

## TABLE OF CONTENTS

<b>1</b>	<b>INTRODUCTION</b>	<b>3</b>
<b>2</b>	<b>EXECUTIVE SUMMARY</b>	<b>1</b>
<b>3</b>	<b>BACKGROUND</b>	<b>6</b>
1.8	INTRODUCTION	6
3.2	TWENTY THREE YEAR PLAN	7
3.3	CURRENT SEWERAGE SYSTEM	8
3.3.1	<i>COLLETTORI AND SBOCCHI</i>	9
3.3.2	<i>FOSSA SETTICA</i>	10
3.4	SEDIMENT	11
3.5	STRUCTURAL DAMAGE	12
3.6	CANAL WALLS	12
3.7	POLLUTION	13
3.8	TEST ISLANDS	13
3.9	VACUUM SEWER TECHNOLOGY	14
3.9.1	<i>SYSTEM COMPONENTS</i>	14
3.9.2	<i>VACUUM SYSTEM FUNCTIONS</i>	15
3.9.3	<i>ADVANTAGES OF VACUUM SEWERAGE SYSTEM</i>	17
3.10	HIFLOTM VACUUM SEWERAGE SYSTEM	18
3.11	ALTERNATIVE SYSTEMS	19
3.12	SITES OF HIFLOTM SEWER SYSTEM IMPLEMENTATION	21
<b>4</b>	<b>LITERATURE REVIEW</b>	<b>26</b>
<b>5</b>	<b>METHODOLOGY</b>	<b>29</b>
5.1	INTRODUCTION	29
5.2	OBJECTIVES	30
5.3	ANALYSIS OF TARGET SITES	30
5.4	GENERAL METHOD OF APPROACH	31
5.5	EVALUATION OF THE CURRENT SEWERAGE SYSTEM	32
5.6	GENERAL PLUMBING DESIGN	32
5.6.1	<i>SIZE OF LATERALS</i>	33
5.7	IMPLEMENTATION OF VACUUM SEWER TECHNOLOGY	33
5.7.1	<i>CITYWIDE IMPLEMENTATION</i>	37
5.7.1.1	PIPING DESIGN	38
5.7.1.2	VALVE ESTIMATIONS LOCATIONS	40
5.7.2	<i>COLLECTION STATION NETWORK</i>	40
5.7.2.1	VOLUME OF COLLECTION TANK AND COLLECTION STATION LOCATION	41
5.7.3	<i>WASTEWATER TREATMENT</i>	43
5.7.3.1	TRANSPORTATION WITHIN VENICE	43
5.7.3.2	TRANSPORTATION OFF OF VENICE	44
5.8	COST ANALYSIS	44
5.8.1	<i>COST ESTIMATES</i>	45
5.8.1.1	IMPLEMENTATION	45
5.9	OPTION 1	46
5.10	OPTION 2	46
5.11	OPTION 3	46
5.11.1	<i>COST COMPARISON</i>	47
5.12	SOCIAL IMPACTS	47
5.13	CONCLUSION	48
<b>6</b>	<b>RESULTS AND ANALYSIS</b>	<b>48</b>
6.1	INTRODUCTION	48

6.2	COVERAGE OF STUDY AREAS	48
6.2.1	<i>MAPS</i>	49
6.2.2	<i>CHARTS</i>	55
6.3	IMPLEMENTATION ON THE CITYWIDE LEVEL	56
6.3.1	<i>COLLECTION STATION NETWORKING</i>	57
6.3.1.1	SEWAGE FLOW	57
6.3.1.2	COLLECTION STATIONS	57
6.4	OPTIONS OF IMPLEMENTATION	60
6.5	COST COMPARISONS	61
6.5.1	<i>COST OF IMPLEMENTATION ON ALL LEVELS</i>	61
6.6	OPTIONS OF WASTEWATER TREATMENT	62
6.6.1	<i>WASTEWATER PUMPING SYSTEM WITHIN VENICE</i>	62
6.6.1.1	RELAY SYSTEM ONE	62
6.6.1.2	RELAY SYSTEM TWO	63
6.6.1.3	RELAY SYSTEM THREE	63
6.6.2	<i>TRANSPORTATION OF WASTERWATER OFF VENICE</i>	64
6.7	COST OF IMPLEMENTATION PER PERSON	65
6.8	MEANS OF ERROR	67
<b>7</b>	<b>SOCIAL IMPACTS</b>	<b>68</b>
7.1	CONTENT OF SURVEY	68
7.2	ANALYSIS	69
7.3	CONCLUSION	70
<b>8</b>	<b>CONCLUSIONS</b>	<b>1</b>
8.1	OPTION COMPARISION MATRIX	1
8.1.1	<i>OPTION ONE</i>	2
8.1.1.1	Advantages	2
8.1.1.2	Disadvantages	3
8.1.2	<i>OPTION TWO</i>	3
8.1.2.1	Advantages	3
8.1.2.2	Disadvantages	4
8.1.3	<i>OPTION THREE</i>	4
8.1.3.1	Advantages	4
8.1.3.2	Disadvantages	5
8.2	CHOICE OF IMPLEMENTATION	5
8.3	FINAL COST OF IMPLEMENTATION	7
8.4	SYSTEM FAILURES	7
<b>9</b>	<b>RECOMMENDATIONS</b>	<b>1</b>

## 1 INTRODUCTION

Venice is perhaps one of the most prosperous and unique cities built in the history of the world. The city began, as a lagoon inhabited by people escaping from Barbarian invasions. Originally the lands were wet marshland, an unsuitable foundation for buildings and structures. In order to overcome this obstacle, the Venetians drove large wooden pillars into the ground to create a pseudo-foundation. Upon the stakes were then piled a layer of bricks and concrete. The ocean and buildings were so intertwined that between the buildings were waterways, which were used as streets. The Venetians used canals to transport themselves as well as to dispose of their sewage. For many centuries the tides flushed away sewage from the city, making it the cleanest and most efficient system at the time.

However, since the 1960's the city of Venice has neglected canal maintenance and excavation. the canals. Lack of canal dredging has allowed for sedimentation levels to increase over the years. The build-up of sediment has created both structural and ecological damages. Sewage outlets have been clogged, causing internal ruptures of the piping. Increased sediment levels have also raised both odor and water pollution levels.

With the aid of sponsor, Mr. Alan Hassett of the Oak Hill Company Ltd. and head of the Department of Public Works, Ivanno Turlon, this project will examine the feasibility of installing a vacuum sewer system into the marginal and historical areas of Venice. The purpose of this study is to propose a sewerage system to prevent further and future damage to the canals, the buildings, and the ecological environment of Venice. In addition, the installation of the vacuum sewer system will provide a low maintenance alternative to the city, as opposed to their current "emergency repairs" method.

The Executive Summary(chapter 2) provides a complete overview of this study.

The Background (chapter 3) discusses the history and information pertinent to understand the contents of the study. This section focuses on the fundamentals of a vacuum sewer system, as well as the history behind the sewage problems of Venice. Additionally, all areas of study are discussed within the section.

The Literature Review (chapter 4) contains a listing of all materials pertinent to this study. Along with this listing, is a summarization of each resource focusing on the key points which aided to the study.

The Methodology (chapter 5) discusses the goals of this study, specifying a step by step approach. Also discussed, are the social impacts of the study, data collection methods, quantification, and methods of analysis.

The Social Aspects (chapter 6) deals with the importance of change in the lives of the Venetians after installing a vacuum sewer system. There are many factors that will be incorporated into this installation, affecting both tourism and daily life for the Venetians.

The complete results and analysis of the study are discussed in Results and Analysis (chapter 7). All of raw data pertaining to the two studies of Santa Marta and Santa Maria Formosa as well as the upscale are provided here. The data contained consists of cost estimates, implimenation locations, as well as all maps for all possible options of implementation. Maps are also presented to propose pumping networking throughout Venice along with sewage treatment transport to the mainland. Costs are analyzed within comparision charts. All data are scrutinized, exposing all means of error. Also the validity of implementation is challenged.

Conclusions (chapter 8) possess the final explains all the data drawn from the

analysis of the data in with the underlying goal of answering the question of feasibility for implementation. It discusses all points of the vacuum sewerage system and its overall impact on Venice. All options are compared on different levels of impact. Both advantages and disadvantages are discussed based on set criteria ratings. The best ways to deal with the analysis of the results are also discussed.

Recommendations (chapter 9) contain the recommendations of the project team on ways to carry out of vacuum sewerage implementation within Venice. Recommendations are addressed to the city for a plan to initiate vacuum sewerage adaptation. Also contained are suggestions for future studies within areas where more research and development need to be carried out.

The Appendices chapter contains all sample calculations for all data both extrapolated and manipulated by equations. Data for each island are organized within Excel spreadsheets. This is to aid the reader in understanding the heart of the study.

It is the project teams' hope that all schematics and cost estimates will be useful for the city of Venice. The data contained in this report provides knowledge of the current gravity piping within Venice, and vacuum sewerage systems, particularly the HIFLO™. It also shows the cost benefits for the city of Venice in implementing a HIFLO™ vacuum sewer system.



## 2 EXECUTIVE SUMMARY

This project examines the feasibility of implementing the HIFLO™ vacuum sewerage system into Venice in terms of applicability, cost and social impact. .

In order to determine feasibility, a solid background was established for both the current and the proposed HIFLO™ vacuum sewerage system.

The current sewerage system within Venice is a unique gravity system called the *fognature*. The system is comprised of three major parts, the *sbocchi*, the *colletore*, and the sedimentation tanks. *Sbocchi* are sewage outlets located along the canal walls from which all sewage enters the canals. *Collettori* are troughs located underneath the streets which carry sewage from the houses located within the interior of the islands to the *sbocchi*. Sedimentation tanks are large brick tanks located within the house foundations. The sedimentation tanks are randomly placed and used to separate the heavier sewerage from the lighter sewage so that the sewage enters the canals at a lower density. When the sewage enters the canals, the tidal flux carries the matter out to sea. This system has recently begun to fail the city of Venice due to lack of maintenance. Pollution levels are rising, building foundations and canal walls are weakening, and certain canals are becoming impassable to boats. The HIFLO™ vacuum sewerage system is proposed as an alternative to these problems.

A vacuum sewerage system contains three main parts, the collection station, sewage valves and the vacuum piping. This system works by creating a pressure differential at the collection station, which makes the pressure at the collection station lower than the pressure at the valve, which is located by the houses. The pressure differential is created by sucking the air out of the collection tank, located at the collection station, using pumps. The sewage

from a residence, which is at atmospheric pressure, enters the vacuum valves and is driven to the low pressure at the collection station, where it fills the collection tank until the pressure is not low enough to suck any more sewage. Air is an important component in driving the sewage to the collection station. It is needed to lower the density of the sewage in order to transport it to its destination. In this system both air and sewage enter through the vacuum valve, diminishing the amount of sewage that can enter through the vacuum valves, making this system unlikely for application in high density residential areas.

The HIFLO™ vacuum sewerage system, whose patent is held by Mr. Allan Hassett, is a likelier choice for application in high density residential areas due to the division of valves for sewage and air. This system functions in the same manner as the conventional system with the exception that the vacuum valve, which interphases the gravity piping from residences to the vacuum piping, only allows sewage to enter. A separate valve, called the air inlet valve, allows air to enter the system. Air inlet valves can be placed along the vacuum piping, where desired, to lower the density of the sewage and speed up the system. The separation of valves allows a much greater amount of sewage to flow through the system.

Due to the sensitivity of Venetian canal walls and building foundations, as well as the high residential density, the HIFLO™ vacuum sewerage system was proposed as an adaptation to the current sewerage system. Within this study, three different options of implementation were chosen. Option 1 proposed installing vacuum piping within the canals only. In this option, vacuum valves would be placed at the *sbocchi*. Option 2 proposed vacuum piping within the canals, as well as vacuum piping running alongside the *collettore*. In this option the sewage valves would be placed in small manholes in the streets, at the

point where the *colletore* meets with the laterals leading up to the houses. Option 3 proposed vacuum piping to be implemented along the entire sewage path between the house and the canal, including the canal. In this option the sewage valves would be placed at the point where the sedimentation tank is located. These three options of implementation were analyzed for two test islands, Santa Maria Formosa and Santa Marta.

Santa Maria Formosa was chosen on the basis that it proved as an excellent model for the historical areas of Venice. It was the desired by the city that the project group performed an analysis of Santa Marta because of its unique piping design and peripheral location on the outskirts of Venice. Current renovation plans pose the possibility of Santa Marta being a prime candidate for test implementation.

To aid the team in this study, downscale schematics of the two test islands were designed showing the piping design, sewage valves, and collection station locations. Schematics for each test island of the current sewerage system as well as the HIFLO™ vacuum sewerage system were designed using a geographical information system called MapInfo. Relations within the schematics were derived and later amplified to map out the entire city of Venice.

For complete vacuum implementation it was necessary to not only design a means of piping adaptation but also a collection station network system to collect the sewage. This network was designed by applying a series of equations from the AIRVAC Corporation. Water consumption data, provided by past studies, was the foundation of all calculations because it was assumed to be equal to the sewage flow. From a series of extrapolations the network, containing all collection stations and locations, and piping criteria was designed for all of Venice.

After designing the collection station network, a piping relay system that transports the sewage from each collection station to the *Ferrovia/Stazione Marittima* area was designed. This relay system was designed as a worst case scenario, taking into account the maximum amount of piping and collection stations that could ever be needed. From the Ferrovia area two plans to take the sewage to the mainland were examined briefly. The first plan transports sewage to the mainland under vacuum below the Mestre bridge. The second plan transports the sewage to the mainland through two islands within the lagoon.

The upscale model for the marginal and historical areas of Venice was designed using the in-depth study of Santa Maria Formosa. It was felt that Santa Maria Formosa was the best model for an upscale of Venice, primarily because it was a good comparative representation of other islands.

A major portion of this feasibility study was to examine the cost of implementing the HIFLO™ vacuum sewerage system. A full cost analysis was performed obtaining figures from the sponsor of the project as well as the *Comune di Venezia*. A cost analysis was performed for each test island. The total costs for the marginal and historical areas including collection stations, were determined for each option. Costs for the piping relay system to the Ferrovia/Stazione Marittima area were designed taking the worst case scenario in mind. A rough cost of the plans to transport sewage mainland were also extrapolated to give the city a ball park figure to work with.

The social impacts of implementing a vacuum sewerage system in Venice were examined by administering a survey to the residents. The survey addressed current problems with the city's sewerage system as well as financial and environmental implications of installing a new sewerage collection system. An analysis of the feedback received was

performed using Microsoft Excel., revealing that 48 percent of the survey supported a new sewer system despite the difficulties with noise and traffic interference, but that an overwhelming majority opposed any tax increase to fund such a new system.

After an in-depth analysis of each option of implementation was performed, the raw results of the study were collected. Schematic maps of all levels of implementation used in analyzing and studying the data, concerning the feasibility of vacuum sewerage implementation, were displayed using a geographical information system. All cost estimates, with an itemized breakdown, from this study were presented. An upscale proposal of vacuum sewerage implementation with all required components and cost figures was also included. The total amount of piping and valves necessary for each island as well as the upscale model were also calculated.

After the cost breakdown, each option was analyzed to determine the advantages and disadvantages. To decide which option was optimal for the cities needs, a comparative decision matrix was made.

It was determined that option one was optimal for implementation within the historical areas, while option two was optimal for implementation in the marginal areas. Option one was chosen for the historical areas due to the city's reluctance to perform construction on a large scale within these areas. This reluctance is due to strict building codes set forth by the city. Option two was chosen for the marginal areas because of the accessibility of the sewage valves and the reduced construction below the building foundations.

Once the options of implementation on the historical and marginal areas were decided upon, a complete cost of implementation was presented. This cost includes all

piping throughout Venice, the transport to the *Ferrovia/Stazione Marittima* area, and the transport to the mainland. An aggregate cost was added to the total cost to account for unexpected costs.

This study is presented as a preliminary feasibility study, of which other studies will follow. Further studies are suggested for other forms to transport the sewage from the collection islands to the *Ferrovia/Stazione Marittima* area. Two other suggestions are made for this transport system involving both a computer controlled vacuum system and a conventional gravity system. Further in-depth studies should also be done for a system to transport the sewage from the *Ferrovia/Stazione Marittima* to the mainland.

It is the project team's hope that the study presented will be valuable for the city of Venice and its residents. Additionally, that the data collected will be useful to present a new sewerage collection system that can help Venice preserve its buildings and canals.

