

**DESIGN OF A WASTEWATER COLLECTION SYSTEM FOR THE
HISTORICAL CENTER OF PARATY, BRAZIL**

By

NANCY CHOI

Bachelor of Science in Environmental Engineering
School of Engineering, Massachusetts Institute of Technology (2002)

Submitted to the Department of Civil and Environmental Engineering
In Partial Fulfillment of the Requirements for the Degree of

**MASTER OF ENGINEERING
IN CIVIL AND ENVIRONMENTAL ENGINEERING**

At the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 2003

© 2003 Nancy Choi
All right reserved

The author hereby grants to MIT permission to reproduce and distribute publicly paper
and electronic copies of this thesis document in whole or in part

Signature of the Author _____
Department of Civil and Environmental Engineering
May 9, 2003

Certified by _____
Professor Donald R.F. Harleman
Ford Professor Emeritus of Civil and Environmental Engineering
Thesis Supervisor

Accepted by _____
Professor Oral Buyukozturk
Professor of Civil and Environmental Engineering
Chairman, Department Committee on Graduate Studies

**DESIGN OF A WASTEWATER COLLECTION SYSTEM FOR THE
HISTORICAL CENTER OF PARATY, BRAZIL**

By

NANCY CHOI

Submitted to the Department of Civil and Environmental Engineering on May 9, 2003 in partial fulfillment of the requirements for the degree of Master of Engineering in Civil and Environmental Engineering

Abstract

The city of Paraty in the State of Rio de Janeiro, currently lacks a wastewater collection and treatment system. Untreated wastewater is carried by two rivers surrounding the city and discharged into a bay in front of the city. This creates many potential health, environmental, and social risks for the city. The city is in need of a plan to deal with its wastewater. The following thesis presents a conceptual design for a wastewater collection system in the historical center of Paraty, Brazil. Such a design can serve as a model that can be implemented to the other sections of the city. The design of this collection system involved investigating wastewater flow requirements, alternatives for wastewater collection, possible locations for a treatment plant, a feasibility study, and cost estimates for the system. A conventional gravity collection system was designed based on the conclusion that for the city of Paraty, a uniform, consistent, simple collection system would be the most appropriate.

Thesis Supervisor: Donald R. F. Harleman

Title: Ford Professor of the Department of Civil and Environmental Engineering

Acknowledgments

I would like to thank a few people for all their guidance and help with this thesis project. Many thanks go to my advisor, Professor Harleman and my other unofficial co-advisor Frederic Chagnon. Thanks to Ricardo Tsukamoto for all the unbelievable amount of help he has provided to our whole team. Thanks to Sylvia Lee for meeting with me and providing much wisdom and guidance. Thanks to all the other engineers I have talked to and acquired invaluable help and information.

I'd like to also thank my group mates, Claire Kfourri, Hyo Jin Kweon, and Eun Chu You. They have made this project fun and enjoyable, and it has been my pleasure working with them.

Finally I would like to acknowledge and thank my family and friends for all their prayers and encouragement. They have been a tremendous source of support and “fighting” during this year.

TABLE OF CONTENTS

1. INTRODUCTION.....	7
2. BACKGROUND.....	8
2.1 Introduction.....	8
2.2 Sanitation in Brazil.....	9
2.3 Current Situation in Paraty.....	11
2.4 Plan for Mangueira.....	13
2.5 City Goals, Requirements and Issues.....	13
2.6 Thesis Focus.....	13
2.7 Challenge for Paraty.....	14
3. METHODOLOGY.....	15
3.1 Objective.....	15
3.2 Project Understanding.....	15
3.2.1 Field Visit.....	15
3.2.2 Paraty’s Mapping.....	16
3.2.3 Wastewater Collection Systems.....	17
3.3 System Criteria.....	19
3.4 Choice of System: Gravity Collection System.....	26
3.5 Technical Approach.....	27
3.5.1 Treatment Plant Location.....	27
3.5.2 Overall Layout.....	29
3.5.3 Gravity Sewer Design.....	30
4. CAPITAL COST ESTIMATES.....	40
5. DISCUSSION/ANALYSIS.....	42
6. SYSTEM RECOMMENDATIONS.....	49
7. CONCLUSION.....	52
8. APPENDICES.....	53
9. REFERENCES.....	65

LIST OF TABLES

Table 2.1 Water and wastewater data reported by CEDAE on State of Rio de Janeiro

Table 2.2 Water and Sanitation Data on Municipality of Paraty

Table 3.1 Typical Costs for Sewer Systems

Table 3.2 Phillippi Creek Project – Summary of Estimated Uniform Annual Costs

Table 1.3 Wastewater Flows

Table 3.2 Wastewater Loads

Table 3.5 Recommended slopes for different pipe (PVC) diameters

Table 3.6 Pipe Segment Data

Table 4.1 Costs Estimates

LIST OF FIGURES

Figure 2.1 Map of the State of Rio de Janeiro

Figure 2.2 Map of Paraty, Brazil

Figure 3.1 Per capita construction costs for different sanitary sewer systems at various population densities

Figure 3.2 Aerial Photo of Paraty – Potential Locations of Treatment Plant

Figure 3.5 Sewer Network Layout Designs

Figure 3.6 Gravity Sewer Network of the Historical Center

Figure 3.7 Profile of the Main Trunk Line

Figure 5.1 Velocity versus Peaking Factor

Figure 5.2 Total Flow versus Peaking Factor

Figure 5.3 Total Flow versus Infiltration Rate

Figure 5.4 Velocity versus Roughness Coefficient

1. Introduction

The purpose of this thesis is to present a conceptual, preliminary design of a wastewater collection system for the historical center of the city of Paraty, Brazil. The city of Paraty currently has no collection or treatment of wastewater. The preliminary design for the historical center presents a step towards the overall goal to collect and treat all of Paraty's wastewater. The process to design this collection system involved an investigation of the wastewater flow requirements of the project, alternatives for wastewater collection, possible locations for a wastewater treatment plant, feasibility study of a collection system and cost estimates.

Chapter 2 provides some background on Paraty, sanitation in Brazil, and the current situation in Paraty. Chapter 3 goes into the methodology of the design and discusses the project understanding, system criteria, and technical approach. The following sections provide cost estimates (Chapter 4), analysis (Chapter 5), and system recommendations (Chapter 6) on the proposed system.

2. Background

2.1 Introduction



Figure 2.1 Map of the State of Rio de Janeiro

Paraty is a small city on the coast of Brazil in the state of Rio de Janeiro (See Figure 2.1). Established sometime in the 17th century, Paraty played an important role as a main port for gold from the Minas Gerais State in the 18th century, and for coffee in the 19th century. Due to the decline of both industries and the geographic isolation of Paraty for most of its history, the historic city was well preserved. The opening of the Rio-Santos highway in the 1980s led to an economic boost from a new industry – tourism. The preservation of historical architecture, the surrounding landscapes and numerous islands and beaches has made Paraty a National and World Historical Monument as well as a desirable location for many tourists.

2.2 Sanitation in Brazil

Until the end of the 1960s, Brazil did not have any federal, state or regional policy on the water and sanitation sector. Local governments were responsible for delivering water and sanitation services. In 1971 the federal government established PLANASA (Plano Nacional de Saneamento), a national plan created to improve water supply and sanitation services. According to the plan, each State created its own State-owned public water and sewage company. The individual municipality then decided to turn over their concessions to the state agency or independently manage their system. Local governments were encouraged to turn to the state water company in exchange for federal funding. About 85 percent of the population is served by the state companies today¹.

The Plan brought great improvements to water supply and sanitation in Brazil, although its goals were not completely met. The urban water coverage, which was 45 percent in 1970, achieved 83 percent coverage by 1985. The percentage of people connected to public sewage systems increased to 35 percent from 24 percent. Although the sewage system increased, wastewater treatment lagged far behind: only about 10 percent of total wastewater received any form of treatment².

Despite the improvements, many of the state companies had a series of problems such as: technical and operational problems; high unaccounted-for water; limited service expansion that could not cope with population growth; commercial and financial problems; human and institutional problems; and environmental problems. The

¹ US Department of Commerce, 1999

² US Department of Commerce, 1999

PLANASA model remains operational as a backbone of sanitation in Brazil, but has since become extinct and a new model is being developed.

The Brazilian Constitution of 1988 defined the municipalities as responsible and legally empowered to grant authority for local services, including water supply and sewage. State companies operate local services by concessions granted by the municipalities. Most concessions were granted in the 1970s, for a duration of 25-30 years. The municipality of Paraty recently acquired responsibility of their water and sewage back from CEDAE. CEDAE is the public state company for the State of Rio de Janeiro. However, due to the dependency on CEDAE, the city has not been able to provide their own technical support, the water supply and sewage services have been contracted back out to CEDAE³. Table 2.1 shows state data on the water and sanitation situation.

Data on the State of Rio de Janeiro	
State Population (1,000)	13,276
State Municipalities	63
Water Connections (1,000)	1,453
Sewage Connections (1,000)	612
Water Network (km)	14,527
Sewage Network (km)	4,586
Water Coverage (%)	78.5
Sewage Coverage (%)	45.5
Water Produced (1,000 m ³)	1,809,144
Unaccounted-for Water (%)	52
Water Average Tariff (R\$/m ³)	0.73
Sewage Average Tariff (R\$/m ³)	0.87
Employees	9,703

Table 2.1 Water and wastewater data reported by CEDAE on State of Rio de Janeiro⁴

³ Personal Communication, Ricardo Tsukamoto

⁴ US Department of Commerce, 1999

2.3 Current Situation in Paraty

Paraty has a summertime population growing up to three times as much as its fixed urban population of 15,000⁵. This annual flux causes large variations in water and sanitation loads. The untreated sewage is carried by the two rivers surrounding the city and eventually the waste is discharged out into the bay in front of the city (See Figure 2.2).

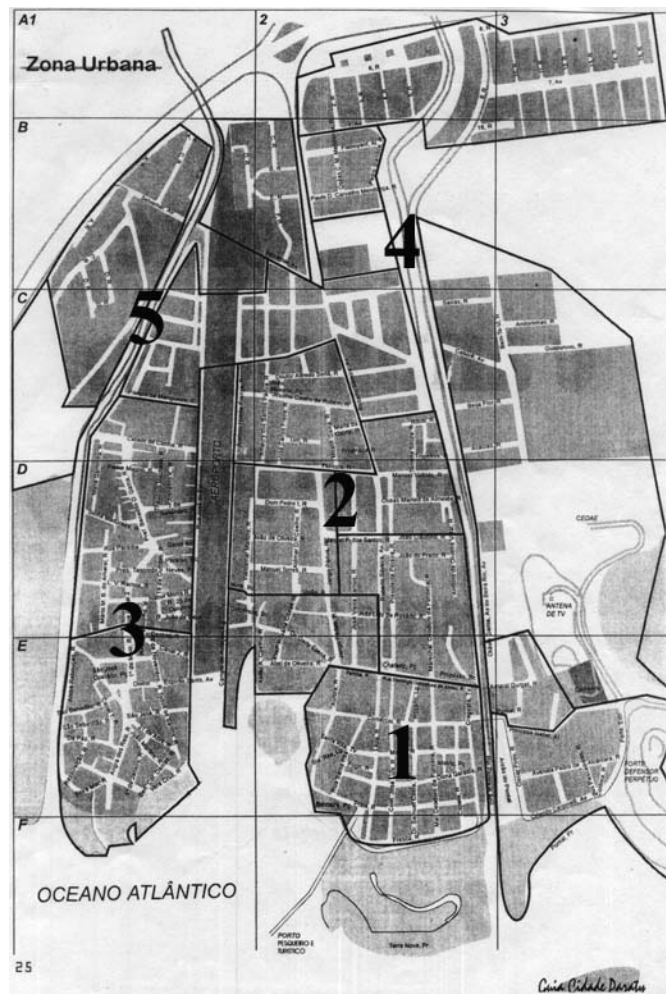


Figure 2.2 Map of Paraty, Brazil: 1. Historical Center; 2. “Upper” part of the city; 3. Mangueira; 4. Pereque River; 5. Matheus Nunes River

Currently, water is collected from a surface source in the surrounding mountains, and distributed in buried pipelines without any treatment other than chlorination. In addition,

⁵ Prefeitura Municipal de Paraty, 2001

the supply suffers from low pressure, especially during the summer tourist season. The present sewerage infrastructure includes many septic tanks, nonfunctional pipes (some of which are periodically immersed in seawater), and discharges to the river.

The Historical Center is the centuries-old part of the city adjacent to the sea. This section has cobblestone streets and cars are not allowed. The buildings are preserved and many are used for shops and hotels. The streets immediately adjacent to the sea are flooded during high tides. The “upper” part of the city, away from the sea, has a normal city structure: the water table there is from 0.5 to 1.0 meter deep. Mangueira, the third main section of the city, is home to many lower income people. This area has grown to be the largest portion of the city. Figure 2.2 indicates the three main sections of Paraty. There is no separate sanitary collection system in Paraty. The sections outside the historical center have a storm water collection system that residents have connected haphazardly to discharge wastewater. The sewage is taken directly into channels that end up in Paraty Bay. All of Paraty’s wastewater goes untreated. Table 2.2 summarizes water supply and sanitation data from the city of Paraty.

Data on the Municipality of Paraty	
Total Population	30,000
Urban Population	15,000
Urban Population Supplied with Water	15,000
Urban Homes with Water Supply	4,300
Supply Capacity (L/sec)	30
Distribution	By gravity
Sanitation	No sanitary sewage system in the urban area

Table 2.2 Water and Sanitation Data on Municipality of Paraty⁶

⁶ Prefeitura Municipal de Paraty, December 2001

2.4 Plan for Mangueira

There is currently a plan for a collection and treatment project in the Mangueira section of Paraty. Mangueira has obtained special outside grants for this project because of its status as a poorer community. The rest of the city does not qualify for such funding. The plan however is not complete. The plan is incomplete as it includes a design for a basic trunk line and a treatment plant. There are no plans to build a network within the residential area. The incomplete system is therefore rendered useless because homes are not able to connect to the collection system. Refer to Appendix A for a more detailed description of this project in Mangueira as well as a layout of the plan.

