December 2013

Canals, Bridges and Urban Maintenance

Brian William Gardner
Worcester Polytechnic Institute

Dominick Christopher Bossalini
Worcester Polytechnic Institute

Mitchell Edwin Wills
Worcester Polytechnic Institute

Tyler Douglas Mathews
Worcester Polytechnic Institute

Canals, Bridges and Urban Maintenance

Venice Project Center

An Interactive Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute

In partial fulfillment of the requirements for
the Degree of Bachelor of Science

Student Authors:
Dominick Bossalini
Brian Gardner
Tyler Mathews
Mitchell Wills

ve13-can@wpi.edu
https://sites.google.com/site/ve13can/

Project Advisors
Professor Fabio Carrera
Professor Fred Hart

AUTHORSHIP

The entirety of the Venice Infrastructure team contributed equally to the completion of this project. All material contained within this report is the original work of the Venetian Infrastructure team, unless otherwise stated.

ACKNOWLEDGEMENTS

We would like to thank the following people:

Georg Umgiesser, Elisa Coraci and ISMAR for lending us their time, support and hydrodynamic model.

Ing. Lorenzo Bottazzo and Insula SpA for providing us with up-to-date data.

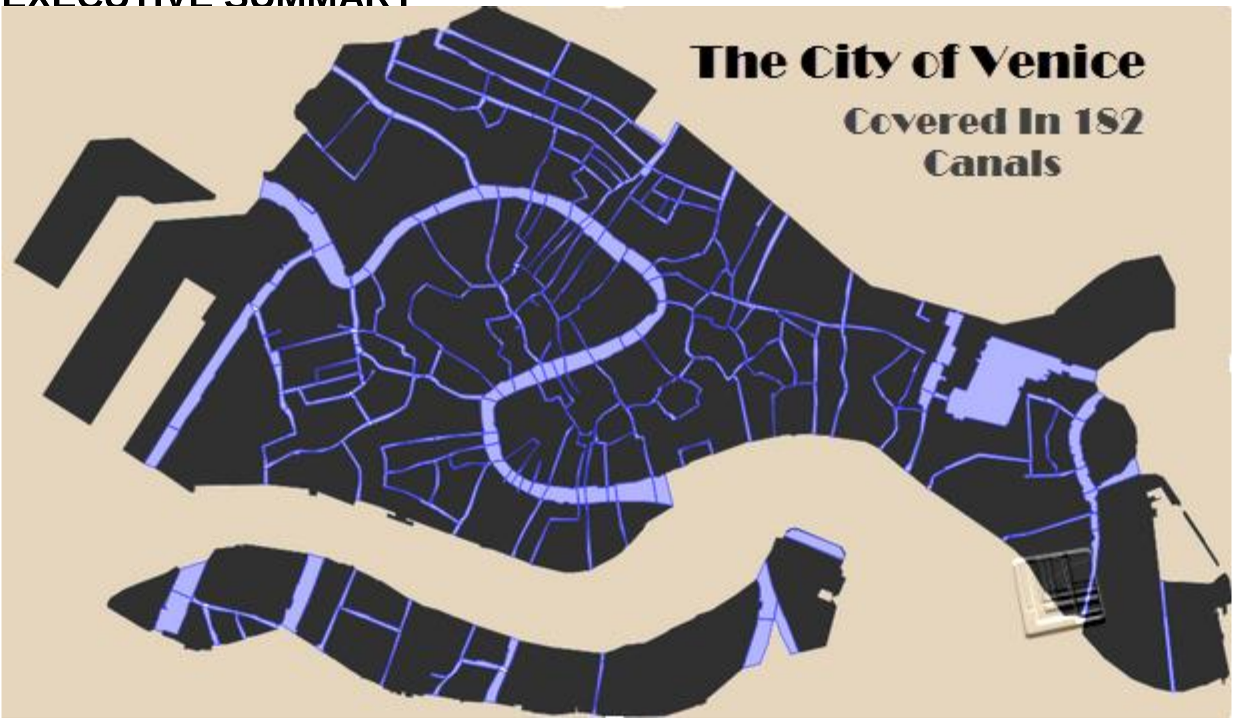
Chip Hassett for providing information on vacuum sewage systems.

