces are delineated with green polygons. These green spaces make up roughly 100 acres of the UPRRP main campus and are distributed at different ratios throughout the campus.

Table 8 summarizes these land cover uses for the 5 different drainage areas identified as potential locations for constructed stormwater wetlands within the University. These 5 locations are the space in front of the Facundo Bueso building near the main entrance of the University, the Centennial Park near the center of the University, the space behind the University Center Building, the space behind the Faculty Residence, and lastly the space behind the ROTC Parking Lot. The percent of pervious and impervious land use for these potential constructed stormwater wetland locations are provided in Table 8.

Figure 28. UPRRP Main Campus Pervious Land Cover

Table 8. Land Area Characteristics of the Chosen Site Locations within the UPRRP Main Campus

Drainage Area	Impervious Area	Pervious Area	Percent Pervious Area	Percent Impervious Area
Facundo Bueso Area	22,365 m²	11,495 m²	34%	66%
Centennial Park	11,095 m²	25,239 m²	69%	31%

University Center Rear	4,957 m²	8,057 m²	62%	38%
ROTC Parking	22,563 m²	14,618 m²	39%	61%
Faculty Residence	16,854 m²	95,178 m²	85%	15%

Nearly two decades ago, back in 2002, green land cover in San Juan was nearly 42% of the municipality, and impervious surfaces made up approximately 55% of San Juan's land area (Ramos-González, 2014). Today, the UPRRP campus presents roughly the same ratios of pervious and impervious land cover. The city may be divided into two sectors based on the distribution of pervious and impervious land area. A greater percentage of green areas may be clearly identified in the southern sector of the city, moving away from the coast. The northern sector possesses a greater percentage of impervious cover due to greater urban sprawl concentrated in this region.

The UPRRP also presents a visible divide when it comes to pervious and impervious land cover. Rather that the divide separating northern and southern sector, the UPRRP is divided into eastern and western sections. The Barbosa Avenue acts as a literal barrier between these two sections dividing the UPRRP physically into two. The difference in the composition of green spaces between the northern and southern sectors was also observed. Grasslands or pastures made up the bulk of the green cover in the north, whereas forest cover predominated the southern sector of San Juan. Table 9 offers a comparison between the green cover and the impervious cover of San Juan and various other cities in the United States. When compared to the other cities used as references, San Juan had less land area and percent green cover than 85% of the cities listed. It did however have had the fourth largest percentage of impervious surface among the referenced cities.

Table 9. Land Area Characteristics of San Juan and 20 Reference Cities in the United States

City, State	Land Area	Green Cover Area	Green Cover	Impervious Cover
Nashville, Tennessee	1225.8 km²	984.4 km²	80.3%	17.7%
Kansas City, Missouri	812.0 km²	648.8 km²	79.9%	18.2%
Atlanta, Georgia	341.4 km²	240.3 km²	70.4%	26.5%
New Orleans, Louisiana	467.8 km²	266.2 km²	56.9%	41.4%
Albuquerque, New Mexico	467.8 km²	233.4 km²	49.9%	35.3%
Houston, Texas	1500.6 km²	906.4 km²	60.4%	37.9%
Spokane, Washington	149.7 km²	74.1 km²	49.5%	33.8%
Denver, Colorado	397.3 km²	207.8 km²	52.3%	40.0%

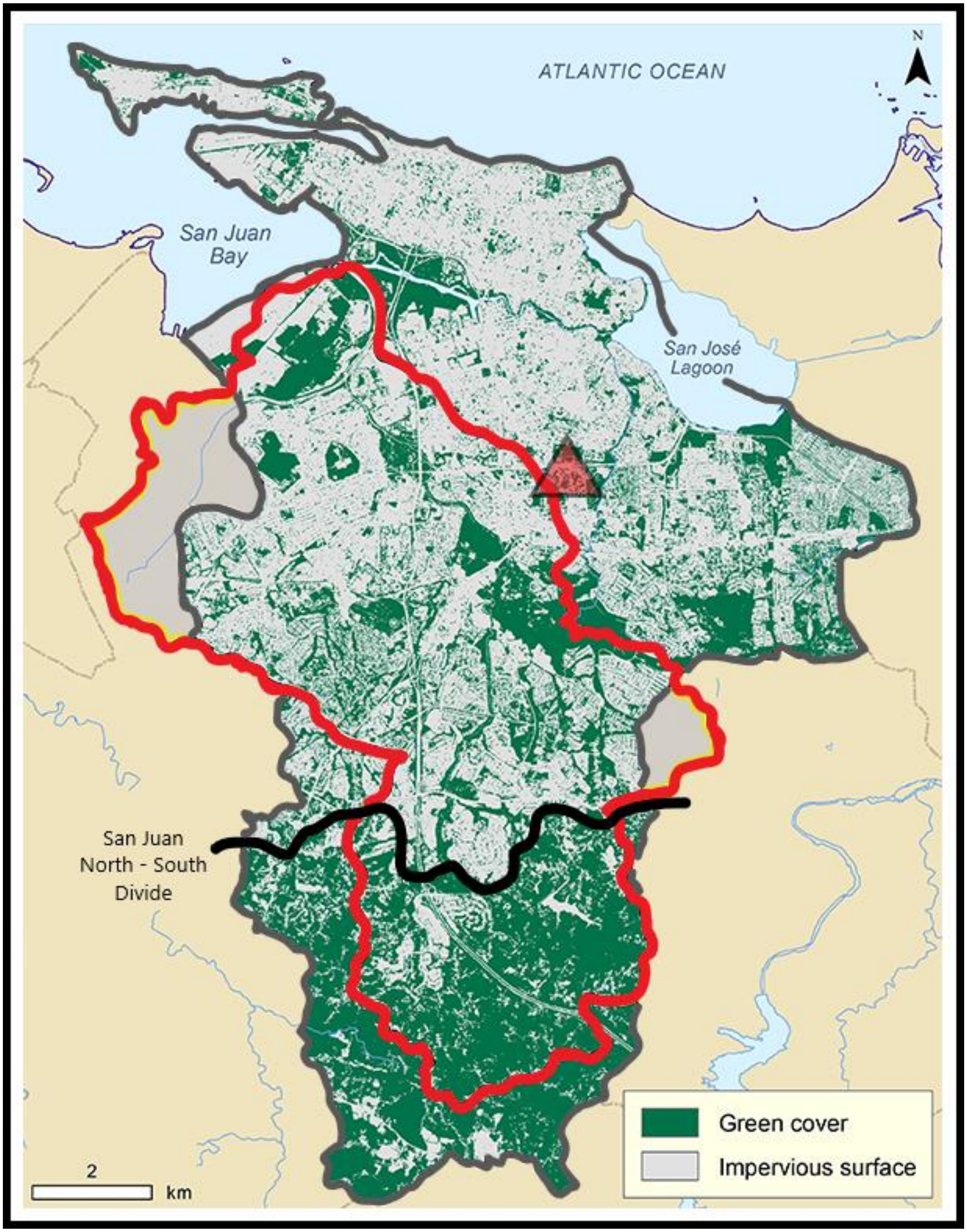
Portland, Oregon	347.8 km²	188.5 km²	54.2%	43.2%
Tacoma, Washington	129.8 km²	66.8 km²	51.5%	40.7%
Pittsburgh, Pennsylvania	144.0 km²	85.0 km²	59.0%	40.0%
Syracuse, New York	65.0 km²	32.5 km²	50.0%	50.0%
Minneapolis, Minnesota	142.2 km²	77.8 km²	54.7%	42.9%
Detroit, Michigan	359.5 km²	185.9 km²	51.7%	46.5%
Baltimore, Maryland	209.3 km²	112.8 km²	53.9%	43.7%
Los Angeles, California	1215.0 km²	526.1 km²	43.3%	52.2%
San Juan, Puerto Rico***	127.3 km²	53.1 km²	41.7%	55.4%
Boston, Massachusetts	125.4 km²	60.0 km²	47.9%	48.2%
Miami, Florida	92.5 km²	35.7 km²	38.6%	60.0%
Chicago, Illinois	588.2 km²	231.2 km²	39.3%	58.5%
New York, New York	785.5 km²	294.6 km²	37.5%	59.8%

(Source of Table: Ramos-González, 2014)

Among the referenced cities, Baltimore, Miami, and Boston are similar to San Juan in terms of land area. Baltimore has greater land are than San Juan but has a lower percent of impervious land cover and greater percent of green land cover. Both Miami and Boston have a smaller land area than San Juan, but Boston has a greater percent of green cover than San Juan and Miami has a lower percent of green cover than San Juan. Miami is 27% smaller in land area than San Juan, it is the closest geographically, and the only other city in the reference set seasonally exhibiting similar tropical climate characteristics (Ramos-González, 2014). Figure 29 presents a map illustrating the green cover and the impervious cover of San Juan back in 2002. The municipality of San Juan is outlined in gray, and the Río Piedras River watershed is highlighted in red. The ratio of green cover to impervious cover has undoubtably been altered notably in the last two decades.

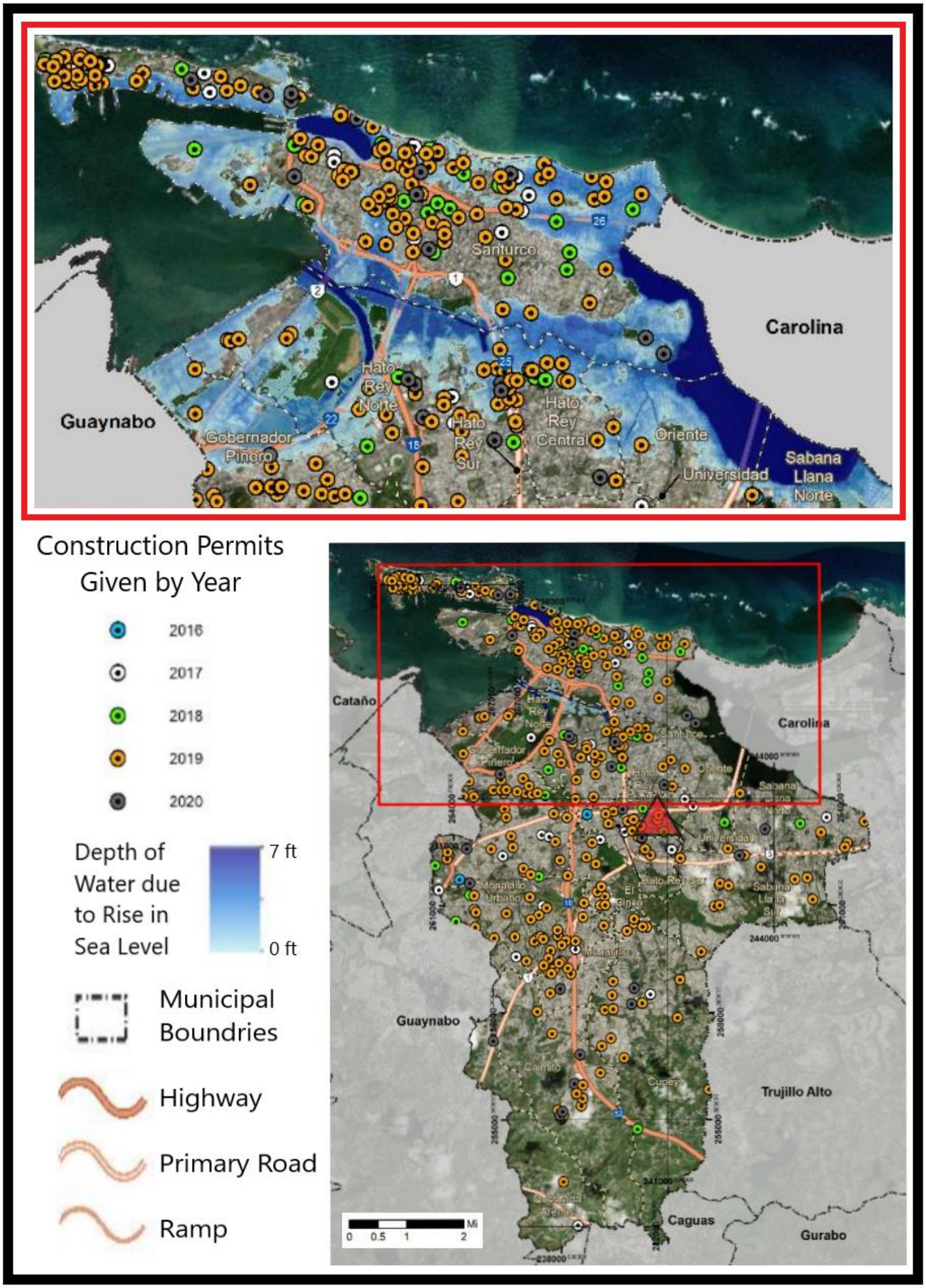
Figure 30 shows an image of all the construction permits awarded in San Juan from 2016 to 2020. The portion outlined in red shows the area in San Juan most likely affected by flooding caused by an increase in sea level. In this figure the UPRRP main campus (represented by a red triangle) is located outside of this vulnerable area. Following the trend of impervious land cover, the majority of these construction permits are distributed along the center and northern sections of San Juan. Following the devastation of hurricanes Irma and Maria in 2017, there is a notable decrease in permits awarded until 2019. Then the restrictions set by the government in the wake of the Covid-19 Pandemic in 2020 impeded construction once again.

Figure 29. Map of the Green Areas of the San Juan Municipality



(Source of Base Map: Ramos-González, 2014)

Figure 30. Map of Construction Permits Awarded in San Juan from 2016 to 2020



(Source: Junta de Planificacion, 2021)

Many small catchments and highway drainage collection sites (where pump stations are needed) produce peak flows soon after the maximum rainfall intensity occurs during a storm (American Association of State Highway and Transportation Officials, 1992). At locations like these the rational method can be used to obtain inflow hydrographs to a pump station. The modified rational method relies on the same assumptions as the rational method, the two most important being that the peak rate of runoff at any location is a function of the average rainfall intensity corresponding to the rainfall duration, and that the frequency of the computed runoff volume equals the frequency of the average rainfall intensity (Froehlich, 1994).

The modified rational method assumes that runoff increases at a linear rate from the start of rainfall for a period equal to the time-of-concentration of the catchment t_c (that is, the time needed for runoff to flow from the hydraulically most remote location of the drainage basin) (Froehlich, 1994). After this time the flow remains constant at the peak rate until rainfall ceases and flow decreases at a linear rate during a period equal to t. The peak stormwater runoff rate was calculated using the formula Q=CiA, and the results are summarized in Table 10 for the UPRRP main campus using the rational method. The Table expresses stormwater runoff using variations of rainfall intensity, starting from 1-year recurrence interval rainfall intensity, and ending with the 500-year recurrence interval rainfall intensity.

Due to the large extension of land and the climatic conditions characteristic to this region, the resulting values for stormwater runoff are increasingly large as well. Table 11 gives the UPRRP main campus stormwater runoff calculations for each site chosen for constructed stormwater wetland development. The values obtained in Table 10 and Table 11 were calculated using the rainfall intensity from the Point Precipitation Frequency (Pf) Estimates with 90% confidence intervals and Supplementary Information from the NOAA Atlas 14, Volume 3, Version 4. The storm duration for each rainfall intensity consists of a 60-minute event ranging from a 1-year recurrence interval to a 500-year recurrence interval in Table 10 while Table 11 only uses a 60-minute event duration with a 100-year recurrence interval.

Table 10. Rational Method Stormwater Runoff Calculations for the UPRRP Campus

Coefficient of Runoff (C)	**Rainfall Intensity (i = in/hr)**	**Drainage Zone Area (A = acres)**	**Storm Water Runoff (Q = CiA)**	
Pervious = 0.18 Impervious = 0.85	1.53 (1-year recurrence interval)	Pervious = 100 Impervious = 140	28 cfs 182 cfs	Q = 210 cfs
Pervious = 0.18 Impervious = 0.85	2.70 (10-year recurrence interval)	Pervious = 100 Impervious = 140	49 cfs 321 cfs	Q = 370 cfs
Pervious = 0.18 Impervious = 0.85	3.29 (50-year recurrence interval)	Pervious = 100 Impervious = 140	59 cfs 391 cfs	Q = 450 cfs

Pervious = 0.18 Impervious = 0.85	3.53 (100-year recurrence interval)	Pervious = 100 Impervious = 140	63 cfs 420 cfs	Q = 483 cfs
Pervious = 0.18 Impervious = 0.85	4.07 (500-year recurrence interval)	Pervious = 100 Impervious = 140	73 cfs 484 cfs	Q = 557 cfs

Table 11. UPRRP Campus Stormwater Runoff Calculations for Individual Site Locations

Site Location	**Coefficient of Runoff (C)**	**Rainfall Intensity (I = in/hr)**	**Area of Drainage Zone (A = acres)**	**Stormwater Runoff (Q = cfs)**	
Facundo Bueso	Permeable: 0.18 Impermeable: 0.85	3.53 (100-year recurrence interval)	Permeable: 2.80 Impermeable: 5.50	1.80 16.50	Q = 18 cfs
Centennial Park	Permeable: 0.18 Impermeable: 0.85	3.53 (100-year recurrence interval)	Permeable: 6.20 Impermeable: 2.70	4.00 8.00	Q = 12 cfs
University Center Rear	Permeable: 0.18 Impermeable: 0.85	3.53 (100-year recurrence interval)	Permeable: 2.00 Impermeable: 1.20	1.00 4.00	Q = 5 cfs
ROTC Parking Lot	Permeable: 0.18 Impermeable: 0.85	3.53 (100-year recurrence interval)	Permeable: 65.00 Impermeable: 95.00	41.00 285.00	Q = 326 cfs
Faculty Residence	Permeable: 0.18 Impermeable: 0.85	3.53 (100-year recurrence interval)	Permeable: 23.50 Impermeable: 4.20	15.0 13.0	Q = 28 cfs

Following the stormwater runoff calculations, we can now compute runoff control volumes and permanent pool volume. If the wetland is being designed for rate control, then a permanent wetland pool volume, V_{pp}, of 1800 cubic feet of storage below the outlet pipe for each acre that drains to the wetland is recommended. This recommendation was adopted for the calculation of the minimum wetland pool volumes of the constructed wetlands proposed by this study. To calculate the permanent wetland pool volume V_{pp} the following formula is recommended by the Minnesota Stormwater Manual:

$$V_{pp} = 1800A$$

where:
A = total watershed area in acres draining to the pool.

In cases where the stormwater is to be treated with other BMPs and the wetland is being constructed only for rate control, a permanent pool may not be necessary, but it may be desirable. Table 12 summarizes the calculations for the permanent wetland pool volumes for the different wetland site locations within the UPRRP. The table also provides a rough estimate of how large the permanent wetland pool volumes allow for given the space available. It's important to note that the permanent wetland pool volumes are lower than the design V_{pp} except for the design V_{pp} of the ROTC parking area wetland. While the wetland design Vpp does not reach the recommended permanent wetland pool volumes, it is however capable of holding over 57% of that volume and whatever excess volume remains is discharged into the adjacent Juan Mendez Creek. These numbers do not reflect the reduction in volume the ROTC Parking area constructed wetland may experience as a result of the runoff intake the other constructed wetlands are expected to manage. The other 4 constructed stormwater wetlands have wetland pool volumes that exceed the minimum required. This is because the space available in each site allows for a greater amount of storage and it is in the University's best interest to develop these green spaces to their farthest extent with green infrastructure.

Table 12. UPRRP Individual Stormwater Wetland Design Volumes

Site Location	**Storm Water Runoff (Q)**	**Drainage Zone Area (A)**	**V_{pp} = 1800*A**	**Design V_{pp}**
Facundo Bueso Area	18 cfs	8 acres	14,400 ft^3	15,000 ft^3
Centennial Park	12 cfs	9 acres	16,200 ft^3	38,400 ft^3
University Center Rear	5 cfs	3 acres	5,400 ft^3	11,500 ft^3
ROTC Parking Area	326 cfs	160 acres	288,000 ft^3	165,000 ft^3
Faculty Residence	28 cfs	27 acres	48,600 ft^3	211,500 ft^3

Of the five locations identified for constructed wetland development within the UPRRP main campus, only two are considered to need the assistance of water pumps to transport excess runoff into the system. The first is the Facundo Bueso stormwater wetland and the second is the ROTC parking area constructed wetland. The basic function and effectiveness of water pumps may be measured in terms of power or work overtime. The unit of measure used for the technical applications of water pumps is watts or kilowatts, but culturally that mechanical output is calculated in terms of horsepower (Pivotal Pumps, 2021). The first step is to decide what you want your pump to do in order to determine how powerful the pump will need to be.

Other factors such as water pressure from the pump is also an important factor for providing good water pressure. Rainwater pumps can be divided into two basic types of pumps: external pumps and submersible pumps. External rainwater pumps sit outside the water tank and are mounted on the adjacent ground. These pumps are more accessible for maintenance but are less esthetically desirable and can also cause a lot of noise. When running, additional housing over the pump is recommended to muffle the noise and protect it from the weather.

On the other hand, submersible pumps are installed inside the rainwater tank making them more difficult to access for maintenance, but generally don't need it frequently. These pumps are usually quieter because the water in the tank muffles the noise. Although they take up a few litres of volume in the rainwater tank, additional housing is not necessary as is the case with external pumps. For these reasons the UPRRP should use submersible pumps instead of external pumps for the two wetland site locations that require pumping water. The installation of the rainwater pump will require a waterproof external power connection near the tank.

Connecting a submersible pump is usually considered a straightforward task. Connect a hose or pipe to the pump's outlet then lower the pump into the tank. You might want to attach a length of water-resistant rope or chain for later retrieval of the pump for maintenance. Features to look for in a pump include automatic power on/off, run-dry protection (prevents motor damage if the tank is empty), and multiple outlets on the pump that let you connect more than one hose. Rainwater sump pump costs may range widely, starting at a few hundreds of dollars to several thousands of dollars, depending on their capacity and features.

The different variables and constants used to calculate the horsepower that will be needed to pump a certain volume of water includes the head, capacity, specific gravity, the constant weight of one gallon of water, and the value of one horsepower. The head may be defined as the vertical distance traveled by the liquid through the system (for the sake of simplifying calculations we are discounting friction loss from the pipe). Capacity may be defined as the rate of flow through the system in gallons per minute. The liquid in the system is water, which has a relative specific gravity value of 1. The constant weight of one gallon of water is 8.33 Lbs/Gallon and one horsepower is defined as moving 1 lb a distance of 33,000 ft/min (Stringam, 2013). Once these variables are defined, they can easily be applied to the calculation until we arrive at our desired horsepower output. The following formula can be used to calculate horsepower (Pivotal Pumps, 2021):

$$HP = \frac{Capacity*Head*Specific\ Gravity}{3960}$$

In addition to the type of pump and the horsepower required to manage the stormwater, the storage space required to hold the rainwater and the pump must also me taken into consideration when designing these sytems. Some small submersible pumps have a capacity of 3,000 gpm or less and generally have minimum cycle times as low as 2 minutes, resulting in significantly smaller system storage requirements than other types of pumps (Smith, 2001). Larger submersible pumps have shorter minimum cycle times than other pumps because of the stormwater's cooling effect. This makes larger pumps preferable for systems to little or no provision for storage other than the wet well. Storage outside the wet wells will reduce the size of the pumps for larger systems and is typically cost effective (Smith, 2001).

The Facundo Bueso constructed wetland, which has a stormwater runoff value of 8,079 gpm, could be equipped with 2 to 3 small submersible sump pumps with a 3,000 gpm capacity. The point where the sump pumps would be placed is not expected to receive the entirety of the 8,079 gpm and therefore does not truly need the full 9,000 gpm capacity three sump pumps would provide. The storage space provided for the runoff should however use the 9,000 gallons as a minimum storage capacity. More than one pump is recommended and therefore more storage is not considered necessary.

The second site deemed to require the assistance of a water pumping system is the ROTC parking area. According to the formula used to calculate horsepower, the total horsepower needed to manage the runoff discharging into the system is 554 hp. In contrast with the Facundo Bueso site, the sump pump system designed for the ROTC parking area does expect to receive the large sum of rainwater runoff calculated earlier. In order to satisfy the horsepower requirements for the ROTC parking area site, 5 to 6 large capacity submersible pumps with 100 hp or higher would cover the demand for horsepower.