### 3 BACKGROUND

#### 1.8 INTRODUCTION

Venice is a city built on swamplands as an escape from Barbarian invasions in the Middle Ages. The city was built around the ninth century at sea level in a lagoon off the north coast of Italy, near the Adriatic Sea. The inhabitants turned to the sea to help them survive in as many ways possible. They depended on the sea for food, travel, and trade. Venice initially was comprised of naturally occurring wet and grassy islands or *barene*; these islands were not structurally sound building sites due to the nature of swamplands. In order to improve the land quality, Venetians drove large wooden pillars into the ground as a pseudo-solid foundation. Above these pillars rest bricks protected from the sea by a thick

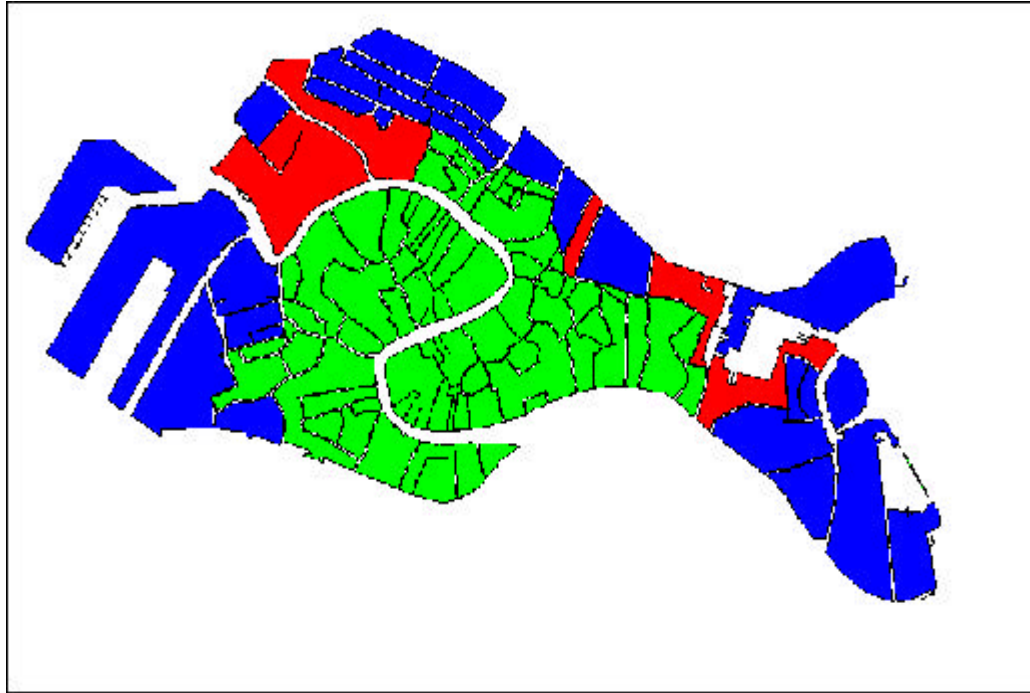
coat of mortar. To connect these islands, the Venetians created a maze of canals. A great uniqueness to the workings of the canals is the way that they are used not only for transportation, but also for sewage disposal. This method of sewage treatment has served the city efficiently for centuries as it has been in existence since the Republic; but over the past thirty years the system has become less effective due to lack of maintenance. The failures have caused ecological, structural, and sociological damage to the canals and the city of Venice. The city is in the process of executing a 23-year long renovation plan<sup>1</sup> of the sewerage system, or *fognature*, budgeting approximately 818 billion *lire* to repair the damages created over the past few decades. This study proposes to install a vacuum sewerage system as a way to avoid future problems. Before considering implementation of a new system, an understanding of the current system workings, why it is failing, and how a new system would correct the current failures is essential.

### 3.2 TWENTY THREE YEAR PLAN

The *Comune di Venezia* has implemented an 818 billion *lire* renovation plan on the entire sewerage system of Venice, taking an approximate 23 years. The renovations consist of total repair of the sewerage system and outlets, up to 3 meters in from the canal wall. The degree of repair depends upon the location of the area. Within this plan the city has broken the islands in two groups, marginal and historical areas, shown in Figure 1 below.

---

<sup>1</sup> *Comune di Venezia*



**Figure 1:** *Historical and marginal breakdown of each island within Venice.*

The green represents historical areas, red half-marginal and half-historical areas, and blue represents the marginal areas<sup>2</sup>.

Two years ago, the city of Venice made a decision to leave the existing sewer system as is in the central sections of Venice, because of the delicate nature of the buildings and heavy tourism. The outside areas of Venice were labeled as marginal, leaving them open to the possibility of a new system. The intentions of this plan are to conserve Venice as much as possible while still trying to avoid the damage and destruction that has already occurred.

### 3.3 CURRENT SEWERAGE SYSTEM

The city of Venice does not possess complete blueprints of the current plumbing for each island. They have extensive knowledge of plumbing for some islands, while the plumbing of other islands is a mystery. The entire Venetian sewerage system can be broken down into three major parts: the *s bocchi*, *collettori* and *fosse settica*. The *fognature* were

---

<sup>2</sup> *Comune di Venezia, Accordo di Programma. 1994*

built during the Republic, adhering to strict regulations. The sewage and run-off water from each house flushes into the canals out of *s bocchi*. Each outlet had to be a minimum of three Venetian feet or 120 centimeters below the sidewalk level.<sup>3</sup> These outlets dump the wastewater into the canals allowing the tidal flux to carry the matter out to sea.

### 3.3.1 COLLETTORI AND SBOCCHI

There are two different pathways the sewage may travel in order to reach the canals. The *fognature* work by a house's relation to the canal wall. When a house is located along the canal wall, the sewage will deposit directly from the house to the canal out a *s boccho*. There are two main types of *s bocchi*, circular and square. Circular outlets tend to serve smaller amounts of waste disposal, not allowing for much sedimentation, and resulting in most of the sediment traveling directly into the canals. Square outlets tend to serve larger quantities of waste disposal. These outlets also allow for sedimentation, therefore less sewage enters into the canal. Circular outlets do not provide sedimentation.

For houses located within the interior of island, sewage travels to the canals by means of a *collettore*. *Collettori* run down the middle of the streets of an island and collect the sewage from each building. The buildings deposit sewage into the *collettore* from a lateral and then the sewage is transported down the *collettore*, finally being deposited into the canals out of a *s boccho*. About seventy percent of the sewage is currently handled by *collettori*. There are two types of *collettori*, an old version and a new version. The older version consists of either a square constructed brick trough, or a filled in canal. The trough is approximately one meter in height and .8 meters in width, while the filled in canal, an unused canal that has been covered over, varies in dimension. The newer version consists

---

<sup>3</sup> *Comune di Venezia*

of a round pipe, forty to fifty centimeters in diameter, composed of a cement fitting within the older *collettore*. This newer version is currently being installed during renovations.

### 3.3.2 FOSSA SETTICA

Within the house, there is an adapted gravity sewerage system. The piping runs throughout the house and deposits the wastes into a *fossa settica*, which is a large decanter located at the bottom of the foundations in the houses. The decanters work as simple septic tanks. The heavy raw sewage settles to the bottom of the hole, forming sediment, while the lighter wastes remains at the top of the decanter, exiting into the canal. These decanters are not found in all foundations and their locations are sometimes randomly placed. The decanters periodically require cleansing depending on the rate of sedimentation build-up.

Another type of septic tank utilized has three subdivisions. This type of tank is a result of a recent Venetian Law, stating that by 1996, fourteen hundred restaurants and hotels must install these tanks, while private residences must install these tanks by the end of the twenty-three year plan. As of July 1997, only eight hundred establishments and ten percent of the private homes have adhered to the mandate<sup>4</sup>.: The tank has three separate compartments, each compartment acting as a settling tank. The heavy sewage settles to the bottom of the tank and the lighter sewage travels over to the next tank. This process occurs within each tank. By the time the sewage exits the third tank, only 5 percent of the original entering sewage is deposited into the canals. The amount of liquid wastes is not calculated within this process.

### 3.4 SEDIMENT

---

<sup>4</sup> *Comune di Venezia*

One of the most significant consequences of the current sewerage system is the formation of sediment onto the canal floors. Sediment is a grayish black matter composed of salt, silt, mud and sewage. These deposits build-up at a rate of 2 cm per year. The sediment forms a thick layer on the bottom of the canals when there is no proper maintenance. Over the past thirty years, canal maintenance has been neglected. Maintenance consists of draining and dredging canal sections. Thirty years prior to 1960, 813,050 cubic meters of sludge was dredged, while approximately 105,000 cubic meters have been dredged since.<sup>5</sup> Sediment build up lowers the depth of the canals, which permits less water to flow, decreasing the rate of sewage extraction because the canals do not sustain a great enough flux of water to stir it up. As a result of the sediment build up, the natural flow of matter out to sea is prevented from occurring. Another problem of sediment build-up is the formation of thick layers, which increases the level of water, potentially causing certain canal ways, with low bridge clearance, to become impassable. The build up of sediment indirectly damages the structure of the city and increases the pollution levels.

### 3.5 STRUCTURAL DAMAGE

The sediment build-up causes structural damage to the outlets as well as the canal walls and buildings. At various points in time, residual levels became too high, blocking the sewage holes. This blockage eventually creates a great pressure build-up, which leads to an eruption of the pipes housed within the canal walls. The pipes burst and sewage can no longer exit properly into the canals; instead, it is rerouted within the bricklayers of the foundation. This explosive action also forms large holes in the walls, which eventually get filled with mud and sediment, corroding the bricks of the foundation. The handling of these

---

<sup>5</sup> UNESCO

problems were addressed by installing new internal piping paths along with new *sbochi*. The new parts of the *fognature* were rerouted above the old system. The outlets were raised, most above the level of the low tide waterline. The internal piping was not redirected properly; so many of the previous sewage paths are still followed. Instead of exiting out of the new outlets, the sewage rerouted itself through the brick foundation, before seeping out through the canal walls.

### 3.6 CANAL WALLS

The canal walls are comprised of brick and istrian stone. The brick begins at the sidewalk, meeting at the waterline with the nonporous istrian stone. The rising water level has moved the waterline more towards the brick layer foundation. The condition of the canal walls can be used as a tool to assess the integrity of the internal plumbing. An instance of the canal damage is that there may be only a few missing bricks visible, but internally there may be large cavities threatening the structural integrity of the building.

### 3.7 POLLUTION

The sediment pollutes Venice visually and physically, producing odors and contaminated water. Raw sewage is visible at low tides and is an eyesore in an area heavily based on tourism. The raw sewage in the sediment also contains dangerous bacteria. It is a potential health hazard if a person comes in contact with these bacteria. Also a foul odor emanates from the canals when gas pockets within the sediments are popped.

### 3.8 TEST ISLANDS

The two test islands are Santa Marta, located in the marginal area, and Santa Maria Formosa, located in the historical area. Santa Marta is a large island, 265,300 m<sup>2</sup>, of which

only half is residential.<sup>6</sup> In the 1960's, Santa Marta was used as a test island for sewage piping to a treatment facility. The island was constructed with no decanters for sedimentation. Instead all new piping was installed within the pre-existing piping along with one large main pipe that would pump all the sewage to a treatment plant. The pilot plans to pump all the sewage to a treatment plant failed. Since there are no existing decanters, there is no sedimentation; therefore all the sewage is pumped out the main pipe about 150 meters into the lagoon.<sup>7</sup> The city will be starting renovations on Santa Marta within the next few months.

Santa Maria Formosa is a small island located within the interior of Venice and apparently has typical plumbing design with decanters, laterals, and main pipelines. The area is completely residential with one hotel, a few restaurants, and some shops along the main *calle*.

### 3.9 VACUUM SEWER TECHNOLOGY

Vacuum sewers should be taken into consideration in any case where a conventional sewer system may be costly to install or operate. Vacuum sewerage systems are often installed under any of the following conditions: low housing density, flat terrain, unstable ground, high groundwater table, water protection area, and low or widely varying flow rates. Vacuum sewers, in all of these cases, can offer great advantages.

#### 3.9.1 SYSTEM COMPONENTS

In order to understand what a vacuum sewer system is, one must be familiar with the basic elements of the system: the vacuum collection tank, the vacuum valves, the sewage

---

<sup>6</sup> *Comune di Venezia*

<sup>7</sup> *Comune di Venezia*

pump and the vacuum piping. The collection tank is housed within a vacuum collection station, which also houses a backup generator, a control panel, and a vacuum pump.

The collection tank is a very important feature of a vacuum sewer system. This tank may be constructed out of steel or fiberglass. The collection tank is sized according to flow rate with typical sizes ranging from 4 to 12 cubic meters.<sup>8</sup> Vacuum valves are used to create a pressure differential at the end of the piping, away from the collection station. Their main function is to allow sewage to enter the pipes when the pressure differential is formed so the sewage can be “sucked” all the way to the collection station. The vacuum piping system connects the houses to the collection station. It is usually constructed of 4-6 inch diameter PVC piping. At the station, an electrical pump is used to create the vacuum in the tank. A stand-by generator keeps the vacuum sewer system in operation during extended power outages. A control panel reads the pressure and oil gauges concerning the effectiveness of the system. When problems arise, an automatic telephone dialer alerts the operator to alarm conditions.

### 3.9.2 VACUUM SYSTEM FUNCTIONS

Vacuum sewers have been altered drastically since their patent earlier in the 20<sup>th</sup> Century. They have been used, modified and developed over the last 30 years. The objective of the sewer system is to transport sewage from a certain point to a collection station by using a vacuum produced in the collection tank. In most systems, the collection tank is set below ground in order to minimize static lift in the piping system, but in many systems, the collection tank can be located at the ground surface. Although these different aspects of the system have been constantly modified, the basic requirements of control,

---

<sup>8</sup> Hassett, Alan. **Vacuum Sewers-Ready for the 21<sup>st</sup> Century**. 1996

logic, and functioning of the vacuum valve have not changed.

The way that a vacuum sewer system operates is; first air is evacuated from the collection tank, to create a vacuum within it. This action creates a pressure differential, making the station end of the vacuum piping at a lower absolute pressure than the atmospheric pressure existing at each vacuum valve connection. This pressure differential creates a hydraulic gradient of energy from the valves toward the collection tank. When a vacuum valve is opened, the pressure differential forces liquids and atmospheric air through the vacuum valve, carrying them to the collection tank at the collection station.

The collection station is the center of the vacuum sewerage system. It houses two vacuum pumps that create vacuum in the sewer lines, an enclosed collection tank, and two duplicated sewage pumps that discharge the sewage from the collection tank when full. The incoming vacuum lines connect individually to the collection tank, effectively dividing the system into zones. As sewage enters the collection tank, driven by air, the vacuum in the system will slowly decrease from 20 inches to 16 inches Hg.<sup>9</sup> The vacuum pumps are sized to increase the system vacuum back, from 16 inches to 20 inches Hg, and usually takes less than three minutes. Each vacuum pump tends to run only two to three hours per day. The 2 non-clogged sewage pumps are each sized for the hourly maximum flow rate.

A simplified view of the collection process shows sewage flowing by gravity from houses into a collection sump. When the amount of approximately 40-60 liters accumulates in the sump, the vacuum interface valve automatically opens and differential air pressure propels the sewage through the valve and into the vacuum main. The sewage then flows through the vacuum lines and into the collection tank at the vacuum station. The sewage

---

<sup>9</sup> Hassett, Alan. **Vacuum Sewers-Ready for the 21<sup>st</sup> Century**. 1996

pumps transfer the sewage from the collection tank to the wastewater treatment facility. A great advantage of this system is that there are no electrical connections required at the home, and power is necessary only at the vacuum collection station.<sup>10</sup>

The vacuum valves are incorporated into the Valve Pit Package, which connects the gravity piping from the homes to the vacuum sewer system. In the upper part of the sump, which collects the raw sewage, a vacuum interface valve is installed. It is pneumatically controlled and operated. The vacuum from the sewer line opens the valve when the pressure differential is big enough. Sewage level sensing works because as the sewage level rises air trapped in the empty sensor pipe pushes on a diaphragm in the valve's controller/sensor unit, which signals the valve to open. The valve is designed to handle nominal 75mm solids.

### 3.9.3 ADVANTAGES OF VACUUM SEWERAGE SYSTEM

The vacuum sewer system provides many advantages. For example, the piping in a vacuum sewer system is smaller in diameter than in a conventional sewer system. This use of small diameter plastic pipes reduces cost per unit length. Also, due to the narrow and shallow trenches, construction costs are decreased. Due to their built-in lifting capability, vacuum sewerage systems make intermediate pumping unnecessary. Vacuum sewers can also pass over or under obstacles like streams, ditches and other service lines. Unlike gravity systems, vacuum systems do not need inspection chambers or manholes, because the vacuum lines are "maintenance-free". Vacuum systems are also tightness tested, meaning that leaks can be easily detected and localized. This testing process

---

<sup>10</sup> EBARA website: [Error! Bookmark not defined.](#)

eliminates infiltration, which results in less sewage and smaller treatment facilities. There is also no threat of exfiltration, due to the fact that if there is a break in the pipe there is no leakage due to the vacuum, which makes the vacuum sewer system ideal for water protection areas. Another important advantage is that since the sewage in the system is highly aerated during transportation, it is less toxic, less corrosive and less odorous. Finally there is no need to enter manholes where maintenance crews could be exposed to hazardous atmosphere. Due to high flow velocities vacuum pipelines are maintenance free.

### 3.10 HIFLO™ VACUUM SEWERAGE SYSTEM

The HIFLO™ is basically an upgrade of the conventional vacuum sewerage system. The difference between conventional sewerage systems and HIFLO™ is found within the design of the vacuum valve. Unlike the conventional vacuum sewer system, the HIFLO™ separates air and sewage inlets into separate valves. This feature allows more sewage to enter through the valve because the wastewater is no longer mixed with the air. The HIFLO™ has many unique features that puts it above the conventional vacuum sewer system in terms of technology. It has high-lift capabilities, high capacity inlet capabilities, and uses off-the-shelf hardware.