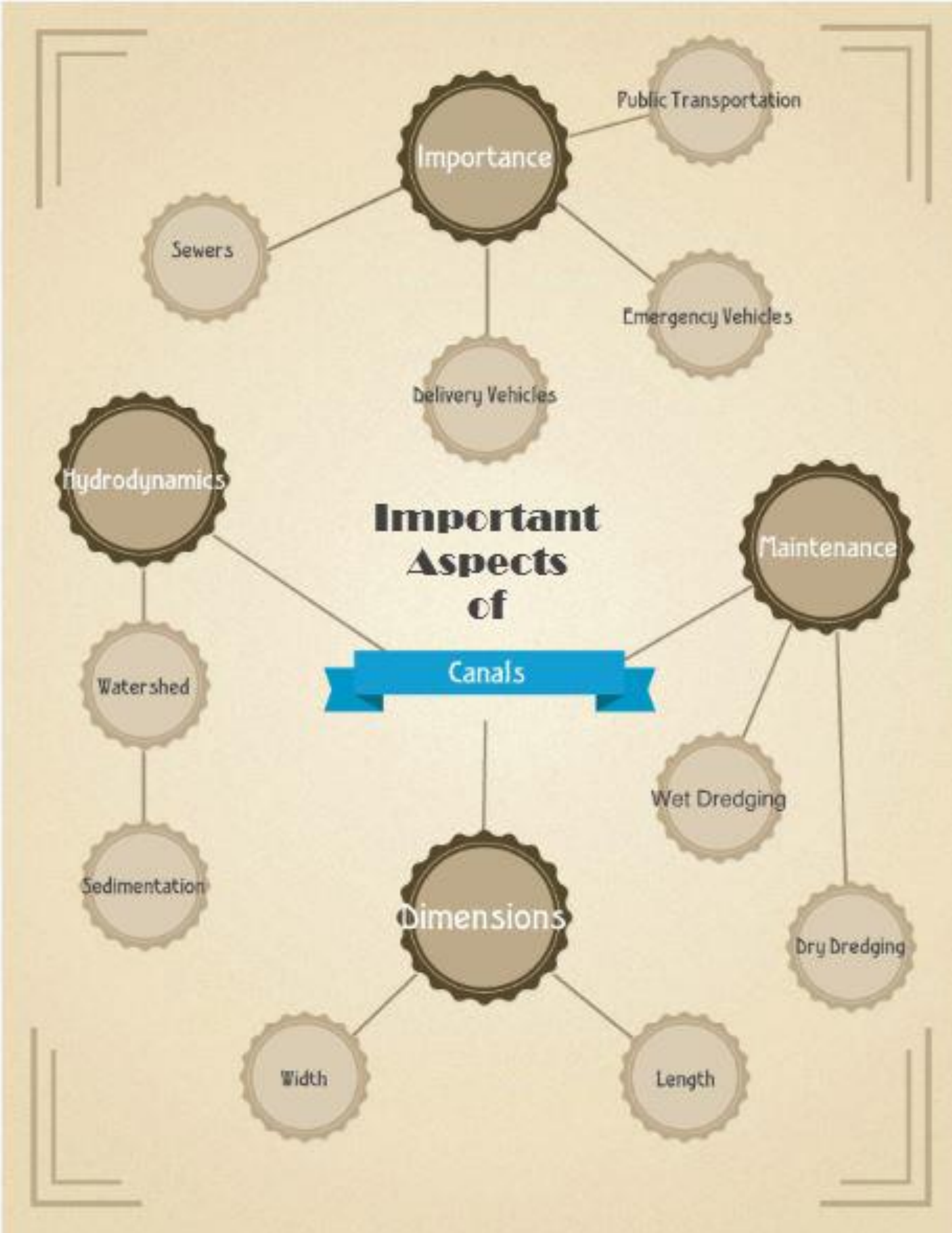
Our advisors Professor Fabio Carrera and Professor Fred Hart for their support and guidance.

ABSTRACT

This project aims to produce up-to-date information for a comprehensive list of canals, segments and bridges, and to study ways to achieve a reduction in the maintenance cost of canals and related infrastructure. To achieve this, information from past WPI projects, as well as local organizations, was examined. This project's results include organized spreadsheets, public information pages, and web applications. These products streamline accessing and understanding the data and encourage continued knowledge of the importance of Venice's unique urban infrastructure.

EXECUTIVE SUMMARY

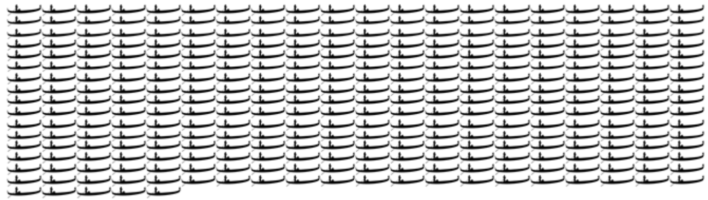



Importance
Public Transportation
Sewers
Emergency Vehicles
Delivery Vehicles
Hydrodynamics
Important Aspects of
Canals
Maintenance
Watershed
Wet Dredging
Sedimentation
Dimensions
Dry Dredging
Width
Length