To determine the minimum storage volume for the ROTC parking area we must identify are the total system inflow rate and the flow at which the pumps will discharge. The required volume of the pump sump depends on factors such as the cycle time for the pump, the pump capacity, and the rate of the inflow and outflow. The minimum cycle time, (T_{min}) is determined by the number of pump starts with regard to the mechanical stress from the temperature rise in the motor (JES, 2012). The intent is to determine the minimum storage volume the pump sump needs to hold between pump starts. Typically, the recommended minimum time between pump starts should be 8 to 10 minutes, or roughly six starts per hour (JES, 2012). This of course varies among manufacturers so check with the particular pump maker. It is important to verify the minimum run time of the pumps with the manufacturer. The following formula was used to calculate the minimum storage volume for the ROTC parking area pump system:

$$V_{MIN} = \frac{T_{MIN} * Q_{OUT}}{4}$$

Q_{OUT} = Discharge flow rate out of wet well (gpm)

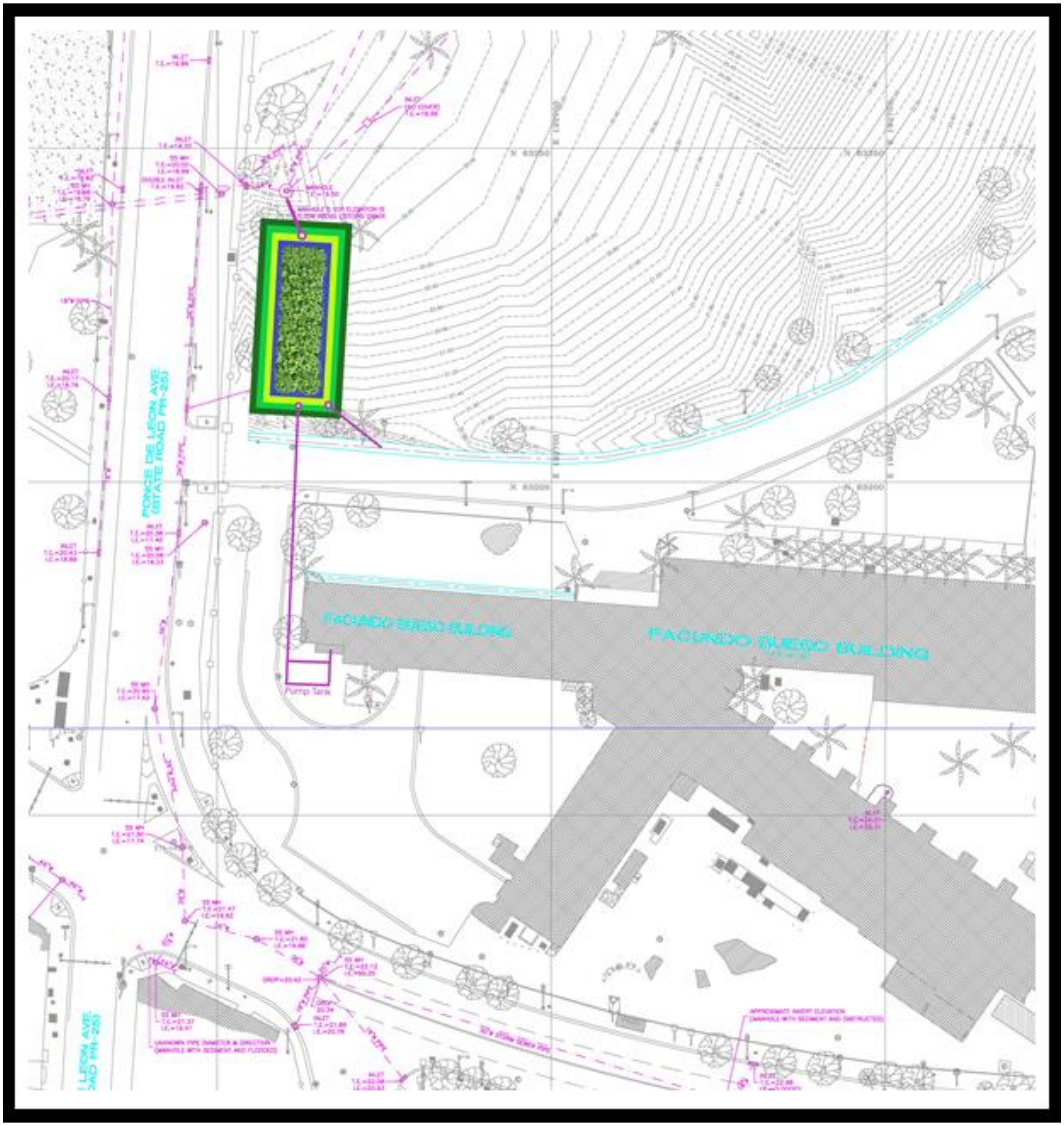
T_{MIN} = Minimum cycle time between pump starts (minutes)

V_{MIN} = Minimum storage volume for wet well to hold fluid during pump off (gallons)

(JES, 2012)

For a pumping station with 2 or more identical pumps, the required volume is greatly reduced if the pumps start in sequence as the water level rises due to increasing inflow and stop in sequence as the water level drops due to decreasing inflow (JES, 2012). To minimize the required sump volume, cyclic alternation among the pumps is recommended. In other words, the last pump to start should be the last pump to stop. Using the formula above, the minimum storage volume for the ROTC parking area was determined to be roughly 292,600 gallons.

Figure 31. Stormwater Wetland Design for the Facundo Bueso Drainage Area



(Source of Base Map: UPRPR Stormwater Management Program)

Figure 31 illustrates what the constructed stormwater wetland system would look like in the Facundo Bueso area of the UPRRP. In contrast with the other constructed wetland sites located throughout the university, this system is the only one that does not discharge its overflow into the stormwater drainage system that empties into the Juan Mendez Creek. This wetland would discharge its overflow into the city of San Juan storm sewer system. The water pumping system is meant to help transport rainwater from in and round the Facundo Bueso building.

This building has been known to flood in the basement level. Runoff from the gutter running along the road would also be deviated into the stormwater wetland. The wetland in the figure presents a rectangular shaped wetland consisting of a vegetated depression in the ground. The primary goal of this wetland is rate control followed by light water treatment. Although a forebay is not strictly contemplated in this design, the microtopography within the wetland may be altered to include a forebay section if deemed desirable.

The ROTC parking lot drainage area stormwater wetland design is illustrated in Figure 32. This wetland in particular is expected to receive a large quantity of stormwater because the water running through the university storm sewer system is meant to be pumped up and out into the stormwater wetland before discharging into the Juan Mendez Creek contemplated above. The wetland design includes diagonal embankments meant to simulate the winding flow of a river in order to reduce the velocity of the water and increasing retention time. These embankments are made of gabion walls filled with stones much like those seen in the Renaissance Park case study.

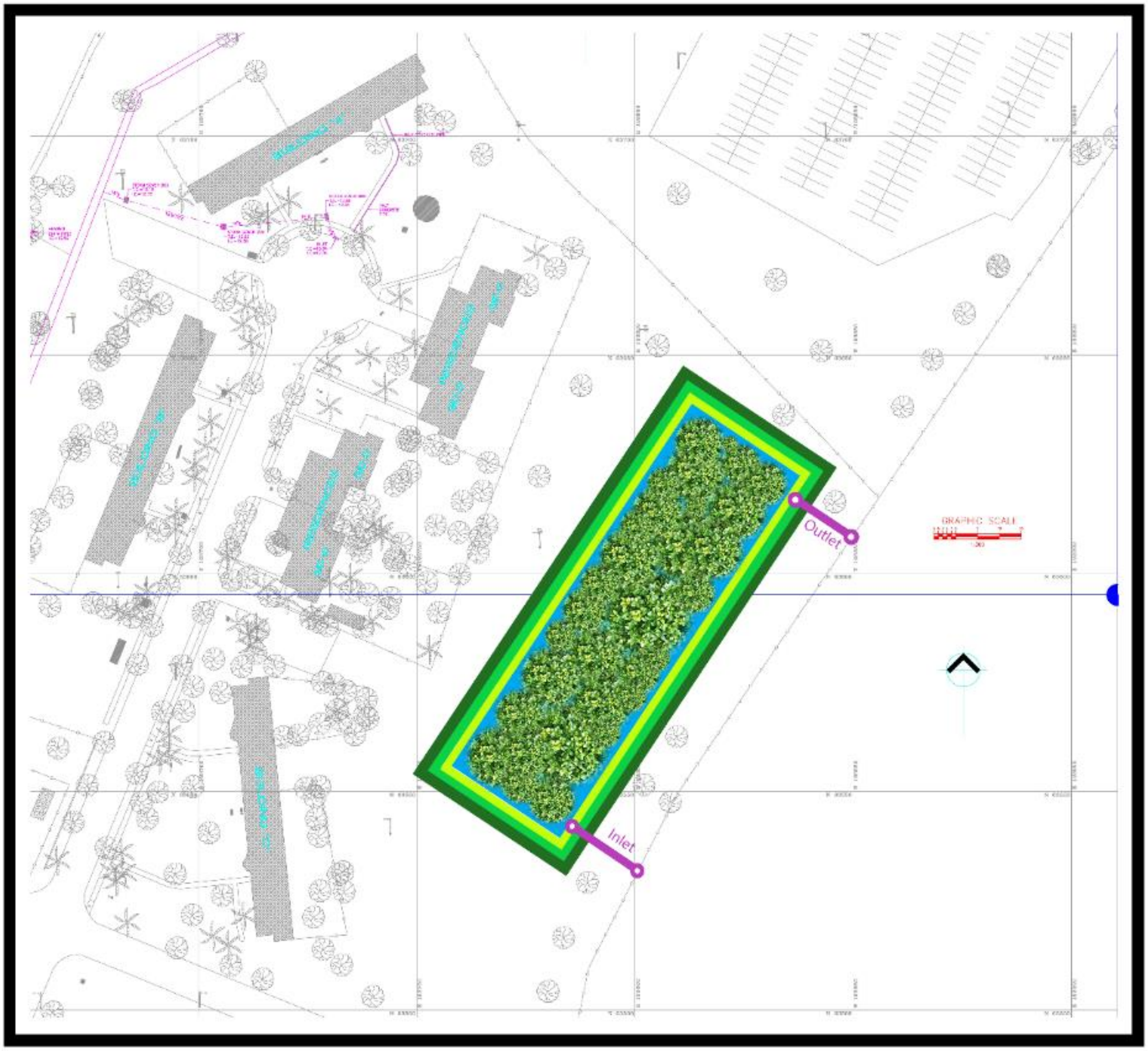
More than one inlet structure may be necessary because multiple pumps are necessary to transport the water from the sewer to the constructed wetland. For this constructed wetland, the use of a liner is not recommended thereby promoting infiltration into the ground. Once again, the first goal of this constructed wetland is rate control followed by treatment. The design doesn't specifically include a forebay but as with the wetland in Figure 32 however, the microtopography within the system may be altered to include a forebay at the inlet point. It's important to note that the elongated rectangular shape common in these wetland designs is meant to aid in rate control, simplify construction/maintenance tasks, and create uniformity among sites. More organic shapes or circular shaped wetlands would work just as well therefore alternative shape recommendations are welcome.

Figure 32. Stormwater Wetland Design for the ROTC Parking Lot Drainage Area

(Source of Base Map: UPRPR Stormwater Management Program)

In contrast to the stormwater wetlands in Figure 31 and Figure 32, the wetland in Figure 33 will not receive runoff deviated from the UPRRP stormwater system. Instead, this system could serve to increase floodplain storage for the Juan Mendez Creek due to excavating soil below 100-year floodplain elevation and creation of a constructed wetland. In addition to increasing floodplain storage, this wetland could serve as a biofuel production constructed wetland. This may be accomplished by replacing the typical wetland vegetation that would be used in the other constructed wetlands with plants used for biofuel production.

Figure 33. Stormwater Wetland Design for the Faculty Residence Drainage Area

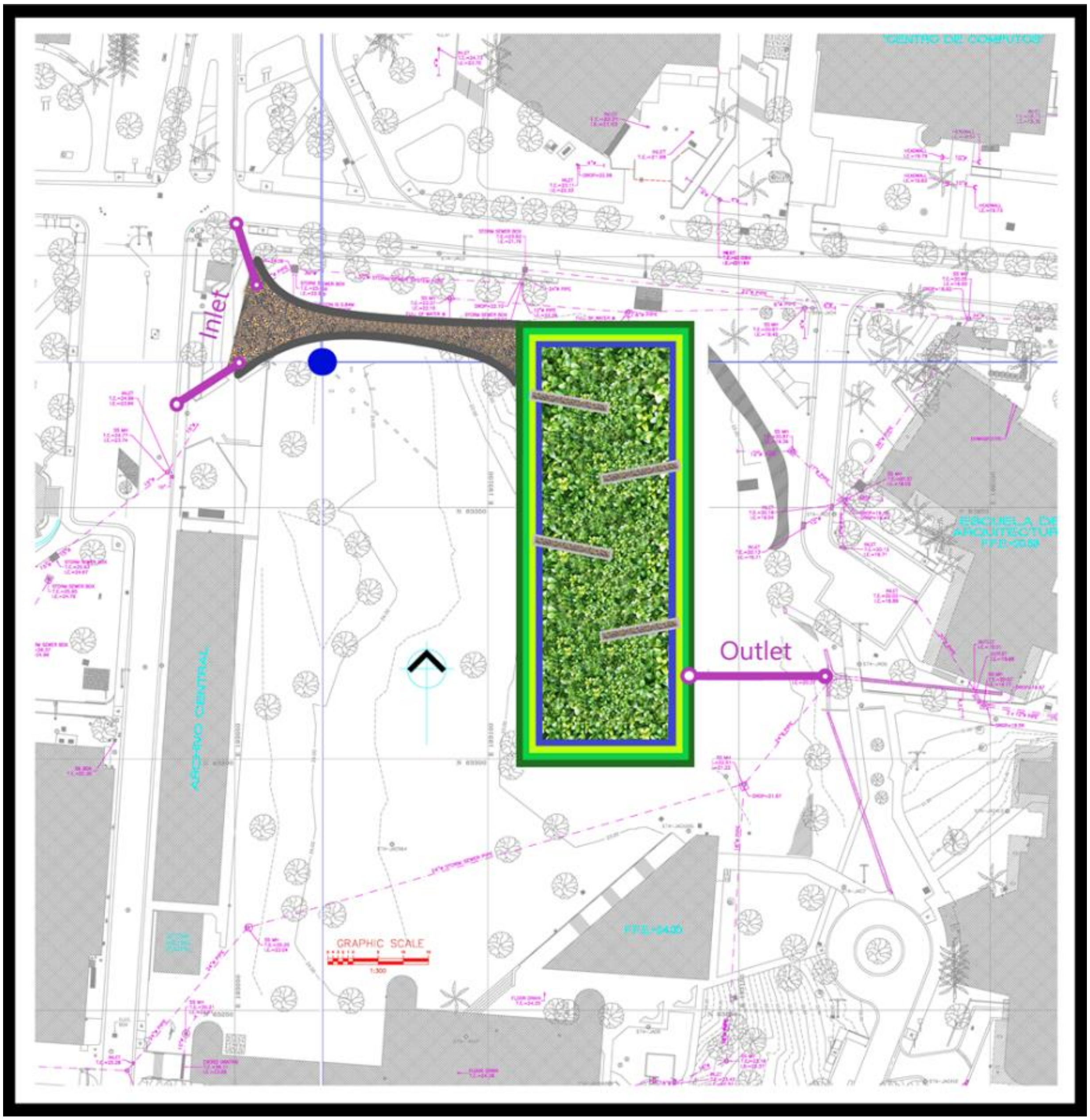


(Source of Base Map: UPRPR Stormwater Management Program)

The goal of turning this constructed wetland into a biofuel wetland creates an educational opportunity to increase student participation by tasking them with maintenance, harvest, and biofuel production with the supervision of qualified faculty members. If biofuel production from this wetland becomes sustainable enough to produce significant amounts of fuel, the UPRRP could even consider reimagining the original student trolley system into a self-sufficient ecologically friendly trolley powered by biofuel produced in-house.

Figure 34 illustrates the stormwater wetland design for the Centenary Park drainage area. Like the stormwater wetland design for the ROTC Parking Lot drainage area in Figure 32, this wetland design also includes embankments designed to redirect stormwater runoff down a winding path. These embankments are made of gabion walls filled with stones much like those in the Renaissance Park case study and the ROTC Parking Lot constructed wetland design. This design is desirable for increasing stormwater retention time while decreasing velocity. The inlet consists of a long French drain style trench filled with a perforated pipe and crushed stone or gravel that allows water to drain naturally. This inlet is meant to receive stormwater runoff deviated from the gutters surrounding the perimeter of the park. The water then fills the wetland, and any overflow then discharges through the outlet into the UPRRP stormwater system that eventually empties into the Juan Mendez Creek.

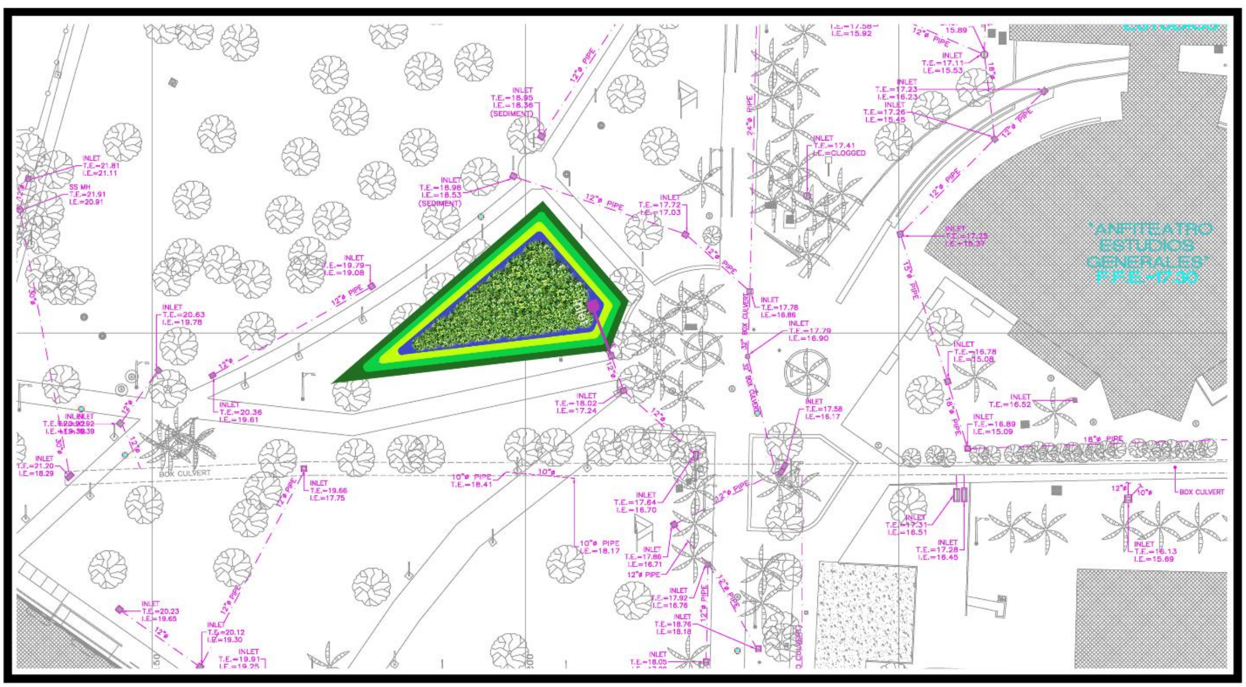
Figure 34. Stormwater Wetland Design for the Centenary Park Drainage Area



(Source of Base Map: UPRPR Stormwater Management Program)

Lastly, Figure 35 shows what the stormwater wetland design for the university center rear drainage area would look like. In contrast with the stormwater wetland design for the other sites, this wetland doesn't have a specific inlet structure that is used to redirect water from the UPRRP stormwater system or a natural body of water like the Juan Mendez Creek. This wetland will rely solely on the rainwater that falls inside and the runoff that naturally flows through this point. The wetland will also use the outlet already set in place by the UPRRP stormwater sewer system that eventually discharges into the Jun Mendez Creek. The wetland design for this location is smaller than the other constructed wetland designs because the space available is fractioned by existing infrastructure. The space available for wetland development only allows for a pocket-sized gravel wetland design in a triangular shape that could make the placement of gabion walls awkward and would reduce even further the retention capacity of the system.

Figure 35. Stormwater Wetland Design for the University Center Rear Drainage Area



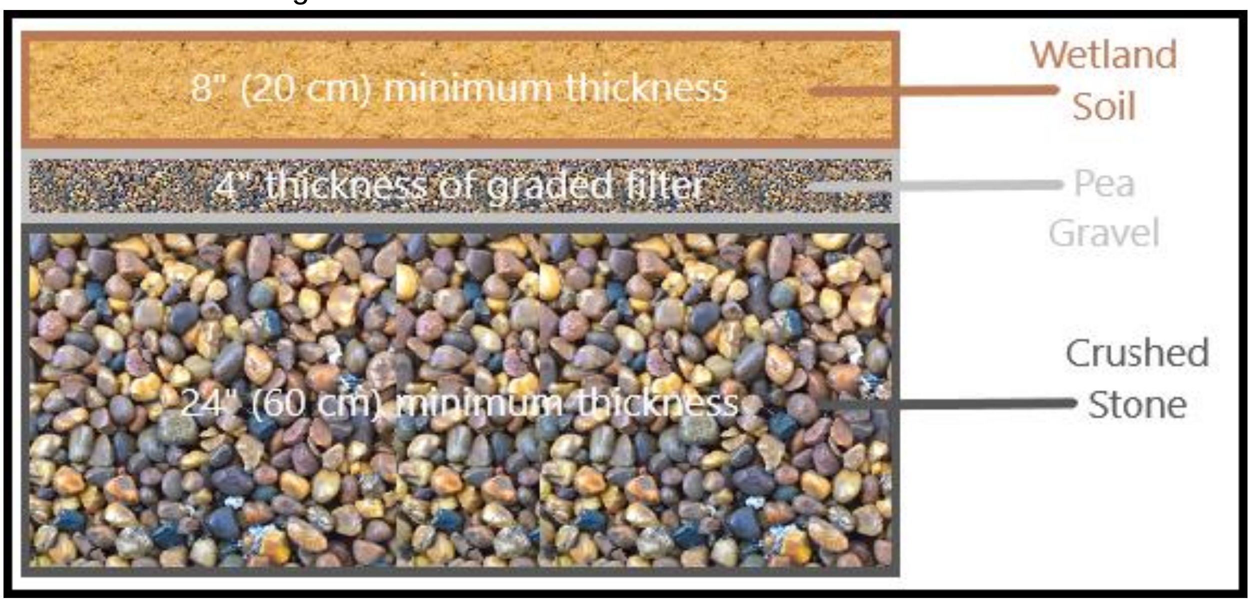
(Source of Base Map: UPRPR Stormwater Management Program)

These constructed wetland systems designed for the UPRRP campus are meant emulate a pond wetland and gravel wetland combination design. The constructed wetland systems consist of roughly 3 feet in depth of open storage space blow normal ground level. Excavations would remove 6 feet of soil and then they will be filled halfway with various materials chosen to promote infiltration, subsurface flow, and sustain wetland vegetation. To maximize retention of water within the stormwater wetlands, the ground must be prepared. The excavated site must then be filled in with about 2 feet of crushed stone, 1/3 foot of pea gravel, and around 2/3 foot of rich wetland soil. The volumes of each material needed to fill the excavated site to prepare the stormwater wetlands are summarized below in Table 13 in the proportions mentioned before and Figure 36 illustrates what a cross section of this material would look like and its composition.