The separation of valves in the HIFLO™ increases the flow allowed through a vacuum sewer system significantly making dense residential applications possible. Conventional vacuum sewer valves are manufactured to handle a typical peak flow of 1 liter/sec.<sup>11</sup> Most households fall within .2-.33 liters/minute range permitting a conventional vacuum sewer system valve to serve only two houses.<sup>12</sup> For the Amtrak installation of

---

<sup>11</sup> AIRVAC Design Manual

<sup>12</sup> Hassett, Alan. **Vacuum Sewers-Ready for the 21<sup>st</sup> Century**. 1996

HIFLO™, design allowed flows of up to 10 liter/sec at each inlet interface.<sup>13</sup> This is a tenfold increase in the standard capacity of vacuum sewer inlets. As stated before this high-capacity capability was accomplished by separating the liquid and air input locations. The sewage-only valves are able to operate in excess of 10 l/sec.<sup>14</sup> The air-only input valves are located on the vacuum main and allow air to enter the pipes at a frequency and duration required to maintain the designated air to liquid ratio for the piping system.

In order to understand well how the HIFLO™ system works one must first understand how the separation of valves functions. The sewage-only valve can be explained by the “ball and basket” model. Basically, the sewage-only valve is composed of a ball and a basket-like container in which the ball floats on. Because the “basket” is under vacuum, the ball is held down until the upward force of bouyancy overcomes the downward force created by the pressure differential between atmospheric and vacuum, times the cross-sectional area of the outlet opening.<sup>15</sup> Sewage flows through the valve until the level of wastewater goes down. The valve is blocked off when the ball floats to the point where its circumference equals the circumference of the “basket”. This action doesn’t allow air to enter the pipes. When more wastewater enters the basket, the ball foats once again allowing sewage to enter the piping system. However if the sewage-only valve was the only valve in the system, the wastewater could not be carried back to the collection station due to its high density. In order to decrease the density of the wastewater, air inlet valves are placed along the piping at the points where the density of the wastewater is too high. One can also place extra air-inlet valves in order to speed up the sewage transport process by decreasing the

---

<sup>13</sup> Hassett, Alan. **Vacuum Sewers-Ready for the 21<sup>st</sup> Century**. 1996

<sup>14</sup> Hassett, Alan. **Vacuum Sewers-Ready for the 21<sup>st</sup> Century**. 1996

<sup>15</sup> Hassett, Alan. email 07/20/97.

density of wastewater.

Overall the HIFLO™'s dual valve is an excellent feature because it allows for all four of the HIFLO™'s previously mentioned capabilities; high flow capacity, high reliability, low-tech, and inexpensive valves and inlet devices.

### 3.11 ALTERNATIVE SYSTEMS

Although the project team focuses canal repair on vacuum sewage instillation, an assessment must find a system best suited for Venice, by studying all the options available in the market currently. The sewerage systems currently available that were studied in order to determine if the vacuum system is the best option are the conventional gravity system, which is currently the most popular system, and the low pressure system.

In a conventional gravity sewer system, wastewater from each house flows directly into the publicly owned sewer without any mechanical interface. In order to provide a service to all residences, conventional gravity sewer must be laid deep enough at its most upstream point to pick up the lowest plumbing fixtures in the building with an allowance for the drop in elevation along the service lateral. It must then maintain a downward grade along its entire length in the downstream flow direction. When the depth of the sewer becomes impractical or uneconomical, due to excessive costs for excavation, dewatering and surface restoration, a conventional pump station lifts the wastewater to a higher elevation where gravity flow in downward sloping pipes resumes.

In a low-pressure sewer system, a small storage tank and a grinder pump serve as the interface between the homeowner's conventional gravity service lateral and the publicly owned pressure sewer. Due to positive pressure driving the flow in pressure sewers, they can be laid at a shallow depth initially and their profile can follow the existing ground

contours, with substantial savings in excavation and restoration costs. These pressure sewers eventually discharge to a conventional pump station, which takes the wastewater to the existing sewerage system. In contrast to the gravity sewerage system, the existence of electrically powered grinder pumps introduces additional potential for failures or mechanical malfunction, making the availability of trained personnel for quick repairs imperative. These requirements can be coped with (for a limited amount of time) by the maintenance of an ancillary individual septic system for temporary use during down periods.

### 3.12 SITES OF HIFLO™ SEWER SYSTEM IMPLEMENTATION

Patents for wastewater collection by barometrical depression date back to 1888. The Liljendahl Corp. of Sweden did the first practical application of vacuum sewage collection in 1959. Since then vacuum sewerage systems have been implemented all over the world. In North America several vacuum sewerage systems can be found from coast to coast. Along the East Coast, there are systems serving residential subdivisions at Matthews Courthouse, Va., the Lake of the Woods development near Fredericksburg, Va., and several resorts in South Carolina. In Indiana, there are systems in Martinsville, North Vernon, Rome City, and Plainville. Industrial applications were implemented in Alabama, Indiana, and Louisiana. In the West Coast vacuum systems can be found in Vancouver, British Columbia, Can., and Bear Lake, Calif. The project looks at two sights, Cavalier/North Linkhorn Park in the city of Virginia Beach, Virginia, and Queen Anne's County, Maryland, in order to further contrast the advantages and disadvantages of VS2001 vacuum sewer system with the other two sewer systems (gravity and low-pressure).<sup>16</sup>

---

<sup>16</sup> O'Brien & Gere, **Cavalier/ North Linkhorn Park Sewer Improvements**, 1984.

The Cavalier/North Linkhorn Park area is close to the sea bounded on most sides by bodies of water. It has rolling terrain with many rises and falls. Most of the area is low-density residential with a very limited portion set aside for offices, businesses and apartments. Most of the neighborhoods have been developed with on site septic tanks, but soil conditions of the general area are usually poorly drained and present a very poor potential for repair when the drainage fields eventually fail. Failure of the septic tanks may result in significant health endangerment due to potential contamination for the public water supply distribution system and nearby natural water bodies.

The two types of sewer systems evaluated for the Cavalier/North Linkhorn Park area were gravity and vacuum. Due to the rolling terrain encountered in Virginia Beach, excessive depths are encountered often and a large number of intermediate collection station would be required in order to implement a gravity system. In the 895 miles of gravity sewers in the city 260 pumping and lift stations are needed to make the system work. For these cost reasons the gravity system is undesirable. Vacuum and low-pressure systems are usually implemented when the terrain makes the capital costs of producing a gravity system excessive. A disadvantage of the low-pressure system is that since each house has an holding tank with a grinder pump, if there is a power outage the system does not work and backs up until power returns. Vacuum pump stations don't share this problem since they have their own power source. Construction predictions showed that:

- ◆ Gravity sewers would slope at 0.004 ft/ft and wouldn't go lower than 16 feet in depth.
- ◆ Low-pressure sewers would be placed at a constant depth of 3 feet.
- ◆ Vacuum sewers would slope at 0.0025ft/ft and wouldn't go lower than 12 feet in-depth.

Two other possibilities were studied, one a combination of shallower Gravity system with Grinder pumps and the other a combination of Vacuum and shallower Gravity with Grinder pumps. The second combination involves building a vacuum system in the northwestern half of the project and a shallow gravity system (with grinder pump connections where needed) in the southeastern portion. The belief behind this combo is that vacuum systems exhibit somewhat greater cost advantages in areas where buildings to be served are more closely spaced. The estimated construction costs for each alternative are as follows:

a. Conventional Gravity System	\$6.1 million
b. Low-Pressure System	\$5.7 million
c. Vacuum System	\$ 3.9 million
d. Shallower Gravity System with Grinder Pumps	\$6.8 million
e. Combination of Vacuum & Shallower Gravity with Grinder Pumps	\$5.3 million

The annual Operation and Maintenance cost estimates for the first three alternatives are:

a. Conventional Gravity System	\$43,900
b. Low-Pressure System	\$36,900
c. Vacuum System	\$39,000

As it can be seen from the price estimates stated above, the vacuum system is the best choice economically speaking. In practical terms it is either as good or better than the other choices. And finally both Low-Pressure and Vacuum systems have less odor potential, and disruption during construction than a Gravity system. Also the long-term

aesthetics of vacuum and pressure systems are preferable than that of gravity systems.<sup>17</sup>

After reviewing their options the City of Virginia Beach chose the vacuum sewer option for the reasons stated above.

The second site chosen as a suitable model for the implementation of vacuum sewerage systems is Queen, Anne's County, Maryland. The service area is composed of a series of peninsulas created by numerous tidal creeks and bays. The overall topography of the area is broad, level plain with elevations ranging from sea level to approximately 9 m (29 ft) above sea level. Most of the terrain is basically flat. The service area covers about 766 ha (1,892 acres). The length of the service area is about 13 km (8 miles) and the width varies from about 1 km (0.6 miles) to about 5 km (3 miles).<sup>18</sup>

Wastewater disposal in the area was accomplished mainly by the use of on-site disposal systems. An abandoned gravel pit received most of the sewage generated within the area. Numerous businesses were dependent on holding tanks, which had replaced malfunctioning septic systems.<sup>19</sup>

Once again, the Gravity, Low-pressure, and vacuum systems were studied to determine which system was the most suitable one. For any of the collection system designs, 12 stations (each serving a separate collection area) would be connected to a transmission system of two collection stations and force mains leading to the wastewater treatment plant adjacent to Chesapeake Bay. The Gravity alternative included 12 pump stations, 51 lift stations, and approximately 56,000 m (184,000 ft) of 200-mm (8-in.) diameter pipe installed at depths varying from 1.5 to 3.6 m (5-12 ft). The Low-Pressure

---

<sup>17</sup> O'Brien & Gere, *Cavalier/ North Linkhorn Park Sewer Improvements*, 1984.

<sup>18</sup> Hassett, Alan F. & Starnes, John C., *Journal of Water Pollution Control Federation*, 1981

<sup>19</sup> Hassett, Alan F. & Starnes, John C., *Journal of Water Pollution Control Federation*, 1981

alternative included 12 pump stations, 1,000 grinder pumps, and about 49,000 m (161,000 ft) of 100- and 150-mm (4- & 6-in.) diameter pipe installed at a depth of 0.9 m (3 ft) below the ground. The vacuum alternative included 12 vacuum collection stations, 1000 vacuum valves, and approximately 61,000 m (199,000 ft) of 80-, 100-, 150-, and 200-mm (3-, 4-, 6-, and 8-in) diameter pipe installed at depths varying from 0.9 to 1.5 m (3-5 ft).<sup>20</sup>

Topography, soil conditions, and groundwater table were all extremely unfavorable for deep pipelines in the proposed service area. Vacuum and Low-Pressure pipelines can avoid these problems by conforming to the ground surface profile. The extremely flat terrain necessitates a relatively high ratio of intermediate lift stations to the length of the gravity sewer. The high groundwater table and poor soil conditions caused the dewatering and restoration costs to increase exponentially as the depth increased. All of these problems make the Gravity sewerage system an unlikely choice for this area. The expense involved providing electrical service to over 1,000 grinder pump installations was a factor detrimental to the Low-pressure system. The vacuum system was found to be more reliable than the Low-pressure because the 12 vacuum stations had standby power incorporated in them, meanwhile it was economically infeasible to incorporate standby power in all of the grinder pump stations. The estimated construction cost for the alternatives was as follows:

a. Conventional Gravity System	\$15.5
million	
b. Low-Pressure System	\$10.4
million	
c. Vacuum System	\$8.1 million

---

<sup>20</sup> Hassett, Alan F. & Starnes, John C., **Journal of Water Pollution Control Federation**, 1981

The annual Operation and Maintenance costs for the alternatives were:

a. Conventional Gravity System	\$330,000
b. Low-Pressure System	\$173,000
c. Vacuum System	\$158,000

Because of the economic and functional advantages that the vacuum sewer system offered over its adversaries it was chosen for construction in Queen Anne's County.<sup>21</sup>

#### 4 LITERATURE REVIEW

##### Analysis of Structural Damage to the Canal Walls of the Sestiere Castello di Venezia

This IQP is a study of the canals separating the Sestiere of Castello on the east side of Venice from the San Marco Sestiere in the central part. The canals evaluated in this study are the Rio del Fontego dei Tedeschi, Rio de la Fava, Rio de S. Zulian, and Rio de Palazzo Canonica. This document was very useful in actually seeing the damage of the canal walls from the current sewerage system. It contains a mapping section of where the sewage outlets are located along the canals, and the percentage of outlets that are damaged. This knowledge of the outlet locations will help in the routing of the proposed piping system. This IQP presents a listing of statistics about the extent and type of damage to the canal walls. The damage is categorized into four degrees. Appendix D contains valuable insight of the actual structure and location of the *fognature*, or sewage holes, along the canals.

---

<sup>21</sup> Hassett, Alan F. & Starnes, John C., **Journal of Water Pollution Control Federation**, 1981

A Study of Water Quality in the Santa Maria Formosa Insula

This IQP tabulates the water quality within the canals. It measures depth and flow rates of each canal. This is useful in determining how much sediment is actually built up. In Appendix E a database was compiled of the average output of sewage in each canal. This was done by taking the average consumption of water per year and relating it to the number of outlets along the canal. This data can be used to estimate the amount of flow into the new piping, and facilitate a prediction of the operation cost of the proposed pumps.

Cavalier/North Linkhorn Park Sewage Improvements, Department of Public Utilities, City of Virginia, Virginia. April 1984.

This document is the recommendation for the implementation of a vacuum sewer system in the Cavalier/North Linkhorn Park area. It was produced by O'Brien and Gere Engineers, Inc. Within this document, an implementation of a gravity, low pressure, and vacuum sewer system is studied for implementation within the spoken area. This document presents a good model for the implementation of a vacuum sewer system. Descriptions of low pressure and gravity sewerage systems were derived from this document.

*Vacuum wastewater collection: the alternative selected in Queen Anne's County, Maryland Journal, Water Pollution Control Federation. January 1981.*

This journal describes how the implementation of vacuum sewers was chosen over other sewer systems in Queen Anne's County, Maryland. It represents a good model of the

advantages that vacuum sewers hold over gravity and low-pressure systems. The terrain of Queen Anne's County is similar topographically to that of Venice.

### Calle, Campielli E Canali

This book gave detailed maps for all of Venice. Each map contained all of the buildings for each Island within the 6 Sestieri of Venice. This provided the list of address ranges necessary for making detailed schematics for each of the project's test islands as well as the upscale model for Venice. It also helped in providing building locations for the laterals, valves, and collection stations of the vacuum sewer system.

### Coses IQP

This IQP provided the water consumption data necessary for our study from 1996. This data was used to determine the size and location of the pump stations.

### Piano Programma degli Interventi Integrati per il Risanamento Igienico ed Edilizio della Citta di Venezia

This book was provided by the city of Venice. It provides useful information related to the *fognature* system of Venice. It identified the division of the marginal versus historical sites for our study. It also provided water consumption data from 1991 for all six Sestieri. This book outlines the 23-year renovation plan for the complete renovation of the sewer system of Venice. This plan is extensive and gave us information about costs of dredging, excavation, etc.

## AIRVAC Design Manual

The AIRVAC Corporation provides this manual. It is an in-depth engineering analysis of the vacuum sewer system provided by the company. It was used in this study to determine the different options of implementation for the vacuum sewer system. Most importantly, it was used to determine the collection station design and location for the implementation of this system

### 5 METHODOLOGY

#### 5.1 INTRODUCTION

The present system in Venice is failing in many ways. It is causing structural damage to the building foundations and canal walls. Several previous project teams have dealt with these problems. In this study, the current project team evaluated the feasibility of installing a vacuum sewerage system on two different levels within the city of Venice. The implementation of a vacuum sewerage system into marginal areas of Venice, as well as the historical areas was examined as ways to eliminate the direct dumping of wastewater into the canals, while reducing the amount of damage to the canal walls. In order to achieve this goal, it was necessary to study the current sewerage system and its flaws. From this study a means of installation of HIFLO™ was determined, and a cost analysis for construction and implementation was also performed. This study was then proposed to the City of Venice as a solution to the prevailing sewage problem.

#### 5.2 OBJECTIVES

- ◆ Inspect how the current sewer system operates in order to provide an estimation of how

complex the current system is.

- ◆ Analyze Santa Maria Formosa and Santa Marta to simulate prototype implementation of the hi-flow vacuum sewerage system, HIFLO™
- ◆ Design comparative schematics of the current sewerage system and the HIFLO™, for both test islands, and then the entire city of Venice.
- ◆ Make a cost estimate of the implementation of the HIFLO™ system.
- ◆ Compare the HIFLO™ with the current sewerage system of Venice on levels of cost, social aspects, and applicability.

### 5.3 ANALYSIS OF TARGET SITES

Since evaluating the implementation of the vacuum sewerage system (HIFLO™) for the entire city of Venice would be impractical and could not fit the time constraint of two months, the project team chose to analyze vacuum sewage technology for two test islands. The two test islands chosen were Santa Marta and Santa Maria Formosa. These test islands were chosen for scaled-down prototypes. The team reviewed these selections with Venice's Department of Public Works, who approved the choices.

The island of Santa Marta, located in the marginal area, was selected for an in-depth analysis of vacuum sewer implementation at the special request of the city. This request was made due to current renovations planned to take place in the near future, as well as severe sewage collection problems within this island. Due to its uniqueness in piping, Santa Marta was not considered a good representative of other islands and was not chosen to form the upscale model.

Due to the fact that Santa Maria Formosa was considered to be typical island of

Venice in geographical and structural terms, it was chosen to form an upscale model for the entire city. For both of these islands, schematics were made along with the internal and external system configurations. Information was also obtained concerning the average diameters, lengths, and routing of the city mains.