Canal Lengths

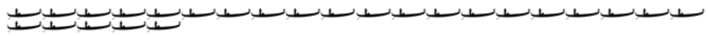
 =11 m

Longest Canal: Grand Canal 4 km



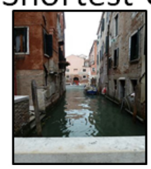
≈ 365

Average Canal: 257 m

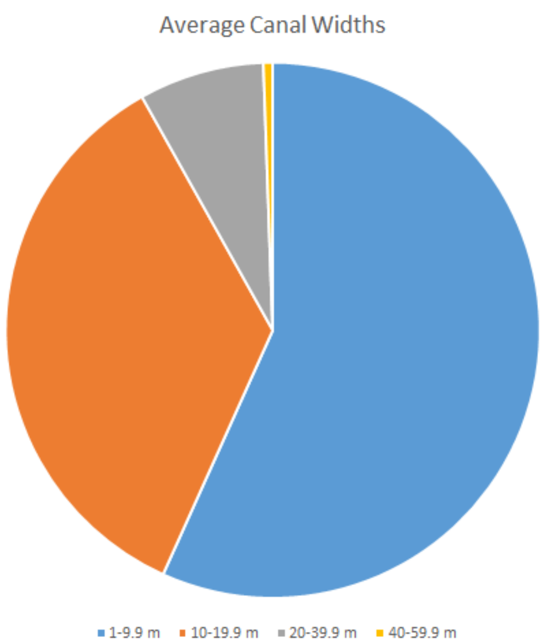


≈ 25

Shortest Canal: Rio Amalteo 26 m



≈ 3



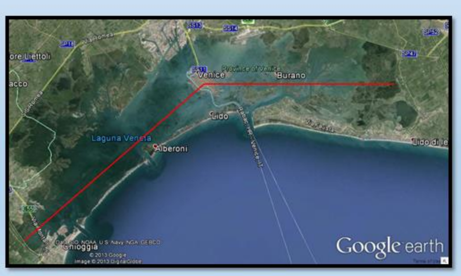
Total Canal Length

All 182 Canals in Venice End To End

≈46 km

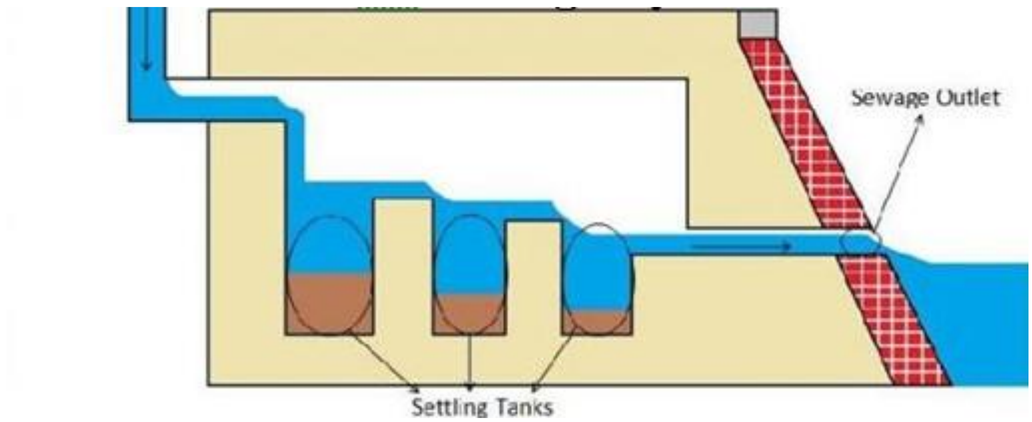