Table 13. UPRRP Stormwater Wetland Site Soil, Pea Gravel, and Crushed Stone Volumes

Drainage Area	Soil	Pea Gravel	Crushed Stone
Facundo Bueso	3,300 ft^3	1,650 ft^3	10,000 ft^3
Centennial Park	8,500 ft^3	4,225 ft^3	25,600 ft^3
University Center Rear	2,500 ft^3	1,270 ft^3	7,160 ft^3
ROTC Parking	36,300 ft^3	18,150 ft^3	110,000 ft^3
Faculty Residence	70,500 ft^3	23,265 ft^3	141,000 ft^3
Total:	121,100 ft^3	48,560 ft^3	293,760 ft^3

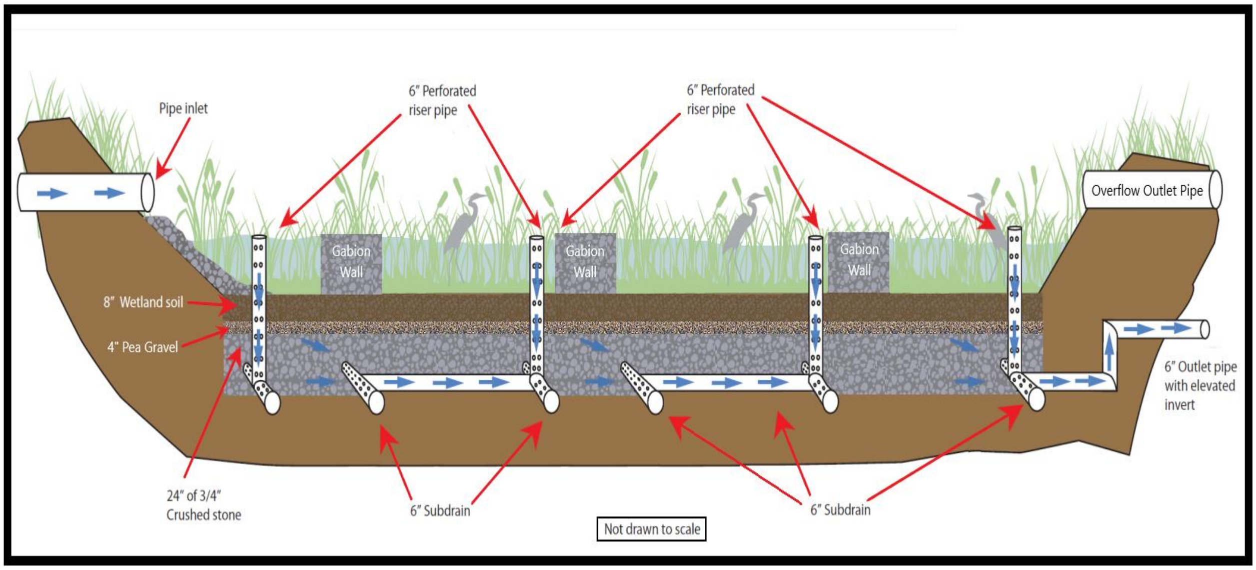
Figure 36. Gravel Wetland Materials Cross Section



(Not drawn to scale)

The cross section of the materials belonging to a gravel wetland in Figure 36 are modeled after the gravel wetlands developed by the UNHSC in the University of New Hampshire case study. The wetlands in this case study heavily influenced the design of the constructed wetlands intended for the UPRRP campus. Figure 37 is a cross section of the constructed stormwater wetlands proposed by this study for the UPRRP main campus. In this figure the wetland design features gabion walls which are not included in each of the 5 constructed wetland designs. The wetland designs that include gabion walls are meant to prolong retention time and extend the treatment process.

Figure 37. UPRRP Constructed Stormwater Wetland Design Cross Section



As with all constructions, the cost factors for stormwater wetlands may vary depending on design, location, and site conditions. The availability of materials for construction, the cost of excavation and grading, maintenance, inspection, as well as the land costs are also significant factors in determining total cost estimates for stormwater wetlands. Technologies such as infiltration trenches may be considered more cost-effective in smaller drainage areas due to construction and long-term maintenance costs (Young et al.,1996). Project costs can be lowered if existing pre-construction site conditions are carefully considered and isolated areas with hydric (wet) soils contained within the project are utilized as stormwater management facilities (Minnesota Stormwater Steering Committee, 2005). To ensure the establishment of the wetland ecosystem additional maintenance may be necessary. These maintenance tasks include culling invasive plants and replacing dead plants. The outlet structures may also need to be adjusted, depending on seasonal observations, to achieve the proper water surface in the pond (FHWA, 1997).

The cost estimate worksheet listed in Table 14 for the constructed stormwater wetlands designed for the UPRRP campus for this study. An appropriate technique for determining the cost to construct and maintain a specific BMP is to apply unit costs to each component of construction, operation and/or maintenance (Minnesota Stormwater Steering Committee, 2005). Table 14 is an example of a typical stormwater wetland cost estimate and presents those components of a construction project that are unique to this best management practice. Other costs associated with construction site variations and the costs of acquiring adequate pump systems (which may amount to several hundreds of thousands of dollars) are not presented in this table. The estimate in Table 14 is therefore below the actual cost of implementing the constructed wetland systems proposed by this study.

Table 14: Stormwater Wetland Cost Estimate Summary for the UPRRP Campus

Implementation Stage	Primary Cost Component	Units	Quantity	Unit Cost	Estimated Price
Site Preparation	-Tree removal -Clear and grub brush	Each Square yard	50 15,000	\$490.00 \$2.10	\$24,500 \$31,500
Site Formation	-Excavation -Grading	Square yard Square yard	16,000 16,000	\$7.00 \$2.10	\$112,000 \$33,600
Structural Components	-Inlet structure -Outlet structure -Pump	Each Each ---	5 5 --	\$2,800 \$4,900 ---	\$14,000 \$24,500 ---
Site Restoration	-Sod -Soil preparation -Planting	Square yard Square yard Square yard	5,000 15,000 15,000	\$6.30 \$35.00 \$42.00	\$31,500 \$525,000 \$630,000
					Subtotal: \$1,426,600

(Suggested unit costs are based on typical design features for Constructed Wetlands BMPs from RS Means prices for Spring, 2005, used by the Minnesota Stormwater Steering Committee in the Minnesota Stormwater Manual. These preliminary cost estimation values were updated using a CPI inflation calculator provided by the U.S. Department of Labor. The CPI inflation calculator uses the Consumer Price Index for All Urban Consumers U.S. city average series for all items. This data represents changes in the prices of all goods and services purchased for consumption by urban households.)

To demonstrate how much the cost factors for stormwater wetlands can vary, a cost estimate summary from a U.S. based company is listed in Table 15. The cost estimate is for a much simpler design than the one being proposed by this study consisting of a pond or basin type constructed wetland. The Wisconsin Lake & Pond Resource LLC company, founded in 2005, works with individuals, corporations, property managers, homeowners' associations, lake associations, municipalities, and campground owners. The pricing provided is an online estimation for budgeting purposes only and does not take into consideration location or site conditions.

Stormwater ponds may look like a wetland and may even have wetland vegetation and wetland wildlife, but they are not natural water bodies, they do not behave like natural bodies of water, and they should not be treated as such. Many differences exist between natural water bodies and constructed ponds. Their water levels can change by several feet whereas most natural water bodies normally have constant water levels (Minnesota Stormwater Steering Committee, 2005). Stormwater ponds are often built to capture sediment from runoff. As a result, sediment may accumulate quickly in the pond sometimes containing pollutants. Grading and sculpting microtopography are not necessary for a stormwater pond nor are they intended to be used for recreational purposes.

Table 15. Stormwater Pond Cost Estimate Summary for UPRRP Campus

Location	**Pond Size (sq ft)**	**Water Source**	**Excavation**	**Estimated Total**
Facundo Bueso	8,000 ft^2	Runoff & Pump	$10,000	$28,400
Centennial Park	13,000 ft ^2	Runoff	$15,000	$27,400
University Center	4,000 ft^2	Runoff	$10,000	$22,400
ROTC Parking	22,000 ft^2	Runoff & Pump	$30,000	$94,400
Faculty Residence	45,000 ft^2	Runoff	$40,000	$135,400
			Subtotal:	$308,000

Conventional wet basin systems require large-scale sediment removal at infrequent intervals. On the other hand, constructed stormwater wetlands require small-scale maintenance at regular intervals to evaluate the health and composition of the plant species. This mean maintenance plans must include careful observation of the constructed stormwater wetland system over time to ensure successful establishment. The first three years after construction, inspect the constructed stormwater wetlands various times throughout the year, especially during both the growing and non-growing seasons. This requirement must be included in the Operation & Maintenance plan. During these inspections, record and map the following information:

- The presence and distribution of planted wetland species
- The presence and distribution of invasive wetland species (must be removed)
- Percentage of unvegetated standing water
- Stability of the original depth zones and the micro-topographic features
- Accumulation of sediment in the forebay and micro-pool
- Survival rate of plants (cells with dead plants must be replanted)

Another important maintenance activity is monitoring and regulating the sediment loading into the constructed stormwater wetland. Sediment accumulating in wetlands can have several detrimental effects over the effectiveness of the system. It reduces water depths, changes the growing conditions for emergent plants, and can seriously alters the wetland plant community. A sediment forebay is used to trap and remove debris in a basin before it reaches the wetland.

For a stormwater wetland to operate as it was intended to on a long-term basis maintenance is of great importance. A summary of annual operation and maintenance tasks are listed in Table 16. The ability to remove pollutants, protect channels, and control flooding may decrease in stormwater wetlands for several reasons. These include debris blocking outlet structures, damaged pipes, invasive plants outcompeting the wetland plants, sediment accumulation, loss of critical wetland vegetation, and if the structural integrity of the embankment or weir is compromised (Minnesota Stormwater Steering Committee, 2005).

Maintenance activities for stormwater wetlands can range in terms of the level of effort and expertise required to perform them. Routine maintenance is needed multiple times each year but can even be performed by citizen volunteers (e.g., mowing and removing debris). Maintenance requiring greater effort and expertise is required less frequently but may need special equipment. Inspection and repair of critical structural features must be performed by a qualified professional that has experience (e.g., structural engineer).

Table 16. Constructed Wetland Annual Operation and Maintenance Tasks

Operation and Maintenance	Units	Unit Cost
Debris removal	per visit	$140.00
Remove invasive plants	per visit	$700.00
Replant wetland vegetation	per plant	$14.00
Repair erosion	square yard	$105.00
Sediment removal and disposal	cubic yard	$14.00
Mow	per visit	$210.00
Gate / valve operation	per visit	$175.00
General Inspection	per visit	$175.00

(Suggested unit costs are based on typical maintenance operations for Constructed Wetlands BMPs adapted from RS Means prices for Spring, 2005, Source of Data: Minnesota Stormwater Steering Committee in the Minnesota Stormwater Manual.)

In addition to regular maintenance activities needed to maintain the function of a constructed stormwater wetland, other features designed to ease the maintenance burden of each wetland can be incorporated. Constructed wetland maintenance reduction features include techniques to reduce the need for maintenance and techniques to make regular maintenance activities easier. These maintenance reduction features include:

- Outlets designed with non-clogging features, such as a weir, trash racks for culverts, and orifice openings.
- To prevent clogging from floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.
- Pools should have a manually operated drain to draw down the pond for infrequent maintenance or dredging of the main cell of the pond.

- Metal components of outlet structures should be corrosion resistant, but not galvanized due to the contribution of zinc to water (Washington, 2000).

Maintenance post-construction is important to the performance and long-term integrity of a stormwater wetland. Potential problems due to lack of maintenance include clogged outlet structures that can increase water levels, killing vegetation and reducing the wetland's ability to attenuate and store floods (Minnesota Stormwater Steering Committee, 2005). According to the Minnesota Stormwater Manual, water quality can be compromised by not providing adequate storage time and excess sediment can reduce storage volumes leading to many of the problems outlined above.

It is recommended that adequate access must be provided for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles such as a maintenance right of way or easement extend to ponds from a public or private road (CWP, 2004). Sediments removed from stormwater wetlands that do not receive runoff from confirmed hotspots are generally not considered toxic or hazardous material and can be safely disposed by either land application or land filling (Minnesota Stormwater Steering Committee, 2005). Some important general post construction inspection and maintenance activities and schedules are provided in the Table 17 below.

Table 17. Typical Stormwater Wetland Inspection/Maintenance Frequencies

Inspection Items	Maintenance Items	Frequency
- Remote television inspection of reverse slope pipes, underdrains, and other hard to access piping	- Sediment removal from main wetland - Pipe replacement if needed	5-25 years
- Monitor wetland plant composition and health. - Identify invasive plants - Assure mechanical components are functional	- Trash and debris clean-up day - Remove invasive plants - Replant wetland vegetation - Repair broken mechanical components	Semi-annual to annual
- Monitor sediment deposition in facility and forebay	- Forebay maintenance and sediment removal when needed	2-7 years or 50% loss of sediment forebay storage
- Inspect low flow orifices and pipes for clogging - Check the permanent pool area for floating debris and undesirable vegetation.	- Mowing - Remove debris - Repair undercut, eroded, and bare soil areas.	Monthly to Quarterly or After Storms (>1")

- Investigate the shoreline for erosion - Monitor wetland plant composition and health. - Look for broken signs, locks, and other dangerous items.		
- Ensure that at least 50% of wetland plants survive. - Check for invasive wetland plants.	- Replant wetland vegetation	One time - After First Year
- All routine inspection items above Inspect riser, barrel, and embankment for damage - Inspect all pipes - Monitor sediment deposition	- Pipe and Riser Repair - Forebay maintenance and sediment removal when needed	Every 1 to 3 years

(Source: Minnesota Stormwater Steering Committee, 2005)

Nuisance issues such as mosquito control is of particular concern within stormwater wetlands located in tropical regions where vector borne diseases such as Dengue, Chinkungunya, and Zika threaten public health. Stormwater wetlands may be designed, constructed, and maintained to minimize the likelihood of mosquito populations establishing themselves. No design is capable of eliminating the risk mosquito populations establishing themselves completely, therefore alternative pest control management options may be implemented. In addition to designs that incorporate constant inflow and outflow movement, habitat for natural predators, and constant permanent pool elevations; certain mosquito repelling wetland vegetation species may be used to control mosquito populations. The ecological risks associated with the use of mosquito control chemicals must be offset by the increased habitat benefits provided by these constructed wetlands (Knight et al., 2003). According to Knight et al., the right balance between these competing goals can be recognized by the design that provides the greatest net environmental and societal benefit.

The use of pesticides and fertilizers in the UPRRP is controlled by the Division of Ornamentation of the Facility Maintenance Department. This division uses the best available techniques to reduce pest populations to acceptable levels while minimizing the impact of pesticides on humans and the environment. Should mosquito control become necessary as a result of the constructed wetlands around the campus, the Division of Ornamentation of the Facility Maintenance Department may be tasked with the application of pesticides as they see fit. Pesticide application within the UPRRP is conducted on as needed basis upon work order requested by the affected Department. According to the UPRRP Stormwater Management Program, once per year slow release, non-phosphorous fertilizers are used around the campus as well as a broad leaf herbicide selectively to areas requiring treatment. Lawn maintenance tasks such as mowing, raking, etc. are conducted twice per month.

Another nuisance issue loosely related to mosquito control is the great number of places within the UPRRP prone to accumulation of rainwater. Not only are these small floods unattractive, but they are also potential places for mosquito reproduction and in severe cases may even affect surrounding structures. Figure 38 presents a series of photographs of commonly observed rainwater accumulations within the UPRRP campus. The photographs in Figure 36 are all examples of small floods in and around the Natural Sciences buildings located near the rear entrance of the university. Several spots like this may be found all over the UPRRP campus. These small floods cannot be deviated into a constructed wetland but may be remedied easily with the implementation of pocket wetlands or rain gardens.

Figure 38. Commonly Observed Stormwater Accumulation Within the UPRRP Campus

Figure 38. Commonly Observed Stormwater Accumulation Within the UPRRP Campus (Continuation)

DISCUSSION

More and more, human beings are seeing the effects of climate change, rapid urbanization, and inappropriate urban planning policies all over the world. These effects result in water-related disasters, such as flooding, water pollution and water shortages. Although there are several management practices that may be used to mitigate these disasters, green infrastructure is rarely at the head of that list and should be considered whenever possible. An urban water management strategy known as Sponge City can serve as the inspiration for the shift toward green infrastructure in urban planning, much like the project being proposed in this paper. A Sponge City is a complex method that has four main principles, these being: urban water resourcing, ecological water management, green infrastructures, and urban permeable pavement (Xia et al., 2017). While this study does not propose altering pavements within the UPRRP, it does hope to promote actively using more green infrastructures, urban water resourcing, and ecological water management. To obtain the multi-ecosystem services of a Sponge City, it should be implemented at the watershed scales and be flexible, depending on different decision levels or catchment characteristics (Xia et al., 2017).

In this work, the goal was to evaluate the opportunities for alternative stormwater management practices within the UPRRP main campus and propose a plan that integrates constructed wetlands to promote green infrastructure among other universities and communities within Puerto Rico. The study had several findings that guided the design of the green infrastructure proposed. First, the UPRRP main campus has a town-like composition much like the composition of the municipality of San Juan, it is not at present in any danger of flooding nor is it located within a flood prone area. Second, the UPRRP main campus has several prime locations for large scale constructed wetlands to be developed and studied, thus providing other universities and surrounding communities with tangible real-world examples of alternative stormwater management practices within the tropics, backed by scientific data produced by students and faculty of the UPRRP. Finally, results suggest although the initial investment into implementing these changes to the UPRRP stormwater management program may be great, the benefits, educational opportunities, and community recognition resulting from the development of green infrastructure on campus far exceed that cost. Below, the significance of these findings are discussed, taking into consideration other studies and the implications for green infrastructure planning.

Much like the green roofs in the UPRRP, another example of green roof infrastructure being used in Puerto Rico is the green roof above the Cuartel de Ballajá. This eco-friendly garden covers 24,000 square feet above one of the most emblematic buildings in San Juan. This green roof has more than 24 species of plants, including bloodroot, liriope, aloe, rosemary, lemongrass, mint, purple basil, chives and succulent plants. Some of these plants include wetland vegetation species. The water used by this irrigation system is recirculated from the pond where over five varieties of fish and aquatic plants can be found (Montcourt, 2021). The roof of the Cuartel de Ballaja is also home to photovoltaic panels that are part of an energy efficiency project. The executive director of the State Office for Historic Conservation, Carlos A. Rubio Cancela explained, “The Mirador Ballajá Garden arises as part of an energy efficiency project started in 2010 to 2011. It consists of a main path that leads to three observation points-platforms that look at different sides of the city and the city. entrance of the Bay of San Juan”. This garden is especially significant because it shows there is interest and willingness to develop green infrastructure within urban spaces and even urban historical spaces.

On the other hand, tree planting has always been marketed as a go-to solution to increase ecosystem services provision, mitigate, and adapt to extreme events such as climate change, increasing temperatures, extreme flooding, and biodiversity conservation. In this study, a more comprehensive plan is proposed to integrate green infrastructure in conjunction with existing gray infrastructure to better manage stormwater resources within the UPRRP main campus. The importance of the potential benefits provided by the services green infrastructure could render in the region go beyond natural hazard moderation, flood control, erosion control, and carbon sequestration. These benefits often go unrecognized by surrounding communities and the government, which is why the UPRRP has such a great opportunity to educate and lead by example in the field of stormwater management. Beyond the benefits that directly benefit human beings there are several benefits that directly impact local fauna. The most important of these benefits is the habitat that is created as a result of building these constructed wetlands.

The University encourages public input in all aspects of its stormwater management program. In order to facilitate public participation, the official stormwater management plan and any information related to the program are made available through OPASO and their web site. When new stormwater management program plans are developed and finalized by the UPRRP, the City, Rio Piedras Public Schools, and any interested local stream and watershed protection organizations are allowed to review and comment on them. Any comments received will be reviewed and evaluated for inclusion in the Stormwater Management Program by OPASO and a reply to the comments submitted will be provided documenting the outcome. The UPRRP tries to offer volunteer opportunities for participants to get involved with stormwater improvement and education programs.

According to the UPRRP Stormwater Management Program, examples of these opportunities include storm drain stenciling/marking and invasive species removal projects. Should the university decide to incorporate constructed wetlands into their stormwater management system the opportunity for public input and involvement would increase greatly. In particular, the opportunity for public involvement in the biofuel production constructed wetland is possible in various phases of management. This wetland needs volunteer work for the planting stage, frequent inspection, regular maintenance, and harvest. Once the biomass is harvested, an entirely new educational opportunity begins by teaching the process of biofuel production.

Studies suggest that in the Rio Piedras watershed, different services may be prioritized differently according to the space therefore, such information should be considered to develop green infrastructure plans. For example, food provision and shade services by trees are more often recognized at the household scale than at the neighborhood scale, while air purification and aesthetic services are more often recognized at the neighborhood scales (Olivero et al., 2020). With this in mind strategies can be developed to maximize ecosystem services within the constructed wetland and minimize and potential disservices. Widely acknowledged disservices including property/structural damage (e.g., pipes, sidewalks, house), power line obstruction, and maintenance hardships, could be addressed by adequate site and species selection and appropriate management. None of the 5 locations chosen to develop a constructed wetland system within the university would cause any existing structures to suffer damages due to any of the plant species recommended for wetland systems. Power line obstruction and maintenance hardships should not be a problem either in any of the proposed locations. These locations were chosen because they possess ample room for development, ease of access, and favorable topographical features.

One could speculate that the recognition of vegetation as problematic could increase due to negative experiences, and that perceptions of disservices associated with vegetation may change as a result (Olivero et al., 2020). Puerto Rico has been subjected to important social and ecological events that have been accompanied by profound demographic changes. Prolonged droughts and catastrophic hurricanes may have changed the values of island residents. Many may believe it is better to limit the debris created by an even such as Hurricane Maria in 2017 and choose to reduce the amount of vegetation in their surroundings. The development of constructed wetlands could serve to alter negative perceptions about vegetation by developing services that can be witnessed by any member of the community.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The UPRRP should reduce its environmental impact through mitigating its stormwater runoff. With this decision, UPRRP has the opportunity to be a leader in sustainable stormwater management among universities and within Puerto Rico. This plan to introduce green infrastructure within the UPRRP campus serves as a first step and sets the stage for a comprehensive management approach that will gradually build on the knowledge gained during each phase of the management effort. The dynamics of urban tropical regions within the Río Piedras Watershed will continue to shed light on the complexities that characterize these systems. With each stormwater planning period, further progress will be made towards a campus that reduces the impact of its stormwater runoff on the environment.

The University should implement stormwater management strategies that prioritize infiltration of stormwater where it flows, storage for infiltration or reuse, and temporary retention and gradual release of stormwater to the Juan Mendez Creek and the city of San Juan's separate storm sewer systems. The UPRRP must envisions a campus where stormwater runoff is reduced sustainably through green infrastructure. To move toward this vision, this plan advocates for investment in green infrastructure within a comprehensive manner throughout the campus. The UPRRP must manage stormwater as a resource in order to enhance its positive effects on the environment and to reduce associated risks to UPRRP assets and infrastructure. Sustainable stormwater management principles recognize stormwater as a resource, prioritize the restoration of watershed functions, promote stormwater research, and incorporate adaptive management. The UPRRP already encourages university-wide participation and stewardship of stormwater management strategies on campus and is commited to collecting and sharing data used in all decision-making process for ongoing stormwater management.

The suggestions for further research and work mentioned here are not prioritized in any order but may be grouped together into similar opportunities. The UPRRP could conduct research on the operational evaluation of long-term performance and cost-effectiveness of constructed wetlands in the tropics, as well as an evaluation of constructed wetland pollutant removal efficiencies. The UPRRP could also develop an official operational and maintenance handbook and inspection routines for constructed wetlands in the tropics based on the knowledge gained during each phase of development and management. A life-cycle assessment is necessary to identify plant replacement requirements, frequency, and costs. Issues related to wetland naturalisation and species colonisation are also very interesting research opportunities with real world applications. Further research opportunities exist in the study of pesticide degradation, pollutant pathways, and plant uptake within constructed wetlands in the tropics. Research may be conducted at all levels from macroscopic to microscopic, including bacterial and pathogen pathways, exposure, degradation and resuscitation and uptake rates in sediments, plants, insects, invertebrates, and other wildlife associated with constructed wetland systems.

Wetland design and management may also be studied from an anthropogenic or social perspective. For example, the role of constructed wetlands in urban areas and in conjunction with conventional drainage systems. The issues surrounding wetland adoption and liability of long-term wetland management, as well as public attitudes and behavioural surveys of local needs for urban wetland systems are great research opportunities that could expand to include community involvement. As mentioned before, the design of the constructed wetlands is open to suggestions and may be altered to improve system services.

Although a design is proposed in this study, there is also an opportunity to collaborate with the UPRRP community in the design process that may give rise to alternative wetland designs that take into account other aspects not considered by this study. This opportunity may also provide a platform for creative expression through wetland landscaping that may incorporate features more aesthetically pleasing. Collaboration in the design phase of this process may also aid in promoting community involvement throughout the harvest and maintenance phases of management. Finally, research may be conducted into community attitudes towards wildlife, ecological issues associated with constructed wetlands, and means of combating vandalism.

Natural wetlands are important components of our rich natural resources. Therefore, more efforts should be made to replace wetlands lost to development through wetland creation and restoration. Stormwater wetlands and treatment wetlands may also be designed and constructed to control the adverse effects of excessive stormwater runoff flows and to use their natural ability to reduce pollutants in water. Scientists and engineers must continue to study the best way to build successful wetlands so these resources can provide the most services to society. Unfortunately, wetlands are often misunderstood or ignored by many of the people they serve. It is hoped this study will help to spot these wetlands, identify whether they are natural or manmade, and enjoy the services they provide.

REFERENCES

American Association of State Highway and Transportation Officials, Highway Drainage Guidelines. Washington, D.C. (1992).