#### 5.4 GENERAL METHOD OF APPROACH

The project group's main task in Venice was to design a schematic for the implementation of a HIFLO™ vacuum sewerage system to serve the city. The project team accomplished this task by using a geographical information system, MapInfo, and previous data regarding the schematics of the piping from the city of Venice to determine the approximate pipe lengths for the mains and laterals. Extrapolation of pipe lengths occurred when there was a lack of information for a certain area. MapInfo was used as a tool to estimate the points at which the laterals join the mains. Another use for MapInfo was to determine possible locations of the air valves and sewage valves specific to the hi-flow HIFLO™ system. The project team completed these schematics in MapInfo for Santa Maria Formosa and Santa Marta. Using the data obtained from the schematics of Santa Maria Formosa, extrapolations were made to form an upscale model of the entire city of Venice.

#### 5.5 EVALUATION OF THE CURRENT SEWERAGE SYSTEM

In order to get a good idea concerning how the current sewerage system functions, the project team met with city officials to obtain all possible knowledge of the current piping system and the practicality of future piping systems to be implemented in Venice.

Data for Santa Marta was obtained directly from the city's current sewage plans and the proposed renovation plans of the island. Due to a lack of knowledge available on an in-depth level for the current plumbing intricacies of Santa Maria Formosa, only rough estimates using MapInfo were made to imagine what current and future piping systems should look like. Databases and maps were created to record the general routing of the plumbing, the discharge points of the sewer pipes, the discharge rate of wastewater, and the locations and sizes of building laterals and collection tanks, as well as vacuum valves.

## 5.6 GENERAL PLUMBING DESIGN

To assess the general routing of the plumbing, city schematics were obtained that describe this subject. It was essential to study how the plumbing is routed at several different locations throughout the city, in order to form a pattern for the plumbing. City engineers Ivanno Turlon and Rinaldo Fidati were interviewed due to their excellent understanding of plumbing routes throughout the city.

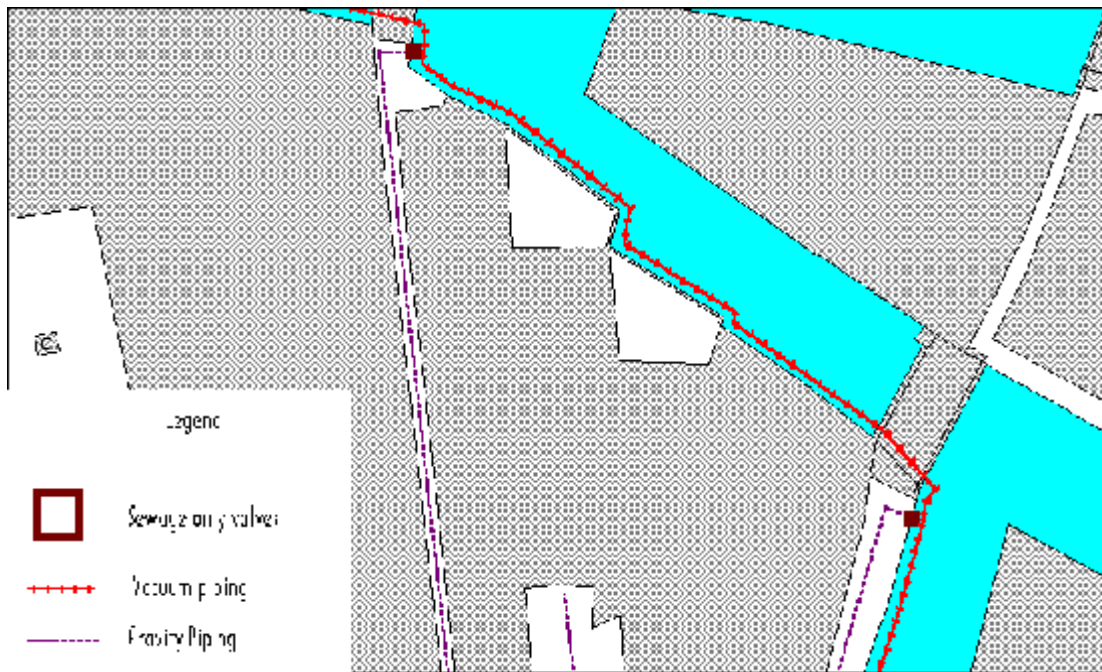
### 5.6.1 SIZE OF LATERALS

Another concern was that not all of the buildings are adjacent to the canals, so "laterals" serve as a means of extension to the canals for sewage disposal. In order to make a general guess concerning how many of these laterals are present in a specific area, an assumption was made that for each door, belonging to a given building, there exists one lateral. Since *collettori* generally run down streets, an assumption was made that each street is served by a *collettore*, which carries the sewage from the street's laterals to the canals.

## 5.7 IMPLEMENTATION OF VACUUM SEWER TECHNOLOGY

The main objective of this was to obtain the most practical form of

implementation of the vacuum sewerage system. The project team proposed different combinations of the extent of implementation. The biggest obstacle at hand was how to connect the internal system to the external piping due to the delicacy of the buildings. In order to create an overall proposal for the City of Venice, downscale schematics of Santa Maria Formosa were created using MapInfo, a geographical information system. The proposed implementation was carried out at three different levels:



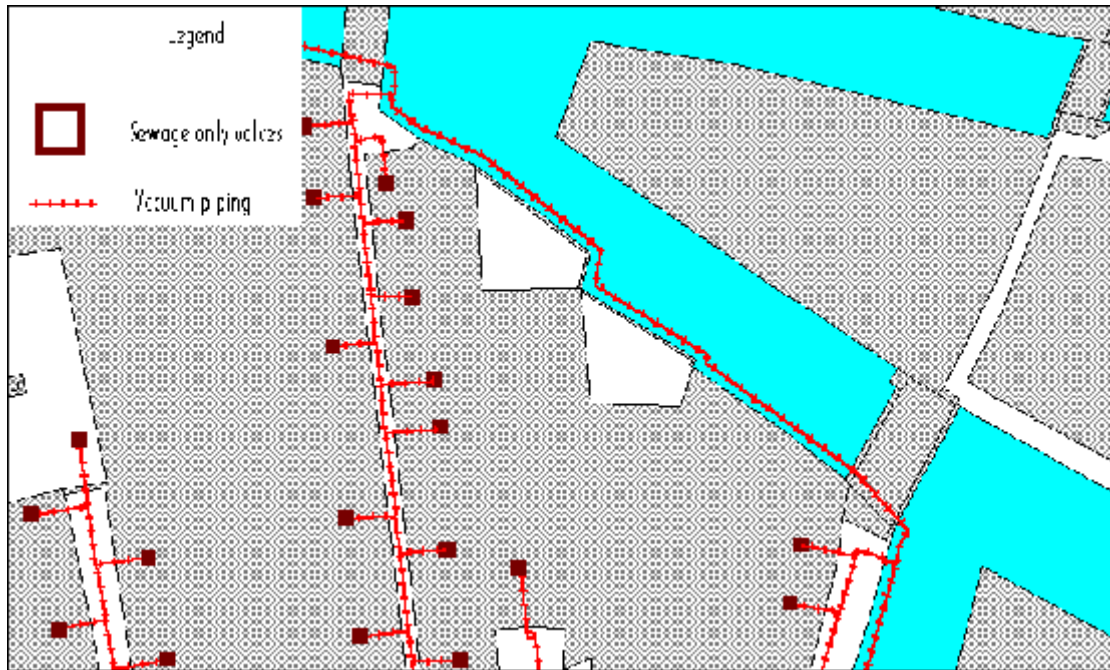
**Figure 2:** *Option one proposal of vacuum sewerage implementation.*

**OPTION ONE:** Option one involved vacuum piping within the canals. The piping was installed below the dredge level or on top of fiberglass support posts, which are designed to anchor the pipes below the water line at all times. The vacuum piping interfaced with the gravity piping from the island at the *s boccho*, the point where the *collettore* decants into the canal, and a sewage only valve is installed. Air inlets are installed every 50 meters along the canal piping.



**Figure 3:** *Option two proposal of vacuum sewerage implementation.*

**OPTION TWO:** Option two is an expansion of option one. Along with the piping design within the canals, vacuum piping was carried along side the *collettore* to the point where it meets with the decanter. The lateral interfaced with the vacuum piping at the *collettore*. The sewage only valves were placed at the interceptor points in the form of a small manhole. “Normal” laterals, within 5 meters of one another, on the same side of the street, were joined in order to reduce the number of valves needed. Once again, air inlet valves were installed at 50-meter intervals.



**Figure 4:** *Option three proposal of vacuum sewerage implementation.*

**OPTION THREE:** Option three is a continuation of options one and two, except lateral rerouting within this option is not necessary. Vacuum piping in this option goes all the way up the laterals. Within this option, the gravity piping interfaced with the vacuum piping at the bottom of the house where the sedimentation tank is located. At this point a sewage only valve was installed. Air inlet valves were also placed at 50 meters intervals.

Both options two and three were designed for both test islands, taking into consideration the differences between building regulations of historical and marginal areas. The upscale for all the piping of both the marginal and historical islands was based on the data collected for Santa Maria Formosa, given that no such data could be collected for Santa Marta because of its unique piping.

It should also be noted that no treatment was applied for outlets that serve only canalside buildings. Canalside building adaptation was not included in this study for two

reasons. The first reason was the project group predicted only 10 percent of the total sewage entering the canals results from canalside homes. The second reason was that in order to serve all canalside homes with vacuum sewerage, the plumbing design must either be rerouted to enter a *collettore* or valves would need to be placed at every *sboccho*. Canalside adaption requires its own detailed and could not be taken to the needed level within the allotted time for this feasibility study.

The vacuum collection applications within this study were designed to collect sewage that was previously collected by the *collettori*. Other sewage will not be collected by this system. Also, option one was designed for the building sensitivities of the historical islands, given that no construction would be performed within or around the buildings in this option. The levels of implementation were decided based on cost and practicality. These investigations were all concluded with the assumption that the city goes through with the canal dredging, sewage outlet and *collettore* renovations; all contained within the 23-year renovation plan.

### 5.7.1 CITYWIDE IMPLEMENTATION

Once the preparation of each option for vacuum adaptation had been completed on the downscale level, an upscale plan for the city of Venice was created accordingly. The upscale was broken down into two categories, historical and marginal, and the total piping, sewage valve, and air inlet valve relations were developed for each option using the downscale models for Santa Maria Formosa. It should be noted that all pipes were designed with the intentions to not cross or run along the Grand Canal. Included within citywide implementation were two schematics demonstrating a suggested collection station

networking system to transport all sewage to a section of the city where it can be collected and transported to the mainland.

### 5.7.1.1 PIPING DESIGN

In all the options, the piping for both the marginal and historical areas was based on the data collected from Santa Maria Formosa. Santa Marta was not modeled because of the uniqueness of its piping. The canal piping, which is the total piping for this option, included the total measured piping for the island (using MapInfo), the amount of piping down into the canals and a piping grade factor. The down piping, which is the amount of piping that went into the canal, was set at 2 meters per *collettore* outlet to account for the vacuum piping going below the water level to the bottom of the canal. The piping grade was a standard degree at which the piping slopes and then climbs back up. The piping drops 30.48 centimeters in 152.4 meters and is then raised vertically 30.48 centimeters (See Appendix C). The total length of canal piping for Venice was determined by the following equations:

$$\frac{S.A._{S.M.F.}(m^2)}{C.P._{S.M.F.}(m)} = V.P.F._1(m) \quad (1)$$

$$\frac{S.A._I(m^2)}{V.P.F._1(m)} = C.P._I(m) \quad (2)$$

Equation 1 divided Santa Maria Formosa's surface area,  $S.A._{S.M.F.}$ , by the total amount of piping,  $C.P._{S.M.F.}$ . The resulting vacuum piping factor,  $V.P.F._1$ , of option 1, was applied within equation 2 to calculate the canal piping length for each island,  $C.P._I$ , in Venice.

For option two, the total amount of piping was calculated by adding together all the

piping obtained in MapInfo, being the down piping, the piping grade and normal laterals (See Appendix C). In order to calculate the amount of land piping, the canal piping in option 1 was subtracted from the total amount of piping in option 2. Land piping for all the islands was then calculated by the following equations:

$$\frac{SA_{S.M.F.}(m^2)}{LP_{S.M.F.}(m)} \cdot LP_{F.2}(m) \quad (3)$$

$$\frac{SA_I(m^2)}{LP_{F.2}(m)} \cdot LP_I(m) \quad (4)$$

Equation 3 divided  $SA_{S.M.F.}$ , the surface area of Santa Maria Formosa, by the total land piping,  $LP_{S.M.F.}$ . Within equation 4, the same extrapolation between the piping factors, as within option one, was correlated, yielding  $LP_I$ , the land piping for each island. Normal laterals within a certain distance from one another were joined to decrease the number of valves. The following formula calculated the amount of piping that was rerouted.

$$S.V._3 - S.V._2 \cdot 5(m) = La.P.(m) \quad (5)$$

Equation 5 is the difference between the total number of sewage valves for option 3,  $S.V._3$  and the total number of sewage valves for option 2,  $S.V._2$ . When this value is then multiplied by 5, the total lateral piping,  $La.P.(m)$ , is calculated. To then calculate the amount of normal lateral piping on the city level, equations 3 and 4 are used once again with  $La.P.(m)$  used as the dividend of surface area.

In option three, the same procedure was applied as in option two but with placement of the laterals under the vacuum piping. The amount of vacuum laterals within this option was simply calculated by subtracting the total land piping in option two from the total

land piping in option three. The calculations of land piping were similar to equations 3 and 4. For each option and area type, each amounts of canal, land, and lateral piping lengths were summed using Excel spreadsheets, to calculate the total of each piping type for all of Venice.

#### **5.7.1.2 VALVE ESTIMATIONS LOCATIONS**

Two valve types were calculated for vacuum design, sewage and air. Sewage valves were calculated first on a downscale level, at each interface between gravity and vacuum. These valves were placed at the *sbocchi* in option one, in small manholes on the street in option two, and in the sedimentation tanks in option three. The air valves were simply placed at 50-meter intervals along the vacuum piping. The relations for valve calculations were derived in the same fashion as in equations 3 and 4, with the number of valves as the dividend. The only differences reside in the value of the factors.

#### **5.7.2 COLLECTION STATION NETWORK**

In order to collect and treat all sewage within the vacuum sewerage system, a network of collection stations was created. The network works under vacuum, not only collecting all sewage but also transporting it out of the city. All calculations took into consideration the equipment for the collection stations and the necessary land. Collection station networking was devised for marginal and historical areas alone, as well as all of Venice.

##### **5.7.2.1 VOLUME OF COLLECTION TANK AND COLLECTION STATION LOCATION**

In order to determine the location and size of collection tanks for Venice, the

individual tank size for each island was calculated based on the average sewage flow (liters per minute) with a peaking factor. To calculate the average sewage flow, the water consumption was used as a rough estimate of sewage flow. An in-depth calculation was executed for the four *sestieri*, while a rough estimation was done for the two remaining *sestieri*.

Water consumption, in cubic meters per year, for each island within the four *sestieri* of San Polo, Cannaregio, Castello and San Croce, was attained from past IQP data of 1994. For the *sestieri* of San Marco and Dorsoduro, the total water consumption was attained from city records, dated for 1991. Knowing that over the past years, the population of Venice has steadily decreased, it was concluded that water consumption also has decreased. In order to maintain data consistency between 1991 and 1994, water consumption between 1991 and 1994, of the known *sestieri* were compared. An average decreasing factor was taken. This fraction, .83, was taken and applied to Dorsoduro. Because San Marco was assumed to decrease because of the high area of tourism, a larger fraction, .90 was therefore applied. These fractions were extrapolated from city provided figures, for 1991 total water consumption, for the four *sestieri* (an explanation of .9 and .83 derivations can be viewed in Appendix A).

The size of the collection tanks needed in each island within the four *sestieri* were calculated by using the following series of equations, given by the AIRVAC Corporation:

$$Q_M = 4 * Q_A \quad (6)$$

$$V_O = 1.64 * Q_M \quad (7)$$

$$V_{C.T.} = 3 * V_O \quad (8)$$

$Q_A$  is the average flow (liters per minute);  $Q_M$  is the maximum flow (liters per minute).  $V_O$  is

the volume of operation and  $V_{ct}$  is the size of the collection tank, both also in liters. 1.64 and 3 are standard conversion factors, while 4 is the peaking factor. From the collection tank sizes of each island, the main collection station sizes were extrapolated. The collection stations were designed by adhering to three guidelines. The first guideline was to connect islands to a collection station with the minimal possible piping. The next guideline was to maintain a variety of tank sizes ranging from 13 to 20 cubic meters. The final guideline was to create an equal balance of sewage influx to the collection tank. The final decision concerning collection station locations and collection tank sizes depended on each island's orientation to one another, availability of building spaces and how they adhered to the set design goals.

Collection tank sizes and collection station locations for the two *sestieri*, lacking individual water consumption data, were extrapolated from the calculations of the four other *sestieri*. A total volume of the collection tank sizes for each *sestiere* was found by dividing the water consumption (cubic meters per year) by 26.7. The 26.7 relation was extrapolated from the collection tank sizes for the four *sestieri*. Taking the total water consumption for each of the four *sestieri*, and then dividing it by the total volume of each collection tank made a relationship. The resulting factor was consistently 26.7. The average number of islands for each collection station for the four *sestieri* was used as a basis to calculate the total number of collection stations. The number of islands and the total collection tank volumes was also taken into consideration. Locations were based on collection station sizes and educated guesses of residential, tourism and business behavior of each island.