≈

The length of the Venetian Lagoon

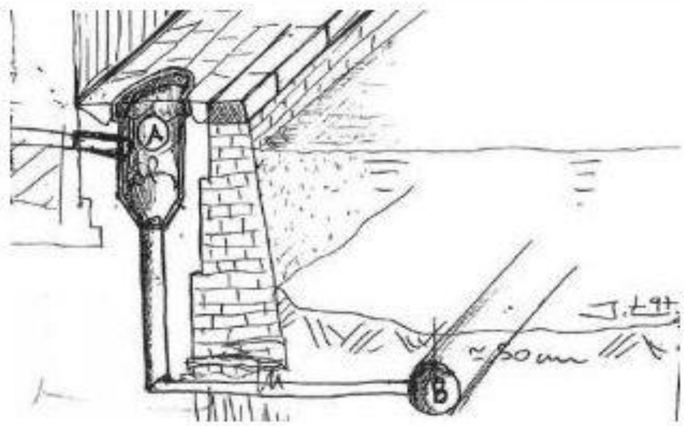


≈47 km

Sewage In The Canals of Venice



Septic Tanks In Venice

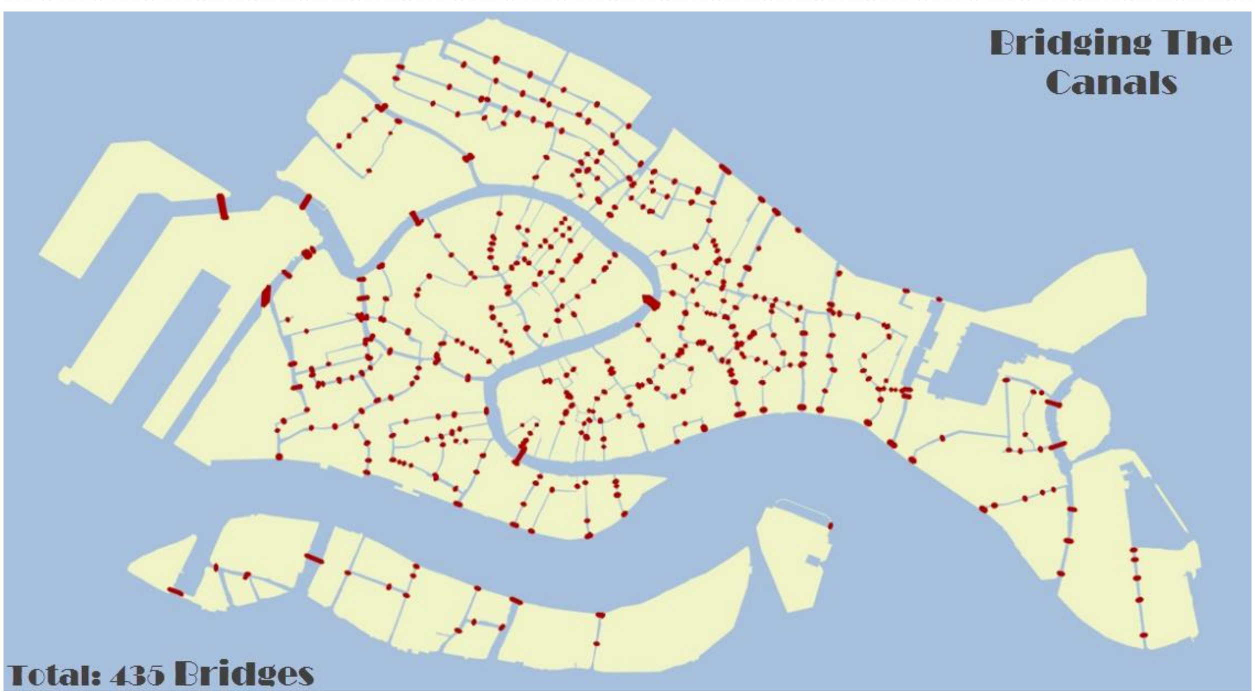


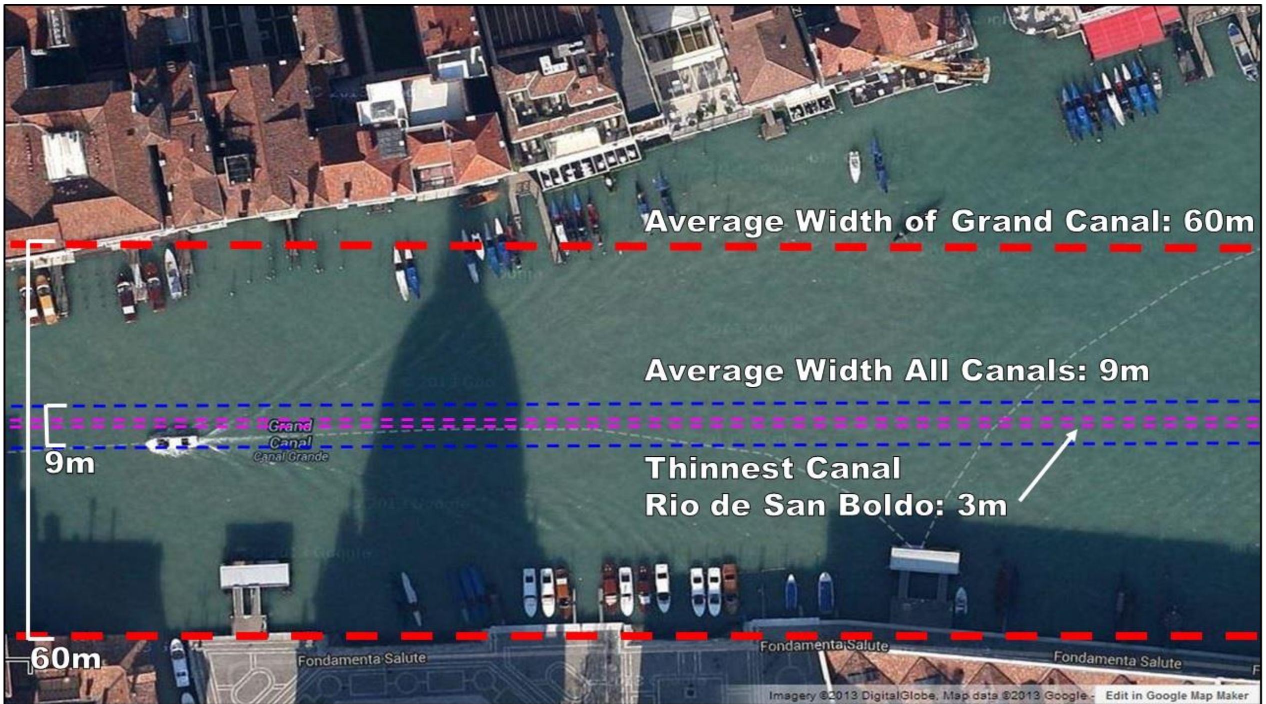
▼ $1.5 million

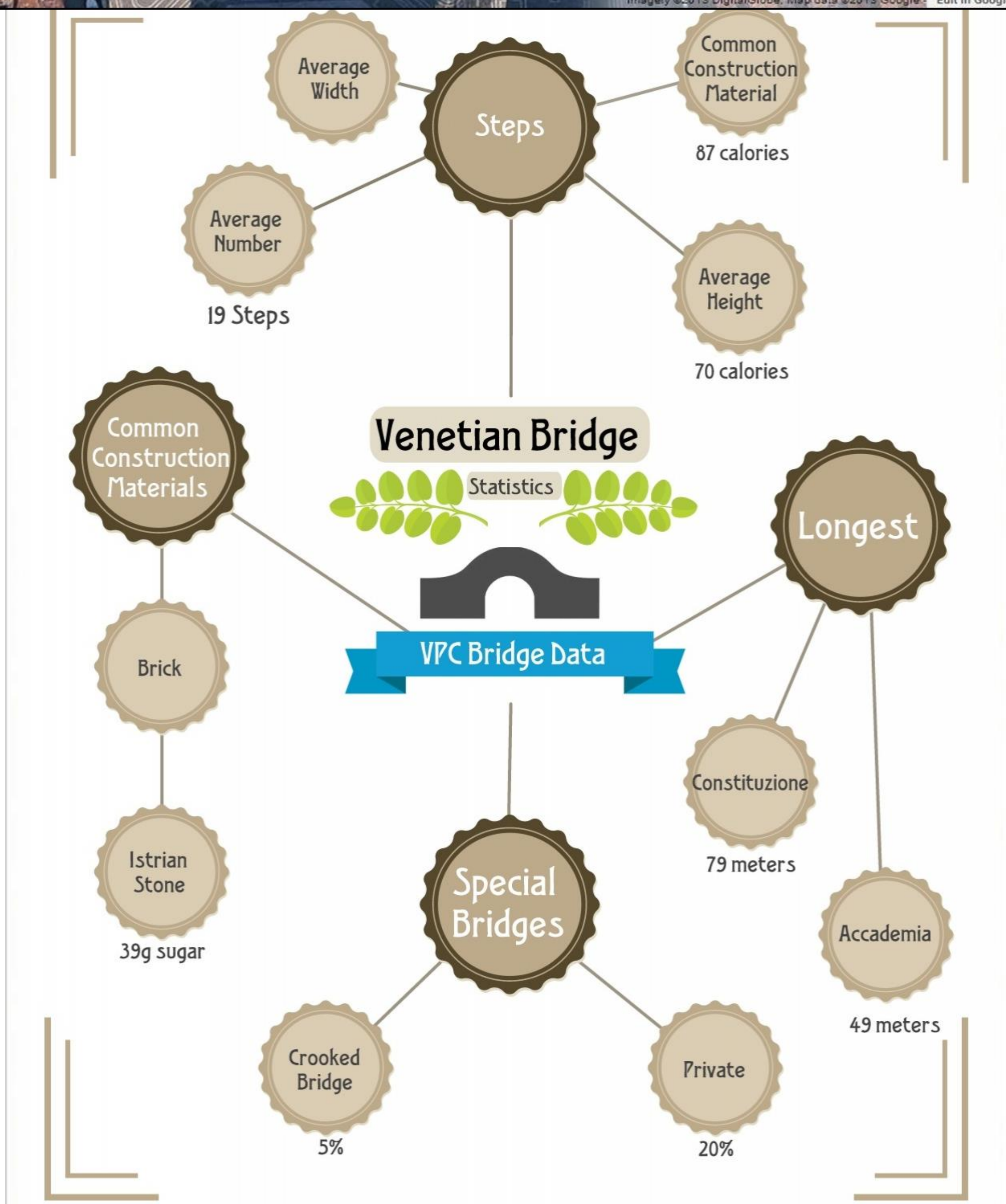
Estimated savings from installing vacuum sewage systems over the next cheapest system