American Society of Civil Engineers (ASCE), Design and Construction of Urban Stormwater Management Systems. Manuals and Reports of Engineering Practice No. 77, New York, New York. (1992).

Bahlo, K. E., and F. G. Wach. "Purification of domestic sewage with and without faeces by vertical intermittent filtration in reed and rush beds." Constructed wetlands in water pollution control. Pergamon, 1990. 215-221.

Ballestero, Thomas P., James J. Houle, and Timothy A. Puls. "UNHSC Subsurface Gravel Wetland Design Specifications." (2016).

Beard, JS. Natural vegetation of the windward and leeward Islands. Oxford Forestry Memoirs 21:1-192. (1949).

Benedict, Mark A., and Edward T. McMahon. "Green infrastructure: smart conservation for the 21st century." Renewable resources journal 20.3 (2002): 12-17.

Beven, Keith, and Peter Germann. "Macropores and water flow in soils." Water resources research 18.5 (1982): 1311-1325.

Blossom, J. “Impervious surfaces and stormwater billing”. GeoSpatial Solutions, 14(8), 28. (2004).

Brix, Hans. "Functions of macrophytes in constructed wetlands." Water Science and Technology 29.4 (1994): 71-78.

Brix, Hans. "Do macrophytes play a role in constructed treatment wetlands?" Water science and technology 35.5 (1997): 11-17.

Brix, Hans. "Plants used in constructed wetlands and their functions." In 1st International Seminar on the use of Aquatic Macrophytes for Wastewater Treatment in Constructed Wetlands, edit. Dias V., Vymazal J. Lisboa, Portugal, pp. 81-109. (2003).

Caribe Environmental Services. “Storm Water Management Program (Swmp) University of Puerto Rico Humacao Campus”. CES PROJECT NO. 06-0045C. https://www.upr.edu/humacao/mdocs-posts/programa-de-manejo-de-aguas-de-escorrentia-de-uprh-stormwater-management-program/. (2007).

Carleton, J.N., Grizzard, T.J., Godrej, A.N., and Post, H.E., 2001, Factors Affecting the Performance of Stormwater Treatment Wetlands, Water Research, Volume 35, No. 6, pp 1552-1562

Center for Watershed Protection. “Stormwater Pond and Wetland Maintenance Guidebook”. (2004).

Comarazamy, D.E.; González, J.E.; Luvall, J.C.; Rickman, D.L.; Bornstein, R.D. Climate impacts of land-cover and land-use changes in tropical islands under conditions of global Climate change. J. Clim. (2013), 26, 1535–1550.

Consumer Reports. Why Flooded-Out Cars Are Likely Total Losses. 2018. Source: https://www.consumerreports.org/car-insurance/whyflooded-out-cars-are-likely-total-losses/

Cook, E. A. “Green site design: Strategies for storm water management”. Journal of Green Building, 2(4), 46-56. (2007).

Daly, Christopher, Eileen H. Helmer, and Maya Quiñones. "Mapping the climate of PUERTO RICO, VIEQUES and CULEBRA." International Journal of Climatology: A Journal of the Royal Meteorological Society 23, no. 11 (2003): 1359-1381.

Damodaram, C., Giacomoni, M. H., Prakash Khedun, C., Holmes, H., Ryan, A., Saour, W., & Zechman, E. M. “Simulation of combined best management practices and low impact development for sustainable stormwater management”. Journal of the American Water Resources Association, 46(5), 907-918. doi:10.1111/j.1752-1688.2010.00462.x. (2010).

Duke Office Of Sustainability. “Reclamation Pond”. Source: https://sustainability.duke.edu/campus-lab-under-construction/cal-endorsed-sites/reclamation-pond. (2018).

Echols, Stuart, and Eliza Pennypacker. "From stormwater management to artful rainwater design." Landscape Journal 27.2. (2008): 268-290. doi: 10.3368/lj.27.2.268

Federal Highway Administration. "Ultra-Urban Best Management Practices". FHWA Ultra Urban BMP Manual. Washington, D.C. (1997).

FEMA. National Flood Hazard Layer. National Flood Insurance Program. Source: https://www.fema.gov/flood-maps/national-flood-hazard-layer

Foundation for Puerto Rico. Mapas de vulnerabilidad y riesgo: Área de Infraestructura - Tema 2.0: Sistema de manejo de aguas pluviales. Programa de Planificación Integral para la Resiliencia Comunitaria.Source:https://wcrp.maps.arcgis.com/apps/MapSeries/index.html?appid=dfb07ae5c91846caa34424c1e6fd4aaf&folderid=b1abaca4798347e8bb502bbae3fcc0ff

Froehlich, David C. "Sizing Small Stormwater Pump Stations." JAWRA Journal of the American Water Resources Association 30.6 (1994): 1055-1062.

Gillard, Steven R. "Comprehensive Stormwater Management Plans on University Campuses: Challenges and Opportunities." (2011).

Gómez-Gómez, Fernando, Jesús Rodríguez-Martínez, and Marilyn Santiago. Hydrogeology of Puerto Rico and the outlying islands of Vieques, Culebra, and Mona. US Department of the Interior, US Geological Survey, (2014).

Gómez-Gómez, Fernando, Rodríguez-Martínez, Jesús, and Santiago, Marilyn, 2014, Hydrogeology of Puerto Rico and the outlying islands of Vieques, Culebra, and Mona: U.S. Geological Survey Scientific Investigations Map 3296, 40 p. plus 2 pls., https://dx.doi.org/10.3133/sim3296.

Grehl, E., & Kauffman, G. "The University of Delaware rain garden: Environmental mitigation of a building footprint". Journal of Green Building, 2(1), 53-67. (2007).

Grullón–Penkova, Iana F., Jess K. Zimmerman, and Grizelle González. "Green roofs in the tropics: design considerations and vegetation dynamics." Heliyon 6.8 (2020): e04712.

Hargreaves, George J. Czerniak, A. Berrizbeitia, L. Campbell Kelly, "Landscape Alchemy: The Work of Hargreaves Associates," ORO Editions, 2009.

Hernández Ayala, José J. & Matyas, Corene J. "Spatial distribution of tropical cyclone rainfall and its contribution to the climatology of Puerto Rico". Physical Geography. (2018). 39:1, 1-20, DOI: 10.1080/02723646.2017.1354416.

Holdridge, L.R. Life zone ecology. San José, Costa Rica: Tropical Science Center. 1967.

Hughes, Mary and Michael Geffel. "The Dell at the University of Virginia." Landscape Performance Series. Landscape Architecture Foundation, 2011. https://doi.org/10.31353/cs0090

Jensen Engineered Systems (JES), Pump Station Design Guidelines – Second Edition, 2012, Jensen Precast, Source: https://www.jensenprecast.com/water-resources/wp-content/uploads/2020/05/Design-Guidelines-Pump-Stations.pdf

Klein-Banai, Cynthia, and Thomas L. Theis. "An urban university's ecological footprint and the effect of climate change." Ecological Indicators 11.3 (2011): 857-860.

Kloss, C., & Calarusse, C. "Rooftops to rivers: Green strategies for controlling stormwater and combined sewer overflows". Natural Resources Defense Council. (2006).

Knight, Robert L., William E. Walton, George F. O'Meara, William K. Reisen, and Roland Wass. "Strategies for effective mosquito control in constructed treatment wetlands." Ecological Engineering 21, no. 4-5 (2003): 211-232.

Landscape Architecture Foundation. "Menomonee Valley Redevelopment and Community Park." Landscape Performance Series. Landscape Architecture Foundation, 2010. https://doi.org/10.313

Larsen, Matthew C. "Analysis Of 20th Century Rainfall And Streamflow To Characterize Drought And Water Resources In Puerto Rico". Physical Geography. (200). 21:6, 494-521, DOI:10.1080/02723646.2000.10642723.

Liu, Dong, Changxin Zou, and Mengjia Xu. "Environmental, ecological, and economic benefits of biofuel production using a constructed wetland: a case study in China." International journal of environmental research and public health 16.5 (2019): 827.

López Pérez, Stephanie L., “Residentes Expresan su Preocupación con la Canalización del Rio Piedras”, June 5, 2021, Source: https://www.elnuevodia.com/ciencia-ambiente/otros/notas/preocupa-la-canalizacion-del-rio-piedras/

Lugo, Ariel E., Olga Ramos, and Carlos Rodriguez. "The Río Piedras watershed and its surrounding environment." FS-980. US Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 46 p. 980 (2011).

Massachusetts Department of Environmental Protection. “Massachusetts stormwater handbook”. Retrieved from http://www.mass.gov/eea/agencies/massdep/water/regulations/massachusetts-stormwaterhandbook.html. (2012).

Minnesota Stormwater Steering Committee. “The Minnesota Stormwater Manual”. Developed by Emmons and Olivier Resources for the Stormwater Steering Committee, Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/pyria84. (2005).

Montcourt, Nahira. “El Jardín Mirador: tesoro en la azotea del Cuartel de Ballajá”. EL VOCERO. 06/11/2021. Source: https://www.elvocero.com/actualidad/otros/el-jard-n-mirador-tesoro-en-la-azotea-del-cuartel-de-ballaj/article_db5fd4a8-3ea2-11ec-98c3-a717e763ce1e.html

Morison, Peter J., and Rebekah R. Brown. "Understanding the nature of publics and local policy commitment to Water Sensitive Urban Design." Landscape and urban planning 99.2 (2011): 83-92.

National Oceanographic and Atmospheric Administration, 1982, Climate of Puerto Rico and Virgin Islands, in Climatography of the United States No. 60, 25 p.

National Small Flows Clearinghouse. “Constructed Wetlands Factsheet”. (2004) Purdue On-Site Wastewater Disposal, Agronomy, Purdue University. Source:https://engineering.purdue.edu /~frankenb/NU-prowd/cwetfact.htm

Natural Resources Conservation Service (NRCS). “NRCS Helps Install Rain Garden on UPR Río Piedras Campus.” Caribbean Area NRCS December 2013 Newsletter. USDA Natural Resources Conservation Service. (2014).

New Jersey Department of Environmental Protection, Division of Watershed Management. “New Jersey Stormwater Best Management Practices Manual”. Chapter 5: Computing Stormwater Runoff Rates and Volumes. Source:https://www.njstormwater.org/bmp_manual/NJ_SWBMP_5%20print.pdf. (2004).

Olivero-Lora, Sofia, Elvia Meléndez-Ackerman, Luis Santiago, Raúl Santiago-Bartolomei, and Diana García-Montiel. 2020. "Attitudes toward Residential Trees and Awareness of Tree Services and Disservices in a Tropical City" Sustainability 12, no. 1: 117. https://doi.org/10.3390/su12010117

Petticrew, Ellen L., and Jacob Kalff. "Water flow and clay retention in submerged macrophyte beds." Canadian Journal of Fisheries and Aquatic Sciences 49.12 (1992): 2483-2489.

Picó, R., 1964, Geografia de Puerto Rico: Parte II Geografia Económica: Editorial Universitaria, Universidad de Puerto Rico, Río Piedras, 220 p.

Pivotal Pumps. “How to Calculate Pump Horsepower”, 2021. https://pivotalpumps.com/articles/how-to-calculate-pump-horsepower/

Programa del Estuario de la Bahía de San Juan. “Estuario”. Source: https://estuario.org/cuencas-hidrograficas/

Programa de Planificación Integral para la Resiliencia Comunitaria (WCRP). Mapas de vulnerabilidad y riesgo: Área de Infraestructura. Indicador 2.1: Sistemas de manejo de aguas pluviales. Foundation for Puerto Rico. Source: https://wcrp.maps.arcgis.com/apps/MapSeries/index.html?appid=dfb07ae5c91846caa34424c1e6fd4aaf&folderid=b1abaca4798347e8bb502bbae3fcc0ff

Portland Parks & Recreation. Tanner Springs Park. City of Portland, Oregon. Source: https://www.portland.gov/parks/tanner-springs-park

Ramos-González, O. M. 2014. “The green areas of San Juan, Puerto Rico”. Ecology and Society 19(3): 21. http://dx.doi.org/10.5751/ES-06598-190321

Smith, Peter N. Highway Stormwater Pump Station Design-Hydraulic Engineering Circular 24. No. FHWA-HEC-24. United States. Federal Highway Administration. Office of Bridge Technology, 2001.

Stringam, Blair. Understanding Horsepower and Water Horsepower Efficiency and Fuel Consumption Costs for Irrigation Pumps. NM State University, Cooperative Extension Service, 2013.

Tischa A. Muñoz-Erickson y Ariel E. Lugo. “Cuenca Hidrográfica Y La Ciudad”. Instituto Internacional de Dasonomía Tropical Servicio Forestal Federal Jardín Botánico Sur. Source: http://www.corrienteverde.com/articulos/la%20cuenca%20hidrografica%20y%20la%20ciudad.html

Torres Molina, Luz E., Sara Morales and Fabian Carrion. "Measuring UHI in Puerto Rico." 2018. Source: http://laccei.org/LACCEI2020-VirtualEdition/full_papers/FP47.pdf

Torres-Valcárcel, Ángel, et al. "Impacts of urban development on precipitation in the tropical maritime climate of Puerto Rico." Climate 2.2 (2014): 47-77.

UNH Stormwater Center. “Gravel Wetland Fact Sheet”. www.unh.edu/erg/cstev/fact_sheets/gravel_wetland.pdf. (2005).

United States Department of Labor. “CPI Inflation”. Calculator U.S. Bureau Of Labor Statistics. Source: https://www.bls.gov/data/inflation_calculator.htm. (2021).

University of Puerto Rico, Rio Piedras Campus. “Stormwater Management Program”. (2018).

Wisconsin Lake & Pond Resource. 2021. “Pond Calculator”. Pond Cost Calculator. Wisconsin Lake & Pond Resource, LLC. Source: https://www.wisconsinlpr.com/pond-calculator/.

Shuler, Thomas, 1992. Design of Stormwater Wetlands Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Middle Atlantic Regions, Metropolitan Washington Council of Governments, Washington, D.C.

Suda, Katherine, Abolghasem Shahbazi, and Yebo Li. "The feasibility of using cattails from constructed wetlands to produce bioethanol." Proceedings of the 2007 National Conference on Environmental Science and Technology. Springer, New York, NY, 2009.

Young, G Kenneth, Stuart Stein, Pamela Cole, Traci Kammer, Frank Graziano, Fred Bank. 1996. “Evaluation and Management of Highway Runoff Water Quality”. Office of Environment and Planning. Federal Highway Administration. Washington, D.C.

Wadzuk, B. M., M. Rea, G. Woodruff, K. Flynn, and R. G. Traver. “Waterquality performance of a constructed stormwater wetland for all flow conditions”. (2010). 46:385–94. DOI:10.1111/j.1752-1688.2009.00408.

Rabêlo, Vitor Gantuss, et al. "University Campuses as Town-Like Institutions: Promoting Sustainable Development in Cities Using the Water-Sensitive Urban Design Approach." Sustainability on University Campuses: Learning, Skills Building and Best Practices. Springer, Cham, 2019. 497-511.

Water, Melbourne. "Melbourne water annual report 2017-18." (2018).

Wetzel, Robert G. “Limnology: lake and river ecosystems”. gulf professional publishing, 2001.

Xia, Jun, et al. "Opportunities and challenges of the Sponge City construction related to urban water issues in China." Science China Earth Sciences 60.4 (2017): 652-658.

Yale Office of Facilities, Utilities & Engineering. 2013. “Yale University Sustainable Stormwater Management Plan 2013 - 2016”. Yale Office of Sustainability. Source: https://sustainability.yale.edu/resources/stormwater-management-plan-2018

ATTACHMENT 1

The University or Puerto Rico Storm Sewer System blueprint.

INDEX OF LAYERS:

(TO USE WITH CAD DRAWING)

LAYER NAME:	DESCRIPTION:
CONT-BOUNDARY	POLYLINE THAT LIMITS THE CONTOUR LINES AREA
CONT-MJR	CONTOUR LINES WITH 1.0 METER INTERVAL
CONT-MNR	CONTOUR LINES WITH 0.5 METER INTERVAL
CONT-TEXT	LABELS FOR ELEVATIONS OF CONTOUR LINES
SURV-BUILD	EXISTING BUILDINGS, HOUSES OR OTHER STRUCTURES
SURV-BUILD-STAIRS	EXISTING STAIRS
SURV-CONC SLAB	EXISTING CONCRETE SLABS
SURV-CONC WALL	EXISTING RETAINING WALLS, LOW WALLS, CONCRETE BARRIERS OR FENCES
SURV-CREEK	EXISTING CREEKS
SURV-FENCE	EXISTING CHAIN LINK, GALVANIZED STEEL OR OTHER TYPES OF FENCES
SURV-FLAG_POLE	EXISTING FLAG POLES
SURV-GARBAGE	EXISTING GARBAGE STATIONS, TRASH CANS OR OTHER GARBAGE DISPENSERS
SURV-GEOM-ACCESS CONTROL	EXISTING MECHANICAL ARMS & ACCESSS CARD READERS
SURV-GEOM-ASPH	EXISTING ASPHALT PAVEMENT AREAS
SURV-GEOM-BOLLARD	EXISTING BOLLARDS OF DIFERENT SIZES & MATERIALS
SURV-GEOM-BRIDGE	EXISTING BRIDGES FOR VEHICLES OR FOR PEDESTRIAN CROSSING
SURV-GEOM-CURB	EXISTING CURB OR COMBINATION OF CURB & GUTTER
SURV-GEOM-DIRT ROAD	EXISTING DIRT ROADS
SURV-GEOM-GUARD RAIL	EXISTING GUARD RAILS
SURV-GEOM-HANDRAIL	EXISTING HANDRAILS ON SIDEWALKS, RAMPS, STAIRS OR OTHER LOCATIONS
SURV-GEOM-HC	EXISTING RAMPS FOR HANDICAPPED OR RELATED ITEMS
SURV-GEOM-PAINT	EXISTING PAINTED LINES OR SYMBOLS ON DRIVEWAYS OR PARKINGS
SURV-GEOM-PARKING	EXISTING PARKING SPACES OR OTHER RELATED ITEMS
SURV-GEOM-PLANTING	EXISTING "GREEN" AREAS, GARDENS, PLANT POTS OR RELATED ITEMS
SURV-GEOM-SW	EXISTING SIDEWALKS
SURV-MONUMENT	EXISTING HISTORIC MONUMENTS, STATUES, ARTISTIC WORKS, ETC.
SURV-SEATING BENCH	EXISTING SEATING BENCHES
SURV-SIGN	EXISTING TRAFFIC SIGNS, INFORMATION, OR OTHER TYPES OF SIGNS
SURV-SITE-CONSTRUCTION	AREA UNDER CONSTRUCTION
SURV-SITE-DEBRIS	AREA FULL OF DEBRIS
SURV-SITE-ROCKS	EXISTING BOULDER OR ROCKS AREA
SURV-SPORTS	EXISTING COURTS, PLAYING FIELDS OR OTHER SPORT FACILITIES
SURV-STA	LAND SURVEY CONTROL STATIONS
SURV-TEXT	GENERAL ANNOTATIONS
SURV-TREE	EXISTING TREES, DENSE WOOD AREAS, BAMBOO TREE AREAS, ETC.
SURV-UTIL	EXISTING UTILITY ITEMS THAT CANNOT BE IDENTIFIED AT THE TIME OF FIELD DATA GATHERING (COULD BE ELECTRICAL, TELEPHONE OR OTHER UTILITY)
SURV-UTIL-AC	EXISTING AIR CONDITIONING UNITS OR RELATED ITEMS
SURV-UTIL-CO	EXISTING CLEAN-OUTS
SURV-UTIL-DIESEL	EXISTING DIESEL TANKS, PUMPS OR RELATED ITEMS
SURV-UTIL-ELEC	EXISTING ELECTRICAL BOXES, POLES, SUBSTATIONS OR OTHER DEVICES RELATED TO THE ELECTRICAL SYSTEM
SURV-UTIL-GAS	EXISTING GAS TANKS, VALVES OR RELATED ITEMS
SURV-UTIL-GASOLINE	EXISTING GASOLINE TANKS, PUMPS OR RELATED ITEMS
SURV-UTIL-MH	EXISTING MANHOLES THAT CANNOT BE IDENTIFIED AT THE TIME OF FIELD DATA GATHERING (COULD BE STORM, SANITARY OR OTHER UTILITY)
SURV-UTIL-SAN	EXISTING SANITARY SEWER SYSTEM MANHOLES, PIPES, GREASE TRAPS OR OTHER RELATED ITEMS
SURV-UTIL-STORM	EXISTING STORM SEWER SYSTEM MANHOLES, PIPES, INLETS, HEADWALLS OR OTHER RELATED ITEMS
SURV-UTIL-TEL	EXISTING TELEPHONE SYSTEM POLES, MANHOLES, PUBLIC TELEPHONES OR OTHER RELATED ITEMS
SURV-UTIL-TRAFFIC	EXISTING TRAFFIC LIGHT POLES, CONTROL CABINETS, PULL BOXES OR OTHER RELATED ITEMS
SURV-UTIL-WATER	EXISTING WATER DISTRIBUTION SYSTEM VALVES, METERS, FIRE HYDRANTS OR OTHER RELATED ITEMS

"AS-BUILT" GENERAL NOTES:

1– DIMENSIONS AND/OR ELEVATIONS ARE SHOWN IN METRIC SYSTEM, UNLESS OTHERWISE NOTED.

2– HORIZONTAL CONTROLS ARE REFERRED TO THE PUERTO RICO LAMBERT COORDINATE SYSTEM.

3– ELEVATIONS ARE REFERRED TO MEAN SEA LEVEL (M.S.L.) ELEVATIONS SYSTEM.

4– THE EQUIPMENT USED TO OBTAIN FIELD DATA WAS:
A – ELECTRONIC TOTAL STATION WITH AN HP 48GX DATA COLLECTOR.
B – STEEL TAPE FOR SHORT DISTANCES.

5– FIELD JOB DONE FROM NOVEMBER 2004 TO MAY 2005. ADDITIONAL FIELD JOB DONE ON OCTOBER AND NOVEMBER 2005.

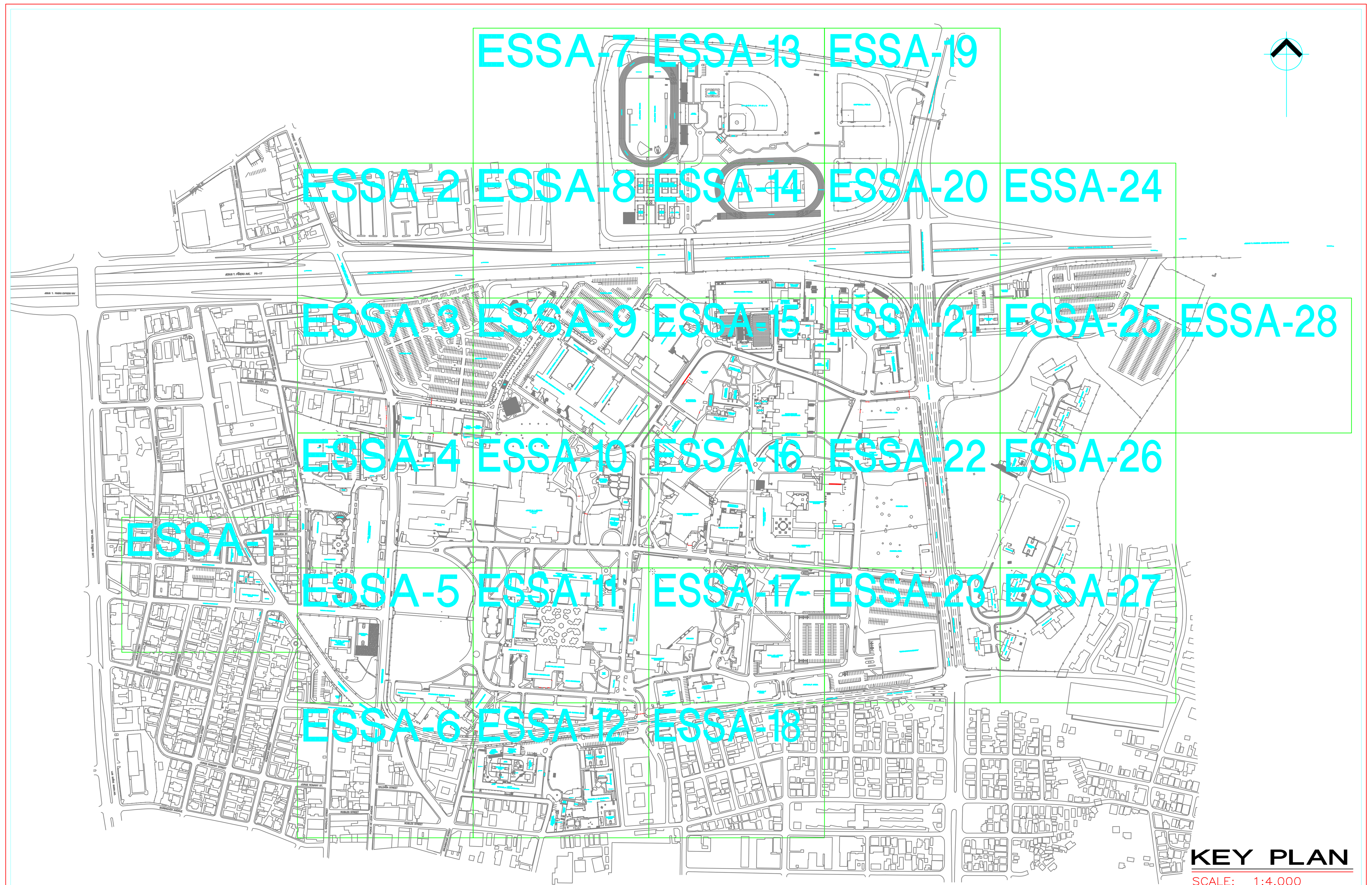
6– SYMBOLS ARE FOR ILLUSTRATING PURPOSES ONLY, THEY ARE NOT NECESSARILY OF THE SAME TYPE AND/OR SIZE OF THE OBJECT WHICH THEY REPRESENT.