2.5 City Goals, Requirements, and Issues

The city of Paraty is making efforts to qualify the historical center as a UNESCO World Heritage Site. Before this can be accomplished, the city must solve two main problems: 1) treat its wastewater and 2) conceal its aerial electric distribution system, by burying it underground. In addition to the economic and status benefits of sewage treatment, there are associated health benefits to treatment of sewage⁷. In order for sewage to be effectively and efficiently treated, a wastewater collection system is needed.

2.6 Thesis Focus

The whole city of Paraty is in need of sewage collection and treatment development project. Due to funding and logistics, a project of this magnitude needs to be taken in steps. The focus for this thesis is on the historical center of Paraty for several reasons.

⁷ Refer to thesis by Eun Chu You (2003) for more information.

First, there is an obvious and pressing motivation to build a collection system in the historical center in order to qualify for UNESCO recognition. Secondly, the focus on one section can provide a model for each successive step in a longterm project to provide sanitation services for all of Paraty.

2.7 The Challenge for Paraty

Although the Historical Center is well preserved, it is a fragile environment for big change and the people of the city want to keep the city in its' original form. The water table is high in the Center and floods with the high tides every day. The land is also flat within the Historical Center.

3. Methodology

3.1 Objective

The objective of this thesis is to provide a conceptual design of a wastewater collection system for the Historical Center of Paraty, Brazil. This section describes the methodology into creating a design. The process investigates the wastewater flow requirements of the project, the alternatives for wastewater collection, the possible locations for a wastewater treatment plant and the cost estimates.

3.2 Project Understanding

Investigation of the area in need of sewerage is important for design and construction. Paraty's sewer design is based on a field visit of the proposed sewer area, a review of the city's mapping, and a preliminary analysis of the different alternatives of collection.

3.2.1 Field Visit

The land of the city is generally flat. The elevation seems to be no more than a half-meter above sea level. The tide floods the streets each day in the area closer to the water. The streets are in poor condition. Due to past road excavation, the stones that make up the streets were put back improperly and subsequently the streets are slanted and rough to walk on. The streets vary in width ranging between 4 and 7 meters. There is a mix of one and two story buildings, and there are no basements in any of the buildings. The existing underground structures include a water distribution system, a telephone wire system and an old, incomplete and nonfunctional sewer collection system. The existing

sewer is a gravity sewer which was implemented 20 years ago in the Historical Center. It was built with a line of short pipes of concrete (1 meter in length) and has its lowest point close to the sea at depths of around 3.5 meters⁸. Because of the material used to build the sewer, the infiltration is too high for use as a sewer.

3.2.2 Paraty's Mapping

The city lacks appropriate and accurate maps of the existing infrastructures. Most of the surveying was performed by interviews with people and by observation. An aerial photo was obtained⁹ and the map was then digitized and georeferenced using ArcView GIS. The coordinates are based in Universal Trans Mercator (UTM) projection. The scale of the map is 1:2000 (See Figure 3.2). This map provided means to plan out a collection system with accurate spatial data.

3.2.3 Wastewater Collection Systems

Combined sewers are used to collect wastewater from residential, commercial, institutional, and industrial sources and storm water. These sewers are common in many older parts of major cities. Old combined sewers discharge wastewater into receiving waters. To reduce or eliminate pollution problems from combined sewers, a separate sewer system is needed. Stormwater is generally less polluted than wastewater, and that treatment of combined wastewater and stormwater is difficult during heavy rainfalls, resulting in untreated overflows (commonly termed combined sewer overflow, CSO)¹⁰. Combined sewage is harder and more expensive to treat. In a city like Paraty, where

⁸ Personal Interview, Wilson Rocha

⁹ Aerial photo was obtained through personal contact and communication with Tymur Klink.

¹⁰ Heaney, 1999

there are large influxes of storm water, a separate sewer system would be best suited. Four options for a wastewater collection system serving the city of Paraty are discussed here. The four types are: 1) gravity sewers; 2) pressure sewers; 3) vacuum sewers; and 4) small diameter gravity sewers.

Conventional Gravity Sewers

Conventional gravity sewers¹¹ transport wastewater by gravity flow from high to low points. They are designed so that the slope and size of the pipe is adequate to maintain flow towards the discharge point without surcharging manholes or pressurizing the pipe. Conventional gravity sewers remain the most common technology used to collect and transport domestic wastewater. Properly designed systems can handle grit and solids in sanitary sewage as well as maintain a minimum velocity which reduces the production of hydrogen sulfide and methane. The need for a self cleansing slope can require deep excavations and/or additions of pumping or lift stations.

Several different types of wastewater collection systems have been developed as alternatives to conventional sewers. The network of piping for an alternative collection system can be laid in much shallower and narrower trenches. The pipes are usually of a smaller diameter than those used in a conventional system (100 mm compared to 300 mm in diameter)¹². They also do not need to be laid in a straight line nor with a uniform gradient. This means they can be laid in such a manner as to easily avoid obstacles. The three main types of alternative collection systems are pressure sewers, vacuum sewers and small-diameter gravity sewers (SDGS).

¹¹ Metcalf and Eddy, 1981

¹² US EPA, 1991

Pressure Sewers

Pressure sewers¹³ use the pressure force supplied by pumps to deliver wastewater to a central location from each property. A pressure system is a small diameter pipeline (typically 100mm), shallowly buried, and following the contour of the land. The systems eliminate the need for lift stations of a conventional system and also infiltration is eliminated because manholes are not required, thus piping materials are not exposed to groundwater fluctuations. There are two types of pressure systems distinguished by the type of pump used. A septic tank effluent pump (STEP) uses septic tanks to capture the solids, grit, grease and stringy material that allows for smaller diameter piping. The effluent pump then provides the necessary pressure to move the wastewater through the system. The second type of pump is a grinder pump (GP) which grinds the solids in the wastewater into tiny particles. The slurry is then pumped into the sewer system that requires a pipe diameter slightly larger than in the STEP system because of the mixture. In the GP system, each household requires a tank containing the pump with grinder blades. Both pump systems require periodic cleaning of local tanks as well as localized electrical supply for each pump.

Vacuum Sewers

Vacuum sewer systems¹⁴ take wastewater from a holding tank. When the wastewater reaches a certain level, sensors within the holding tank open a vacuum valve that allows the contents of the tank to be sucked into the network of collection piping. The vacuum

¹³ US EPA, 1991

¹⁴ US EPA, 1991

within the system is created by a vacuum station at a central location. Vacuum stations are small buildings that house a large storage tank and a system of vacuum pumps.

Small Diameter Gravity Sewers

Small diameter gravity sewers¹⁵ provide primary treatment at each connection and convey only the effluent. This system is similar to the STEP system in that it would require homeowners to maintain their existing septic tank. Grit, grease and other troublesome solids which might cause obstructions in the collector mains are separated from the flow and retained in the septic tanks. Effluent from each tank is discharged to the collector sewer via gravity. There is a lower required velocity in the sewers because solids are not transported through the system. Therefore the pipes do not have to be as large or as sloped.

3.3 System Criteria

While analyzing the different types of collection systems, there were four criterion to guide the decision in choosing the best fit option for the historical center. These four criterion are: economics, adaptability, expandability, and simplicity. Addressing the issues associated with these criteria is key to developing the right choice of sewers for the Historical Center.

¹⁵ US EPA, 1991

3.3.1 Economics

Capital Costs

Cost is always a main factor in any project decision. The capital costs for any of the options available involves a number of factors such as house connections, sewer mains and pumping stations. The primary cost trade-offs to develop a plan are discussed here.

Table 3.1 provides a summary of the cost comparisons described below.

	House Connections (\$/household)	Sewer Mains (\$/meter)	Pump Stations starting costs (\$)
Gravity Sewer	2,500	230-330	200,000
Vacuum Sewer	5,000	130-200	400,000
Pressure Sewer	7,000	115-165	None

Table 3.1 Typical Costs for Sewer Systems¹⁶

House Connections. Gravity sewers have the simplest and lowest typical cost¹⁷ of about \$2,500 for a house connection. Vacuum sewers require a vacuum valve station at each property with typical costs starting at \$5000 per household. Pressure sewers are the most expensive option with pump costs approaching \$7,000 per household. SDGS have a house connection cost of installing and maintaining the interceptor tanks. Similar to pressure sewers, the cost of installing interceptor tanks is a significant cost. Usually existing septic tanks cannot be used as interceptor tanks because they are not watertight and cannot be inspected and repaired cost effectively. Pressure and small diameter gravity sewers are both well suited for communities with houses that are far apart. The historical center of Paraty, where the houses are close together, is therefore not conducive for pressure and small diameter gravity systems.

¹⁶ Harrington, 2003

¹⁷ Harrington, 2003

Sewer Mains. The conventional gravity system has slope requirements to maintain gravity flow. This demands deep excavations and/or additions of pumping or lift stations which drive up construction costs. Pressure sewers are the most cost effective sewer mains to implement. They do not require deep excavation and typical cost per meter range from \$115-165¹⁸. Small diameter gravity sewers have a small diameter (~100mm) and can be also buried at a relatively shallow depth. Vacuum sewers are typically 15-25% higher in cost than pressure sewers and gravity sewers are generally more than 100% higher in cost than the lower cost pressure sewers. The historical center of Paraty is not a large area (14 hectares), and therefore, deep excavation is not a large concern. Where the required length of sewer between service connections is comparatively short, the cost of providing conventional sewers is usually affordable unless some other obstacle is present.

Pump Stations. Pump systems must have sufficient head to transfer wastewater all the way to the treatment plant. Therefore there are no additional associated costs for pump stations. Standard pumping stations for gravity systems begin at \$200,000 (Reference) while vacuum stations for the same design flows can cost up to 100% more than a sanitary pump station. The average number of customers per station in vacuum systems is about 200-300¹⁹. Although it is possible to have a station serve the whole historical center, which would need to serve about 700, it could not serve the whole city of Paraty. More stations would need to be built and drive up costs.

¹⁸ Harrington, 2003

¹⁹ Hassett, 1995

Operation and Maintenance

The operation and maintenance cost for pressure systems tend to be high because of the pumps. In areas where electric supply is not reliable, these systems could be more trouble than help in that constant monitoring or the addition of backup power is needed at each household. There is less risk with a vacuum system since the vacuum station has a central location, so just one back up power system is required. There is also a cost of cleaning and maintaining each tank at each home. In higher density areas, this could prove to be more costly than the savings from pipe network installations fees for pressure sewers and SDGS.

Site Examples

Table 3.2 shows some capital cost as well as O&M estimates of different collection systems for a project in Sarasota, Florida. In Sarasota, Florida, an evaluation was performed on possible wastewater collection system alternatives on a project there. Preliminary design and cost information for low pressure and vacuum sewer systems were obtained from various equipment manufacturers. Table 3.2 provides the estimated annual costs per connection for each collection system alternative based on different densities selected for analysis. The densities were categorized as either low (>0.5 acre average lot size), medium (0.25-0.5 acre average lot size), or high (<0.25 acre average lot size) density²⁰. The historical center falls into a high density category for this case. The analysis reiterates the economic impracticality of a pressure system for Paraty. Based on

²⁰ Sarasota County, 2000

the comparison, the vacuum system is the most cost effective alternative for a “high” density area like the historical center.

	Collection Alternatives	Capital Cost	Annualized Capital Cost ^[1]	Annual O&M Cost ^[2]
LOW DENSITY				
	Low Pressure	\$10,400	\$1,140	\$190
	Vacuum	\$12,800	\$1,370	\$140
	Gravity	\$18,200	\$1,800	\$ 90
MEDIUM DENSITY				
	Low Pressure	\$8,100	\$ 920	\$180
	Vacuum	\$7,100	\$ 820	\$ 70
	Gravity	\$9,000	\$1,010	\$ 50
HIGH DENSITY				
	Low Pressure	\$8,000	\$ 910	\$180
	Vacuum	\$6,100	\$ 730	\$ 60
	Gravity	\$7,700	\$ 890	\$ 50

Table 3.2 Phillippi Creek Project²¹ – Summary of Estimated Uniform Annual Costs (per connection).
1. Annualized capital costs were based on an interest rate of 7.0% over 20 years and include a capacity fee of \$1,642. 2. Replacement costs were annualized based on an interest rate of 7.0%

A further support for the cost-effectiveness of the vacuum system is from a study by Alan Hassett²² in Virginia. Hassett provides a cost comparison for vacuum sewers for an actual project location in Virginia. The service area was assumed flat with a three foot depth-to-ground water, an area of 750 acres (300 hectares), and approximately 750 residential units housing 3,000 people. The density was then varied to provide the construction cost information presented in the figure below.