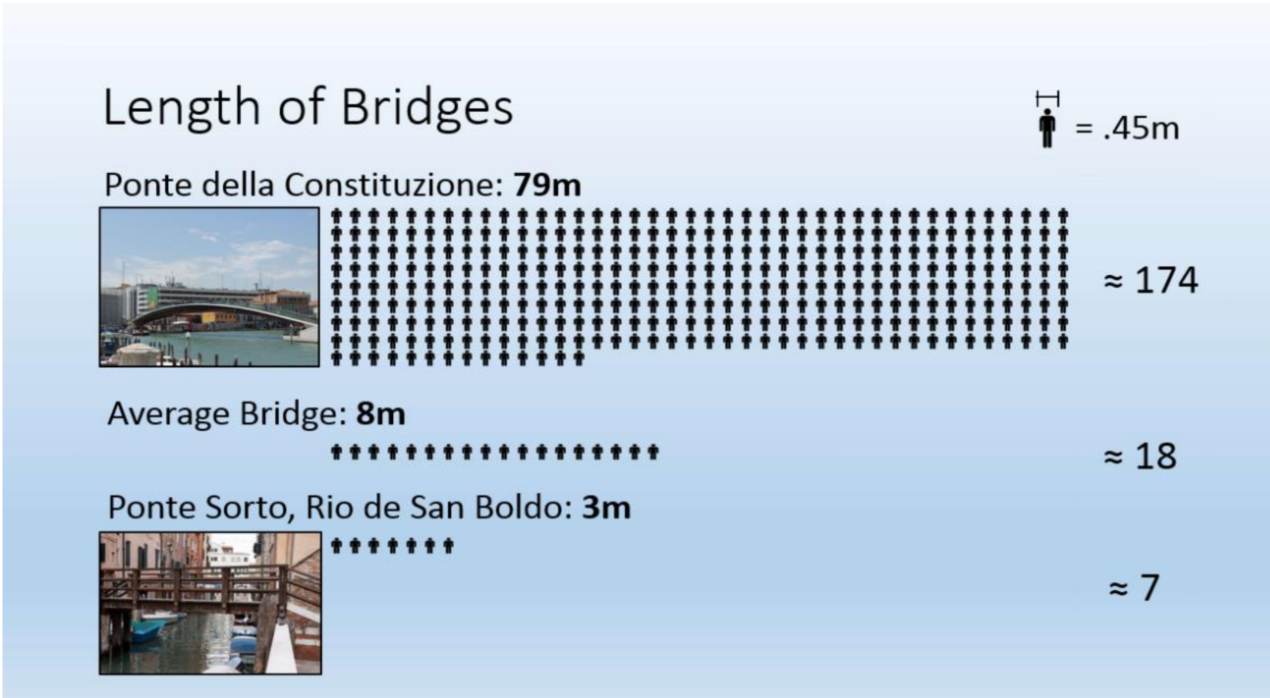
0

Amount of sewage discharged into canals




Average Width of Grand Canal: 60m
Average Width All Canals: 9m
Thinnest Canal
Rio de San Boldo: 3m
9m
60m
Grand Canal
Canal Grande
Fondamenta Salute
Fondamenta Salute
Fondamenta Salute
Imagery ©2013 DigitalGlobe, Map data ©2013 Google - Edit in Google Map Maker


Venetian Bridge
Statistics
VPC Bridge Data
Steps
Average Width
Common Construction Material
87 calories
Average Number
19 Steps
Average Height
70 calories
Common Construction Materials
Brick
Istrian Stone
39g sugar
Longest
Constituzione
79 meters
Accademia
49 meters
Special Bridges
Crooked Bridge
5%
Private
20%


Length of Bridges
= .45m
Ponte della Constituzione: 79m
≈ 174
Average Bridge: 8m
≈ 18
Ponte Sorto, Rio de San Boldo: 3m
≈ 7