STORM SEWER LEGEND:

Symbol	Description
	INLET
SS	STORM SEWER MANHOLE
	HEADWALL
	CURB INLET
10"ø PIPE	STORM SEWER PIPE

"AS-BUILT" LEGEND:

Symbol	Description	Symbol	Description
7.72	EXISTING ELEVATION	WM	WATER METER
STA-1	CONTROL STATION		WATER VALVE
GAS	GAS VALVE		ELECTRICAL POLE
	TRAFFIC SIGN		LIGHTING POLE
T	TELEPHONE SYSTEM MANHOLE		ORNAMENTAL LIGHTING POLE (3'–0" HEIGHT APPROX.)
E	ELECTRICAL SYSTEM MANHOLE	TEL	TELEPHONE POLE
S	SANITARY SEWER MANHOLE		ELECTRICAL POLE WITH LIGHTING
MH	MANHOLE		FLAG POLE
TEL	PUBLIC TELEPHONE		TRAFFIC LIGHT POLE
	TREE	F.F.E.	FINISHED FLOOR ELEVATION
	PALM TREE	R.C.P.	REINFORCED CONCRETE PIPE
	FIRE HYDRANT		
	HOSE BIBB		
	CLEAN–OUT		



KEY PLAN

SCALE: 1:4,000

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300

Date: – JULY 27, 2006

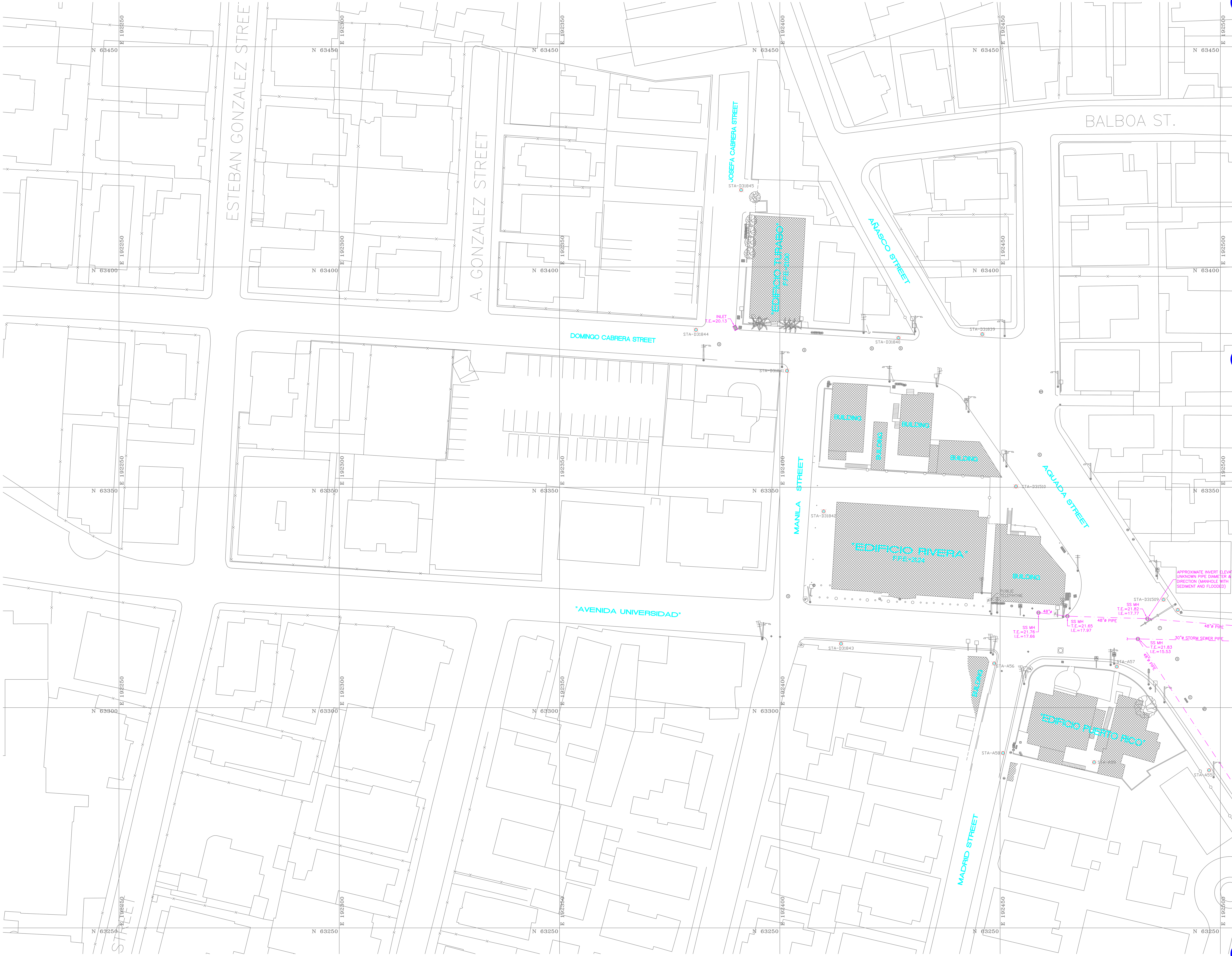
Job #: –

Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-LGN-1



REFER TO PAGE ESSA-4

REFER TO PAGE ESSA-5

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300

Date: – JULY 27, 2006

Job #: –

Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-1

REFER TO PAGE ESSA-3

REFER TO PAGE ESSA-3

REFER TO PAGE ESSA-8

REFER TO PAGE ESSA-8

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

- ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

- ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

- JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

- JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

- telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: - 1:300

Date: - JULY 27, 2006

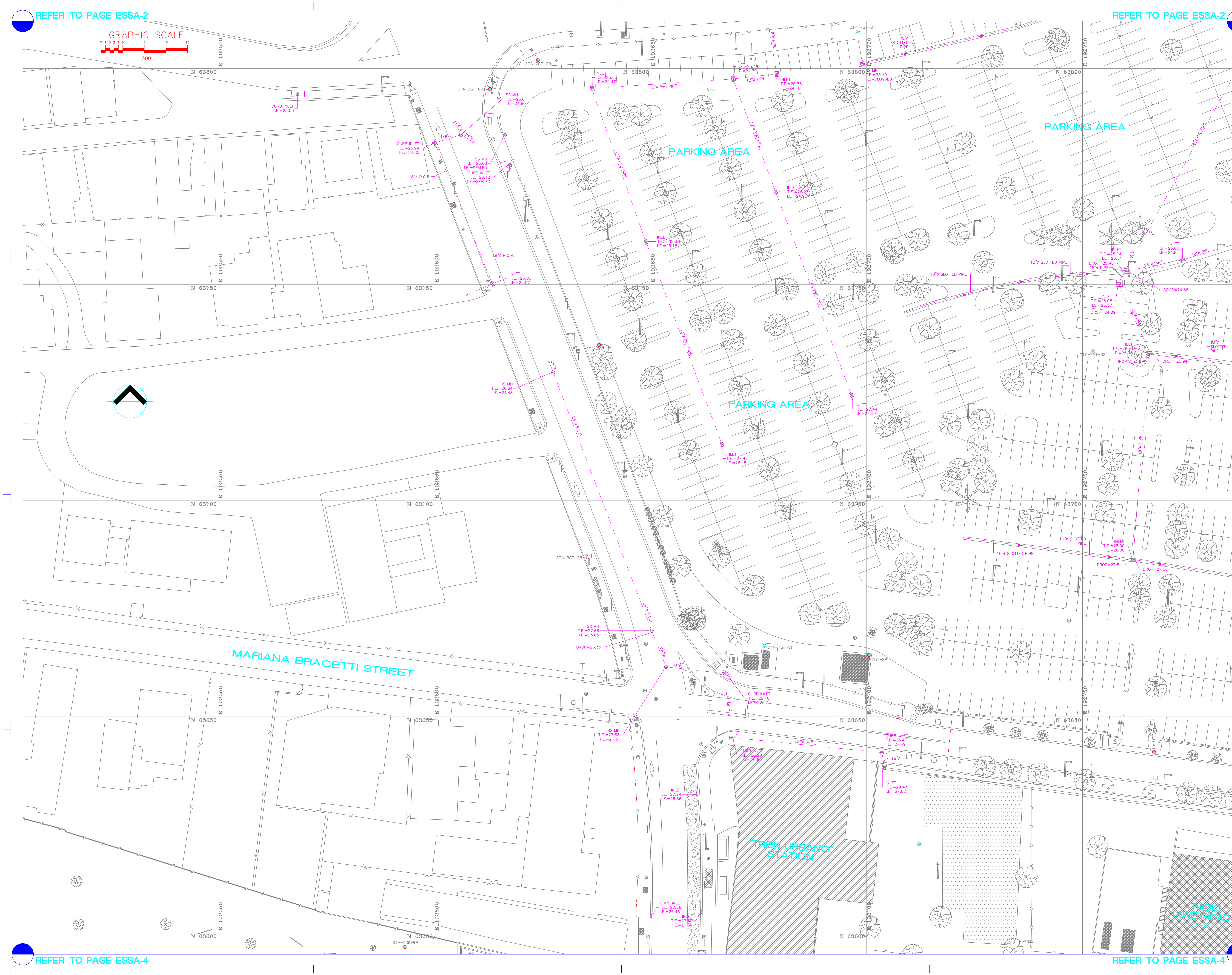
Job #: -

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-2



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

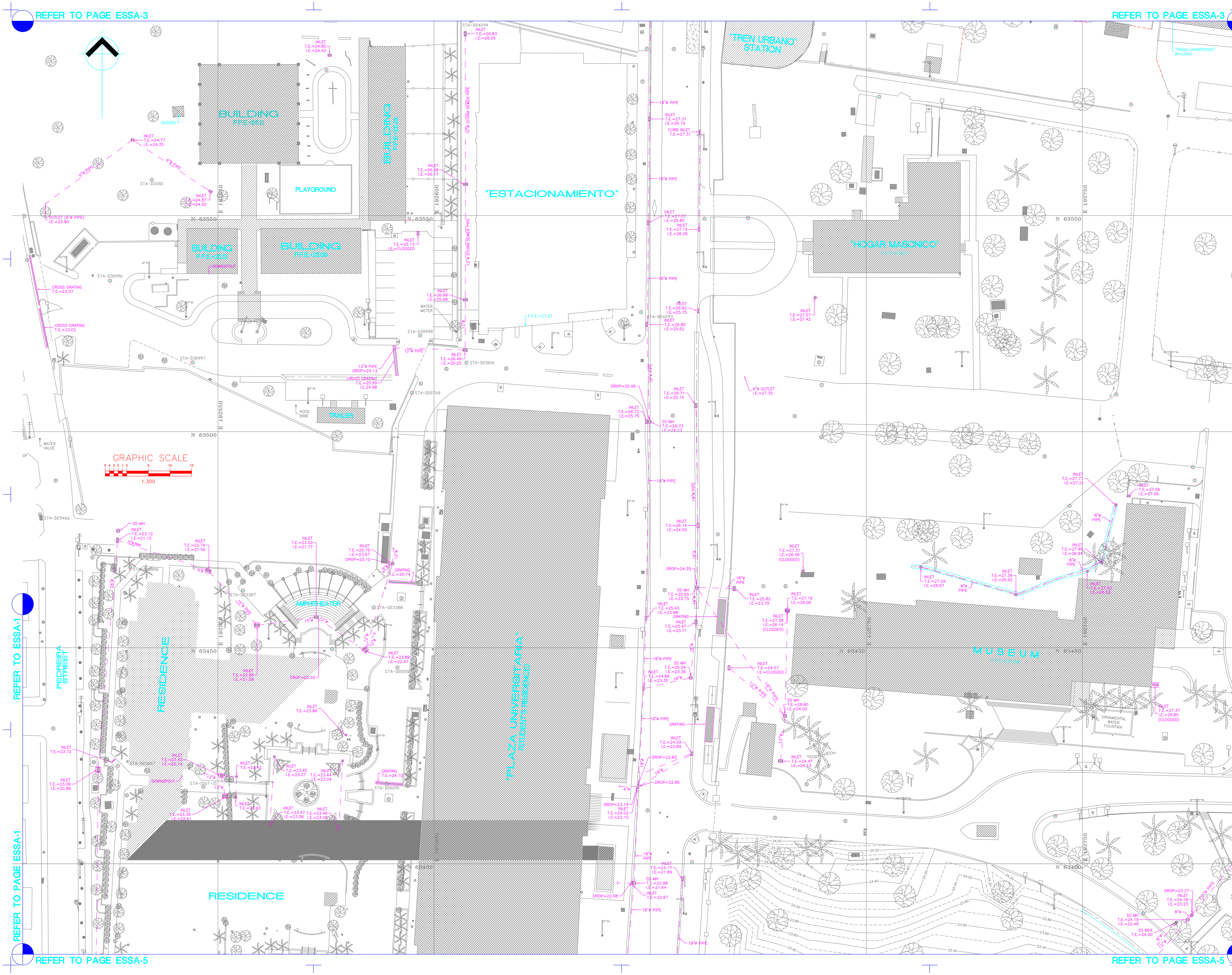
Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #: ESSA-3



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. # | Date | Description

Consultants:
Civil
ebp design group

Electrical
ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical
JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Telephone & Data
telec engineers

Stamp

SCALE: - 1:300
Date: - JULY 27, 2006
Job #: -

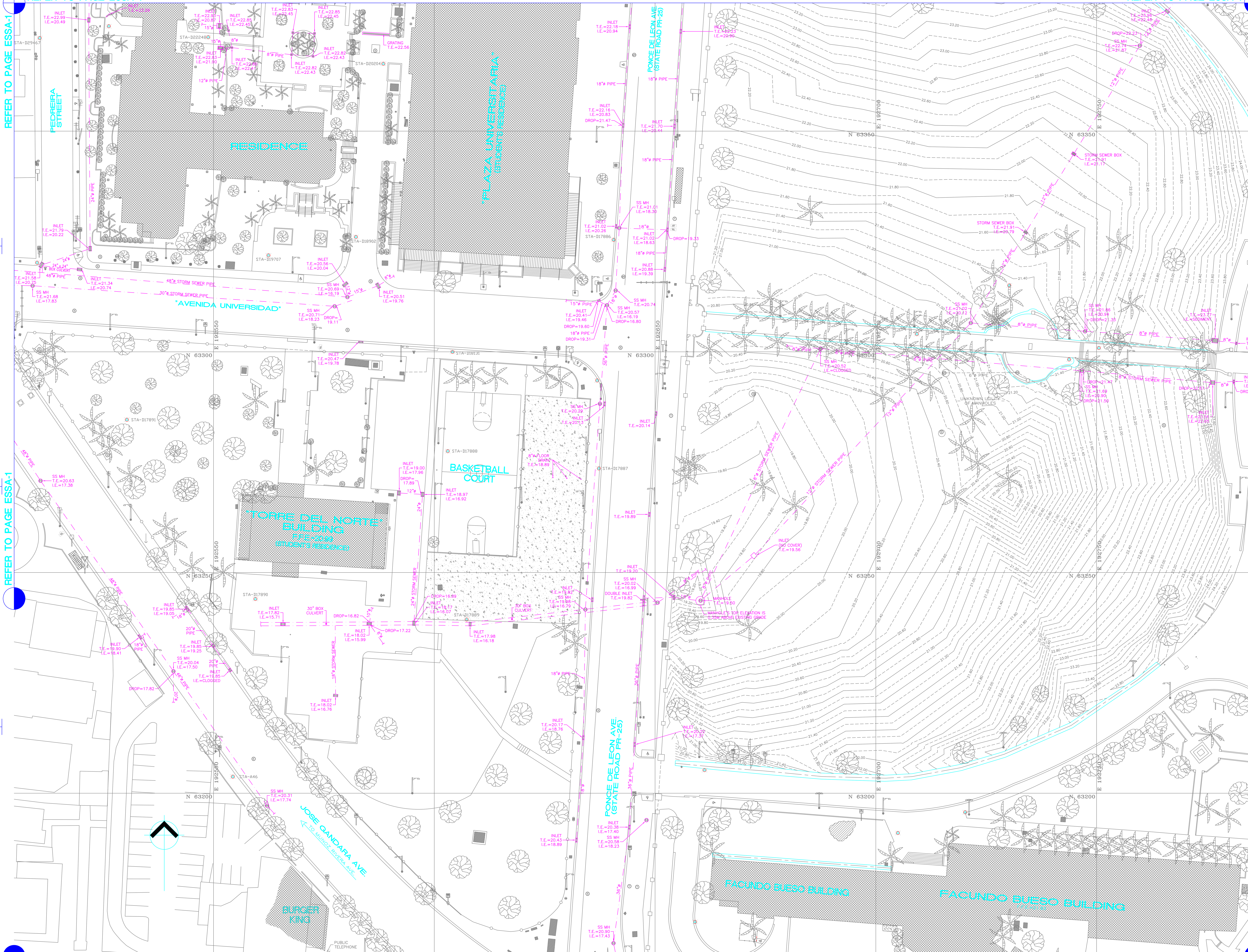
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #
ESSA-4

REFER TO PAGE ESSA-4

REFER TO PAGE ESSA-1



REFER TO PAGE ESSA-6

REFER TO PAGE ESSA-11

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300

Date: – JULY 27, 2006

Job #: –

Drawing

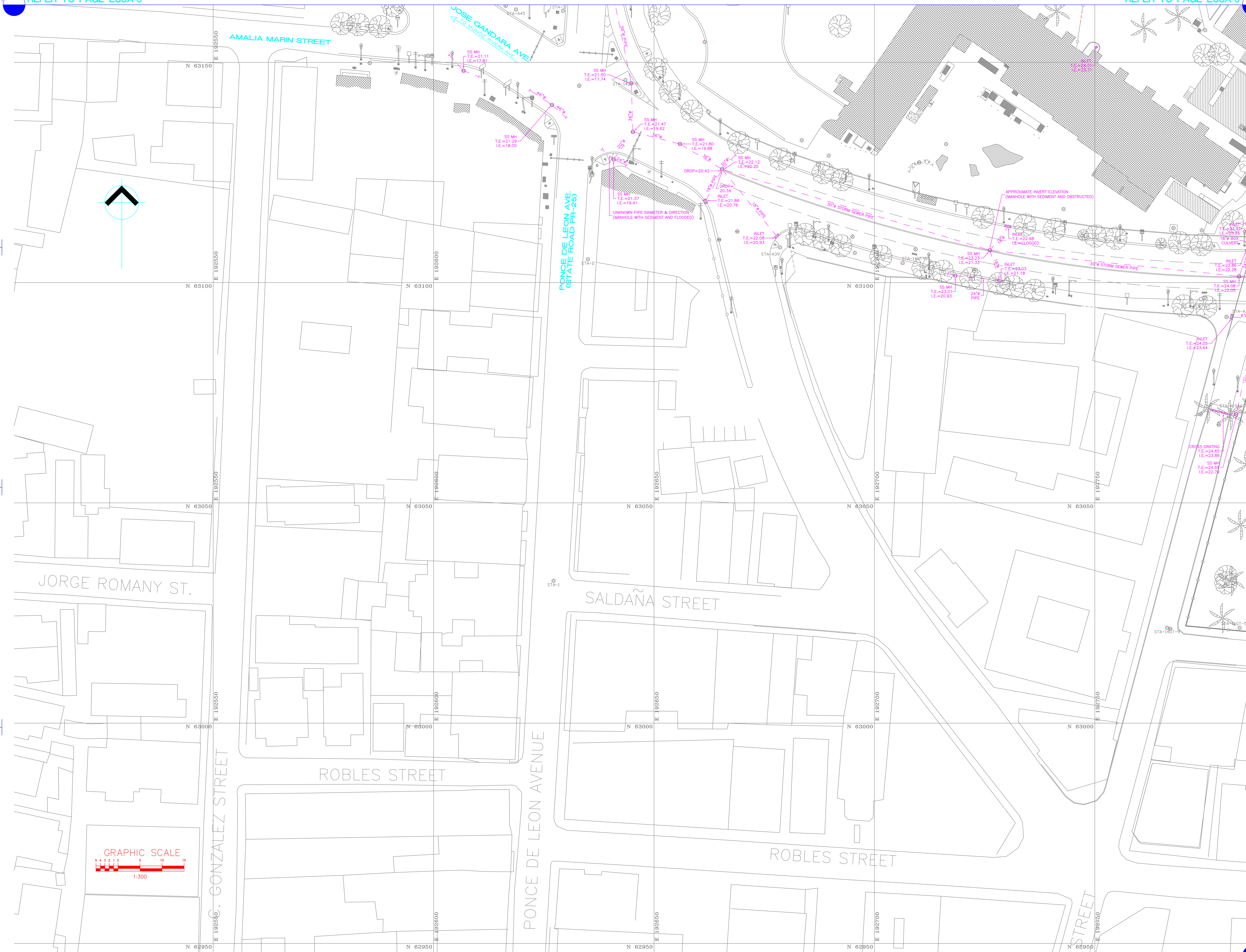
EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-5

REFER TO PAGE ESSA-5

REFER TO PAGE ESSA-5



REFER TO PAGE ESSA-12

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. # | Date | Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

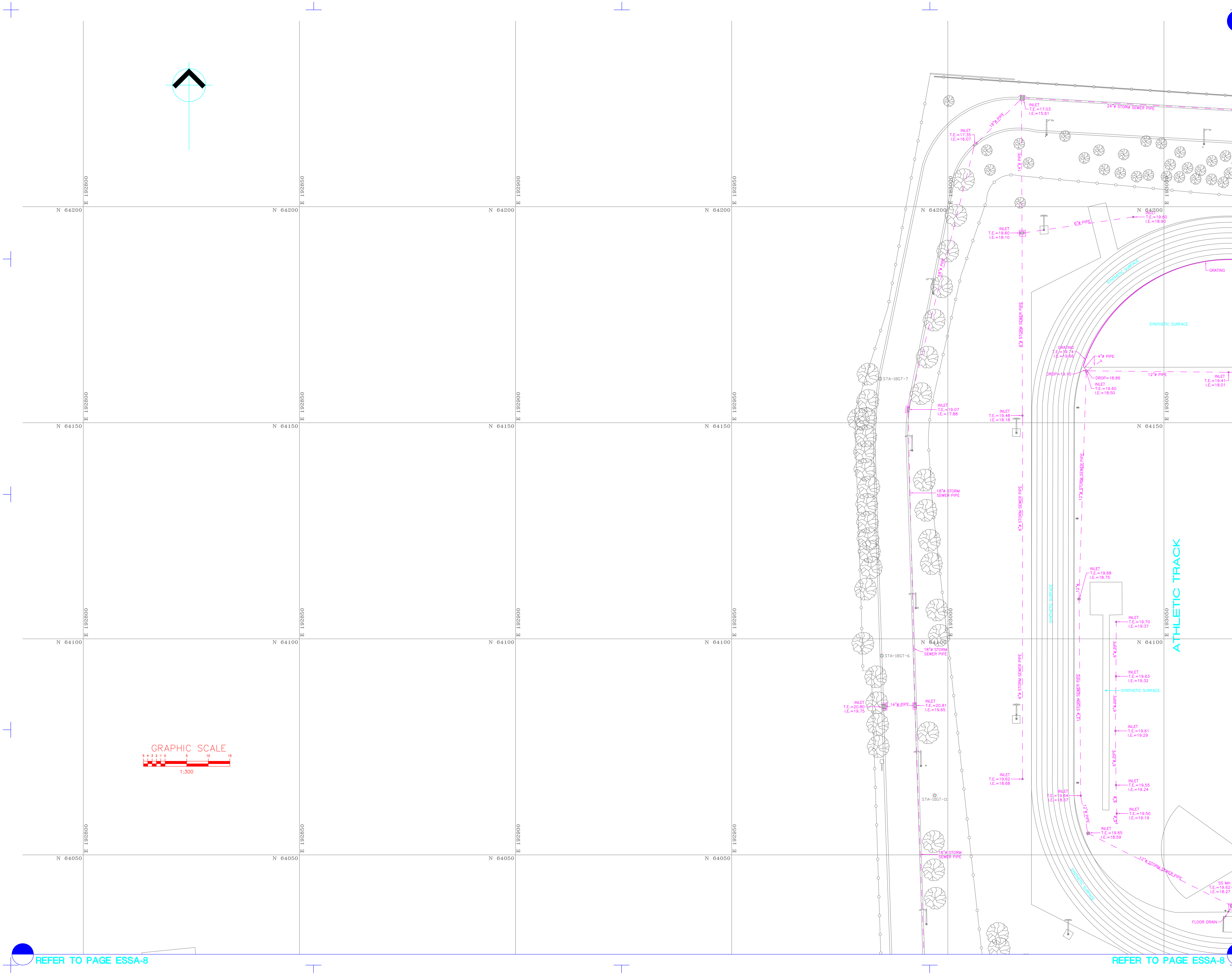
SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