Building size of the stations were also calculated. The collection tank sizes were first converted into cubic meters. The building sizes were calculated as simply twice the size of

the collection tank to account for the collection tank and all piping equipment, control panels, electrical, storage and personal. The optimal dimensions were determined by keeping the height of the sheds 2 meters or less. The tank can be buried up to certain-depth below sea level but this was not used to calculate building size in cases where the building was below sea level.

### 5.7.3 WASTEWATER TREATMENT

#### 5.7.3.1 TRANSPORTATION WITHIN VENICE

After determining a method for implementation of the HIFLO™ sewerage system for all of Venice, it was necessary to determine a method to transport the sewage. In order to pump the sewage to a certain section of Venice, a piping scheme was designed. The general idea behind the scheme was to run routes around the *sestieri* on either side of the Grand Canal. Two different piping plans were designed; one on the top of the Grand Canal, and the other on the bottom. A subordinate objective was to avoid crossing the Grand Canal due to excessive costs of traversal construction. The destination points for these two piping plans were *Ferrovio* for the top and *Stazione Marittima* for the bottom. Using the piping scheme, the maximum distance from each pumping station to the respective destination was approximated. Each value that was obtained was set to be a separate pipe in order to give each collection station its own piping to the area. For each set of pipes the approximate number of collection stations and air inlet valves were placed in the appropriate areas to carry the sewage to its respective station. Additionally, the total cost was determined for this pumping relay system.

### **5.7.3.2 TRANSPORTATION OFF OF VENICE**

It was necessary to investigate a site where the wastewater will exit the sewerage system, where it will be transported to the lagoon or to a treatment plant. The investigation was a general means of approach for transportation. The analysis was not as in-depth as it was for the piping schematics. Below three plans of sewage disposal that were devised:

***PLAN A:*** Pump the sewage to treatment facilities on the mainland underneath the Mestre Bridge, placing extra collection stations throughout Venice and two large central collection stations located on either side of the bridge.

***PLAN B:*** Pump the sewage to treatment facilities on the mainland through the lagoon.

Extra collection stations were placed on the deserted islands.

For Plans A and B, piping routes were devised to transport sewage for all of Venice to a treatment plant on the mainland. Extra collection stations were placed at intervals of 1,400 to 1,500 meter intervals to maintain the force needed for proper sewage flow. Plans A and B also adhered to strict environmental laws enacted to protect life in the lagoon.

## **5.8 COST ANALYSIS**

An important aspect of the feasibility of implementing the VS2001 system into Venice is the cost. In order to prepare a comparative budget for implementation, the team used two test islands. On these islands, it was determined exactly how much material would be used; specifically, amount of piping, and the number of valves and pumps. In addition, the team accounted for an approximate figure for a network to transport the sewage to a treatment facility.

## 5.8.1 COST ESTIMATES

Costs were broken down into two sections, marginal and historical. These estimates were further separated into the three options of implementation. All figures for implementation were attained from the *Comune di Venezia* while all HIFLO™ components were obtained from Alan Hassett.

### 5.8.1.1 IMPLEMENTATION

After incorporating all of the factors stated in the previous section, a cost breakdown was derived as a realistic estimation for the cost of implementing the HIFLO™ on both test islands. Later, this function was expanded and amplified to serve the entire city of Venice. Cost estimates of labor and parts were also obtained from city officials. All figures were broken down for each option within an itemized chart shown below in Table 1.

	5.9 OPTION 1	5.10 OPTION 2	5.11 OPTION 3
<b>Total land piping (m)</b>			
<b>Implimentation of land piping (£)</b>			
<b>Total canal piping (m)</b>			
<b>Implimentation of canal piping (£)</b>			
<b>Sewage valves</b>			
<b>Cost of valves (£)</b>			
<b>Cost of valves with manholes (£)</b>			
<b>Total air inlet valves</b>			
<b>Cost of air inlets (£)</b>			
<b>Normal laterals (m)</b>			
<b>Vacuum laterals(m)</b>			
<b>Implimentation of laterals (£)</b>			
<b>Total cost of collection station networking (£)</b>			
<b>Total cost (£)</b>			
<b>Total cost (U.S. \$)</b>			

**Table 1:** Sample chart of cost breakdown for Vacuum Sewage installation.

Implementation of land piping included installation of parts with labor, site excavation and covering, and the ninety-degree turns of land piping. The canal piping estimate included installation with parts and labor, price to keep the canal dry, fiberglass supports for the piping, and also for ninety-degree turns within the canals. Canal piping estimates were based on assumption that the canal at the time of pipe installation was already dry-dredged due to city restoration plans. Also, it is assumed that there be no piping installed within the Grand Canal. Cost for sewage valves with manholes included the price for sewage valves and manholes with lids, excavation and restoration. Cost of collection stations were a fixed price for each option. The price included all station components, construction and land.

For the implementation for the city as a whole, the surface area of the Santa Maria Formosa as well as all facets of installation were taken into account to calculate the cost for all of Venice. Using Excel, a spreadsheet was created to calculate each component of implementation for each island within Venice. Each island's component was totaled and respectively entered into Table 1. All price estimates were then multiplied by these figures to give an overall cost for each part of vacuum installation. Each part was then totaled for options 1, 2, and 3. Additionally to each option was added each respective price for the collection station networking system as well as a flat price for wastewater . Implementation for the entire city the cost was separated into three phases of implementation historical alone, marginal alone or all of Venice. With each price came the standard of piping costs but different figures were used for the pumping station networking. A Venetian standard of 15 percent inflation was calculated into the finalized costs to account for unforeseen expenditures.

#### 5.11.1 COST COMPARISON

After calculating the cost of implementing the HIFLO™, the project team compared the costs of implementation and maintenance for each option. Also population density was measured to compare the average price per hectare for HIFLO™ to the price of other systems.

#### 5.12 SOCIAL IMPACTS

To determine the overall impact of this renovation, many aspects that may affect the Venetians were taken into account. The new system may tie up traffic for some time while installation commences, and may be unsightly at first. As with most changes, the people

would have to adapt, and eventually the new piping would disappear. Operation noise of the system may be a downfall for the vacuum sewer system, and thus may play a role in the social impacts of the implementation. Surveys were administered to the local population to find out their opinions, and informed them of the project's objectives. These surveys revealed to the project team more about the people of Venice, and shed some light on how to go about changing their sewerage system. The survey, in both Italian and English, can be found in Appendix B.

### 5.13 CONCLUSION

Following these procedures, the project team was able to determine a method for the optimal implementation of the HIFLO™ by a comparison chart. The comparisons were categorized on the following levels: applicability, aesthetic impact, initial cost, maintenance, efficiency and environmental effects. The project team hopes that this proposal incorporates all factors leading to a system that will be beneficial to the citizens of Venice, as well as the structural integrity of Venice's building.

## 6 RESULTS AND ANALYSIS

### 6.1 INTRODUCTION

This chapter contains the raw results of study. It contains the schematic maps of all levels of implementation used in analyzing and studying the data, concerning the feasibility of vacuum sewerage implementation. All cost estimates, with an itemized breakdown, from this study are presented here, as well as a presentation of the raw data, and the building blocks of data for the areas of study. An upscale proposal of vacuum sewerage implementation with all required components and cost figures is also included.

## 6.2 COVERAGE OF STUDY AREAS

This section contains information of the current sewerage system and the proposed vacuum sewerage system for both test islands. These results are presented in map form and detailed charts. Upscale implementation was broken down into costs for historical and marginal areas; based on the data provided by the city for Santa Marta and logically based assumptions for Santa Maria Formosa, the two prototype areas of this project.

### 6.2.1 MAPS

Maps were created for the in-depth studies both of Santa Maria Formosa and Santa Marta. The first series of maps are schematics of the current sewerage system. Assumptions were made for the island of Santa Maria Formosa that for each alley lined with doors there exists a lateral. This assumption has been illustrated in Map 1, as the door locations are fairly consistent down many of the alleys. This lateral placement relation was useful in determining where to connect a main line traveling around the entire island. The lateral locations for Santa Marta, displayed in Map 2 were given to the project team from the *Comune di Venezia*.

The second series of maps are of the proposed vacuum sewerage implementation. Series A is for Santa Maria Formosa and series B is for Santa Marta.

Map 3: Proposed vacuum piping of option one in Santa Maria Formosa. Vacuum piping is implemented in the canals only, with sewage valves located at the *collettori* and air valves at 50-meter intervals.

Map 4: Proposed vacuum piping of option two in Santa Maria Formosa. Vacuum piping is run along the path of the *collettore* until the lateral interface. Laterals were combined to

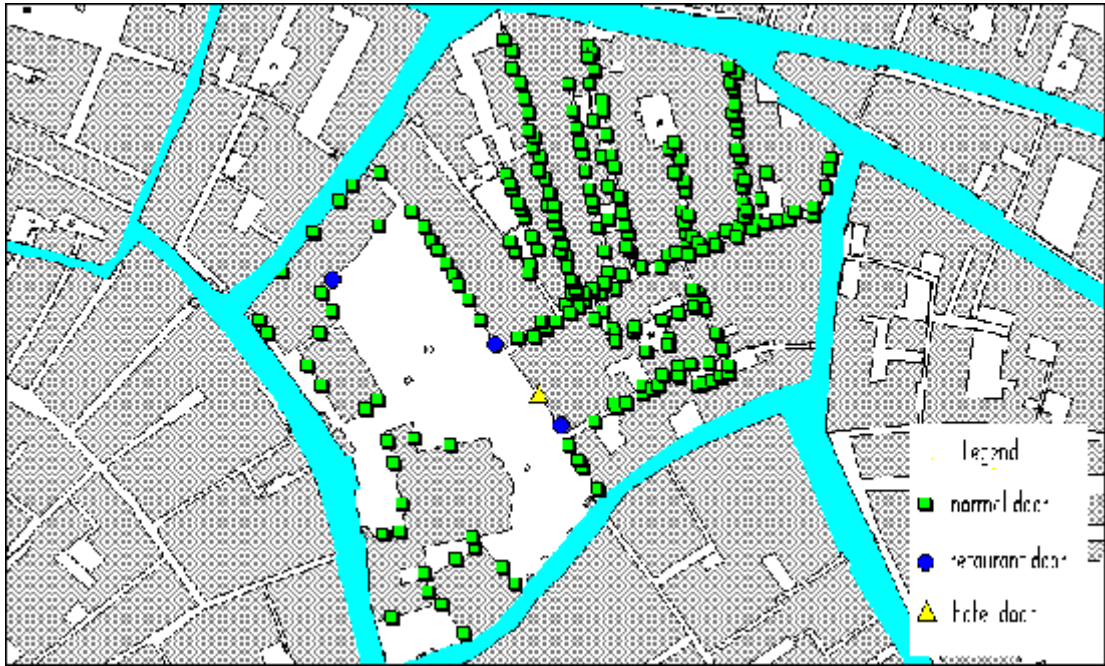
decrease the number of sewage valves. Sewage valves were placed at the interface along with small access manholes directly above. Air valves are also at 50-meter intervals.

Map 5: Proposed vacuum of option two in Santa Marta. Vacuum piping implementation is identical to that of Map 4 but without the canal piping.

Map 6: Proposed vacuum piping of option three in Santa Maria Formosa. Vacuum piping is run within the canals, along the path of the *collettore*, and also along side the path of the laterals. Sewage valves are located at the interface between the laterals and gravity. Air valves are located every 50-meters.

Map 7: Proposed vacuum of option three in Santa Marta. Vacuum piping implementation is identical to that of Map 6 but without the canal piping.

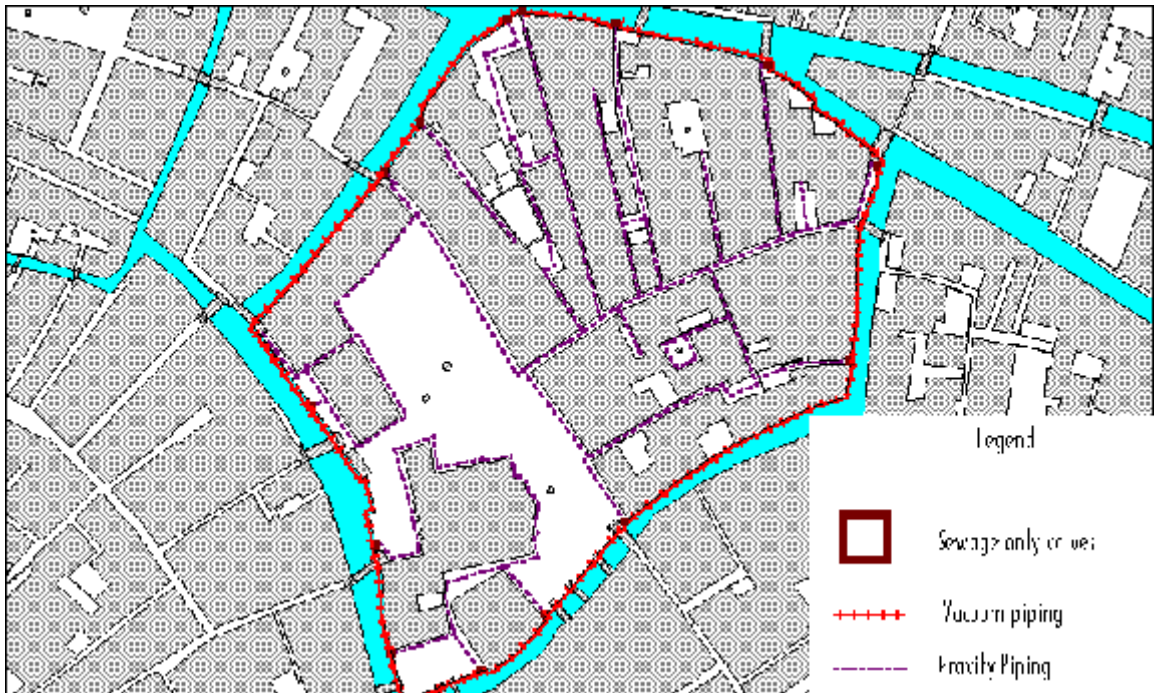
All maps were created using MapInfo, logical assumptions and collected data.



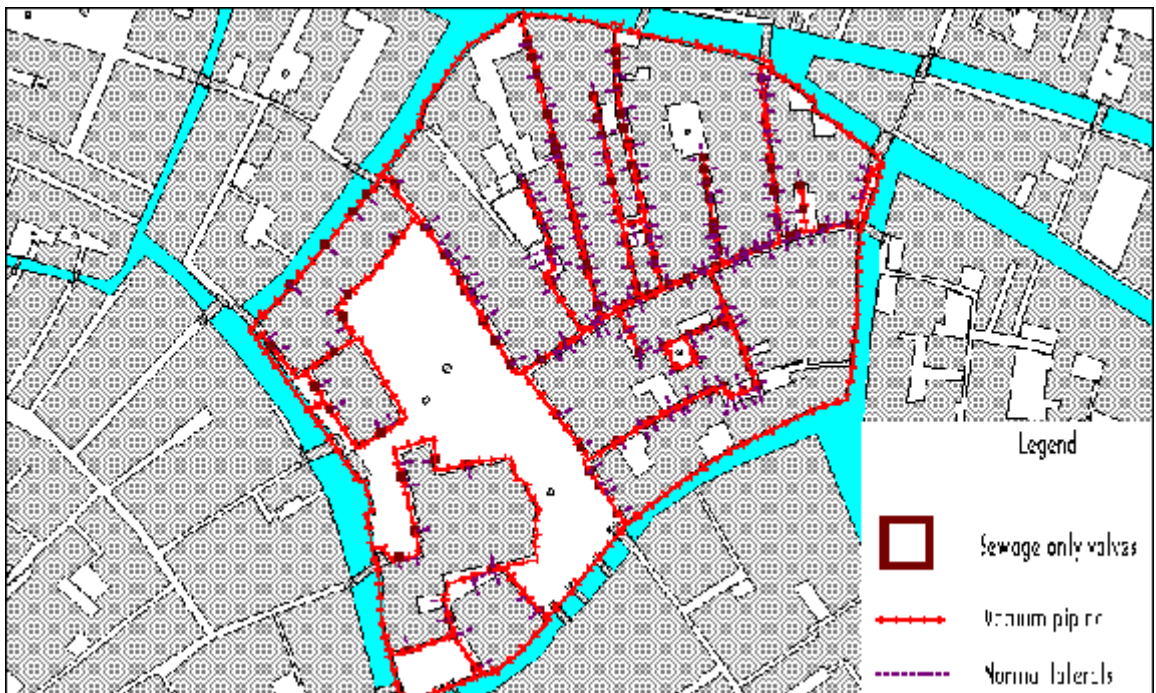
**Map 1:** Location of active doors for Santa Maria Formosa.