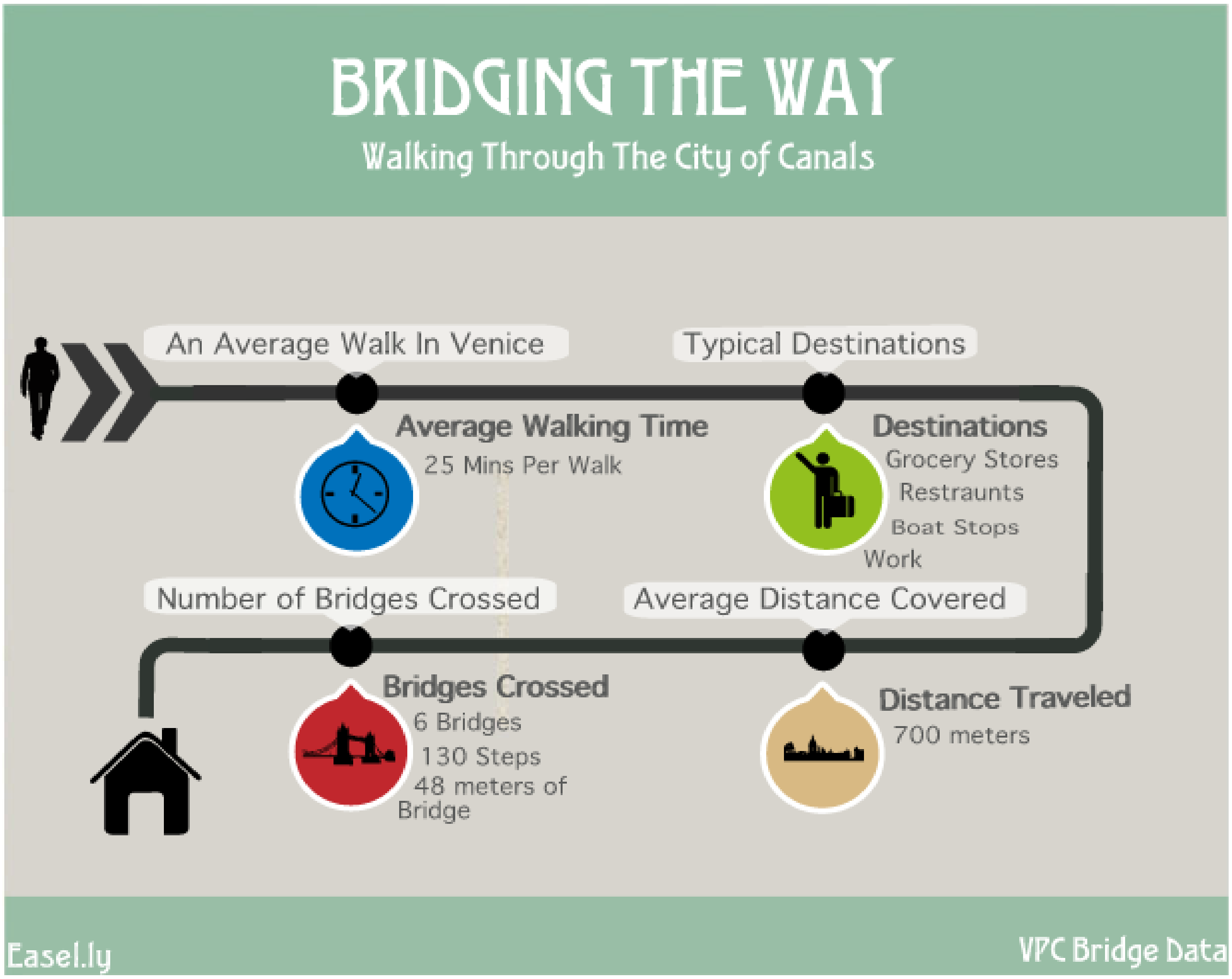

BRIDGING THE WAY
Walking Through The City of Canals
An Average Walk In Venice
Typical Destinations
Average Walking Time
25 Mins Per Walk
Destinations
Grocery Stores
Restraunts
Boat Stops
Work
Number of Bridges Crossed
Average Distance Covered
Bridges Crossed
6 Bridges
130 Steps
48 meters of Bridge
Distance Traveled
700 meters
Easel.ly
VPC Bridge Data

TABLE OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION

The mission of this project is to produce up-to-date information that leads to a comprehensive list of all canals, segments and bridges, and to study ways to achieve a reduction in the maintenance cost of canals and related infrastructure.

Many coastal metropolitan areas around the world are facing problems relating to erosion[1]. Tides cause water to encroach on populated areas and significantly damage its infrastructure. This causes coastal regions to dedicate a large portion of government spending to repairs[2]. To ease the burden on taxpayers caused by this constant maintenance, coastal regions have made cost reductions of such repairs a priority[3]. In addition, many coastal regions discharge sewage directly into their waterways resulting in extremely unsanitary situations. Since this method of disposing refuse makes an already costly problem more complicated, identifying alternate solutions enabling efficient disposal of sewage is paramount to improving the maintenance of these unique regions.

Venice, a city built on many islands around a network of 182 canals, is one of the most vulnerable cities in the world to these issues[4]. Its canals are both the main transportation infrastructure of the city as well as the sewer system for the city. The canals themselves are damaged by water flowing through them and the wakes caused by constant boat travel. Additionally, the many canals cause the city to be prone to flooding during "Acqua Alta," the high tides, which are most common during the winter months[5]. This causes polluted water to invade the streets and buildings of the city, resulting in considerable maintenance costs. Although these issues put pressure on the city to find solutions, as a World Heritage Site, Venice must combat these problems while maintaining its historical and cultural significance and appearance[6].

---

[1] Felicity Barringer, "Both Coasts Watch Closely As San Francisco Faces Erosion," *The New York Times*, 2012/03/25/ 2012.
[2] Gilbert M. Gaul, "Along the Water, Disasters Waiting for Their Moment Billions of Dollars Are Spent to Sustain Expensive Properties Imperiled by Storms.," (The Philadelphia Enquirer, 2000).
[3] James Neumann, "Adaptation to Climate Change: Revisiting Infrastructure Norms," *Resources for the Future*, no. 9-15 (2009).
[4] "Canal - Venipedia," http://www.venipedia.org/wiki/index.php?title=Canal.
[5] Sylvia Poggioli, "MOSE Project Aims to Part Venice Floods : NPR," (2008).
[6] UNESCO World Heritage Centre, "Venice and its Lagoon - UNESCO World Heritage Centre," (sThemes All Cities Cultural Landscape Forest Marine & coastal Earthen Architecture Criteria with only with Cultural Criteria: i ii iii iv v vi Natural Criteria: vii viii ix x).

To address problems relating to Venice's canals, it is important to understand the structure of the canals and the way that water runs through them. Many of Venice's problems stem from attempts to alter the surrounding lagoons without fully understanding the hydrodynamic repercussions[7]. Likewise, attempting improvements to protect Venice against the tides, without fully understanding the way that the water flows through the city and the factors that influence it, could easily be detrimental to the city. The structure of the canals is both an important step in understanding the hydrodynamics of the city and vital to creating a solution preserves the functionality and appearance of the canals. Proposing a solution to Venice's sewage problems requires much of the same data, although it also requires an understanding of the existing sewage system, the location of sewage outlets, and how effective the canals are at moving the sewage out of the city.

There were attempts made in the past to catalog this data by groups such as Insula, ISMAR, and the Tide Center. Insula made a point of gathering and maintaining background data about Venice's canals, sewers and various utilities. Recently, however, Insula's ability to sustain itself has decreased significantly, meaning that the future of the company, as well as the records, are in jeopardy[8]. Other records of this information belong to institutes like the Tide Center, which collects extensive data on the lagoon surrounding Venice to provide early warning in the event of a flood. The main issues with this data are that much of it is in Italian, not in a standardized format or is outdated. One way to help preserve these records would be to make them publicly available, as well as by allowing a wider group of people to update and maintain these records. In the past, WPI has created an online repository for data relating to Venice called Venipedia. Over the years, work has been done to create and maintain content; however, there are still gaps in much of the information. Through the continued collection of data, and by obtaining and utilizing existing data sources such as Insula's, Venipedia will work to become the main source for information on Venice. Currently, Venice's upkeep costs are high, with 35 million euros spent on canal repair in 2006 alone[9]. Utilizing data collected from all of the previously listed sources, it is possible to focus on the particular maintenance costs of the canals and related infrastructure. We can identify particular factors responsible for Venice's high

[7] Miroslav et al. Gacic, "Temporal variations of water flow between the Venetian lagoon and the open sea," *Journal of Marine Systems* 51, no. Issues 1–4 (2004).
[8] Insula, "Budget 2010."
[9] Kevin Black et al., "Urban Maintenance And Venetian Accessibility " (2008).

upkeep costs by closely assessing this data. To significantly reduce the maintenances costs of Venice making changes to these areas is a priority. Past IQP projects have been providing the tools necessary to analyze alternatives for decades, however there is very little data utilizing these tools to propose a solution. As Venice floods more frequently, Venice's maintenance costs will only continue to grow[10]. As such, it is imperative that action be taken sooner rather than later. Providing analysis and the following proposals are important steps towards this goal.