²¹ Sarasota County 2000

²² Hassett, 1995

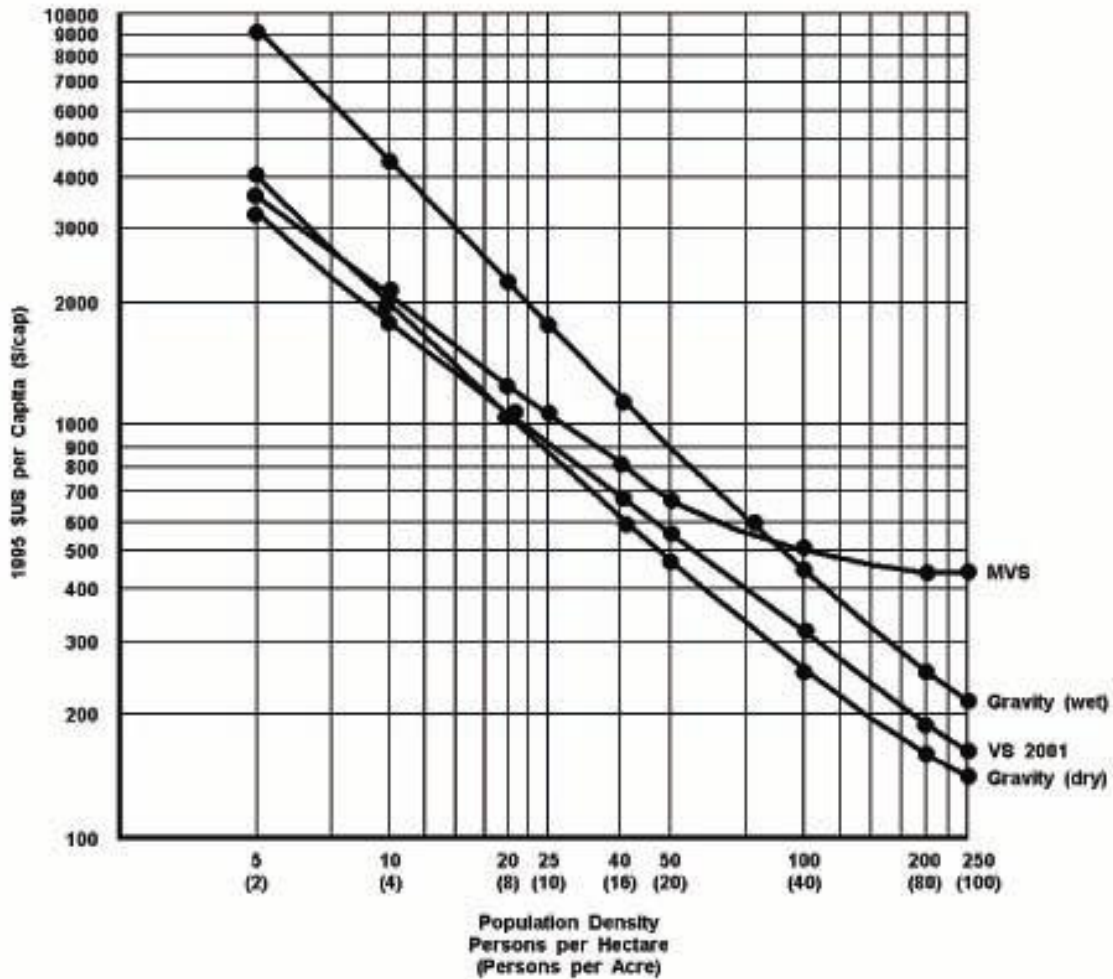


Figure 3.1 Per capita construction costs for different sanitary sewer systems at various population densities²³. Note: MVS means modern vacuum system and VS 2001 represents 21st century vacuum system. Wet means that the system includes lift stations and is below the water table.

The population density in Paraty is around 200 persons/ha (refer to section 3.5.3 for population data). In the above figure, the vacuum system costs about \$60 dollars less than the wet gravity system at that population density. A wet gravity system is a system that includes lift stations and is below the water table. The graph is used for comparative purposes so the exact dollar amount cannot be taken literally. This suggests that for a city like Paraty, a vacuum system can be slightly more cost effective than a gravity system.

²³ Hassett, 1995

3.3.2 Expandability

The overall longterm goal of Paraty would be collect and treat all of its wastewater. This report goes through a plan for only the historical center section of the city. Expandability is therefore a criterion for the system to be selected for Paraty. Future collection additions must be taken into account. Being comparatively large in diameter and capacity, conventional sewers are often seen as being growth inducing. Both pressure sewer and vacuum technology have less flexibility than gravity sewers in accommodating future flow increases. For example a disadvantage of the vacuum system is that the length and amount of pumping possible is restricted due to head limitations²⁴.

3.3.3 Adaptability

A third criterion for this system is adaptability and flexibility to seasonal fluxes. Paraty is a tourist city and has a large flux in population as well as rain in the summer months. All four systems can handle such a variation in flow, but a gravity system can probably handle these peak flows the best because of it's comparatively larger size and capacity.

3.3.4 Simplicity

The final criterion is simplicity. Given the history and political climate in Paraty, a simple system is needed. Having a system that is widely known enables ease of transition from changing administrations. An advantage to conventional collection is that the technology is well established with relatively simple operation and maintenance. Pressure sewer and SDGS systems involve maintenance of septic tanks and pressure

²⁴ US EPA, 1991

sewers require even more operation and maintenance due to the addition of pumps at each household. Vacuum systems require a full-time system operator with the necessary training. Possible vacuum leaks can render the whole system inoperable. The city lacks the expertise and resources to handle such involved systems as the pressure, vacuum and small diameter gravity sewers. Also the irregular electrical supply in the city, especially during the summer can cause a problem for the pressure and vacuum systems.

A gravity system is the simplest alternative. There are plans to build a gravity collection system in the Mangueira section of Paraty (Appendix A). This would be another reason to pursue gravity collection for the historical center and have gravity collection in the whole city. The more of a mix of collection systems, the harder it will be to operate and maintain. A uniform, consistent collection system would be the most simple in Paraty, where technical support is limited.

3.4 Choice of System: Conventional Gravity Collection

A conventional gravity design was chosen for the historical center of Paraty based on a preliminary analysis of collection systems. Although the conventional sewers are slightly more expensive than vacuum sewers, their use may be preferred as conventional sewerage is an old and mature practice. Vacuum sewers are not well established in Brazil and are found mostly in large cities²⁵. Paraty needs a system that is easy to maintain and does not require much technical support. The overall plan for a treatment and collection system needs to be expandable, adaptable and centralized. This thesis covers only the design of one section of the city of Paraty, but the entire city is in need of an adequate

²⁵ Personal Communication, Fernando Craveiro

wastewater treatment and collection system. A conventional gravity sewer system is more easily expandable than the alternate systems of collection. Paraty also needs an overall collection and treatment system that is adaptable and robust to the different fluxes in seasonal population and rain. A conventional gravity system coupled with Chemically Enhanced Primary Treatment (CEPT) is ideal for these types of seasonal fluxes. CEPT is a type of wastewater treatment that can handle such variations²⁶. Finally a simple system that is adaptable and expandable would be ideal for Paraty, because it would minimize the personnel needed to handle operation and maintenance.

3.5 Technical Approach

The first step in developing a plan was to identify the alternatives for a preliminary design evaluation. After a review of the factors previously discussed, the next step in this process was to evaluate the feasibility for the chosen system. This section will discuss a conceptual design of a gravity sewer collection system for the historical center of Paraty.

3.5.1 Treatment Plant Location

Before sewer networks can be drawn, the location for a potential treatment plant must be determined. This will shape the layout of pipes. Two potential locations were considered – the first near the city’s hospital (Location 1 – see figure below) and the second in Mangueira (Location 2 – see figure below)

²⁶ Refer to thesis by Kfoury and Kweon (2003) for more information.



Figure 3.2 Aerial Photo of Paraty – Potential Locations of Treatment Plant²⁷.

Both locations are situated strategically near the historical center as well as close to the bay. Location 1 is approximately 3000 square meters in area and Location 2 is approximately 6500 square meters. The proximity to the water will allow for a marine outfall of treated wastewater. Although the site near the hospital is closer to the historical center, it is an undesirable location because of its proximity to a beach. The site on Mangueira is more desirable because since there is already a plan to build a plant there (Appendix A), the cost of upgrading the plant is less than building another treatment plant. Also the area is larger for Location 2, allowing space for future upgrades. In conclusion, Manguiera (Location 2) was chosen as the treatment plant site for the wastewater in the historical center.

²⁷ Klink, 2003

3.5.2 Overall Layout

ESRI's ArcView GIS was used to lay out the general pipe network in the Historical Center. GIS allows for easy "management, analysis, and mapping of infrastructure and geographic information and descriptive data with cartographic accuracy."²⁸ A line was drawn to represent the proposed sewer in each street to be served. Two different pipe networks were designed (See Figure 3.5). Design 1 places the trunk line along the edge of the historical center and Design 2 places the trunk line through the middle of the historical center. Design 2 was chosen because it potential saves on excavation costs. Gravity sewers need to be sloped in order to create velocities large enough to convey wastewater. As pipe segments increase in length, the downstream depth of the pipe also increases. By having the trunk line in a more central location for the network, sewer lines do not have to go as deep because sewer line segments are not as long. Therefore, there is a decrease in installation/excavation costs because of the decrease in the depth of pipe. Each line has an arrow indicating the direction in which the wastewater is to flow. Manholes were then placed at 1) changes in direction; 2) changes in slope; 3) at pipe junctions; and 4) at the upper ends of all laterals for cleaning and flushing the lines. The catchment areas were then established and quantified in ArcView. The catchment areas, manholes, and pipe segments between manholes were all assigned with labels.

²⁸ Shamsi, 2002

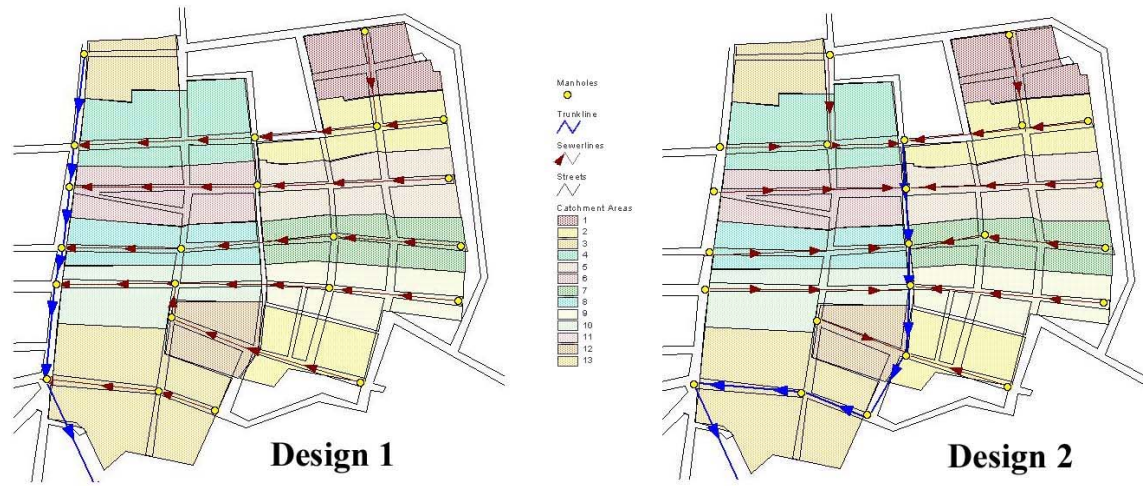


Figure 3.5 Sewer Network Layout Designs

3.5.3 Gravity Sewer Design

Gravity flow sanitary system design involved reviewing design considerations and selecting basic design data and criteria. Once these factors were set, the system was designed, which included preparation of a preliminary sewer system design and design of the individual sewers. The system was designed for peak hourly flow of the base population.

Design Factors

Average Daily Flow. The wastewater flow in Paraty consists of wastewater from residential, commercial and institutional sources and infiltration. Determining the rate of flow is crucial in the design of a collection system. A common indicator and quantifier of wastewater flow is drinking water consumption and use. According to the city of Paraty²⁹, the average potable water consumption is 180 liters/person*day. Few assumptions were made about the population in the historical center. The base population of the historical center was assumed to be 3,000. This is reasonable

²⁹ Prefeitura Municipal de Paraty, 2001

considering the size of the whole urban area (15,000 people)) and the known population size of another section of the city, Mangueira (5,000 people³⁰). Mangueira is a primarily residential area as well as a densely populated area. The historical center is slightly smaller in area as well as less populous and therefore a based residential population of 3000 is a reasonable estimate. The total base flow was calculated as the product of the base population and the average water consumption per person. That product is around 540,000 liters per day. Table 3.3 provides a summary of this calculation. The average summertime population is 9,000 and is assumed to be three times the base population. The total summertime flow is therefore around 1.6 million liters per day.

Average Base Population	Average Summertime Population	Average Wastewater Flow Rate (L/person*day)	Total Base Flow (L/day)	Total Summertime Flow (L/day)
3000	9000	180	540000	1620000

Table 3.3 Wastewater Flows

Loading. The average wastewater flows were inputted into the network as loads at different manholes. Each catchment area contributed a load to a predetermined manhole. Table below shows the distribution of loads. An average flow per hectare is used under the assumption that all the different types of property are evenly distributed throughout the historical center. The average summer flow per hectare (39,000 L/ha*day) was determined from the total base flow (540,000 L/day) divided by the total area of the historical center (14 ha). The load to each manhole was then calculated by finding the load contribution from the corresponding catchment area. Table 3.4 displays the wastewater loads to each manhole that has a catchment area associated with it.

³⁰ Prefeitura Municipal de Paraty, December 2001

Manhole Number	Catchment Areas	Area (sq. m)	Area (ha)	Catchment Load (L/day)
MH1	HC1	8,377	0.8	33,000
MH2	HC2	9,505	1.0	37,000
MH4	HC3	5,610	0.6	22,000
MH5	HC4	13,956	1.4	54,000
MH8	HC5	13,016	1.3	51,000
MH9	HC6	11,360	1.1	44,000
MH11	HC7	10,725	1.1	42,000
MH13	HC8	9,011	0.9	35,000
MH15	HC9	10,862	1.1	42,000
MH16	HC10	10,846	1.1	42,000
MH18	HC11	7,552	0.8	29,000
MH19	HC12	6,338	0.6	25,000
MH20	HC13	20,133	2.0	79,000

Table 3.4 Wastewater Loads

Peak Flow. The sewers are designed for peak hourly flows during the non summer months. Peak hourly flow should be the design average daily flow in conjunction with a peaking factor. In Brazil, the common peaking factor is 1.8³¹. The peak flow rate is then 1.8 times the mean flow rate. The peak hourly flow is therefore on the order of 1 million liters per day (= 540,000 L/day * 1.8).