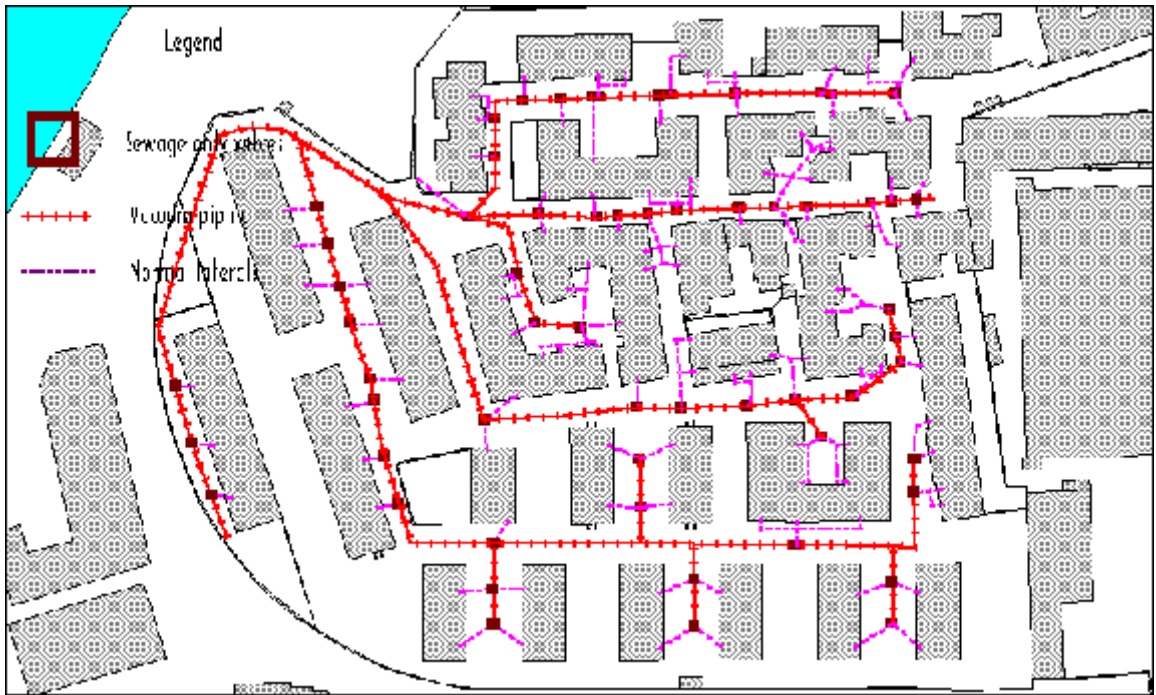
**Map 2:** Current piping schematic of Santa Marta.



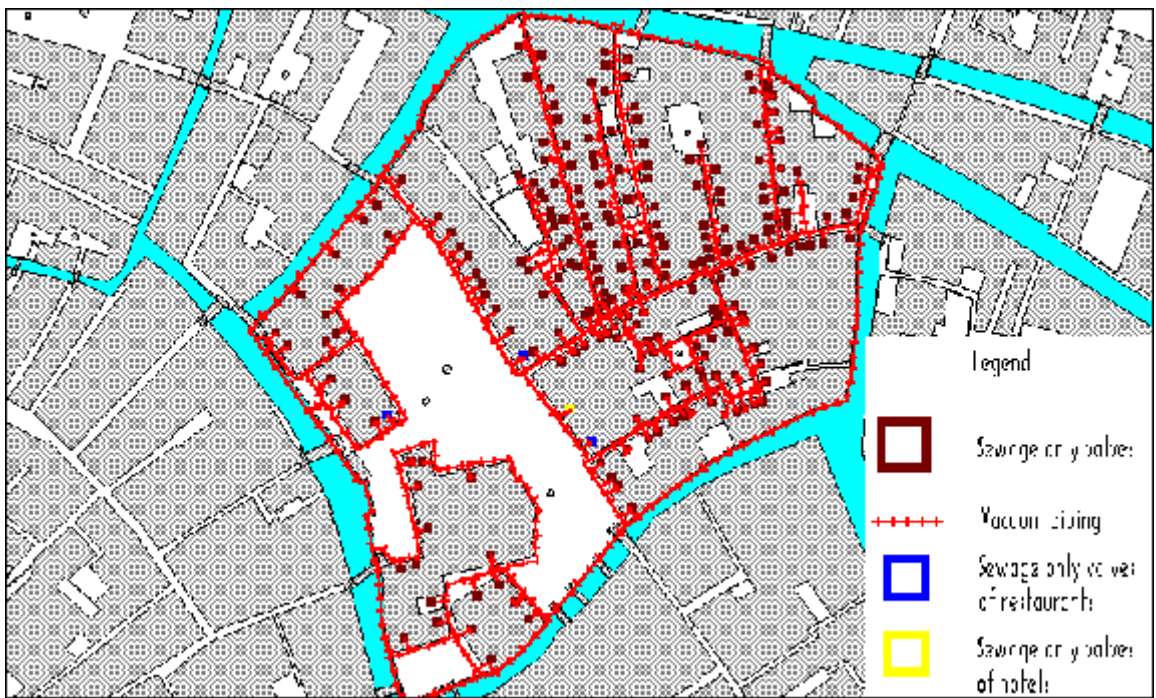
**Map 3:** Proposed vacuum piping for option one for Santa Maria Formosa.



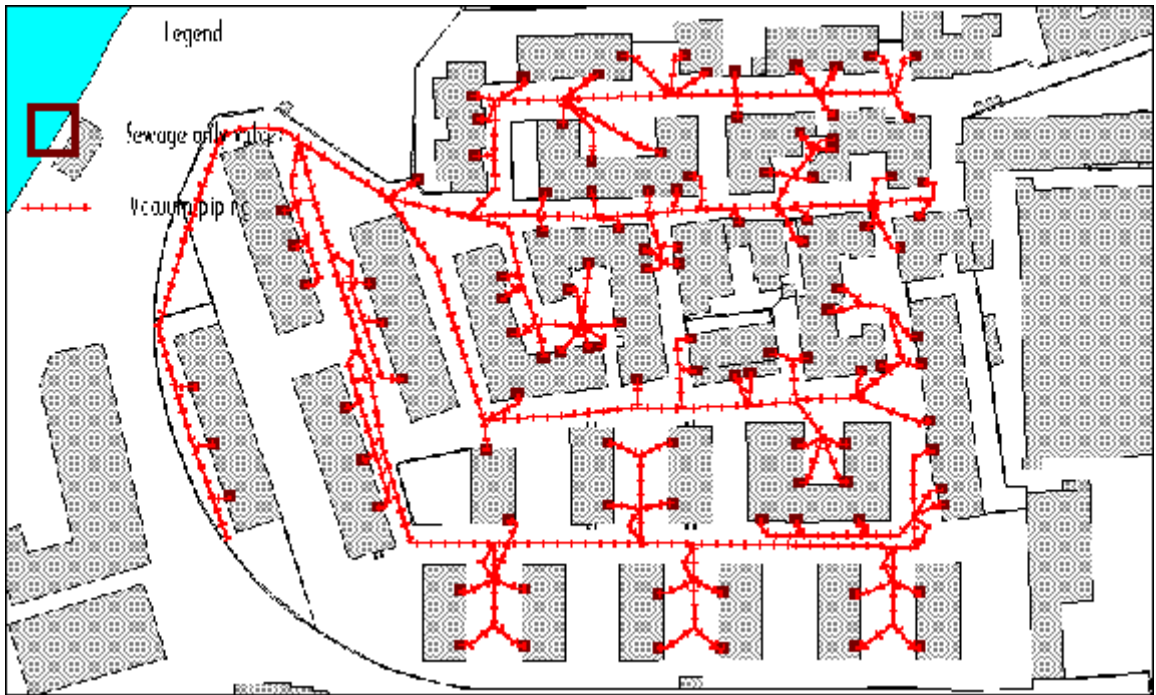
**Map 4:** Proposed vacuum piping for option two for Santa Maria Formosa.



**Map 5:** Proposed vacuum piping for option two for Santa Marta.



**Map 6:** Proposed vacuum piping for option three for Santa Maria Formosa



**Map 7 :** Proposed vacuum piping for option three for Santa Marta.

## 6.2.2 CHARTS

Charts were created for both Santa Maria Formosa and Santa Marta prototypes, to organize the different facets for all levels of implementation along with itemized cost of implementation. Table 2 contains all data for historical implementation, while Table 3 contains all data for marginal implementation. All levels of implementation required both sewage and air inlet valves. The density of piping became greater going from option 1 to option 3.

	OPTION 1	OPTION 2	OPTION 3
<b>Total land piping (m)</b>	<b>0</b>	<b>1,239</b>	<b>2,167</b>
<b>Cost of land piping (£)</b>	<b>-----</b>	<b>80,101,350</b>	<b>140,096,550</b>
<b>Total canal piping (m)</b>	<b>682</b>	<b>682</b>	<b>682</b>
<b>Cost of canal piping (£)</b>	<b>318,835,000</b>	<b>318,835,000</b>	<b>318,835,000</b>
<b>Sewage valves</b>	<b>14</b>	<b>142</b>	<b>243</b>
<b>Cost of valves (£)</b>	<b>44,800,000</b>	<b>-----</b>	<b>777,600,000</b>
<b>Cost of valves with manholes (£)</b>	<b>-----</b>	<b>569,931,200</b>	<b>-----</b>
<b>Total air inlet valves</b>	<b>18</b>	<b>49</b>	<b>72</b>
<b>Cost of air inlets (£)</b>	<b>8,640,000</b>	<b>23,520,000</b>	<b>34,560,000</b>
<b>Normal laterals (m)</b>	<b>0</b>	<b>505</b>	<b>0</b>
<b>Vacuum laterals(m)</b>	<b>0</b>	<b>0</b>	<b>926</b>
<b>Cost of lateral routing (£)</b>	<b>-----</b>	<b>68,175,000</b>	<b>137,048,000</b>
<b>Total cost (£)</b>	<b>372,275,000</b>	<b>1,060,562,550</b>	<b>1,408,139,550</b>
<b>Total cost (U.S. \$)</b>	<b>232,672</b>	<b>662,852</b>	<b>880,087</b>

**Table 2:** Cost comparison for all three options of implementation for Santa Maria Formosa.

	OPTION 2	OPTION 3
<b>Total land piping (m)</b>	<b>766</b>	<b>1,693</b>
<b>Cost of land piping (£)</b>	<b>33,014,600</b>	<b>72,968,300</b>
<b>Total canal piping (m)</b>	<b>0</b>	-----
<b>Cost of canal piping (£)</b>	-----	-----
<b>Total sewage valves</b>	<b>60</b>	<b>109</b>
<b>Cost of valves (£)</b>	-----	<b>348,800,000</b>
<b>Cost of valves with manholes (£)</b>	<b>224,544,000</b>	-----
<b>Total air inlet valves</b>	<b>20</b>	<b>43</b>
<b>Cost of air inlets (£)</b>	<b>9,600,000</b>	<b>20,640,000</b>
<b>Normal lateral (m)</b>	<b>245</b>	<b>0</b>
<b>Vacuum laterals (m)</b>	-----	<b>926</b>
<b>Cost of lateral routing (£)</b>	<b>22,050,000</b>	<b>91,674,000</b>
<b>Total cost (£)</b>	<b>289,208,600</b>	<b>534,082,300</b>
<b>Total cost (U.S. \$)</b>	<b>180,755</b>	<b>333,801</b>

**Table 3:** Cost comparison for options two and three of implementation for Santa Marta

All calculations of data contained within Tables 2 and 3 are can be found in Appendix C. For Santa Marta, only options two and three were analyzed for possible installation because there was no need for canal piping. Due to the unique, one main inner pipe running throughout the island. All costs were calculated on the basis of 1600 *lire* to one U.S. dollar.

### 6.3 IMPLEMENTATION ON THE CITYWIDE LEVEL

Upscale models for each option were produced for all of Venice, based on data acquired by the project team, schematics from MapInfo, and extrapolation from Santa Maria Formosa. Implementation was expanded from the test island to not only contain the proposed vacuum sewerage piping system, but also a collection station networking system. Also included were three different plans of sewage disposal. Islands categorized as half-marginal and half-historical were assumed to be historical.

## 6.3.1 COLLECTION STATION NETWORKING

### 6.3.1.1 SEWAGE FLOW

A very important aspect in determining if the HIFLO™ system was a feasible application in Venice was the amount of sewage discharge for each island. This data served as the basis of the collection station network. The daily flow was calculated from yearly water consumption and then inputted into a MapInfo browser (See Appendix D). For the areas lacking water consumption data, extrapolations were calculated (See Appendix A). All sewage flow was based on 1994 water consumption data. It is permissible but perhaps invalid to conclude that these figures have decreased over the past three years since there was an average decrease of 17% from 1991 to 1994. This error results only in an overestimation of collection tank volume and number of collection stations.

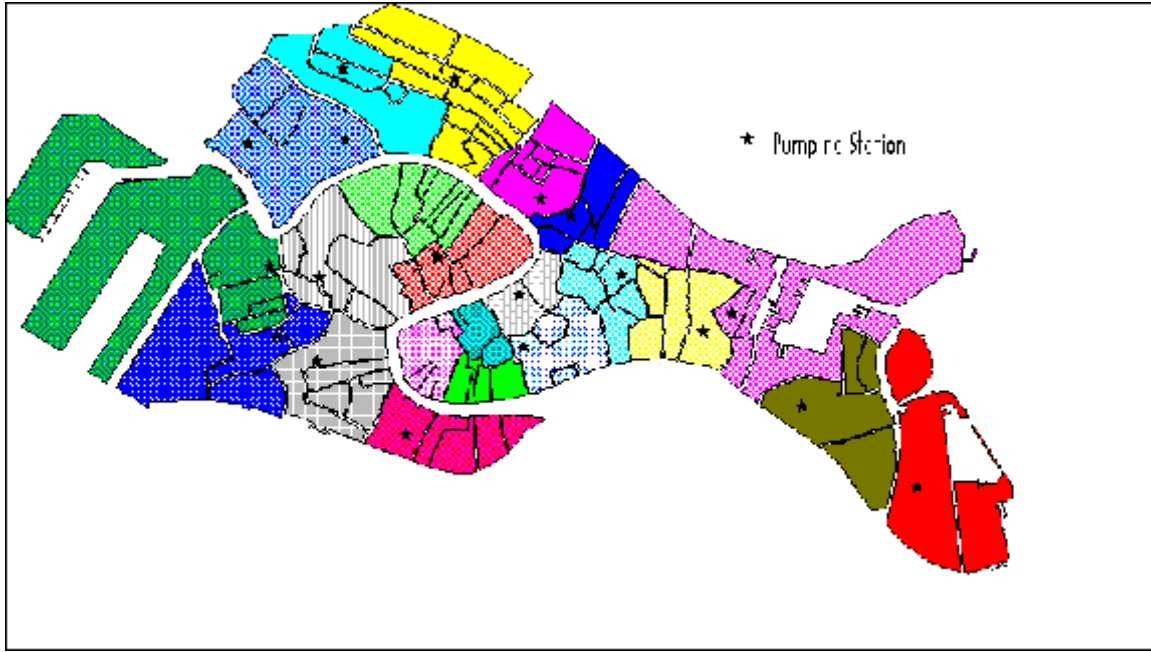
### 6.3.1.2 COLLECTION STATIONS

The sizes of collection tanks for each individual island is found in Appendix E, along with the tank size for each collection station. All collection tanks were sized for the worst case scenerio using a peaking factor of 4. The station locations and islands that are served by that collection station are seen on Maps 6- 8.

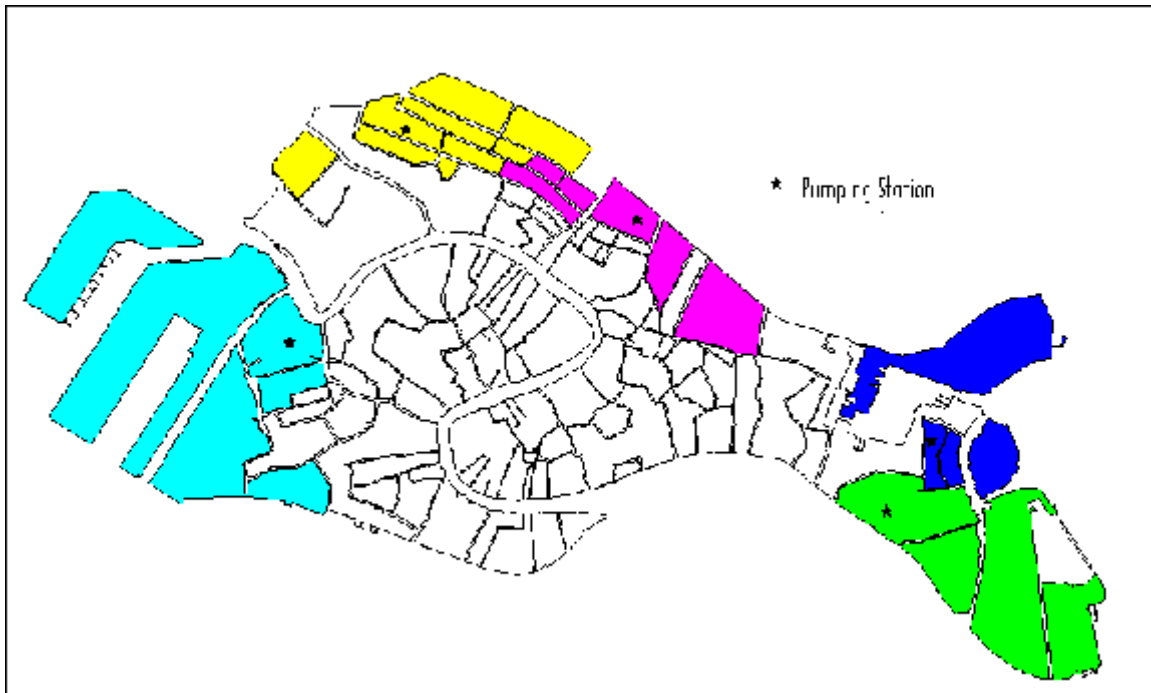
Map 6: Collection station network for all of Venice. This is a thematic map that contains all collection stations. Each color denotes all islands that are served by a particular collection station.