[10] "City of Venice - Distribuzione annuale delle alte maree >= +110 cm," http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/EN/IDPagina/2968.

2 CANALS

The city of Venice is located in a 212 square mile lagoon along the Northern edge of the Adriatic Sea in the Italian Region of Veneto, which can be seen in Figure 1. This lagoon is separated from the Adriatic by two long barrier islands, Il Lido and Pellestrina, as well as a series of sea walls. These barrier islands form the three inlets to the lagoon, known as Lido, Malamocco, and Chioggia. It is home to the 125 islands that make up the city of Venice, several other island communities such as Murano and Burano, as well as the largest wetlands in the Mediterranean[11].

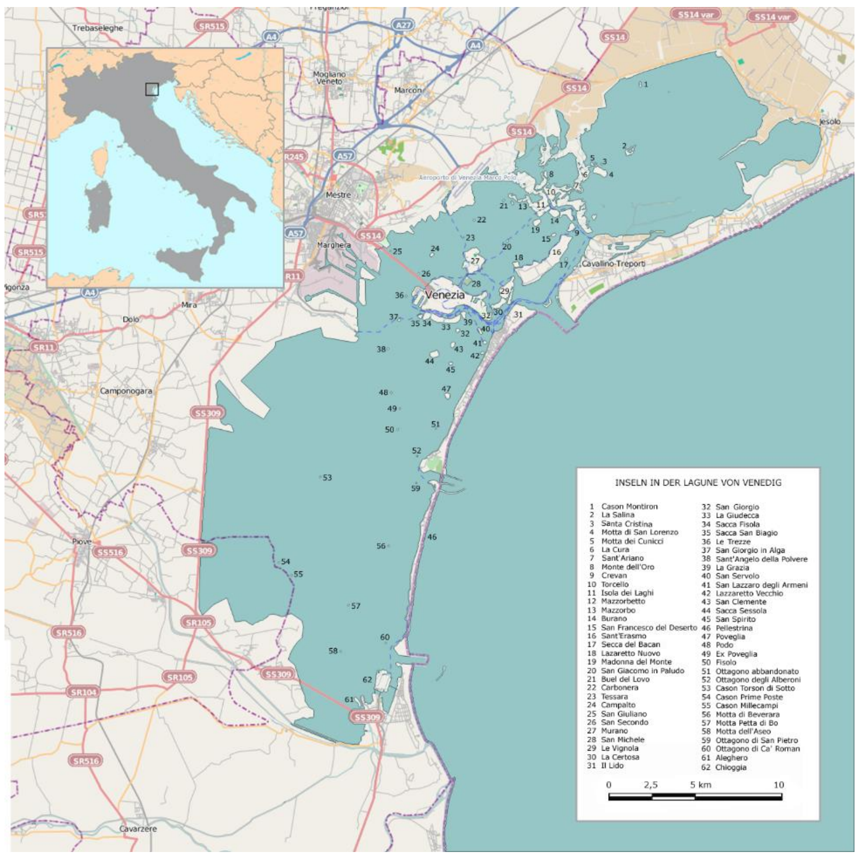


Figure 1: Venetian Lagoon [12]

2.1 The Canals of Venice

Venice is known as "The City of Canals" because of the 182 different canals (called rii in Italian)[13] which run through it. They make up most of the transportation infrastructure. Water from the Adriatic Sea serves as the primary source for these canals, with the water level rising

[11] Poggioli, "MOSE Project Aims to Part Venice Floods : NPR."
[12] http://upload.wikimedia.org/wikipedia/commons/e/ee/Venedig-lagune.png
[13] "Canals - Venipedia," http://www.venipedia.org/wiki/index.php?title=Canals.

and falling with the tides. The canals also serve as the sewers. While the use of canals as the sewer system was revolutionary at the time of its introduction, the constant dumping of sewage into the canals is now having a negative impact on the city and the local environment.