Infiltration. In the design, allowance was made for unavoidable infiltration as well as for the expected wastewater. One source³² indicates an infiltration rate of 0.02 L/day/mm diam/m for pipes with a diameter in the range of 200-675mm (8-27in). This infiltration rate does not significantly change the total flow and the summer peak hourly flow is still around 1 million liters per day (See table 3.6).

Sewer pipe material and sizes. The proposed pipe material is Polyvinyl chloride (PVC). PVC is favored because it is light-weight but strong. It is also smoother than other materials (Mannings n of 0.010) and highly resistant to corrosion. Other types of pipes,

³¹ Personal Communication, Ricardo Tsukamoto

³² City of Arvada, 2001

such as concrete pipes ($n=0.013$), are susceptible to corrosion due to acid and hydrogen sulfide attack³³. Sewer pipes must have a minimum diameter to account for large objects that may enter the sewers. The minimum pipe size is 150 mm in diameter. The pipe size used for the historical center range from 150 to 375 mm in diameter.

Depth of cover. The depth of a sewer depends upon the depth of existing underground structures, specifically water lines and basements. In Paraty there are no basements so the depth of the basement is of no concern. The water distribution lines are close to the surface as well as close to the sidewalks. Therefore the minimum pipe depth of sewers for this design is 0.4 meter below ground surface within the historical center. In Brazil the typical standards for minimum cover is 0.6 meters, but for the historical center since there is no vehicle traffic, 0.4 meter is acceptable. In addition, a relatively inexpensive geotextile can be applied above pipes to absorb pressure and allow for the shallower depth of cover.

Depth of Excavation. A maximum excavation depth was set because it is expensive and impractical to excavate deeper than a certain level, especially in the historical center where the water table is high. The maximum excavation depth was set at one meter below mean sea level. This value was based upon input from various engineers working in an areas with a high water table much like Paraty.

Velocity. The flow within the sewers must retain a sufficient velocity in order to flush out any solids that deposit during low flow. The typical minimum velocity for gravity

³³ Metcalf and Eddy, 1981

pipes in Brazil as well as in the U.S. is 0.6 m/s³⁴. Table 3.5 lists a recommendation for PVC pipe slopes at corresponding pipe sizes. It is based on a minimum velocity, when flowing 75% full, of 0.6 m/s.

Diameter (mm)	Slope
200	0.004
250	0.003
300	0.002

Table 3.5 Recommended slopes for different pipe (PVC) diameters³⁵

These slopes were a starting point when designing the sewer network. The velocity at less than one-half full depth will be less than 0.6 m/s.

Elevation. The land in the historical center is flat. The tidal range in the region is 0.9 m in the sea (difference between highest and lowest tide)³⁶. Groundwater levels therefore range between 0.5 m above mean sea level (msl) to 0.4m below msl. Since tidal flooding has been observed in the historical center the elevation of the ground is probably around 0.3 m above msl. The elevation for modeling purposes was assumed to be 0.5 meters above mean sea level.

Profiling and Modeling

After all the design factors and constraints were set, a more detailed profile and model of the sewer network was created. A spreadsheet was prepared in Microsoft Excel to record the data and steps in the computations for each section of sewer between manholes. In conjunction with Haestad Method's SewerCAD, the sewer invert elevations, pipe

³⁴ Metcalf and Eddy, 1981 and Tsukamoto, 2003

³⁵ City of Arvada, 2001

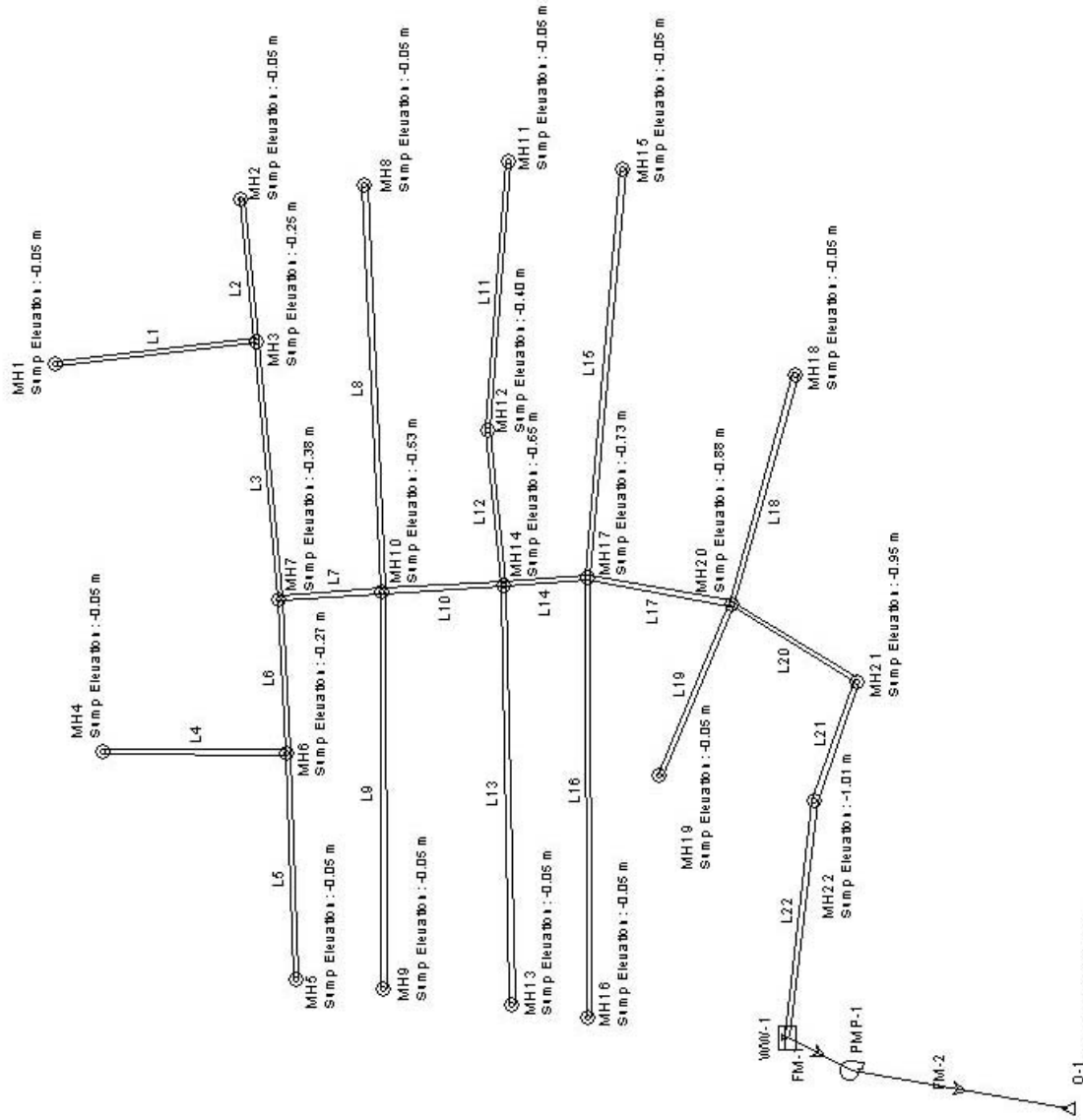
³⁶ Personal Communication, Paulo Cesar Colonna Rosman

diameters, pipe slopes and velocities were determined by trial and error to find the best fit design given the design factors and constraints.

SewerCAD³⁷ is a powerful design and analysis tool that allows you to layout a collection system, develop and compute sanitary loads, and simulate the hydraulic response of the entire system - including gravity collection piping and pressure force mains. SewerCAD has features such as steady-state analysis using various standard peaking factors, extended-period simulations of complete collection systems, and advanced automatic system design. The program provides import and export wizards to transfer data between GIS and the model in SewerCAD. This enabled an initial layout within GIS, an import of that layout into SewerCAD, and an export of the model back into GIS. Figure 3.5 provides a SewerCAD layout of the pipe network and Figure 3.7 that displays the profile of the main trunk line of the optimal preliminary design. All other profiles for the network can be found in Appendix B.

³⁷ Haestad, 2002

Diversion Network
Scenario: Gravity Sewer Network



File: Historical Center of Paraty
 I:\...theislaptop_stuff\src\basel\peakflow.swf
 3/21/03 10:55:45 PM

© Haestad Inlethods, Inc. 37 Brookside Road Waterbury, CT 06706 USA +1-203-755-1666
 Academic Edition

Project Engineer: Nancy Choh
 SewerCAD v6.0 [5.00246]
 Page 1 of 1

Figure 3.6 Gravity Sewer Network of the Historical Center

Profile
Scenario: Gravity Sewer Network

Profile: maintrunkline

Scenario: Gravity Sewer Network (0.00 hr)

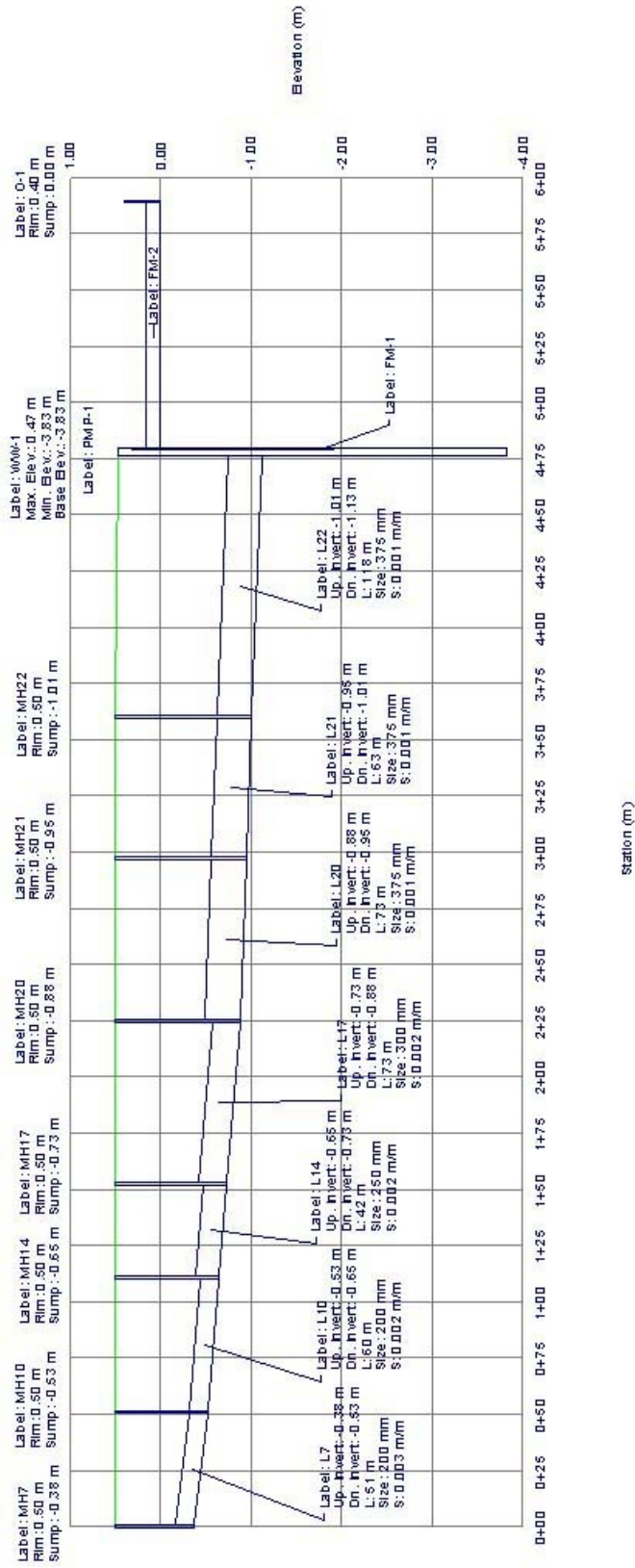


Figure 3.7 Profile of the Main Trunk Line

Using the loads, the sewer network components (elevation, pipe diameter, slope, velocity) were designed for a peak hourly flow and a maximum excavation depth of one meter. Table 3.6 presents the network component data for each pipe segment. All elevations were relative to mean sea level. The maximum depth of a sewer segment was the most downstream segment, L22, with an invert elevation of around -1 m relative to mean sea level. The length in pipe ranges from 40-200 meters and all the average pipe depth of cover were above the minimum constraint of 0.4 meter. The contribution of local infiltration is small compared to the total flow. The total flow of the entire system is found at the most downstream point of 1 million liters/day. The velocities at the upstream point of each pipe did not meet the minimum velocity requirement of 0.6 m/s. The flow within all of the pipes were less than half full.