Map 7: Collection station network for only marginal areas within Venice. This is a thematic map that contains all collection stations. Each denotes all islands that are served by a collection station for marginal areas only.

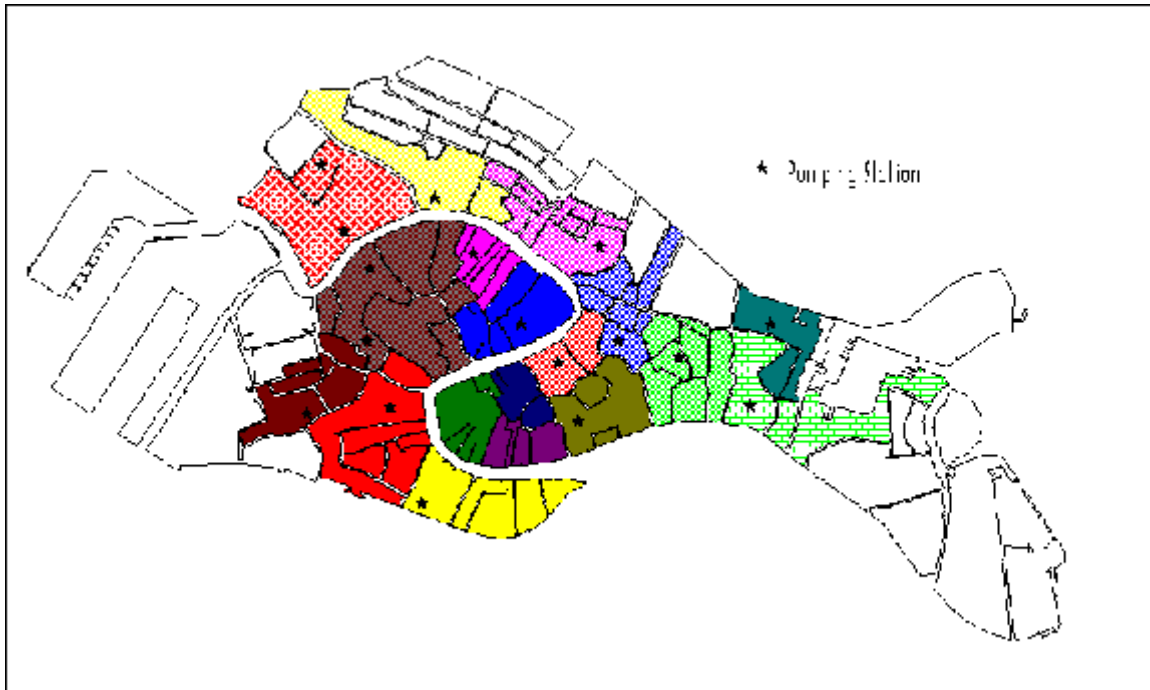
Map 8: Collection station network for only historical areas within Venice. This is a thematic map that contains all collection stations. Each color denotes all islands that are served by a collection station for historical areas only.



**Map 8:** Collection station network for all of Venice.



**Map 9:** *Collection station network within marginal area only.*



**Map 10:** *Collection station network within historical area only.*

It was determined that 24 collection stations were needed to maintain a vacuum sewerage system for Venice, where the average tank size was 17,300 liters. The collection tanks for each collection station ranged from 13,000 – 20,000 liters. Tank sizes were calculated to be as large as possible to optimize space and minimize cost. For collection stations within marginal areas only, there were 5 stations, ranging from 11,000-20,000 liters, and 20 stations for historical areas, ranging from 13,000-20,000 liters.

The size and cost of the collection station's buildings were calculated separately in Appendix F. Real estate was estimated to be £3,000,000 per linear meter while each collection station costs an estimated £380,000,000. The costs for the entire networking of Venice is approximately £10,392,000,000. The cost for marginal networking only is

approximately £2,149,000,000, while the cost for historical networking only is £8,659,000,000. This figure included the building space, collection tanks, sewage pumps, vacuum pumps, controls, generators, and electrical requirements necessary. The extra piping needed to connect islands to collection station servers was not included do to the fact that the exact location of collection stations can not be determined within this study. The sizes of the collection stations were calculated based on twice the tank size and that tanks were not buried. This assumption can be changed in turn, greatly altering the price of collection stations.

#### 6.4 OPTIONS OF IMPLEMENTATION

Implementation was extrapolated for both historical and marginal areas. All upscale relations were based around the surface area, 24,000 m<sup>2</sup>, of Santa Maria Formosa. Calculations of vacuum technology for each option are contained within Excel spreadsheets in Appendix G. Table 4, shown below, contains the total components and compares the costs for each level of implementation for historical Venice. Table 5, contains values for marginal Venice.

	OPTION 1	OPTION 2	OPTION 3
<b>Total land piping (m)</b>	<b>0</b>	<b>230,498</b>	<b>342,002</b>
<b>Cost of land piping (£)</b>	-----	<b>14,901,695,700</b>	<b>22,110,429,300</b>
<b>Total canal piping (m)</b>	<b>81,876</b>	<b>81,876</b>	<b>81,876</b>
<b>Cost of canal piping (£)</b>	<b>38,277,030,000</b>	<b>38,277,030,000</b>	<b>38,277,030,000</b>
<b>Total sewage valves</b>	<b>1,681</b>	<b>17,049</b>	<b>29,173</b>
<b>Cost of valves (£)</b>	<b>5,379,200,000</b>	-----	<b>93,353,600,000</b>
<b>Cost of valves with manholes (£)</b>	-----	<b>68,427,866,400</b>	-----
<b>Total air inlet valves</b>	<b>2,111</b>	<b>5,853</b>	<b>8,554</b>
<b>Cost of air inlets (£)</b>	<b>1,013,280,000</b>	<b>2,809,440,000</b>	<b>4,105,920,000</b>
<b>Total normal laterals (m)</b>	<b>0</b>	<b>60,632</b>	<b>0</b>
<b>Total vacuum laterals (m)</b>	<b>0</b>	<b>0</b>	<b>29,627</b>
<b>Cost of lateral routing (£)</b>	-----	<b>8,185,320,000</b>	<b>4,399,609,500</b>

Cost of collection stations(£)	8,659,000,000	8,659,000,000	8,659,000,000
Total cost (£)	53,328,510,000	141,260,352,100	170,905,588,800
Total cost (U.S. \$)	33,330,319	88,287,720	106,815,993

**Table 4:** Cost comparison of all three options of implementation within Historical Venice

	OPTION 1	OPTION 2	OPTION 3
Total land piping (m)	0	117,985	273,818
Cost of land piping (£)	-----	5,085,153,500	11,801,555,800
Total canal piping (m)	64,999	64,999	64,999
Cost of canal piping (£)	30,387,032,500	30,387,032,500	30,387,032,500
Total sewage valves	1346	13,534	23,358
Cost of valves (£)	4,307,200,000	-----	74,745,600,000
Cost of valves with manholes (£)	-----	50,649,641,600	-----
Total air inlet valves	1,686	4,646	6,848
Cost of air inlets (£)	809,280,000	2,230,080,000	3,287,040,000
Total normal routing (m)	0	48,133	0
Total vacuum laterals (m)	0	0	90,834
Cost of laterals (£)	-----	6,497,955,000	8,992,566,000
Cost of collection stations(£)	2,149,000,000	2,149,000,000	2,149,000,000
Total cost (£)	37,652,512,500	96,998,862,600	131,362,794,300
Total cost (U.S. \$)	23,532,820	60,624,289	82,101,746

**Table 5:** Cost comparison of all three options of implementation within Marginal Venice

Cost breakdowns are the same as those in Appendix C.

## 6.5 COST COMPARISONS

### 6.5.1 COST OF IMPLEMENTATION ON ALL LEVELS

<u>LEVEL OF IMPLEMENTATION</u>	OPTION ONE(£)	OPTION TWO(£)	OPTION THREE(£)
MARGINAL	37,652,512,500	96,998,862,600	131,362,794,300
HISTORICAL	53,328,510,000	141,260,352,100	170,905,588,800
ALL OF VENICE	90,565,022,500	237,543,214,700	301,852,383,100

**Table 6:** Comparison of implementation cost for all three options in both marginal and historical areas as well as all of Venice.

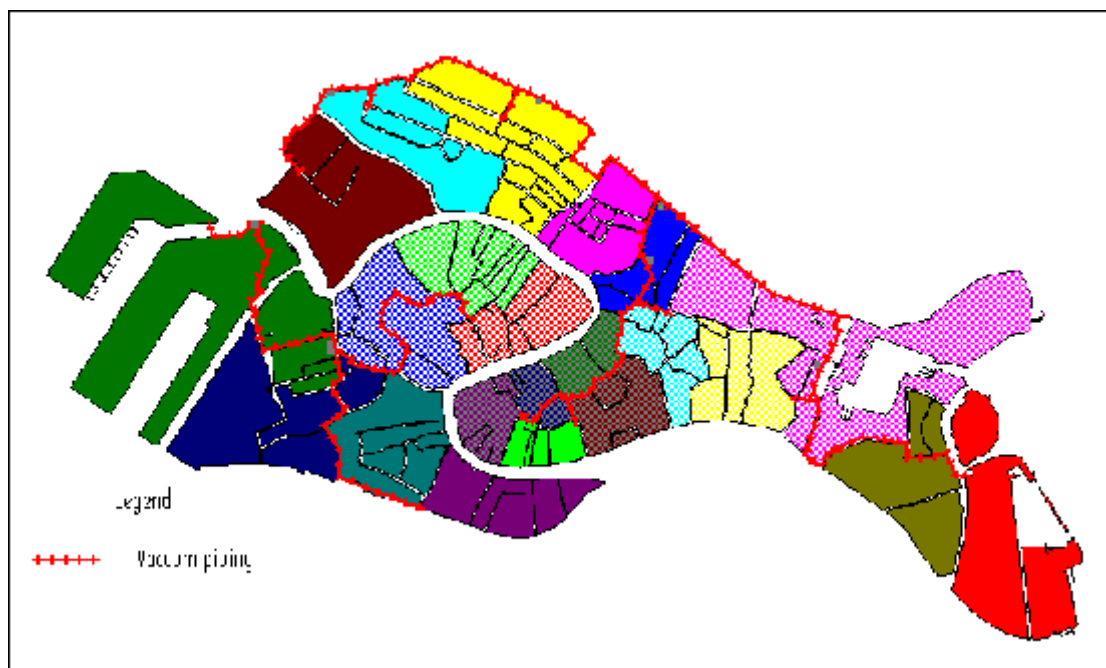
## 6.6 OPTIONS OF WASTEWATER TREATMENT

### 6.6.1 WASTEWATER PUMPING SYSTEM WITHIN VENICE

The wastewater relay systems designed were based on the sewage travel needed for collection stations beyond a 1500 meter radius of the final destinations of either *Stazione Marittima* or *Ferrovia*. Relay system one was the only system that was indepthly analyzed with schematics and cost figures. All systems were designed with the intention that all of Venice would be under vacuum and, further collection stations would be built to carry the sewage to the mainland.

#### 6.6.1.1 RELAY SYSTEM ONE

A schematic of the extra canal piping is seen in Map 11. The different colors represent the differnent collection areas serving Venice.



**Map 11:** Map of relay system one throughout Venice.

	<b><i>CITYWIDE</i></b>
<b>Total piping (m)</b>	72,590
<b>Total cost for piping (£)</b>	33,935,825,000
<b>Total air inlet valves</b>	1815
<b>Total cost for air inlet valves (£)</b>	871,200,000
<b>Total pumping stations</b>	59
<b>Total cost for pumping stations (£)</b>	22,030,000,000
<b>Total cost (£)</b>	<b>56,837,025,000</b>
<b>Total cost (USD)</b>	<b>35,523,141</b>

**Table 7:** Cost of relay pumping system within Venice for the transportation of sewage.

For relay system one to function properly, 59 additional collection stations were placed throughout the city along with 72,590 extra meters of canal piping, 1,815 air valves. The total cost relay system for the entire city of Venice is an approximate £56,837,025,000. All values were calculated with within Appendix H.

### **6.6.1.2 RELAY SYSTEM TWO**

The second relay system would involve the conventional approach used in most sewage collection studies. In this approach, the sewage collected at the vacuum collection stations throughout Venice would be transported using two force mains, one to the north of the Grand Canal and one to the south. In order to produce the pressure required to run the force mains, one conventional collection station would be built for each force main around the *Ferrovia-Tronchetto-Stazione Marittima* area.

### **6.6.1.3 RELAY SYSTEM THREE**

The third relay system would involve a controlled vacuum collection station

network. In this setup, one or two main vacuum lines would be placed on the northern and southern sides of the Grand Canal. One vacuum collection station would be placed in each set of pipes every 1,500 meters. A computer system would determine the sewage level of collection tanks on the islands and selectively empty them into the main piping scheme. All tanks that were not full at this time would be temporarily shut off from the main piping scheme. This selection would be accomplished by putting electric controls in the valves exiting from the collection tanks in the islands. This setup would involve designing a new sewage valve and a specialized computer system to control the valves.

## 6.6.2 TRANSPORTATION OF WASTERWATER OFF VENICE

Transport under vacuum from the *Ferrovìa* area to the mainland was analyzed roughly for two different routing plans. In plan A the vacuum piping is run below or alongside the Mestre bridge to the mainland. This distance was measured to be 3,600 meters. In plan B, the vacuum piping was run through two different islands within the lagoon, until the piping reached the mainland. The distance to run piping through the lagoon was measured to be 6,900 meters. To measure for a worst case scenario, it was found that the total number of pipes in Venice (24 different sets) and the total number of collection station systems (24) should be used. This does not mean that 24 pumping station systems should be placed in the *Ferrovìa* area as well as at each station on the way to the mainland. It only means that the project is calculating the cost for the 24 stations in every pumping point in order to prevent an underestimation of costs and sewerage flow rates. Table 7 compares the cost breakdowns for plan A and plan B. The methods of calculation for the piping are the same as those within Appendix C. Also, the sample calculations of pumping station are the same as those within Appendix F.

	<b>PLAN A</b>	<b>PLAN B</b>
<b>Total piping (m)</b>	86,572	165,930
<b>Total cost for piping (£)</b>	40,472,410,000	77,572,275,000
<b>Total air inlet valves</b>	2,164	4,148
<b>Total cost for air inlet valves (£)</b>	1,038,720,000	1,991,040,000
<b>Total pumping stations</b>	72	120
<b>Pumping station cost (£)</b>	31,177,800,000	51,963,000,000
<b>Total cost (£)</b>	<b>72,688,930,000</b>	<b>131,526,315,000</b>
<b>Total cost (USD)</b>	<b>45,430,581</b>	<b>82,203,947</b>

**Table 8:** Cost comparison of Plan A and Plan B.

## 6.7 COST OF IMPLEMENTATION PER PERSON

The calculated population density was figured to be 189 persons per

hectare(Appendix I). Figure 7 is a comparative graph showing a general per capita construction cost based on population density. From analysis of this the graph, cost of implementation per person calculates to be approximately \$210 U.S. dollars or 336,000 *lire*. This figure displays only the cost benefits of using HIFLO™ to other sewerage systems. This value cannot be interpreted as a means for installation cost because of the uniqueness of the current Venetian sewerage system. It is valuable only on a comparative scale.

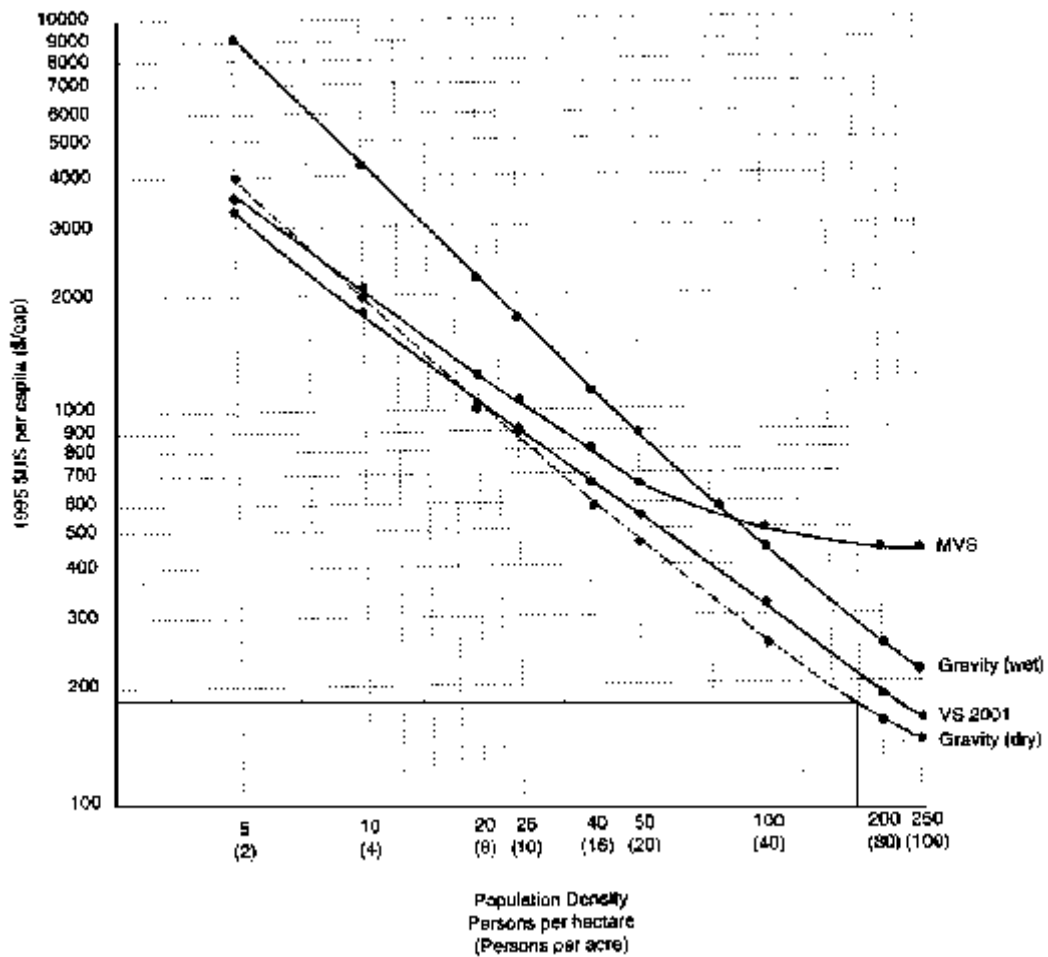


Figure 5: Per Capita Construction Cost at Various Population Densities.