REFER TO PAGE ESSA-12

Sheet #: ESSA-6



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903 ·

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300

Date: – JULY 27, 2006

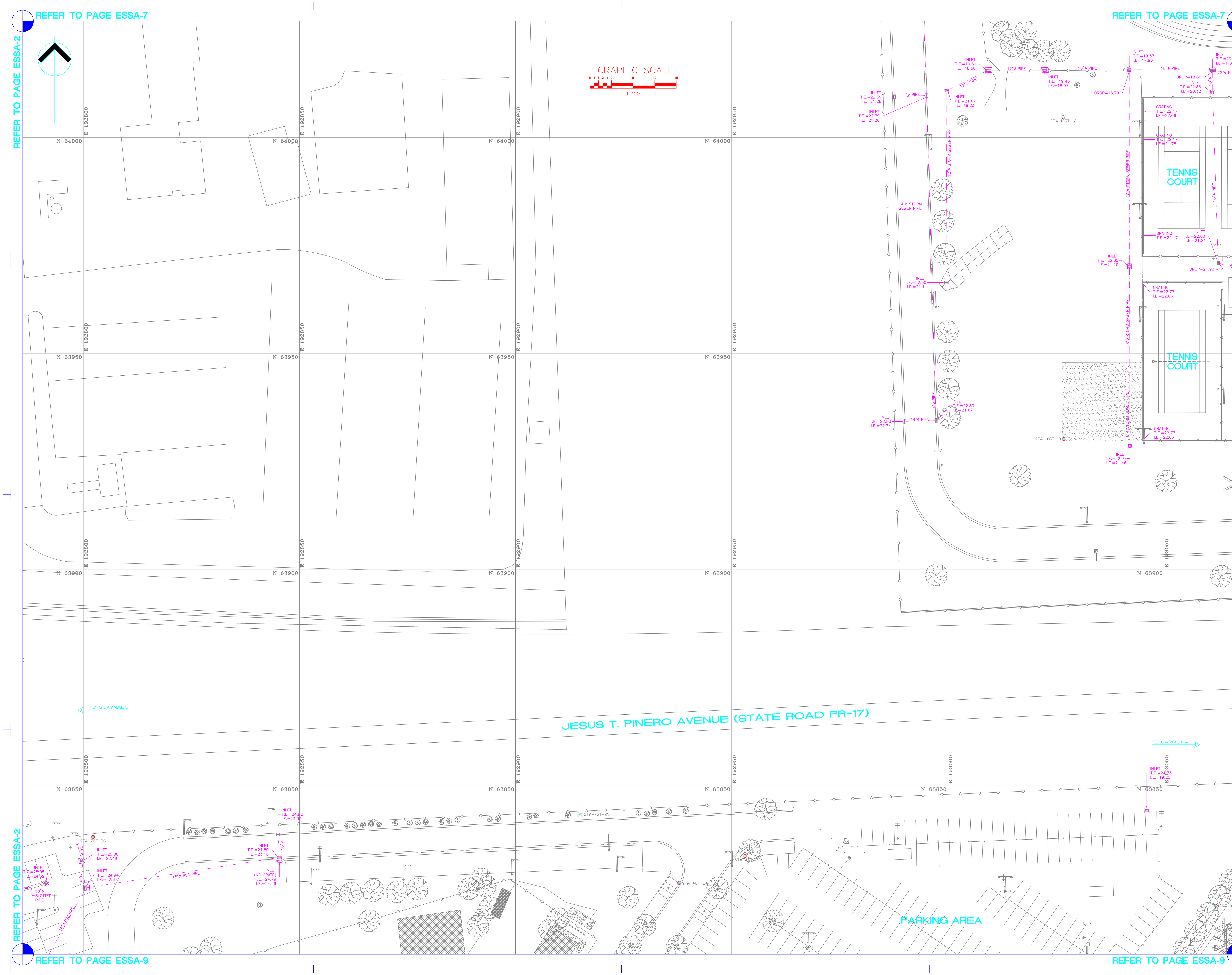
Job #: –

Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-7



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

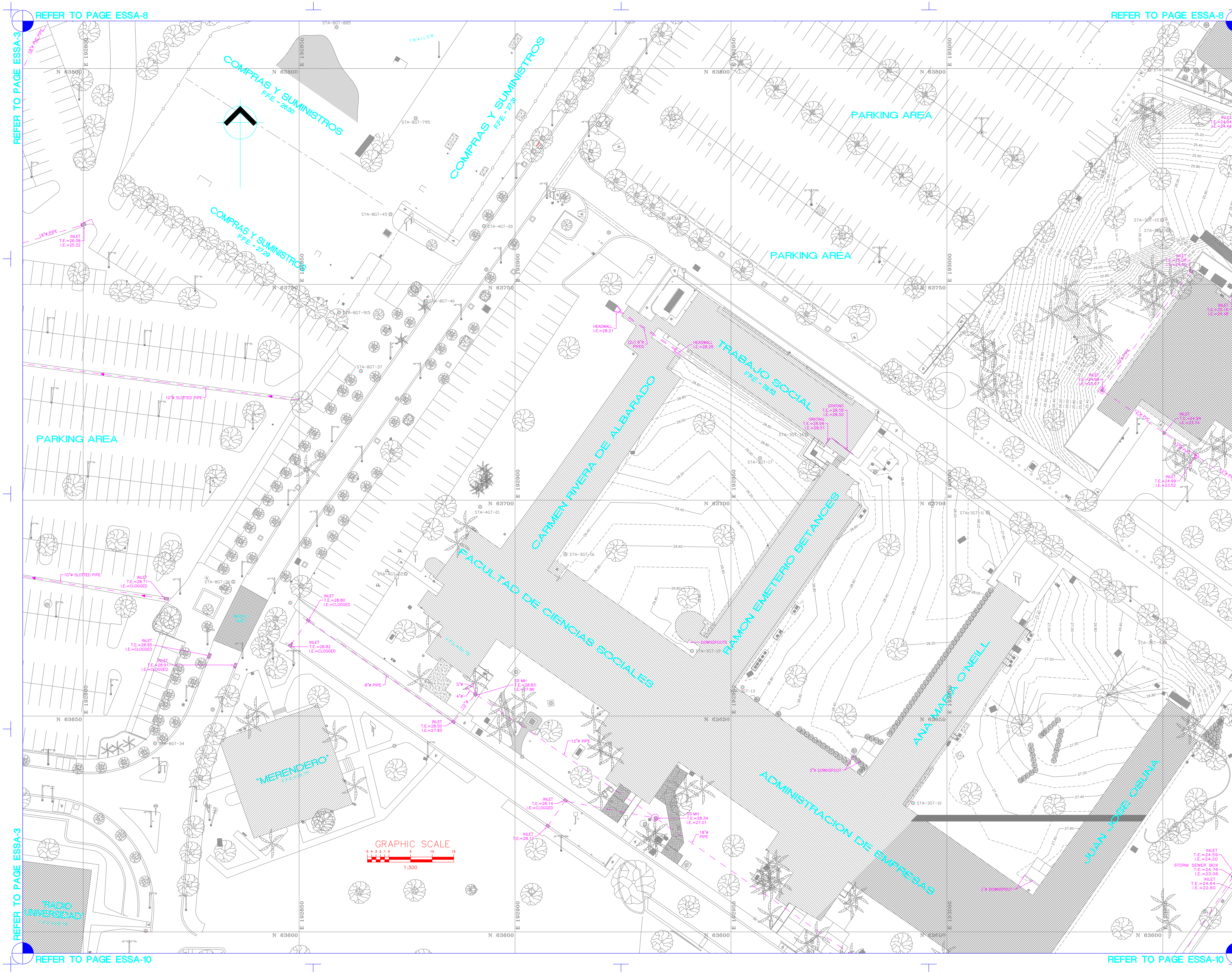
Stamp

SCALE: 1:300
Date: JULY 27, 2006
Job #:
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-8



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

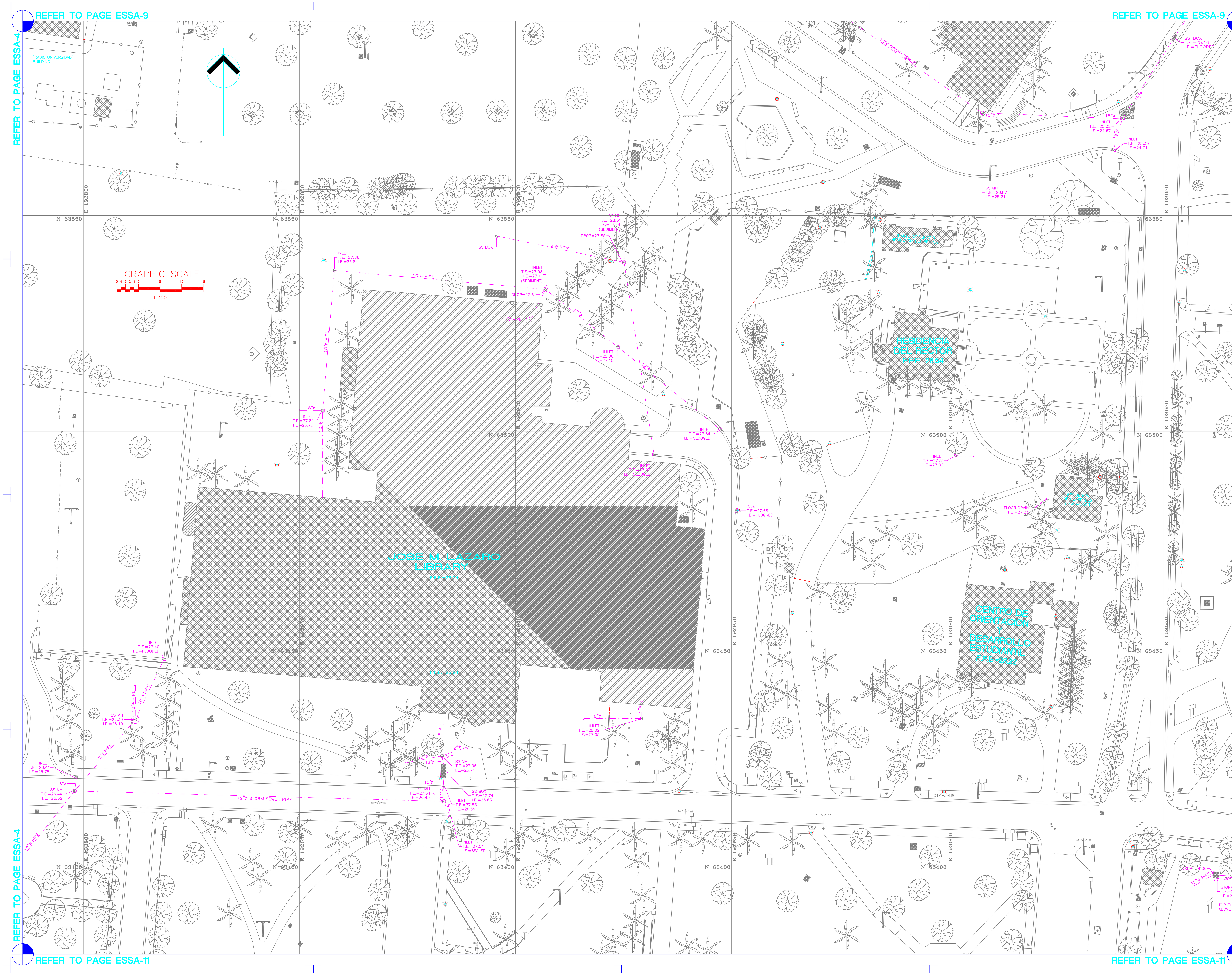
SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-9



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

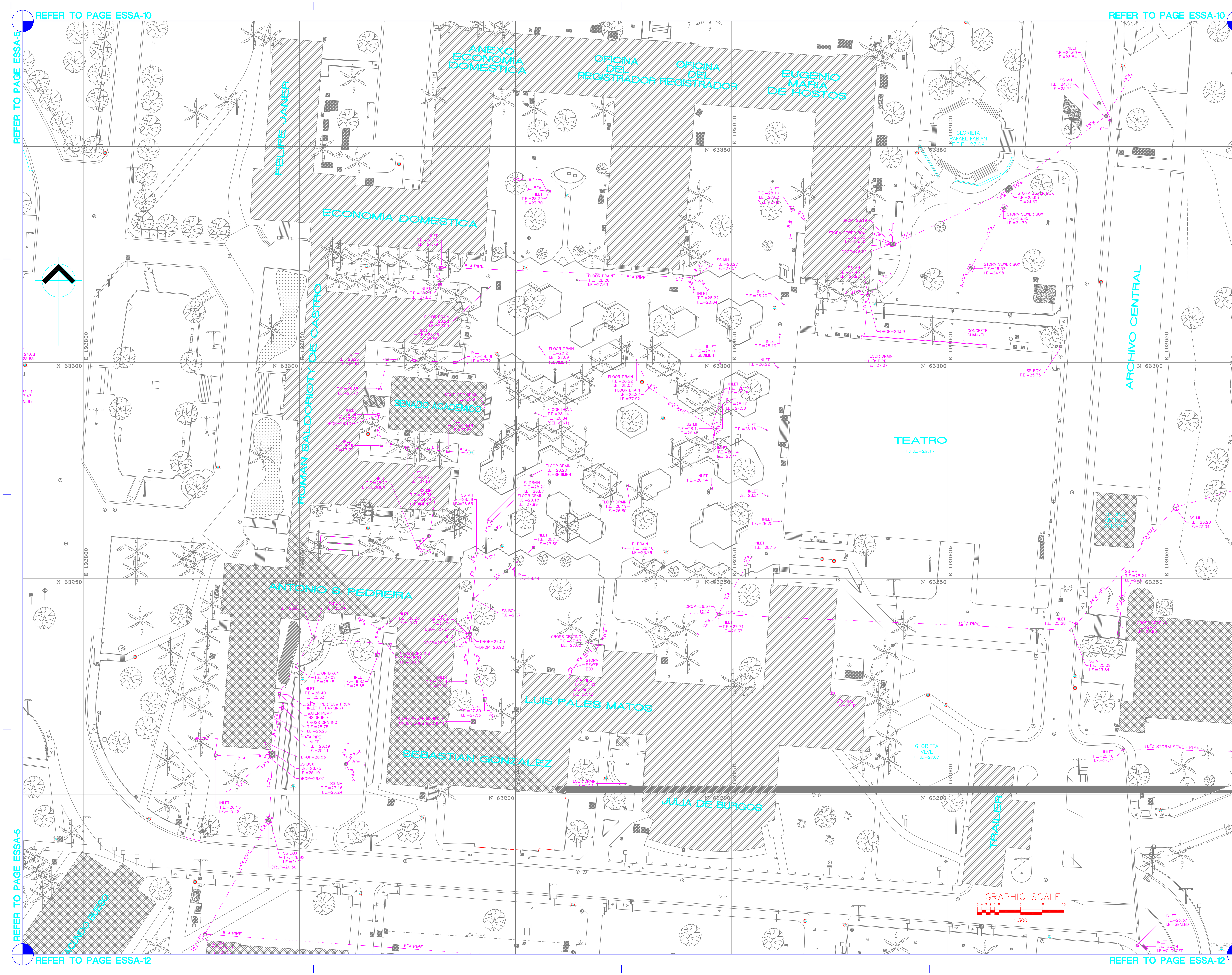
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-10

REFER TO PAGE ESSA-10
REFER TO PAGE ESSA-10
REFER TO PAGE ESSA-5
REFER TO PAGE ESSA-5



REFER TO PAGE ESSA-12
REFER TO PAGE ESSA-12
REFER TO PAGE ESSA-17
REFER TO PAGE ESSA-17

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

- ebp design group CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

- ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

- JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

- JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

- telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300

Date: – JULY 27, 2006

Job #: –

Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-11

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. # | Date | Description

Consultants:
Civil

ebp design group

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

Telephone & Data

telec engineers

Stamp:

SCALE: - 1:300

Date: - JULY 27, 2006

Job #: -

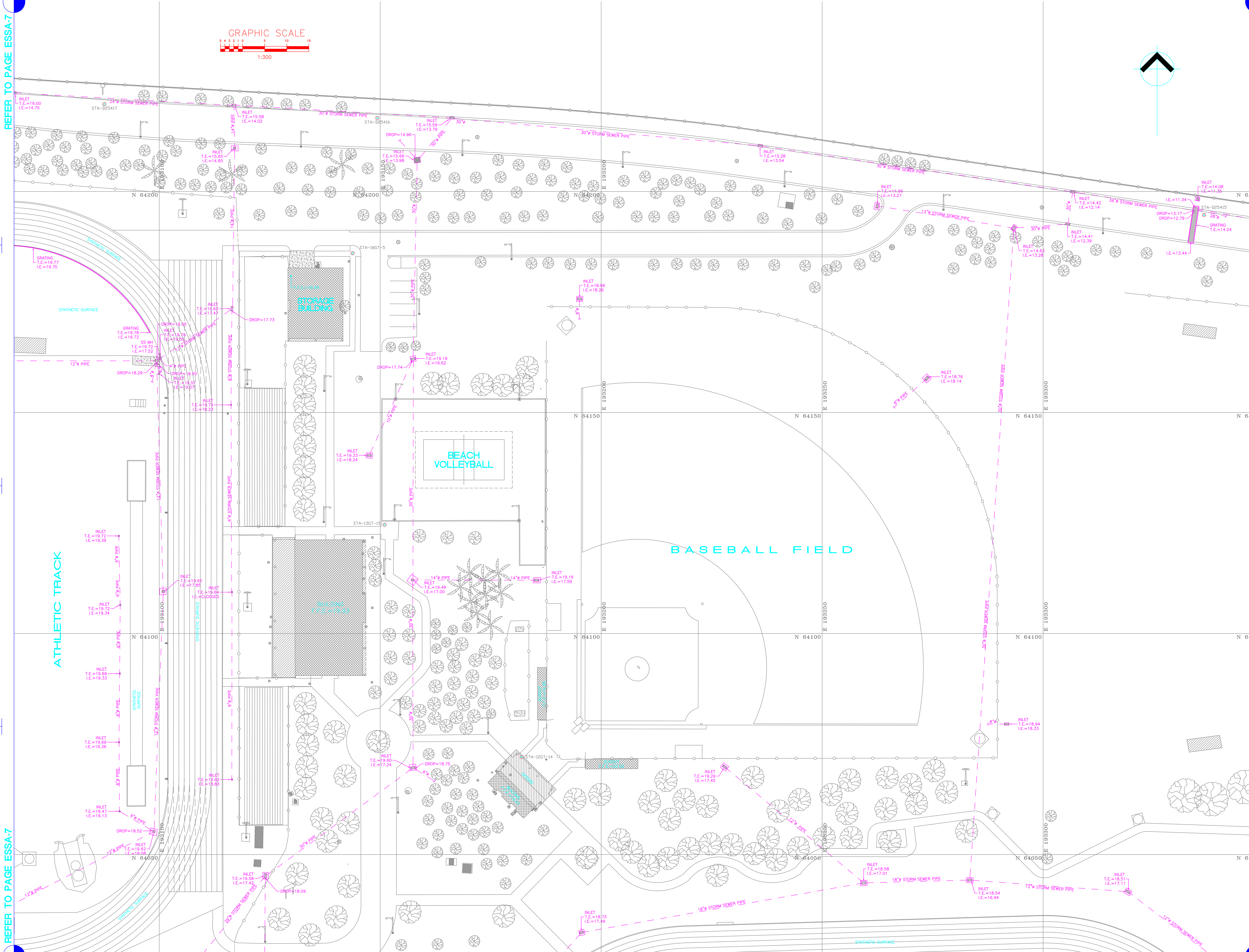
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-12

REFER TO PAGE ESSA-7



REFER TO PAGE ESSA-14

REFER TO PAGE ESSA-19

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. # | Date | Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

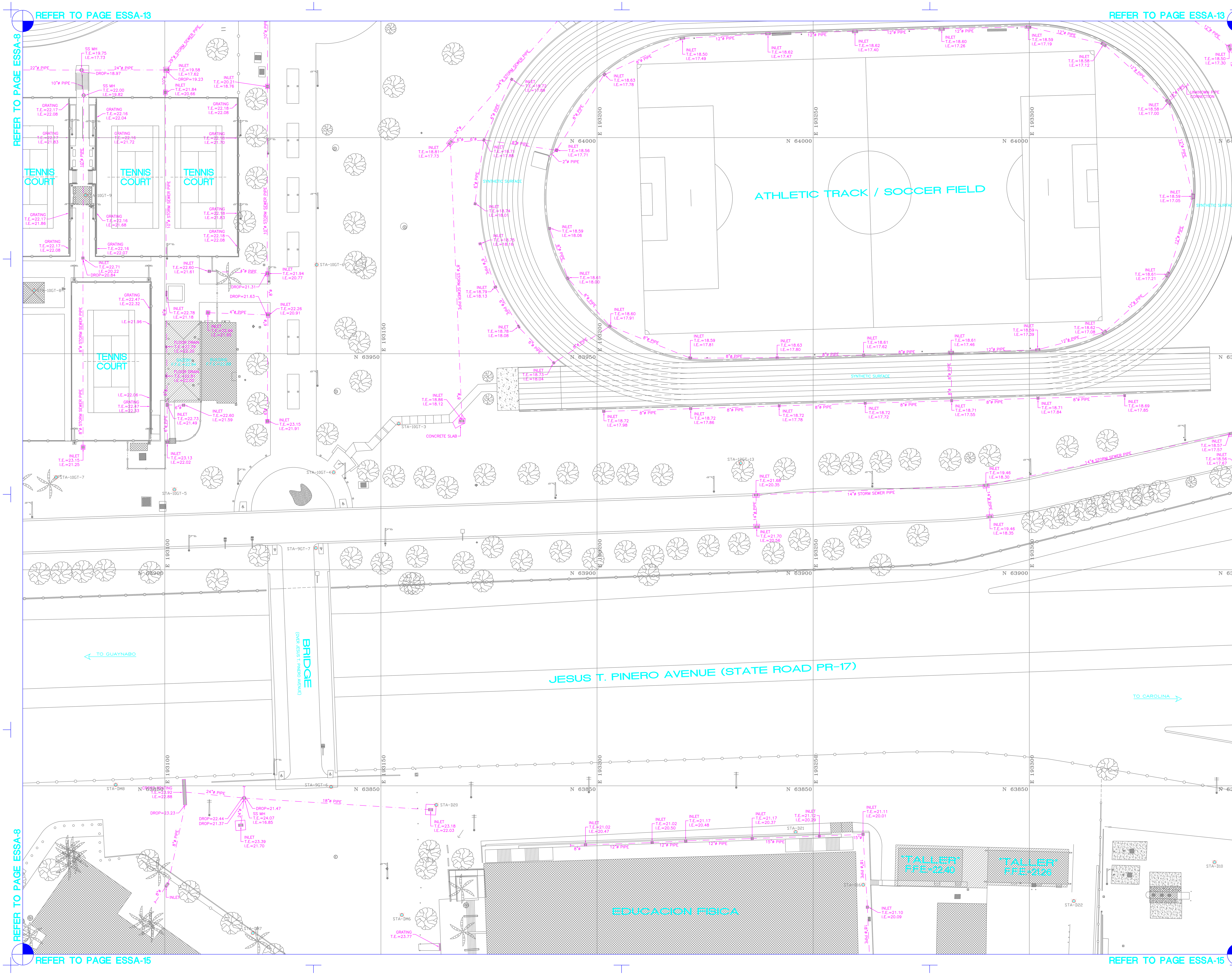
SCALE: - 1:300
Date: - JULY 27, 2006
Job #: -

Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-13



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. # Date Description

Consultants:
Civil

ebp design group

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

Telephone & Data

telec engineers

Stamp

SCALE: - 1:300
Date: - JULY 27, 2006
Job #: -

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-14

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300

Date: – JULY 27, 2006

Job #: –

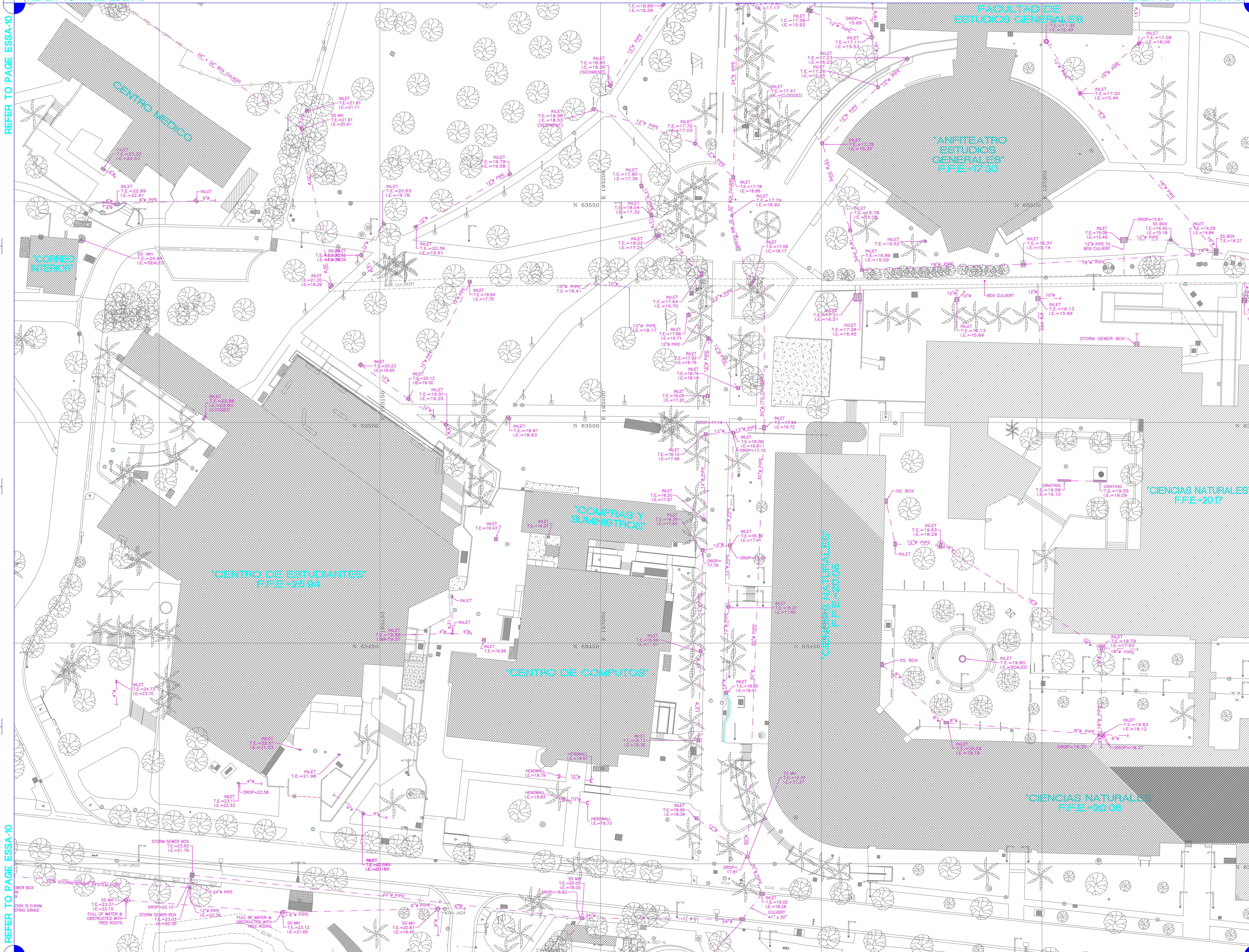
Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-15

REFER TO PAGE ESSA-15



REFER TO PAGE ESSA-10
REFER TO PAGE ESSA-22
REFER TO PAGE ESSA-17

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

Telephone & Data

telec engineers

Stamp:

SCALE: – 1:300

Date: – JULY 27, 2006

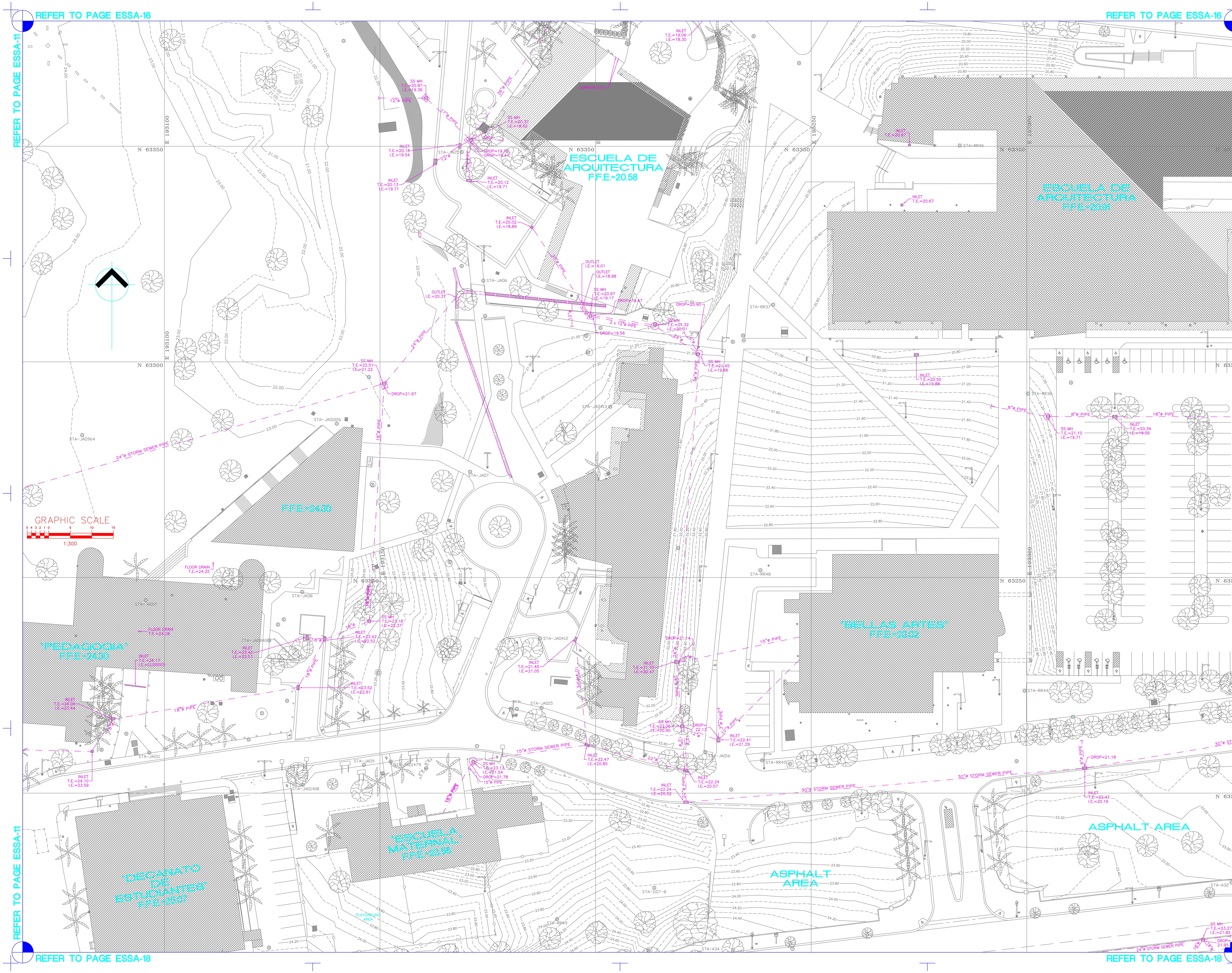
Job #: –

Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-16



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-17

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

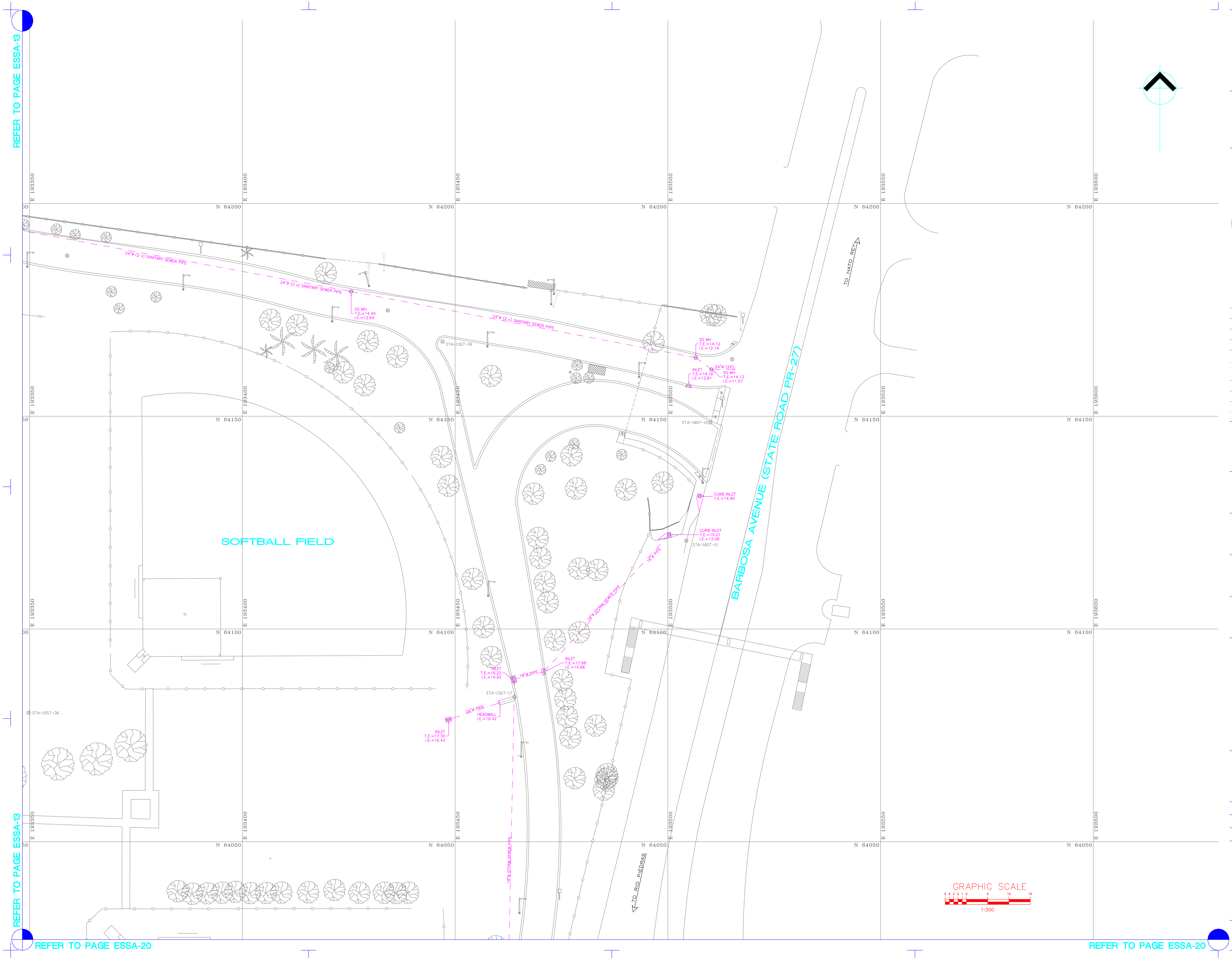
Stamp:

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-18



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

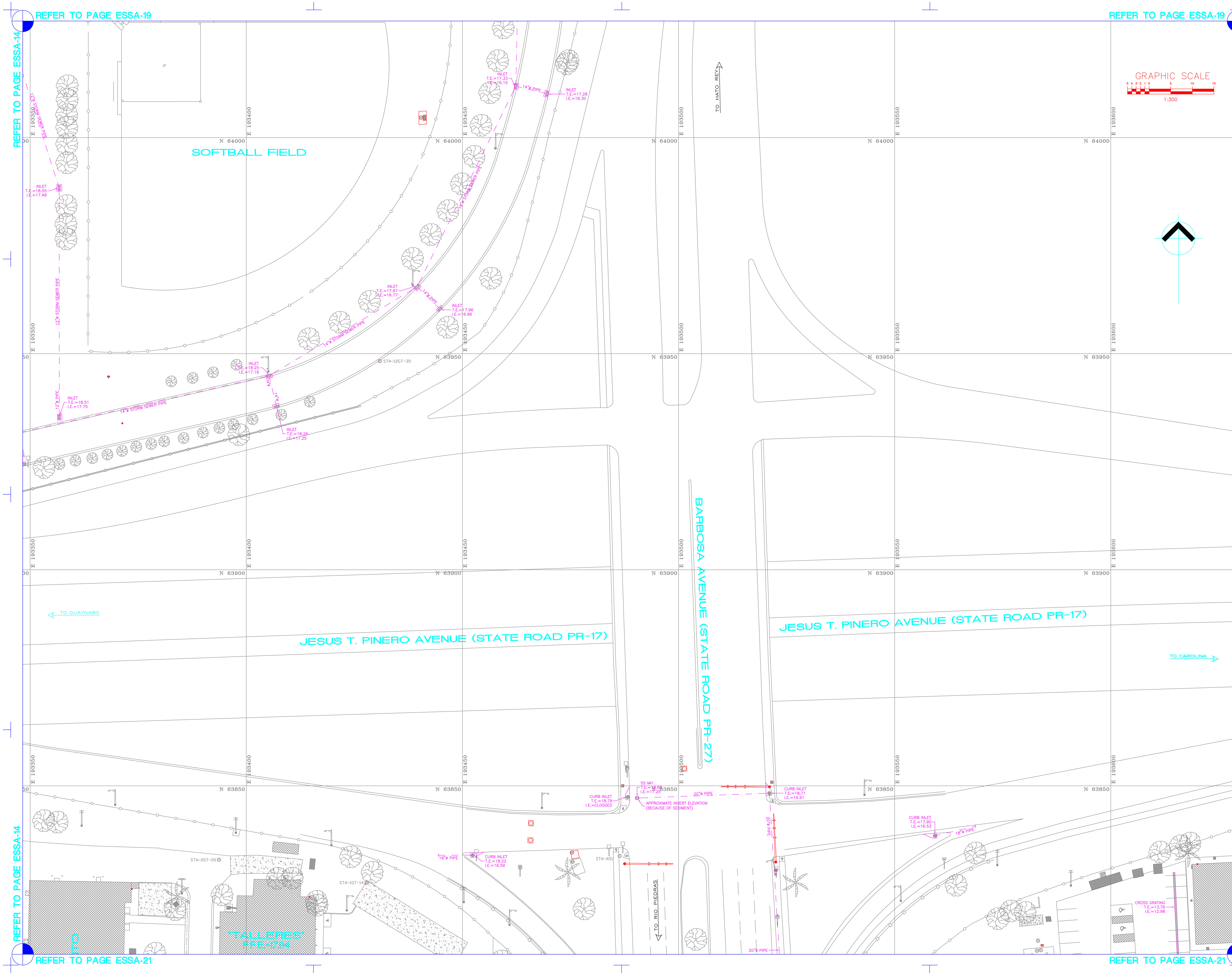
SCALE: 1:300
Date: JULY 27, 2006
Job #:

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-19



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp:

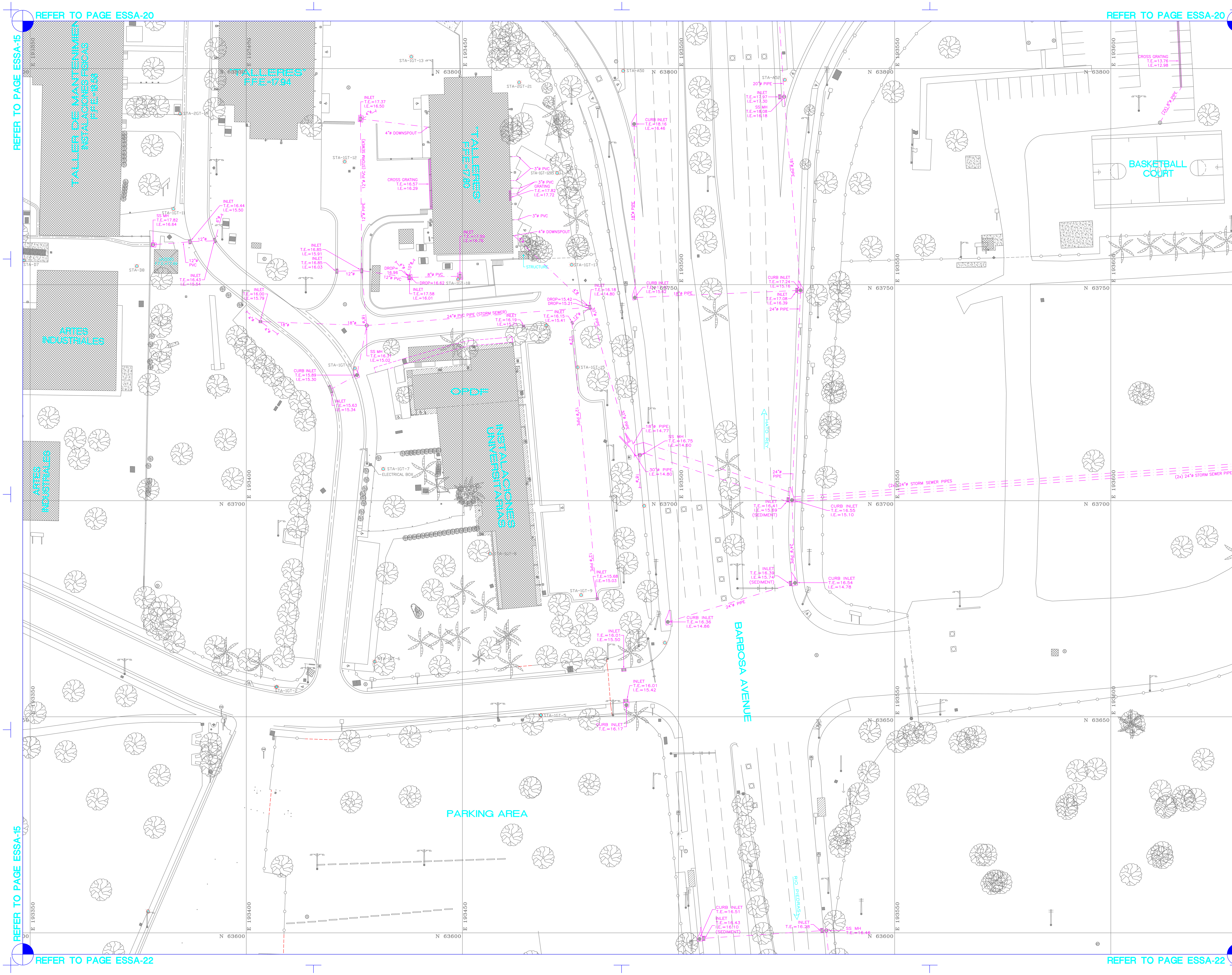
Scale: - 1:300
Date: - JULY 27, 2006
Job #: -

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-20



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

- ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

- ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

- JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

- JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

- telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

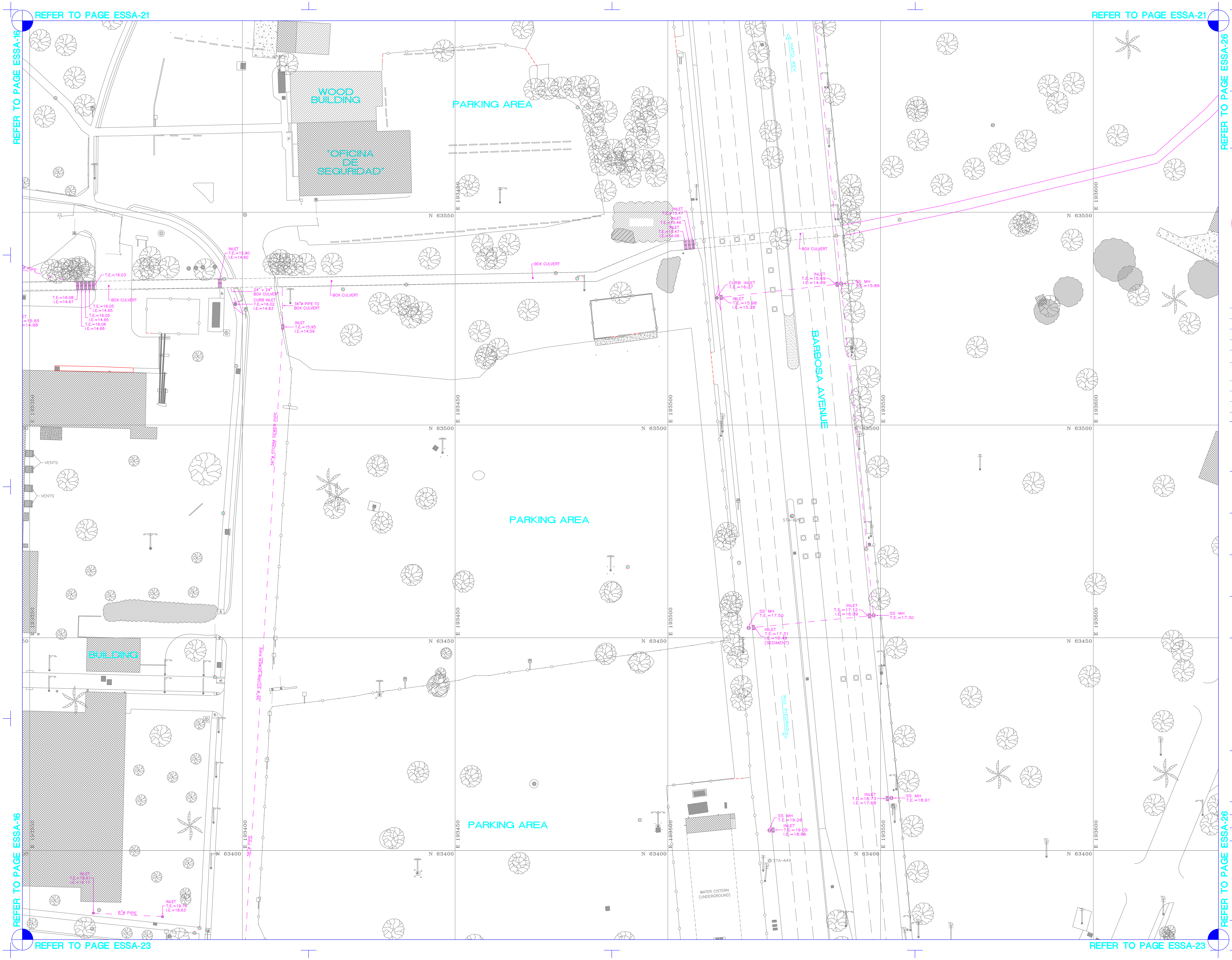
SCALE: - 1:300
Date: - JULY 27, 2006
Job #: -

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-21



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTRURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil
ebp design group

Electrical
ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical
JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

Telephone & Data
telec engineers

Stamp:

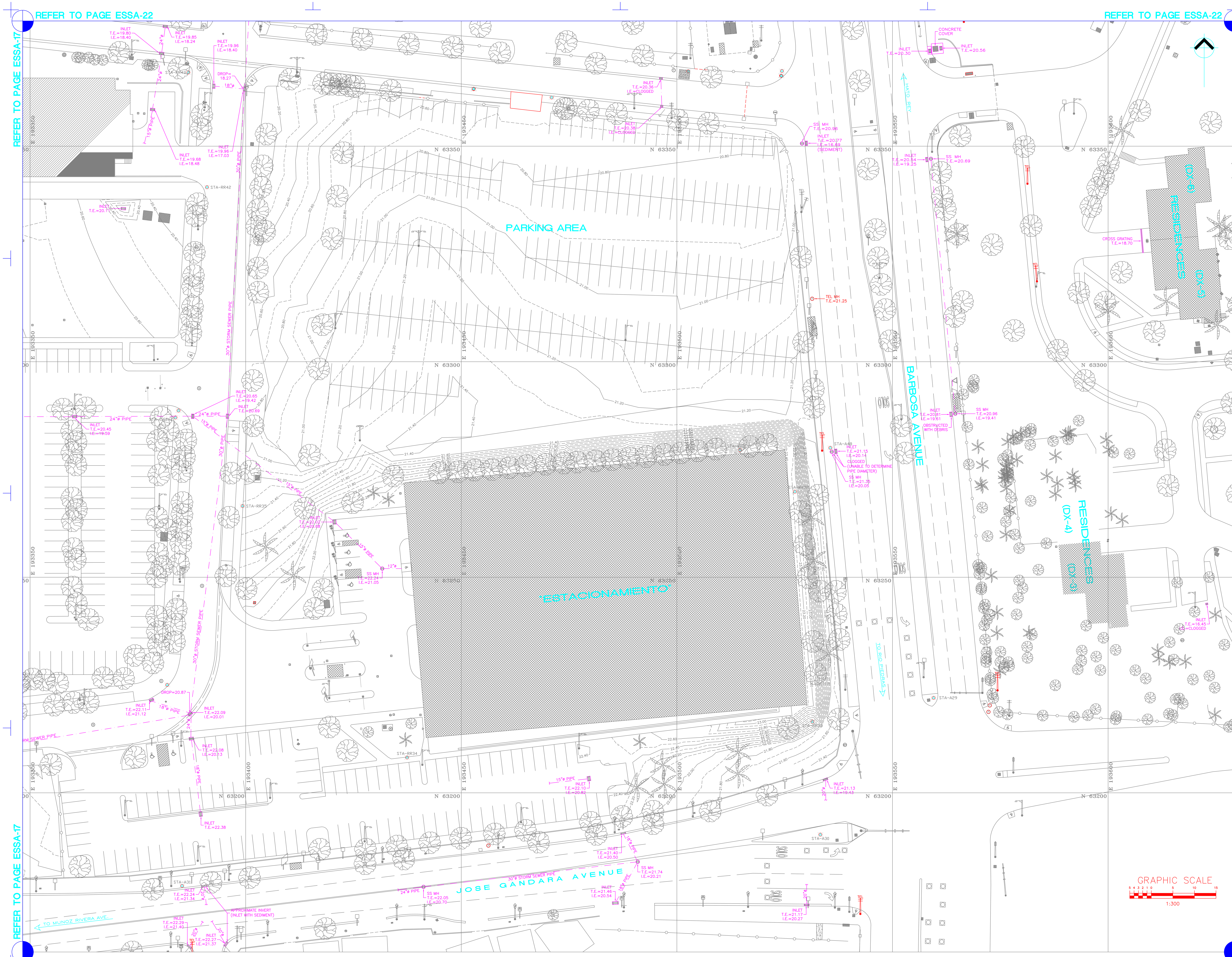
SCALE: - 1:300
Date: - JULY 27, 2006
Job #: -

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-22



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

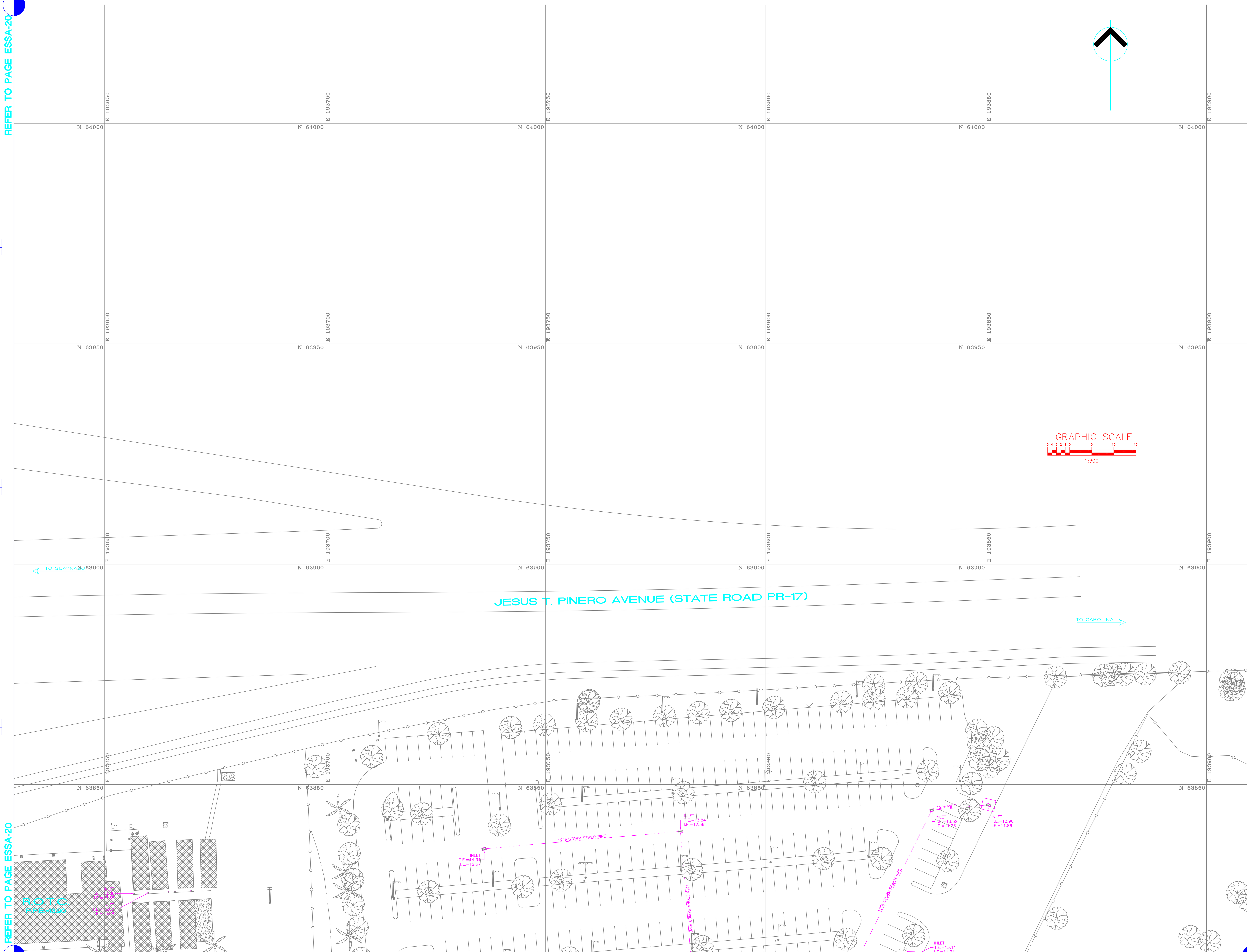
SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-23

REFER TO PAGE ESSA-20



REFER TO PAGE ESSA-20

REFER TO PAGE ESSA-25

REFER TO PAGE ESSA-25

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil
ebp design group

Electrical
ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical
JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

Telephone & Data
telec engineers

Stamp:

SCALE: - 1:300

Date: - JULY 27, 2006

Job #: -

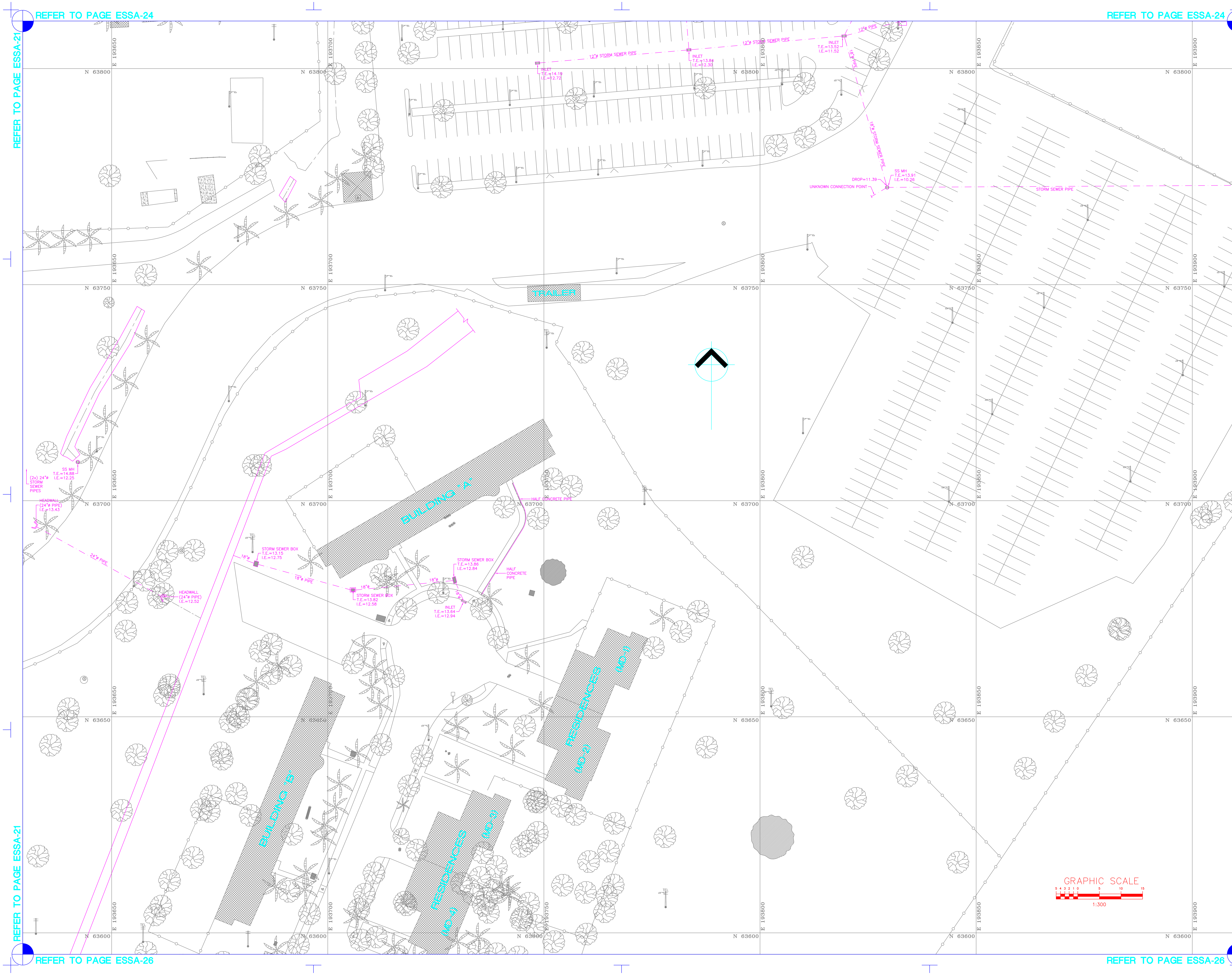
Drawing

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-24

REFER TO PAGE ESSA-24
REFER TO PAGE ESSA-21



REFER TO PAGE ESSA-26
REFER TO PAGE ESSA-28

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

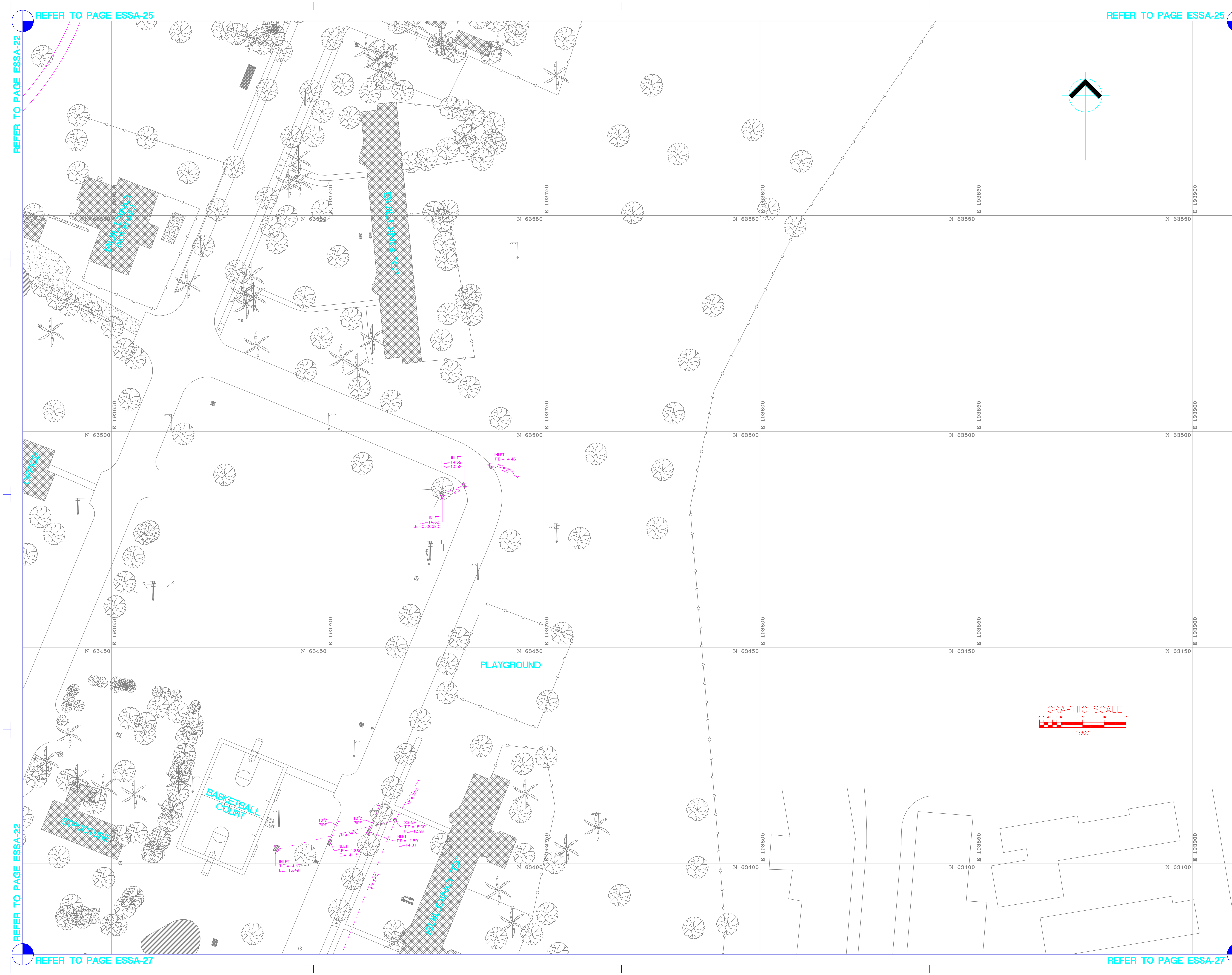
Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #
ESSA-25

REFER TO PAGE ESSA-25
REFER TO PAGE ESSA-22



REFER TO PAGE ESSA-27
REFER TO PAGE ESSA-27

Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

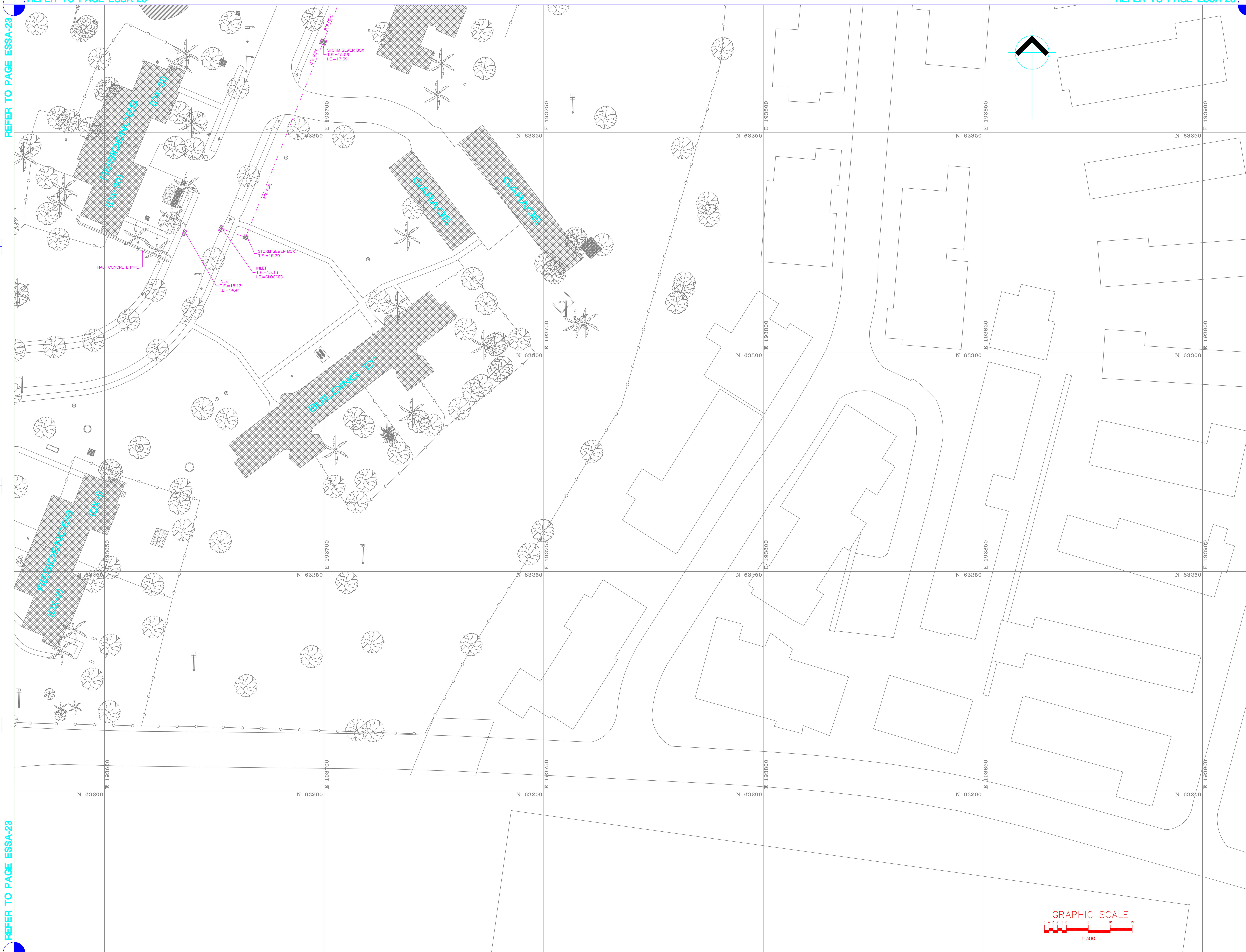
Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-26

REFER TO PAGE ESSA-26
REFER TO PAGE ESSA-26
REFER TO PAGE ESSA-23
REFER TO PAGE ESSA-23



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL: ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641-6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

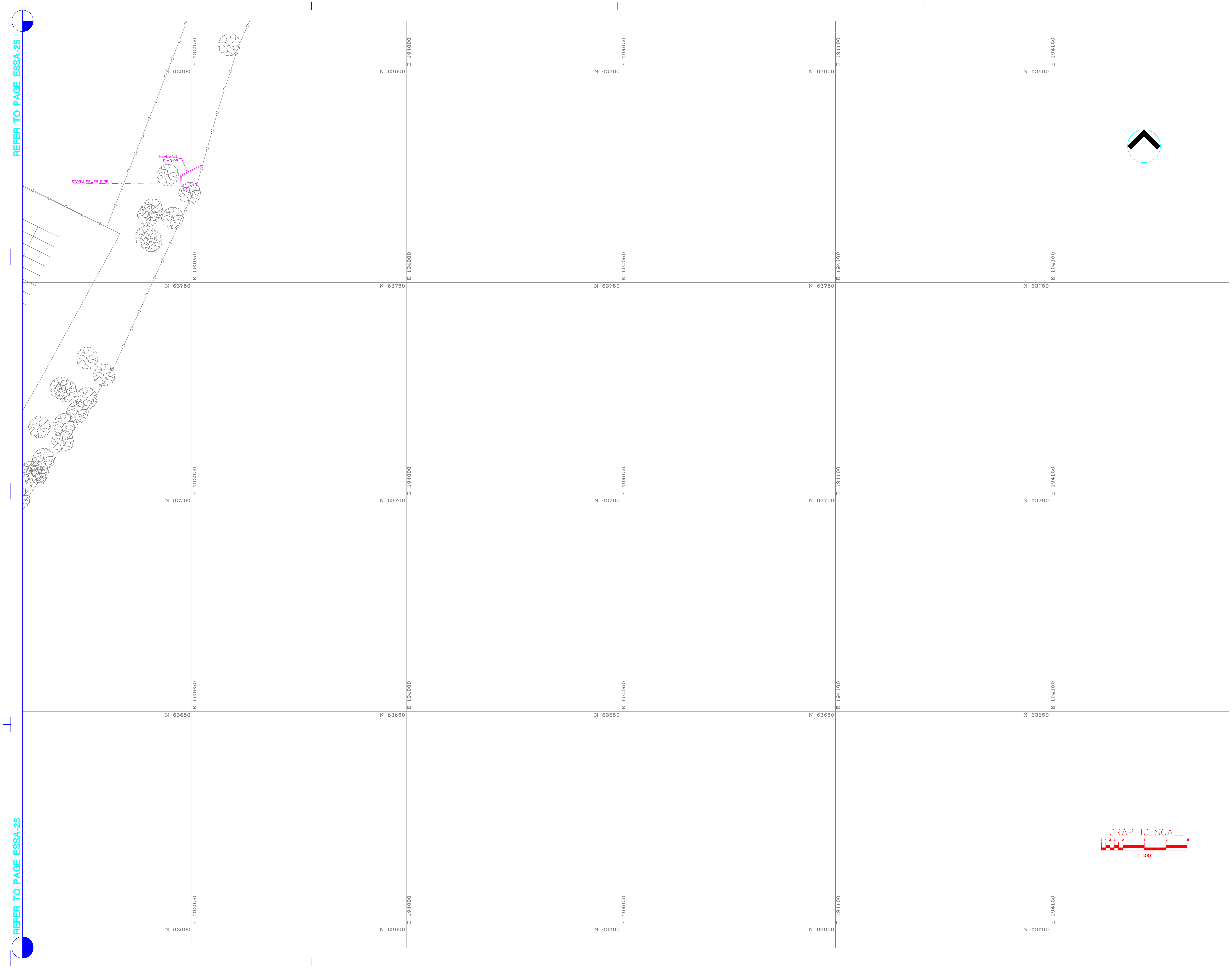
Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #
ESSA-27



Project Name:

LEVANTAMIENTO Y DIAGNOSTICO DE LA INFRAESTRUCTURA DEL RECINTO DE RIO PIEDRAS

Client:

Universidad de Puerto Rico
Oficina de Diseno y Construccion
Oficina del Presidente
Jardin Botanico Sur
Calle Flamboyan 1187
San Juan PR 00926-1117

UNIVERSIDAD DE PUERTO RICO · RECINTO DE RIO PIEDRAS · 1903

Sheet Notes:

Rev. #	Date	Description

Consultants:
Civil

ebp design group
CONSULTING ENGINEERS, P.S.C.
ENRIQUE BLANES PALMER – CIVIL ENGINEER LIC. 6416
207 DEL PARQUE ST., 4TH FLOOR, SAN JUAN, P.R. 00912
TEL.: 787-268-0550 FAX: 787-268-1410 E-MAIL:ebpdesign@prtc.net

Electrical

ANDRES SANCHEZ CARRION
ELECTRICAL ENGINEER
LICENSE NO. 4596
TEL. 641–6750

Mechanical

JOSE L. GARCIA
CONSULTING MECHANICAL ENGINEER
LIC. NO. 7079
OLD SAN JUAN, PUERTO RICO.

Mechanical

JORGE A. TORRES SCANDALI & ASSOCIATES
CONSULTING ENGINEERS
1111 HUMACAO ST., SANTA RITA
RIO PIEDRAS, P.R. 00925
TEL. (787) 763-5190
JORGE A. TORRES SCANDALI
MECHANICAL ENGINEER, LIC. 10906
JORGE TORRES LOPEZ
MECHANICAL ENGINEER, LIC. 4951

Telephone & Data

telec engineers
design & consulting for technology environments
PMB 191, P.O. BOX 70171, SAN JUAN, PR 00936-8171
T: 787-731-2213 F: 787-789-0766

Stamp

SCALE: – 1:300
Date: – JULY 27, 2006
Job #: –

Drawing:

EXISTING STORM SEWER "AS-BUILT" PLAN

Sheet #

ESSA-28