Pipe	Upstream Node	Upstream Invert Elevation (m)*	Downstream Node	Downstream Invert Elevation (m)*	Constructed Slope (m/m)	Length (m)	Pipe Size (mm)	Local Infiltration (l/d)***	Total Flow (l/d)	Average Pipe Cover (m)**	Velocity In (m/s)
L1	MH1	-0.05	MH3	-0.25	0.002	100	150	300	60,000	0.5	0.2
L2	MH2	-0.05	MH3	-0.19	0.002	71	150	220	67,000	0.5	0.3
L3	MH3	-0.25	MH7	-0.38	0.001	128	200	520	127,000	0.6	0.2
L4	MH4	-0.05	MH6	-0.23	0.002	92	150	280	40,000	0.5	0.2
L5	MH5	-0.05	MH6	-0.27	0.002	112	150	340	98,000	0.5	0.3
L6	MH6	-0.27	MH7	-0.35	0.001	76	200	310	138,000	0.6	0.2
L7	MH7	-0.38	MH10	-0.53	0.003	51	200	210	265,000	0.8	0.4
L8	MH8	-0.05	MH10	-0.53	0.002	201	200	820	93,000	0.6	0.3
L9	MH9	-0.05	MH10	-0.53	0.002	197	200	800	80,000	0.6	0.3
L10	MH10	-0.53	MH14	-0.65	0.002	60	200	240	438,000	0.9	0.4
L11	MH11	-0.05	MH12	-0.4	0.003	134	150	410	76,000	0.6	0.3
L12	MH12	-0.4	MH14	-0.65	0.003	77	200	310	76,000	0.8	0.3
L13	MH13	-0.05	MH14	-0.65	0.003	208	200	850	64,000	0.7	0.3
L14	MH14	-0.65	MH17	-0.73	0.002	42	250	210	578,000	0.9	0.4
L15	MH15	-0.05	MH17	-0.73	0.003	203	200	820	76,000	0.7	0.3
L16	MH16	-0.05	MH17	-0.73	0.003	217	200	880	76,000	0.7	0.3
L17	MH17	-0.73	MH20	-0.88	0.002	73	300	440	732,000	1	0.5
L18	MH18	-0.05	MH20	-0.88	0.007	118	150	360	53,000	0.8	0.4
L19	MH19	-0.05	MH20	-0.88	0.009	92	150	280	45,000	0.8	0.4
L20	MH20	-0.88	MH21	-0.95	0.001	73	375	550	972,000	1	0.4
L21	MH21	-0.95	MH22	-1.01	0.001	63	375	480	973,000	1.1	0.4
L22	MH22	-1.01	WW-1	-1.13	0.001	118	375	900	974,000	1.2	0.4

Table 3.6 Pipe Segment Data. Notes: Ground level assumed to be +0.5m (MSL); Minimum Depth of Cover +0.4m (MSL) * all elevations are relative to mean sea level (“0” datum) **infiltration rate 0.02 L/d/mm-m

4. Cost Estimates

The gravity sewer system consists of 2,500 meters of gravity sewer, 22 manholes and 1 pump station. The cost estimates for the construction of this gravity sewer system can be found in Table below.

	unit amount	unit cost	units	Capital Costs	O&M Costs
Total Pipe Length (m)	2506	320	\$US/meter	\$801,920	
Number of manholes	22	5,400	\$US/manhole	\$118,800	
Number of Lift Stations	1	135,000	\$US/station	\$135,000	
Totals:				\$1,055,720	\$150,000

Table 4.1 Costs Estimates³⁸

The cost data for this study were collected from different sources and their reliability and validity were assumed. Costs were estimated based on similar projects in communities in the United States³⁸. The lift station costs were based on estimates reported by the EPA³⁸. Annual operation and maintenance costs are estimated at approximately \$150,000. These cost estimates are based on situations in the United States and might not accurately account for pricing in Brazil. Since Brazil has undergone two devaluations in currency, the scales are price are different than in the United States. After personal communication with engineers in the United States and Brazil³⁹, it was agreed that the prices in the US are much higher than in Brazil. Other than the currency exchange between the two countries, labor in Brazil is typically cheaper than in the US as is the cost of construction because of less regulation. The United States tends to have more regulation and more conservative standards than Brazil. For example Appendix A contains a plan for a wastewater infrastructure project in Brazil. According to the cost matrix, the prices for

³⁸ Estimates based on information from Engineer Sylvia Lee and EPA (2000)

³⁹ Personal Communication, Fernando Craveiro, Ricardo Tsukamoto, and Flygt Corporation

each of the items in the table below are much less. Since the currency in Brazil has been changing so much in the last couple of years it is hard to compare solidly between the two countries.

5. Discussion/Analysis

Due to a lack of available information, numerous assumptions and extrapolations of data were made leaving a large margin of error. This section will discuss all the assumptions made in the design and also explore the robustness of the system through a sensitivity analysis. The main assumptions made were on population, flow, peaking factor, infiltration rate, elevation, and pumping.

The collection system was designed for peak hourly flow. Several choices were involved in determining the peak hourly flow. Paraty lacks data on wastewater flows throughout the city. The city did however, have information on potable water use, which is often a valid indicator of wastewater flow when actual data does not exist. This goes in line with the idea of continuity, that what goes in (potable water), must come out (wastewater). The water use was based on per person per day consumption, so a population of the historical center needed to be found to find an appropriate wastewater flow for the area. The base yearly population as well as the the three fold increase in the summer tourist season were both assumptions made by observations of people of the city. In order to separate the total wastewater flow into each catchment area, it was assumed that flow is evenly distributed throughout the city. In this preliminary design it was not necessary to get an exact measure of the wastewater flow. In a survey conducted by the city the historical center contains about 700 properties⁴⁰. Of those 700, 400 are residential, 200 are commercial, and the rest are other types of property (includes vacant lots). Another method to quantify the flows would be to break down the area by property and take

⁴⁰ Prefeitura Municipal de Paraty, 2002

typical wastewater flows for each type of property. For example in Brazil a high class house typically has a wastewater flow rate of 150 L/person/day, a hotel discharges 100 L/person/day, and a restaurant has flows of 25 L/meal/day⁴¹. However because there is not an explicit detailed breakdown of the types and locations of each property, many more assumptions would need to be made. Therefore, the result from taking the population and average water consumption data is the most appropriate number for this preliminary design.

In the proposed system it is found that pipe flow is not half full, and therefore it is unknown what an acceptable minimum velocity would be. However changing some parameters such as pipe diameters or pipe roughness coefficient has a lot of effect to flow and velocity and hence sediment transport in the pipes. Since there are assumptions being made, a sensitivity analysis was performed to look at different flows and the affects of different magnitudes of flow on the wastewater velocity within the pipes as well as the total overall flow capacity. In order to see the effects of different magnitudes of load, the peaking factor was varied in order to see the robustness of the designed system. Typically an hourly peaking factor of 1.8 is used in Brazil⁴². Figure 5.1 shows the affect of different peaking factors on the velocities within the pipes. Many of the points overlap and therefore cannot be seen. It is important to note the trend of increasing velocities with increasing peaking factors.

⁴¹ Tsukamoto, 2003

⁴² Tsukamoto, 2003

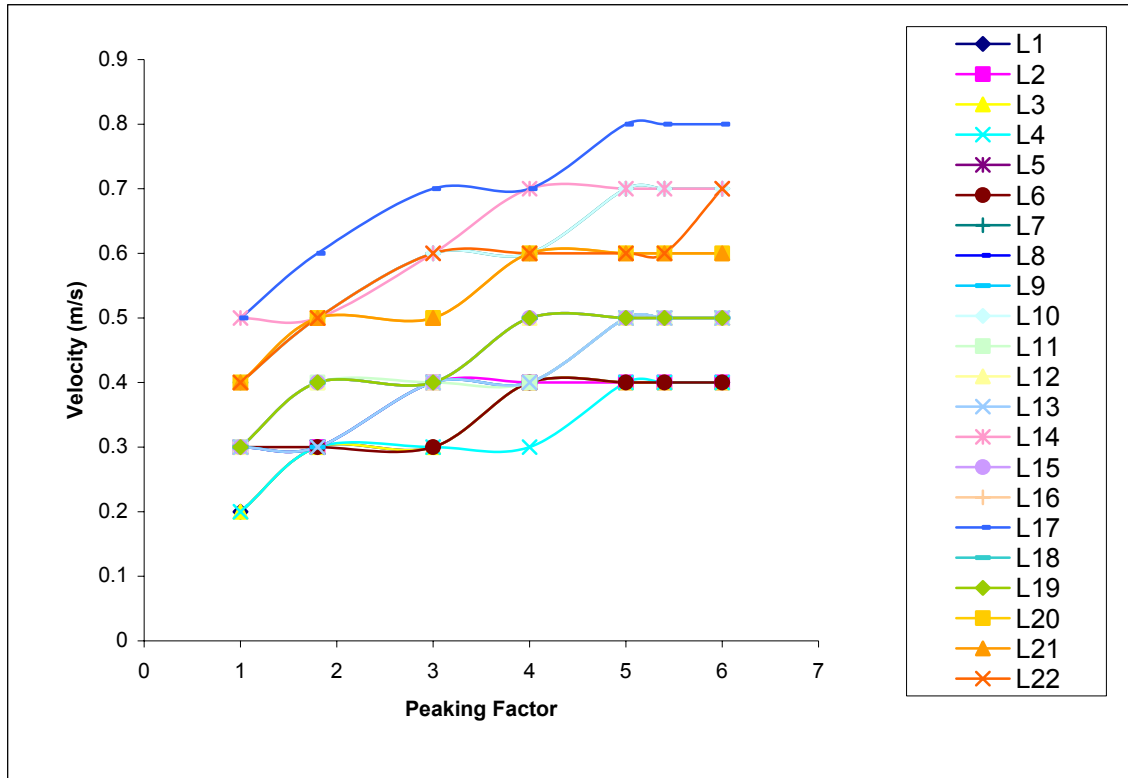


Figure 5.1 Velocity versus Peaking Factor

It can be seen in the figure above that the velocity in many branches is less than 0.6 m/s. This means some deposition of sediment may occur. However after some preliminary studies of Paraty’s wastewater⁴³, there does not appear to be much sediment or suspended solids. Therefore the lower velocities may be effective in self cleansing mechanisms. This suggests that the design needs to be further calibrated with an acceptable minimum velocity and that periodic cleanouts may be needed for the system if deposition of sediment is to occur in the off peak seasons. The system has the capability to handle a peaking factor of about 6, where above that point, the sewers and manholes become flooded and pressurized. This limit to capacity may be a reflection of the capacity of the pumping station. It is observed that the pump operation has a lot of effect on the systems

⁴³ Kfourri and Kweon, 2003

operation. Different pump operation curves can give different flow conditions in pipes. For the purpose of the preliminary model, a single point pump was used which had a specified design head of 5 meters and a discharge of 2.5 m³/min. This basic pump was used to represent a pumping station but was not meant to be an exact model of an actual station that will need to be built. Refinement of pump operation rules are needed but will not be addressed in this model. The pumping station is necessary for this network as the depth of excavation at the final collection point of the entire catchment area is at a maximum.

Another analysis was performed on the effect the peaking factor as well as the infiltration rate had on the total flow. The figures below show that obviously as either factor increases, the total flow will increase. The impact the peaking factor has on the total flow is much greater than the impact of a change in infiltration rates. There is about a four fold difference between the slopes of the two trends. Since the infiltration rate does not have such a profound effect on the total flow within small ranges, the accuracy of the infiltration rate assumption is not as large a factor as other assumptions, as shown here. The concern is whether the infiltration rate is extremely underestimated because at smaller infiltration rates, the amount of infiltration is not a significant portion of the flow. This can be noted in the results for the proposed design in Table 3.6. If the infiltration rates are vastly underestimated however, the potential affect on the system is great because it will contribute a majority of the flow. This is highly unlikely however, especially with a new system with PVC pipes.

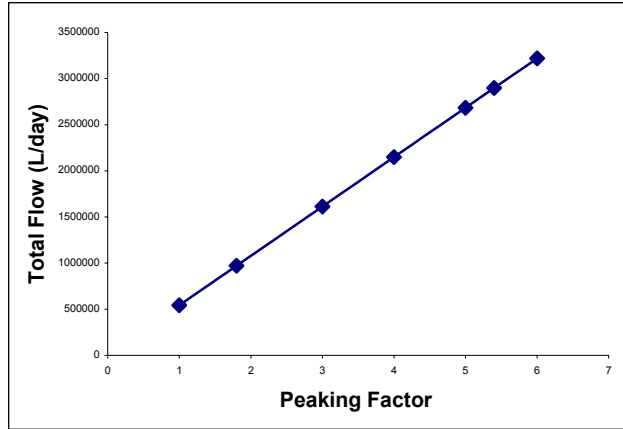


Figure 5.2 Total Flow versus Peaking Factor

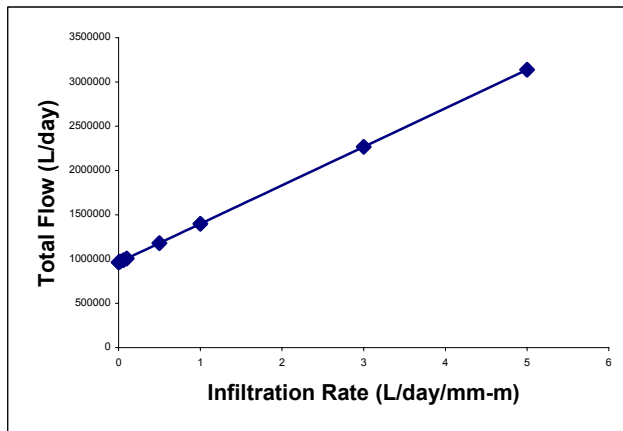


Figure 5.3 Total Flow versus Infiltration Rate

A third sensitivity analysis was performed on the roughness coefficient of the pipes. The range of coefficients studied was 0.010 to 0.013. The velocity of each segment was observed with the range of roughness coefficients. Most manufacturers have advocated the smaller n value for plastics, but some guides recommend using a Manning n value of 0.013 for a new sewer regardless of the smoother material. As seen in Figure 5.4, the velocities of flow within the pipes decrease as the roughness coefficient increases.