## 6.8 MEANS OF ERROR

The feasibility of vacuum sewer technology was determined by the adaption of the current sewerage system to the proposed system. Due to the fact that this study was only a preliminary study, many calculations were based on rough estimates and logical assumptions. The use of the test island, Santa Maria Formosa, served as a sufficient basis to model an upscale version of a vacuum sewerage system for this study. The relationship of surface area to all areas of the system provided only a general idea of cost and piping intricacies. Error can be found in almost all areas of calculations. All figures were rounded off to whole numbers. No figures were left in decimal values. The areas of calculations are as follows:

- ◆ Sewage Flow
- ◆ Collection Tank size
- ◆ Collection station size
- ◆ Piping Lengths
- ◆ Cost Estimates

Sewage flow calculations were based on an assumption that is equivalent to the water consumption for each area. Also the water consumption of 1994 for Dorsoduro and San Marco was not available, therefore logical extrapolations were made. The error for calculation could easily vary between a range of plus or minus 40 percent.

Calculations of collection tank sizes were dependent on the sewage flow per minute. A peaking factor of four was accounted for in order to calculate the total possible flow. This peaking factor could be less, but four was used to account for the worst case scenario. Tank sizes, theoretically, could be smaller.

The size of collection stations were calculated by doubling the collection tank size to

take into account the room necessary for the electrical equipment. The tanks could be buried, but this all depends on the building's relations to sea level. The size of the building could possibly house a tank being higher than two meters but this can not be determined until the exact location is assessed.

All piping lengths for the upscale were related only to the surface area. This relation proves valid and trustworthy for the project group's study, but all figures were rounded to the whole number. Additionally, down piping and normal and vacuum laterals were calculated on sheer logic and assumptions. The down piping would need to be calculated by calculating the number of active outlets that serve a *collettore*. The normal and vacuum piping would be calculated by measuring the true piping lengths.

Cost estimates were taken from the *Comune di Venezia*. These figures were proposed to be valid, but it should be noted that a system of this sort has never been installed in Venice

## 7 SOCIAL IMPACTS

The implementation of a vacuum sewerage system, like any major renovation project, requires many changes that will affect the people. An important factor to consider when implementing a new sewerage system is the impact it will have on the residents of the area.

### 7.1 CONTENT OF SURVEY

In order to assess the views of the residents, a survey was developed. This survey consisted of nine questions that were broken down into four categories; evaluation of the current sewerage system, factor of pollution, financial concerns, and possible side effects of the vacuum sewerage system. Residents were asked to either agree or disagree with a

particular statement on a 1 through 5 scale; 1 being strongly disagree, and 5 being strongly agree with a neutral factor at 3. Initially the survey was analyzed at face value. To facilitate the analysis of the thoughts of the Venetians, the scale was broken down into three divisions; agree, neutral, and disagree.

The first questions (1 & 2) dealt with the current sewerage system in Venice. These are important questions because they give feedback as to the ignorance level of the surveyed Venetians on this subject.

A large problem with the current sewerage system is the amount of pollution that is being fed into the canals. Questions 3 & 6 were asked to see if the Venetians cared about this pollution, and if they would be willing to change the current system to fix this problem.

Questions 4 & 5 were asked to see if the Venetians would be willing to have a slight increase in their taxes to help fund this project. The city would be funding this reconstruction, and may want community input to help it along.

The last three questions (7, 8, and 9) all dealt with some possible effects that this new system may bring forth. These were asked to see if the people minded having a change from the current system as far as noise and construction are concerned.

The survey was made taking into consideration all of these factors. A bias in any of the questions was avoided to the highest extent. The survey was taken only by residents of Venice. All results of the survey are broken down into pie graphs that are located in Appendix J.

## 7.2 ANALYSIS

From analysis of the previous mentioned pie graphs overall conclusions of residents were stipulated. **69%** of the surveyed Venetians believed that the current

sewerage system was failing, and **55%** have been inconvenienced by emergency canal repairs and dredging at one time or another. **71%** believe that a new sewerage system, designed to clean up the canals would be a good idea, and **82%** would prefer the sewage to be transported to a treatment plant. Yet only **48%** of the residents would support a new sewerage system, **77%** were against any raises in taxes for it. **45%** felt uneasy about having collection stations placed about the city, but **62%** would not mind a slight increase in noise. The Venetians interviewed seemed unconcerned about prolonged construction in order to install this new system.

### 7.3 CONCLUSION

The results of this survey show that the people of Venice are concerned about the failures of the current sewerage system and would be willing to fix the problems. They want sewage treatment, which cannot be made possible with the current system, but is possible with a vacuum sewerage system. They feel rather uneasy with the idea of collection stations scattered around the islands, but they are not knowledgeable enough about them at the time. As far as financial questions are concerned, the Venetians want a new sewerage system, yet are opposed to paying for it. This is a typical scenario for any new project or undertaking by a city. These results can someday help in the actual implementation as they reflect the thoughts of the residents.



## 8 CONCLUSIONS

This study is an initial preliminary feasibility study of vacuum sewerage implementation within the marginal and historical areas of Venice. Because of the various aspects that needed to be incorporated for the system design, numerous assumptions and extrapolations of data were made leaving a large margin of error. Additionally, the data for this study were collected from a variety of resources such as previous Interactive Qualifying Projects, as well as data and figures from Alan Hassett and the *Comune di Venezia*. Reliability and validity were assumed for all data collected and used.

The three options of implementation within this study give the City of Venice a wide spectrum of alternatives for vacuum sewer implementation. It was concluded by the project team that vacuum sewage implementation be executed at two different levels. A decision for the level of implementation was made based on the advantages and disadvantages of each option. The following comparison matrix rated these advantages and disadvantages.

### 8.1 OPTION COMPARISON MATRIX

<b>CRITERIA</b>	<b>OPTION 1</b>	<b>OPTION 2</b>	<b>OPTION 3</b>
<i>Total cost</i>	A	B	B
<i>Difficulty of installation</i>	A	B	C
<i>Odor potential</i>	B	A	A
<i>Aesthetics</i>	A	B	B
<i>Reduction of emergency repairs</i>	C	B	A
<i>Leakage detection</i>	C	B	A
<i>Durability</i>	C	B	A
<i>Accessibility of sewage only valves</i>	A	A	B

## Key to Matrix

A – Preferable

B – Less Preferable

C – Least Preferable

### 8.1.1 OPTION ONE

#### **8.1.1.1 Advantages**

Option one possesses two great advantages, making it the most desirable option on a short-term basis. The advantages are the low cost of installation and least amount of construction needed for implementation.

The cost of implementation would be £37,652,512,500 (\$23,532,820) for the marginal area, and £53,328,510,000 (\$33,330,318) for the historical area. These costs are presented for both areas with intentions for gradual implementation, first within the marginal and then the historical islands. The cost for a unified implementation in Venice is £90,565,022,500 (\$56,503,139). The costs for option one are significantly lower than the costs for option two or three. Due to the reduced number of valves and piping. The second advantage of this option is the minimal amount of construction during its implementation. Construction would take place mostly on the canals. There would not be excavation within the streets or building foundations, an excellent benefit given the fragile state of the buildings in Venice. Also, the lack of construction on the streets would not inconvenience the daily life of the Venetians.

In terms of aesthetics, the only change made to the city's structure would be at the canal level. There would be visible pipes climbing from the bottom of the canals, to meet

with the sewage valve at the end of each active *sbochi*. Air valves would be placed discretely every fifty meters above high tide level. These adaptations would be an eyesore only at times of low tide. The sewage valves can be placed with the intentions of remaining as far beneath the waterline as possible.

### **8.1.1.2 Disadvantages**

Setting aside the short-term advantages of this option, when analyzed on a long-term basis this option is the least desirable. The major disadvantage of this option is that it does not solve the problems the current sewerage system is creating within the buildings and streets. The piping on land would still remain vulnerable to piping ruptures and undetectable leakage, which consume the foundation of buildings. The amount of emergency repairs on land would not be reduced. These leakage and ruptures within the gravity piping will still add to the deterioration of building structures.

This option would also be less durable because the gravity piping on land has a life span of only five years as compared to the vacuum PVC piping used on land for options two and three that have a life span of 20 years.

## **8.1.2 OPTION TWO**

### **8.1.2.1 Advantages**

*Option two can be considered the median point between options one and three. It would be better than option one on a long-term basis since vacuum piping would collect sewage where the laterals used to meet with the collettore. This connection would reduce the risk of emergency repairs on land. It would be less expensive than option three, costing £34,363,931,700 (\$21,477,457) less for*

*implementation in the marginal area, £29,645,236,700 (\$18,528,273) less for implementation in the historical area, and £64,309,168,400(\$ 40,193,230 ) less for overall implementation of Venice. Option two would also have less construction than option three. Construction would only take place within the streets, not going below the building foundations. A third advantage of option two over option three is sewage valves are kept out of the private domain. This option also gives the easiest access to the sewage valves because the valves are placed in manholes in the streets, allowing public access. Detection of leakage within the vacuum piping is functional only until the lateral interfaces.*

#### **8.1.2.2 Disadvantages**

*A large disadvantage of option two is that numerous manholes would have to be placed on the streets for sewage valves. Also construction on the streets would be quite extensive, disrupting the daily life of the Venetians for a certain period of time. A third disadvantage is that since the laterals would still be gravity, undetected lateral leakage could still degrade the building foundations. Also laterals within this option, except the PVC rerouted laterals, have a life span of five years increasing the frequency of repairs of these pipes.*

### **8.1.3 OPTION THREE**

#### **8.1.3.1 Advantages**

*Option three would be the best long-term option due to the fact that all the current sewage piping within Venice would be under vacuum with PVC piping. This would set the life span for all the piping within Venice at 20 years, decreasing the*

*frequency of repairs the most within the three options. Also any leakage within the city can be detected immediately, reducing to a null the degradation of the building foundations. Also odor potential would be minimal since all of the sewage would be vacuum. This option would be better than option 2 aesthetically, because the sewage valves would be hidden within the sedimentation tanks of the buildings, instead of in manholes in the middle of the streets.*

### **8.1.3.2 Disadvantages**

*The two big disadvantages for option three are the cost and the extent of the construction. It would cost £131,362,794,300 (\$82,101,746) for implementation into the marginal area, £170,905,588,800 (\$106,815,993) for implementation in the historical area and £ 301,852,383,100 (\$188,657,740) for combined implementation in Venice. Construction would have to take place all the way to the bottom of the houses, possibly disrupting the building foundations, which are already quite fragile. This disruption would affect the life of the pedestrians and also building tenants whose sedimentation tanks would have to be replaced with sewage valves inside. Another disadvantage is that the sewage only valves are within buildings, under private domain, making it harder for repair crews to access them.*

## **8.2 CHOICE OF IMPLEMENTATION**

After analyzing the advantages and disadvantages of each proposed option, the project team concluded that a vacuum sewerage system should be implemented on two different levels throughout Venice; option one in the historical areas and option two in marginal areas.

Option one was found to be optimal for implementation within the historical areas due to the fragility of the buildings and the city's reluctance to perform changes in the area. This option would not greatly alter the aesthetics of the historical area. During low tide, the only visible part of the system would be the pipes connecting to the *sbocchi*. This option would not disrupt tourism since a majority of the construction would occur within the canals. No excavation of the streets and the building foundations would take place, avoiding any unnecessary disruption of the sensitivity of the building structures. Another advantage of this option was that it was the most inexpensive of the three proposed options. If the city decided in the future that a more extensive vacuum piping array should be implemented throughout the historical islands, option one could easily be upgraded to option three by bypassing the valves at the canals once the constructions required (on land) to implement option three were concluded. Option two was not considered for this area due to the extensive number of manholes that would have to be built on the streets to implement it. For the time being though, option one is the most feasible option for implementation in the historical areas.

Option two was found to be optimal for implementation in the marginal areas because a greater level of implementation can take place in these areas due to reduced strictness of building codes. Option two was chosen over option three in the marginal areas for various reasons. Firstly, the sewerage only valves in option two, which are placed on manholes in the streets, are much more accessible than the sewerage only valves in option three, which are placed within the sedimentation tanks of buildings. Secondly, all construction in option two takes place on the canals and streets, not going below building foundations, which would have to take place if option three were implemented. Thirdly, the decreased number

of valves in option two decreases the overall problems that can take place with the system.

And finally, option two is not as costly as option three.

### 8.3 FINAL COST OF IMPLEMENTATION

After determining that option one was best suited for the historical areas and option two for the marginal, the costs of transporting the sewage to wastewater facilities were calculated. To determine the overall cost for the entire implementation of the HIFLO™ vacuum sewerage system, the costs for the marginal, historical, and the transportation of sewage to *Ferrovìa* or *Stazione Marittima* were summed. Additionally the cost of transporting the sewage from Venice to the mainland via the lagoon or the Mestre bridge were calculated. The results are shown in Table 9 below.

	<b>PLAN A</b>	<b>PLAN B</b>
<b>Option 1 (historical) (£)</b>	53,300,000,000	53,300,000,000
<b>Option 2 (marginal) (£)</b>	97,000,000,000	97,000,000,000
<b>Pumping around Venice (£)</b>	56,800,000,000	56,800,000,000
<b>Pumping to the mainland (£)</b>	72,700,000,000	131,500,000,000
<b>Total cost (£)</b>	279,900,000,000	338,700,000,000
<b>Total cost + 15% (£)</b>	<b>321,800,000,000</b>	<b>389,500,000,000</b>
<b>Total cost + 15% (USD)</b>	<b>201,100,000</b>	<b>243,400,000</b>

**Table 9:** Finalized cost of complete vacuum sewerage system implementation within Venice.

All finalized estimates seen above in table six contains all components for implementation; piping networking, collection station networking and wastewater treatment. In addition, a fifteen- percent increase was accounted for the consideration of unforeseen problems. All values were then rounded off to three significant figures.

#### 8.4 SYSTEM FAILURES

If ever there should be failure to the system, the proposed implementation is designed so that the new system can easily convert sewage flow back over to the old system. A simple valve can be installed within the vacuum system to switch the system from vacuum to gravity. The proposed vacuum piping was calculated to be laid next to the current system, not within the *collettore*, to provide a fall back system in event of failure and also decrease cost of piping installation. This backup system is functional only for on land vacuum piping.

Another system, which could be used as a back up for both canal and land vacuum piping, would involve using temporary hoses. If a pipe were to break, the leak would be detected by isolating the strip of piping between two adjacent vacuum sewer valves in which the pressure is unusual. Once the broken section is located, it would be isolated by division valves and bypassed by using temporary hoses. This plan is similar to the plan, which Virginia Beach will employ, if the Sandbridge vacuum mains are damaged by a hurricane or other problems<sup>22</sup>. The actual system design and operating procedures need to be established ahead of time, but are not established within the scope of this study.

---

<sup>22</sup>Hassett, Alan.

## 9 RECOMMENDATIONS

It is the recommendation of this project team that option one be implemented for historical areas, with a plan to upgrade in the future to option three. For marginal areas, option two is the favored recommendation of the team. The project team further suggests that a piping relay system to the *Ferrovia/Stazione Marittima* area be implemented. A final recommendation is that a vacuum transportation system to the mainland be implemented after further in-depth study.

There are many areas that must be taken to a greater level of detail. Specifically, there needs to be an in-depth design of transporting the sewage, collected within the collection stations, to a treatment plant on the mainland, due to the fact that the findings within this study for a working system were preliminary and inconclusive. Further analysis of the canal-side buildings needs to take place as to decide if they should be rerouted through the *collettori* or if they should be picked up directly by the vacuum piping.

This study serves only as a basis for vacuum sewage technology within the city of Venice. It is proposed as an alternative to the current failures of the sewerage system. At this time the adaption of vacuum sewerage system to the gravity system of Venice is feasible, these conclusions may be altered as further studies are carried out. It is the hope of this project team that all data and conclusions contained within this report are worthwhile in aiding future studies to the problems of the current sewerage system.