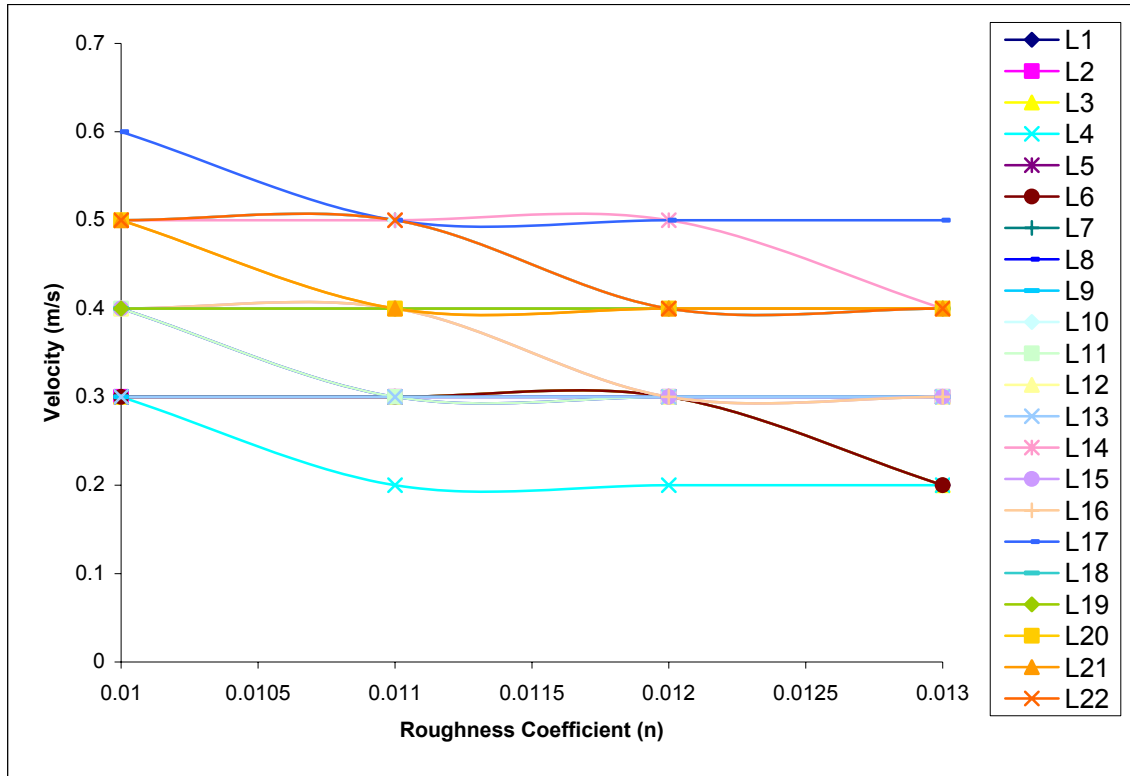


Figure 5.4 Velocity versus Roughness Coefficient

Under the designed system operation, there is no node or branch that has flooding. Also all of the pipes are sloped to maintain a minimal flow of 0.6 m/s for the designed flow. Overall, the system designed has some flexibility, but needs some more calibration to become a more robust system for the fluctuating seasons in Paraty. Producing a self cleansing velocity within the pipes should be a main design factor. Further investigation on acceptable minimum velocities are needed. In addition, the economic tradeoffs between deeper excavation (in order to increase pipe slopes/velocity) and continual O&M costs of pipe cleaning should be studied. The flow conditions and population numbers should be further studied and quantified. Also, various pump station schemes should be considered to see the effects of the flow and hydraulic condition in the sewer system and to find the most suitable operation rule. It is important to remember that this is a

conceptual preliminary design. Further investigations should also be made into vacuum sewerage in addition to gravity sewerage. While it may be best to stay uniform throughout the city with a gravity system, a feasibility study should still be looked into the apparently cheaper vacuum system. The results from this study suggest that a gravity collection system is a feasible and viable option for the historical center of Paraty.

6. System Recommendations

Several options exist for the construction of a wastewater collection system to serve the historical center of Paraty. Based on a review of current and future service areas, projected wastewater flows, topography, collection system and transport options, capital costs, and operation and maintenance costs, a conventional gravity collection system is recommended. The capital cost is estimated to be around \$1.1 million with an annual operation and maintenance cost of \$150,000.

The general schematic for the wastewater collection and treatment system is as follows:

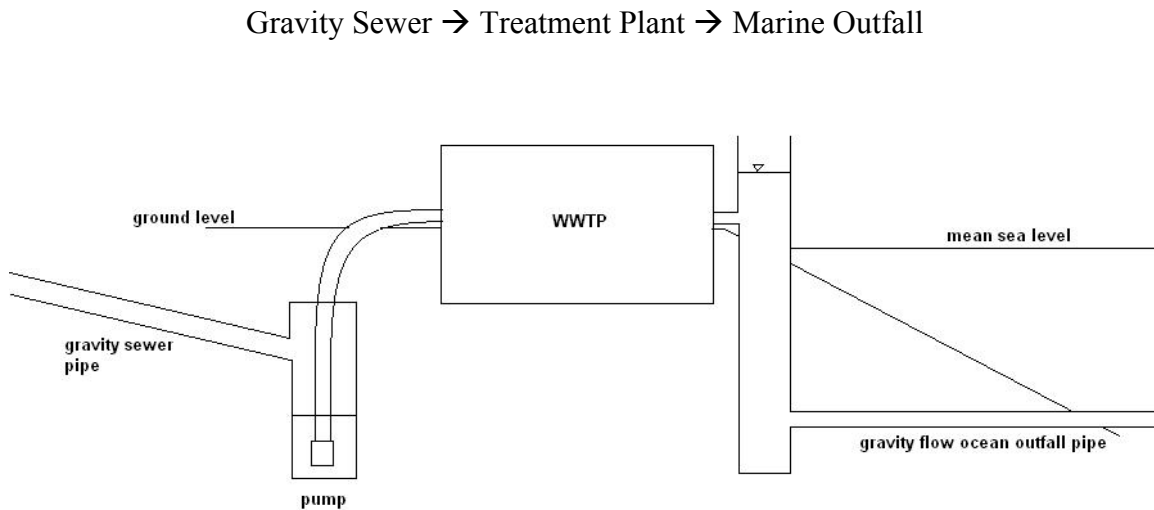


Figure 6.1 General picture of wastewater infrastructure plan

Figure 6.1 is a pictorial representation of the basic plan for wastewater collection and treatment. The wastewater is conveyed through gravity sewers to a wet well for temporary storage before being pumped to the treatment plant. After treated, the disinfected effluent is discharged through ocean outfall. Chemical Enhanced Primary Settlement is an attractive treatment process because it can easily adapt to the seasonal changes in population in the tourist driven city of Paraty. It is important to note that the

head of the effluent from the treatment plant must be high in order to maintain a gravity flow ocean outfall. The collection system is designed for peak hourly flow of 1 million L/day. The wastewater treatment plant should be sized for the average daily flow of 500,000 L/day.

There are three possibilities to install the gravity sewers – 1) revive and reuse existing structures, 2) noninvasive, nondestructive installation, and 3) trench excavation.

Revive and reuse existing structures. It is recommended to review and explore the condition of the existing collection structures in the historical center. Although the system itself probably could not be used for a wastewater collection system directly, perhaps it could be cleaned and used for a new collection system to be layed within the existing structures. The existing collection system consists of 1 meter in length sections of concrete pipe with a diameter of about 1 meter, making it more than possible for the new pipes to fit inside.

Noninvasive, nondestructive installation. Microtunneling is a process that uses a remotely controlled Microtunnel Boring Machine⁴⁴ (MTBM) combined with the pipe jacking technique to directly install product pipelines underground in a single pass. This process avoids the need to have long stretches of open trench for pipe laying, which causes extreme disruption to the community. This process can be extremely cost effective and cost efficient for a place like the historical center, where the water table is high and the buildings are old.

⁴⁴ <http://www.huxtedtunnel.com>

Trench excavation. Open trench excavation is the traditional method of installing sewer pipes. This installation process could be favored over the two previously mentioned ones because of the added benefit projects of rehabilitating the roads and burying electrical lines. The streets within the historical center are in horrible position because of a road renovation in the past where the stones in the roads were placed back misaligned. Given this project, excavation would be favored to provide an opportunity to renovate the existing roads as well as place all electrical wires underground. Another qualification for the UNESCO recognition is to place all electrical wires underground. If these additional projects were to be taken, much planning would be needed to organize a much larger project.

Further study needs to be taken in all three of these possibilities as well as in further designing for a gravity sewer collection system. This project provided a conceptual design as well as a feasibility study of a design for the historical center of Paraty. May any further developments to this project provide as a model for the rest of the city for future expansion and planning.

A strong recommendation is given to the city to plan for both a wastewater collection system and a wastewater treatment system. The two components should not stand alone and another strong recommendation is made to look into the treatment of Paraty's wastewater by Chemically Enhanced Primary Treatment.

7. Conclusions

This thesis proposes a conceptual design of a gravity collection system for the historical center of Paraty, Brazil. The report investigated wastewater flow requirements, wastewater collection and transport alternatives, possible wastewater treatment plant locations, capital requirements, and operation and maintenance costs.

Four criteria were used to choose gravity sewers as the system of collection in the historical center. The criteria were economics, expandability, adaptability and simplicity. The results of the analysis concluded that the two major systems to consider would be a vacuum system and a gravity system. Although the study revealed that a vacuum system might be less expensive to construct, there were other costs that factored in the decision to pursue a gravity collection system. One hindering cost for the vacuum system was the future operation and maintenance of such a relatively new technology in a city that does not have much expertise or knowledge with collection systems. It has been concluded that for the city of Paraty, a uniform, consistent, simple collection system would be the most appropriate.

As a result of the feasibility study, it is recommended that the city of Paraty pursue construction of a gravity sewer system, pumping stations, and a wastewater treatment plant. This appears to be the best fit solution for the community. Paraty is in need of infrastructure development and the construction of wastewater collection facilities will allow Paraty to minimize the impact of wastewater on public health and environmental resources.

Appendix A

Plan for Manguera – Summary and rough translation of plan described in “Programa Morar Melhor – Acao Saneamento Basico Plano de Trabalho: Tronco Coleter Estacao de Tratamento de Esgotos”

Cost of project: R\$643200.00

The work consists of the construction of 1800 meters of a gravity main collector of 200 mm in diameter of PVC. There are 25 manholes with a medium height of 2.5 meters and a wastewater treatment plant using slime with a capacity for 5,000 inhabitants (60 m³/hour). The intent is to handle approximately 16.6% of the urban population of the municipality.

The Station of handling as well as the log collector that will be built and maintained by the Municipal city Hall of Paraty, specifically from the Municipal Office of the secretary of Works.

Type	Material	Unit	Quantity	Cost (R\$)	Construction Time (Months)
Trunk Collector	PVC 200 mm	Meter	1800	114,229.99	3
Manholes	Concrete	NA	25	12,740.42	3
Pump Station	Premade	NA	1	26,048.00	3
Treatment Plant	Capacity: 60 m ³ /hr	NA	1	398,106.47	3

Table A.1 Cost Estimates

Population to benefit from project:

Actual population - 4000, 800 families

Projected population and design - 5000, 1000 families



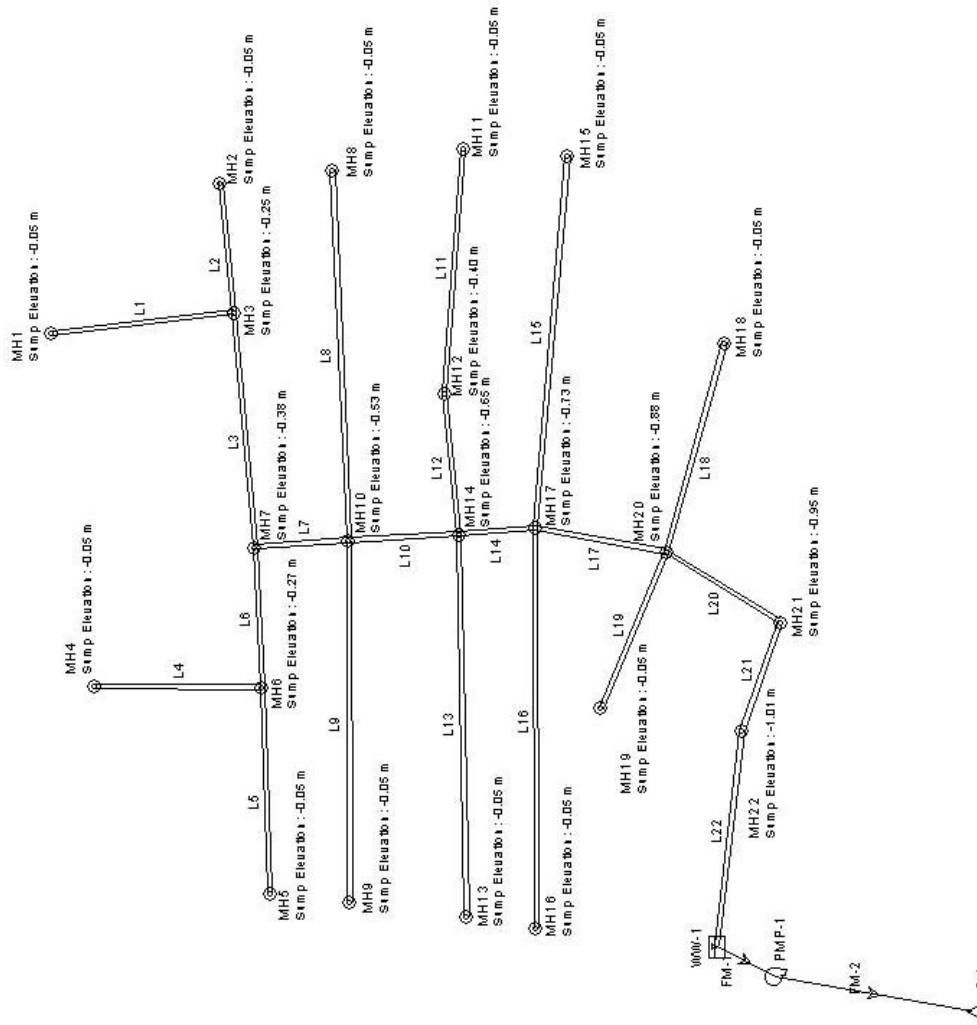
Figure A.1 Trunk Sewer Layout

Appendix B

Profile Drawings

All these profiles were created using Haestad Method's SewerCAD.

Diversion Network Scenario: Gravity Sewer Network



Project Engineer: Nancy Chol
SewerCAD v6.0 (6.0024a)
Page 1 of 1

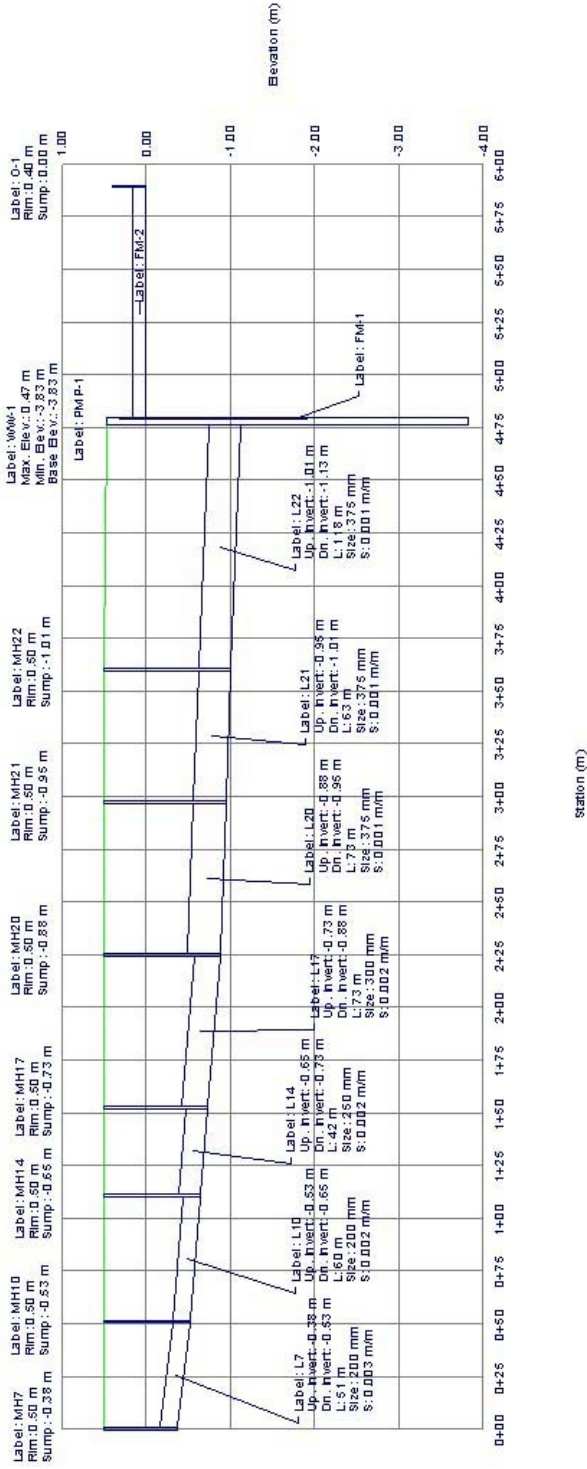
Academic Edition
© Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708 USA +1-203-755-1666

Title: Historical Center of Parity
I:\...theis\jtop_stuff\flow\baseplan\flow.swr
3/5/21/03 10:55:45 PM

Profile

Scenario: Gravity Sewer Network

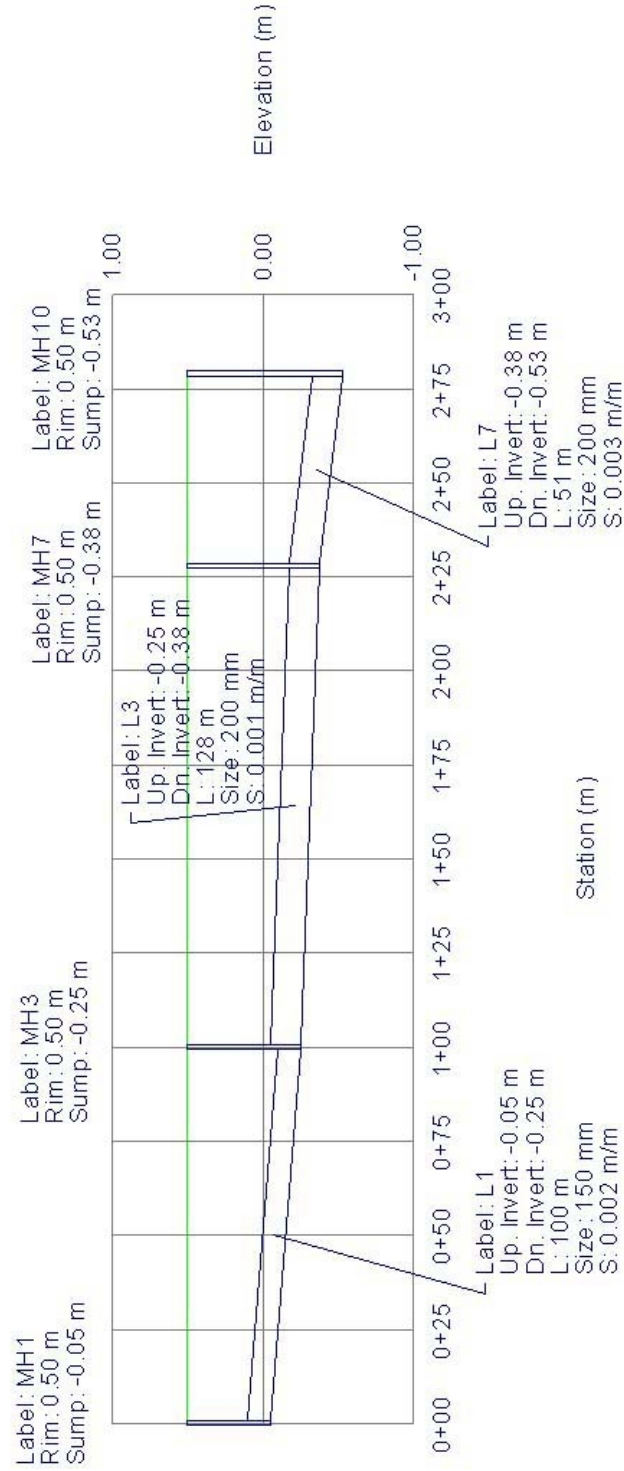
Profile: maintrunkline
Scenario: Gravity Sewer Network (0.00 hr)



Profile
Scenario: Gravity Sewer Network

Profile: L1-L3-L7

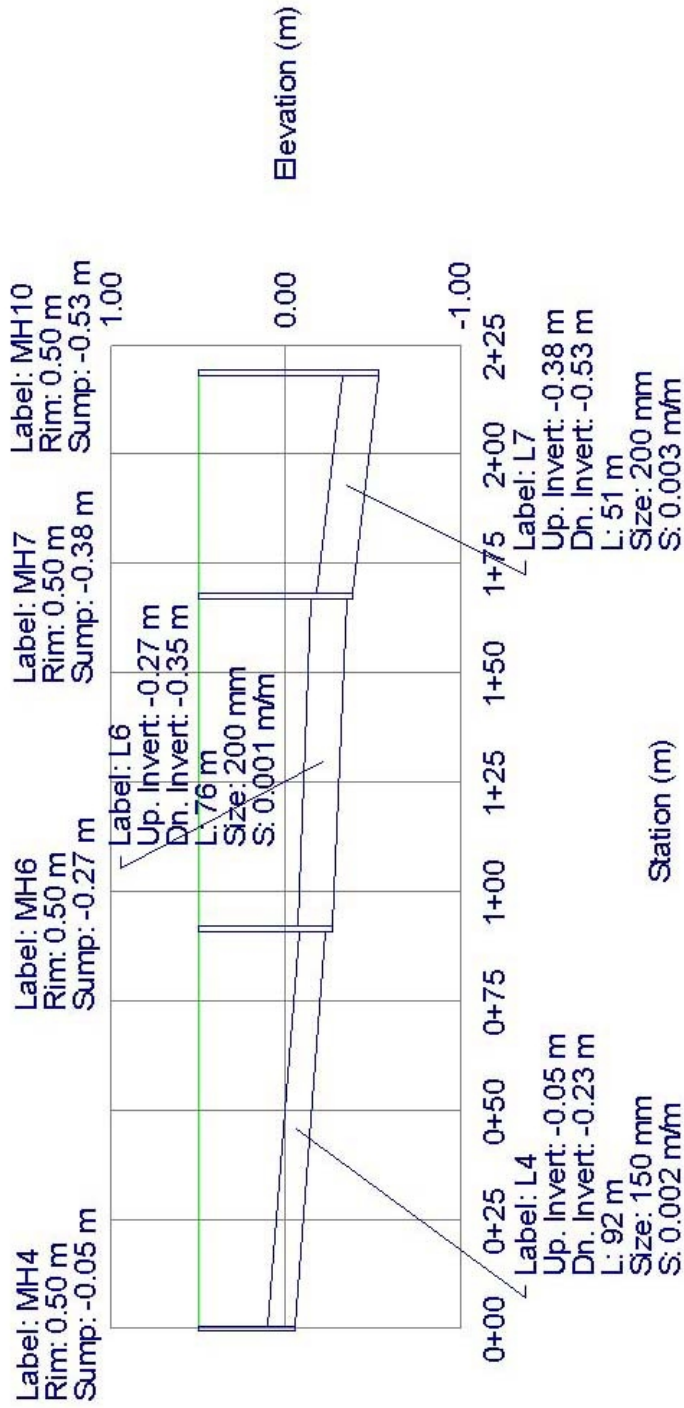
Scenario: Gravity Sewer Network (0.00 hr)



Profile
Scenario: Gravity Sewer Network

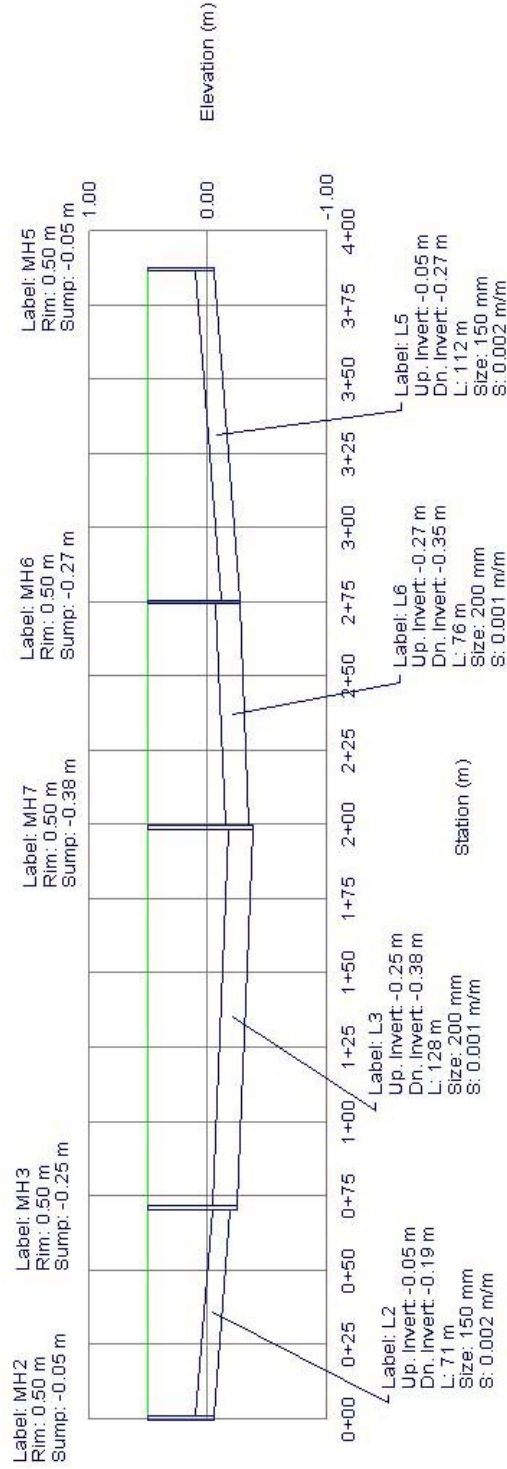
Profile: L4-L6-L7

Scenario: Gravity Sewer Network (0.00 hr)



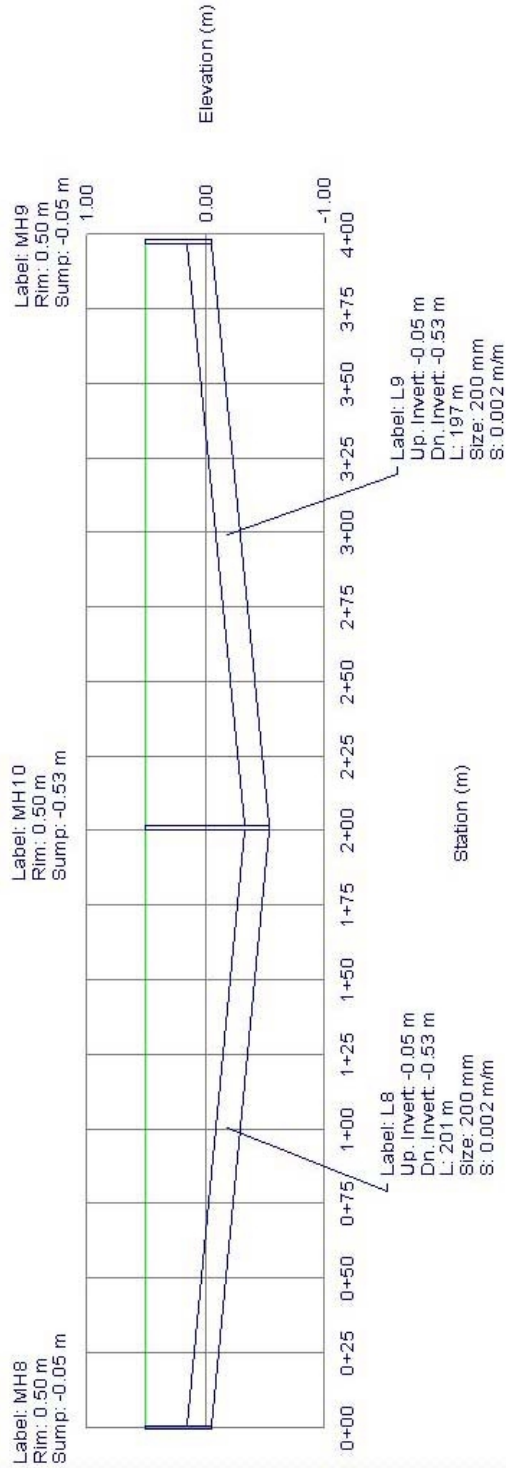
Profile
Scenario: Gravity Sewer Network

Profile: L2-L3-L6-L5
Scenario: Gravity Sewer Network (0.00 hr)



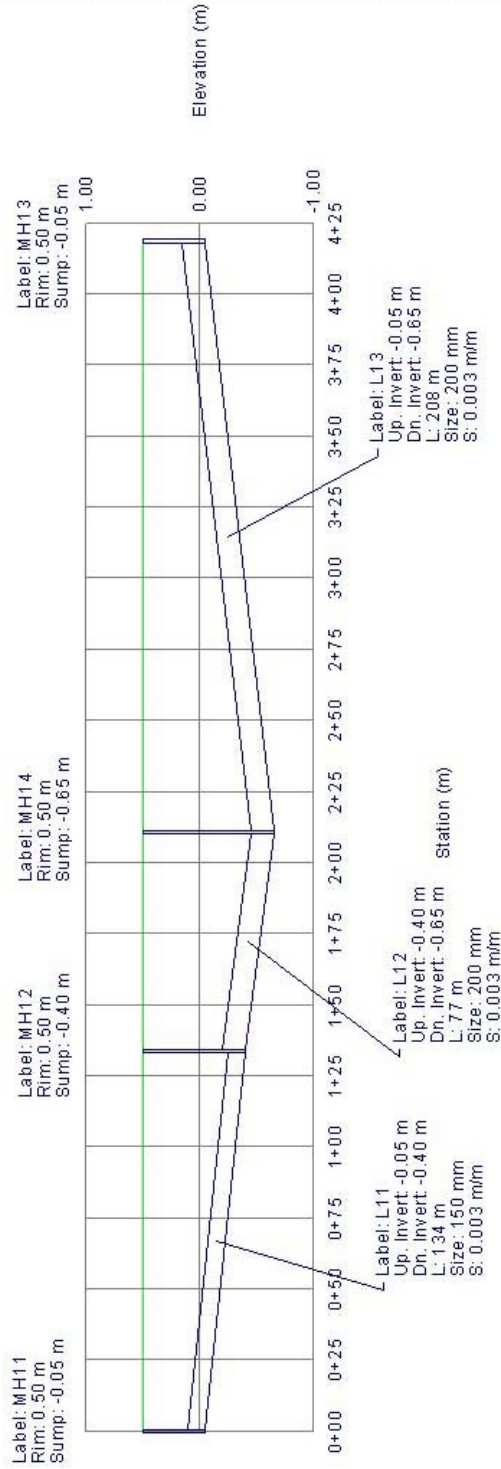
Profile
Scenario: Gravity Sewer Network

Profile: L8-L9
Scenario: Gravity Sewer Network (0.00 hr)



Profile
Scenario: Gravity Sewer Network

Profile: L11-L12-L13
Scenario: Gravity Sewer Network (0.00 hr)

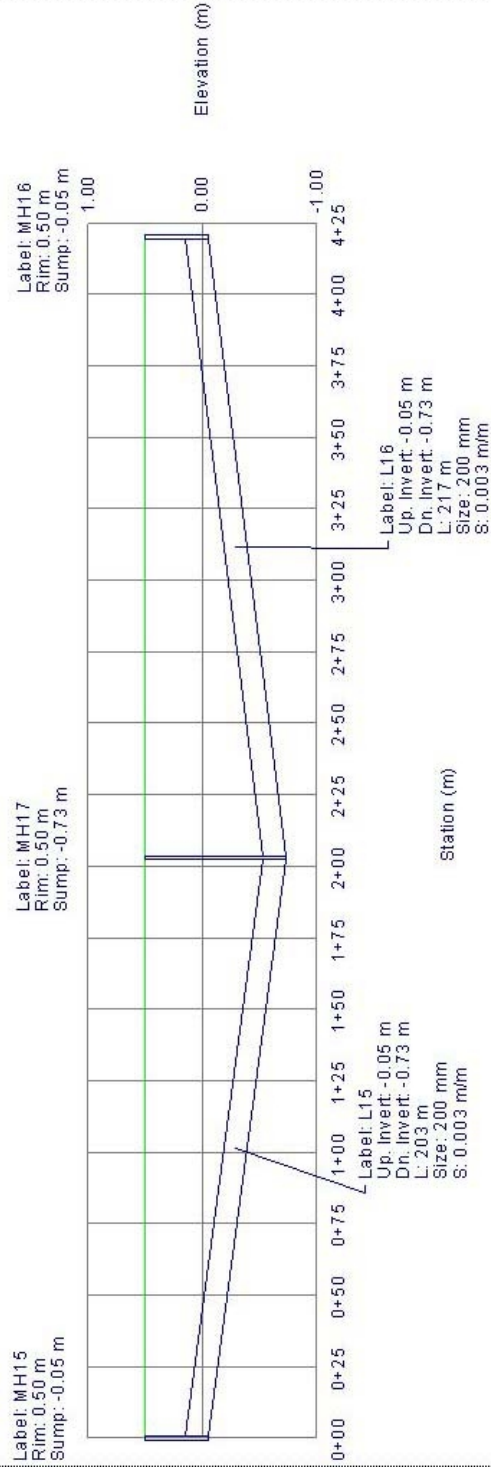


Profile

Scenario: Gravity Sewer Network

Profile: L15-L16

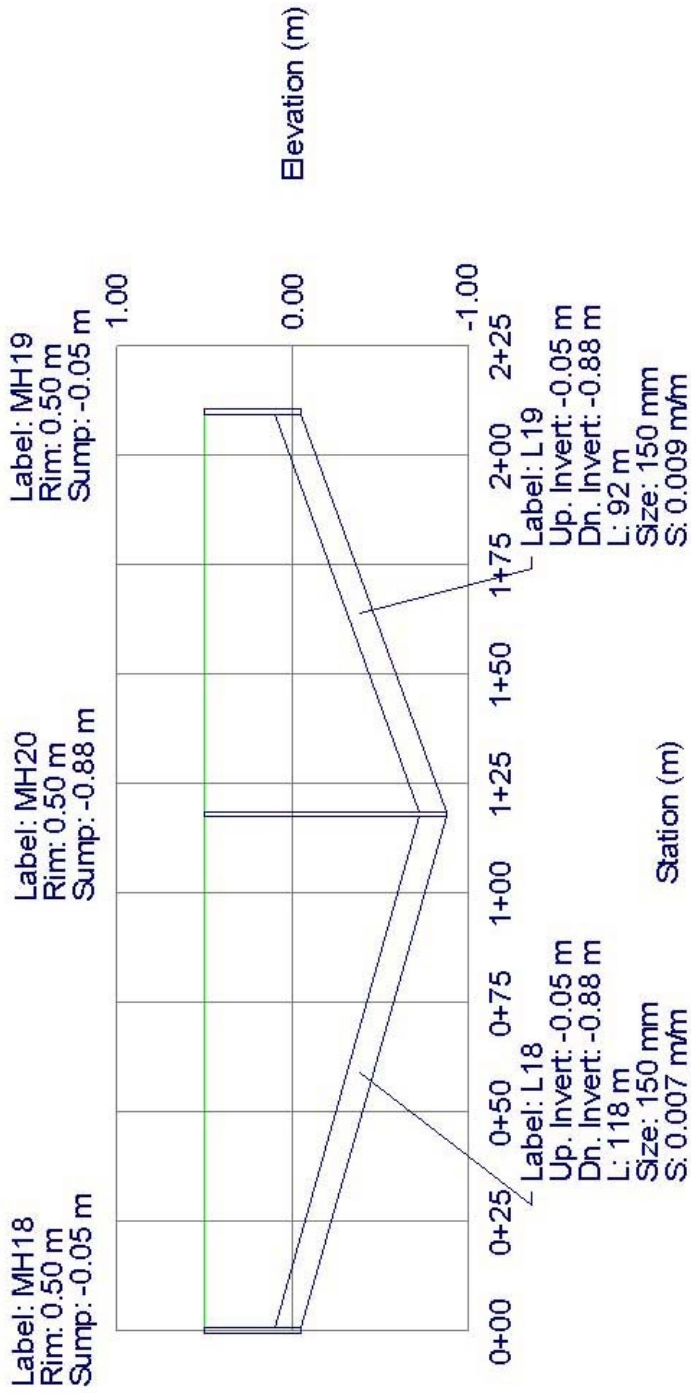
Scenario: Gravity Sewer Network (0.00 hr)



Profile
 Scenario: Gravity Sewer Network

Profile: L18-L19

Scenario: Gravity Sewer Network (0.00 hr)



References

- Arvada, City of. Minimum Design Standards Section 110 Sanitary Sewers. Arvada, Colorado: http://www.ci.arvada.co.us/HTML/Spec_Book/New-S-SEC110-2001.pdf, 2001.
- Craveiro, Fernando. Personal communication with Regional Water Business Group Manager CH2M HILL of Brazil. May 2003.
- Flygt Corporation. Personal communication with Engineer. May 2003.
- Haestad Methods. Computer Applications in Hydraulic Engineering – Connecting Theory to Practice. 5th ed. Waterbury: Haestad Press, 2002.
- Harrington, Brian. Personal communication with Engineer at Metcalf and Eddy. March 2003.
- Hassett, Alan F. Vacuum Sewerage – Ready for the 21st Century. Proceedings from “Sewers of the Future” Conference, September 10-13, 1995, Houston Texas. Published in Virginia: Water Environment Federation, 1995.
- James P. Heaney, Robert Pitt, Richard Field. Innovative Urban Wet-Weather Flow Management Systems. Cincinnati: U.S. Environmental Protection Agency, 1999.
- Kfoury, Claire and Hyo Jin Kweon. Seawater as a Substitute Coagulant and Effects on Disinfection in Chemically Enhanced Primary Treatment: A Case Study of Paraty, Brazil and Deer Island, Boston. Thesis (M. Eng.) – Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering, 2003.
- Klink, Tymur. Personal communication with architect and land owner in Paraty. January 2003.
- Lee, Sylvia. Personal communication with Engineer at Montgomery Watson Harza. January – May 2003.
- Metcalf and Eddy. Wastewater Engineering: Collection and Pumping of Wastewater. New York: McGraw-Hill, 1981.
- Prefeitura Municipal de Paraty. Divisao de Vigilancia Sanitaria. Paraty: GPO, 2002.
- Prefeitura Municipal de Paraty. Programa Morar Melhor – Acao Saneamento Basico Plano de Trabalho. Paraty: GPO, December 2001.
- Prefeitura Municipal de Paraty. Vigilancia da Qualidade da Agua de Consumo Humano – VQACH. Paraty: GPO, 2001.

Rocha, Wilson. Personal interview with past water and sanitation engineer for Paraty. January 2003.

Rosman, Paulo Cesar Colonna. Personal communication with Professor at the Universidade Federal do Rio de Janeiro, 14 April 2003.

Sarasota County Environmental Services. "Evaluation of Onsite Wastewater Treatment and Wastewater Collection System Alternatives." Phillippi Creek Septic System Replacement Program: September 2000 Executive Summary TM No. 7 (2000).

Shamsi, U.M. GIS Tools For Water, Wastewater and Stormwater Systems. United States: ASCE Press, 2002.

Tsukamoto, Ricardo. Personal communication with Engineer and concerned citizen of Paraty. January – May 2003.

U.S. Department of Commerce. Market Assessment. <http://strategis.ic.gc.ca/SSG/dd73927e.html>: STAT-USA on the Internet, 1999.

U.S. Environmental Protection Agency. Collection Systems Technology Fact Sheet: Sewers, Lift Station. Washington D.C.: U.S. Government Printing Office, September 2000.

U.S. Environmental Protection Agency. Manual: Alternative Wastewater Collection Systems for Small Communities. Washington D.C.: U.S. Government Printing Office, October 1991.

You, Eun Chu. Policy for Development of Water and Sanitation Infrastructure in Paraty, Brazil. Thesis (M. Eng) – Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering, 2003.