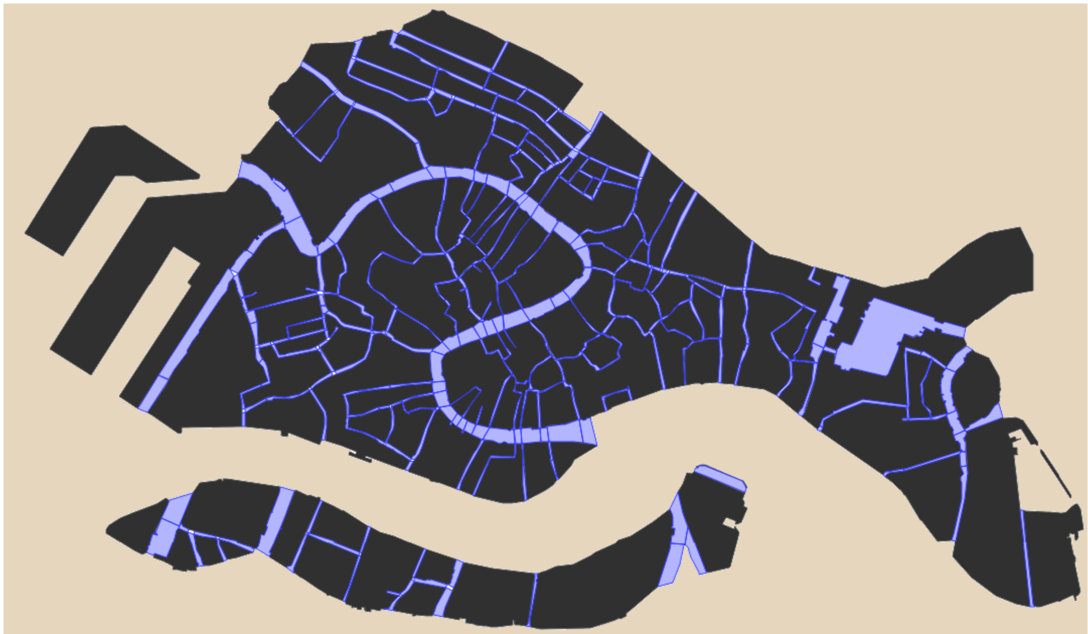


Figure 2: The canals of Venice

The canals are connected to the lagoon and therefore make the city especially prone to flooding during high tide[14]. The rising tides in the lagoon cause water to pour in from the north; however, this water is unable to leave due to the canals on the southern side of the city being effected by the Sirocco, the southern winds[15]. “Acqua Alta,” or high waters in English, are when canal levels approach 80 cm above the average water level for the city;[16] these high tides occur about four times a year[17]. When the tide level reaches about 100cm, 5% of the city is flooded and transportation is hindered, whereas when it reaches 140 cm 59% of the city is flooded and much of the city is impaired[18]. On November 4, 1966, water levels reached a historic 194cm as seen in

[14] Gacic, "Temporal variations of water flow between the Venetian lagoon and the open sea."
[15] "Citta di Venezia - La marea," http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1753.
[16] Ibid.
[17] "City of Venice - High water in Venice: Frequently Asked Questions (FAQ)," http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/22795.
[18] "Citta di Venezia - La marea."

Figure 3[19]. The current solution to this issue is the construction of the MOSE floodgates, which will close when tides reach flood levels to prevent tide levels in the lagoon from rising further.

Figure 3: A photo from the flood of 1966[20]

2.2 Canal Models

In 1999, a WPI Interactive Qualifying Project team gathered extensive information about several canals. The measurements largely consisted of sediment and flow rate data. Using their contribution, ISMAR was able to create finite element models of the canal segments[21]. Finite element modeling is based on the idea that a complicated system can be simplified by breaking it into many smaller geometries[22]. An example of this can be found in Figure 4 where finite element modeling is used to map the lagoon around Venice. The model of Venice's canals graphically represented the behavior of the currents in the canals as a function of time. By 2012, this model was outdated and as a result, a second WPI team supplied ISMAR with data that is more recent. This allowed ISMAR to create a second model in a largely similar manner to the first[23].

[19] "City of Venice - The exceptional high waters," http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1850.
[20] http://images.fineartamerica.com/images-medium-large/venice-flood-1966-granger.jpg
[21] Junbo Chen et al., "An Update on the Hydrodynamics of the Venice Canals " (Worcester Polytechnic Institute 2011).
[22] Liwei Lin, "Introduction to Finite Element Modeling," (University of California Berkeley).
[23] Chen et al., "An Update on the Hydrodynamics of the Venice Canals ".

Figure 4: Finite Element Model-Venetian Lagoon[24]

2.3 Hydrodynamics

The study of the way that water moves is hydrodynamics[25]. Hydrodynamics are important to the Venetian canals as they determine where there are stagnant canals versus rapid flows. Shape of the canal, the sedimentation within the canal, friction from the walls of the canals, as well as how water enters or leaves the canals[26] change how the water flows through the canal. Areas with poor flows rates tend to accumulate more sediment, therefore understanding the hydrodynamics of Venice is important to determining an efficient maintenance schedule[27].

2.4 Methodology of Data Aggregation

To ensure that there is a single comprehensive data set on the canals of Venice, information must be collected from a number of sources. The primary source of information will be the GIS Layers and spreadsheets produced by Insula and past WPI Venice Project Center groups. This information not only provides a comprehensive collection of data, but it also allows for the tracking of how the canals and canal segments have changed over time, given that much of the information has been collected over the past two decades. This data will include physical

---

[24] DeMaio et al., "Streamlining Canal Hydrodynamic Measurements in Venice ".
[25] "Hydrodynamics - Definition and More from the Free Merriam-Webster Dictionary," http://www.merriam-webster.com/dictionary/hydrodynamics.
[26] Christine L. Biscotti et al., "Hydrodynamics of the Inner Canals of Venice," (1999).
[27] Ibid.

properties such as dimensions, and dynamic information, such as sediment depth, hydrodynamic measurements, and canal maintenance.

2.5 Finalized Data & Created Venipedia Pages

Thanks to the work that we have done in Venice, as well as the work of past WPI students, all data relating to Canals has been organized and updated for publication. In addition to the Canal and Canals pages, there are now 230 individual canal pages as well as 475 pages for the individual canal segments and 2 sortable pages: List of Canals and List of Canals segments. To ensure that future changes to the pages are of good quality, updates and editing are currently restricted to WPI students and the Venice Project Center. All of the new canal pages include the most up to date information available on location, depth, length and number of segments, while including a brief history of a significant number of canals.

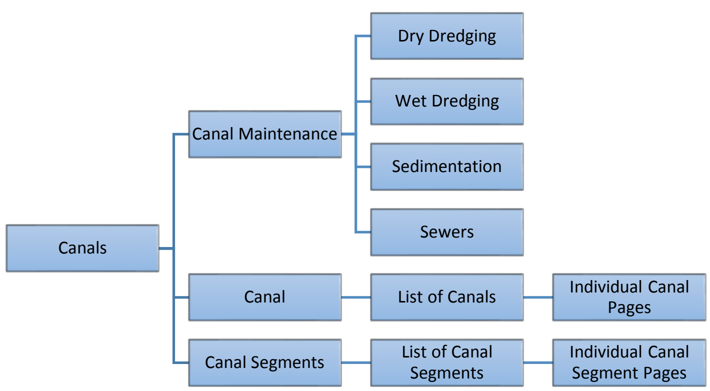


Figure 5: Canal Pages organization

2.6 Canals Infrastructure Application

All of the information that was collected has also been presented in an interactive map online. Users are able to view all of the canals, canal segments and bridges overlaid on a map of Venice. Users can click on different objects to see more information on them. In addition to physical properties, canals have a list of segments and all of the segments have past maintenance information as well as boat count information collected by past projects. There is also a link to the corresponding Venipedia pages.

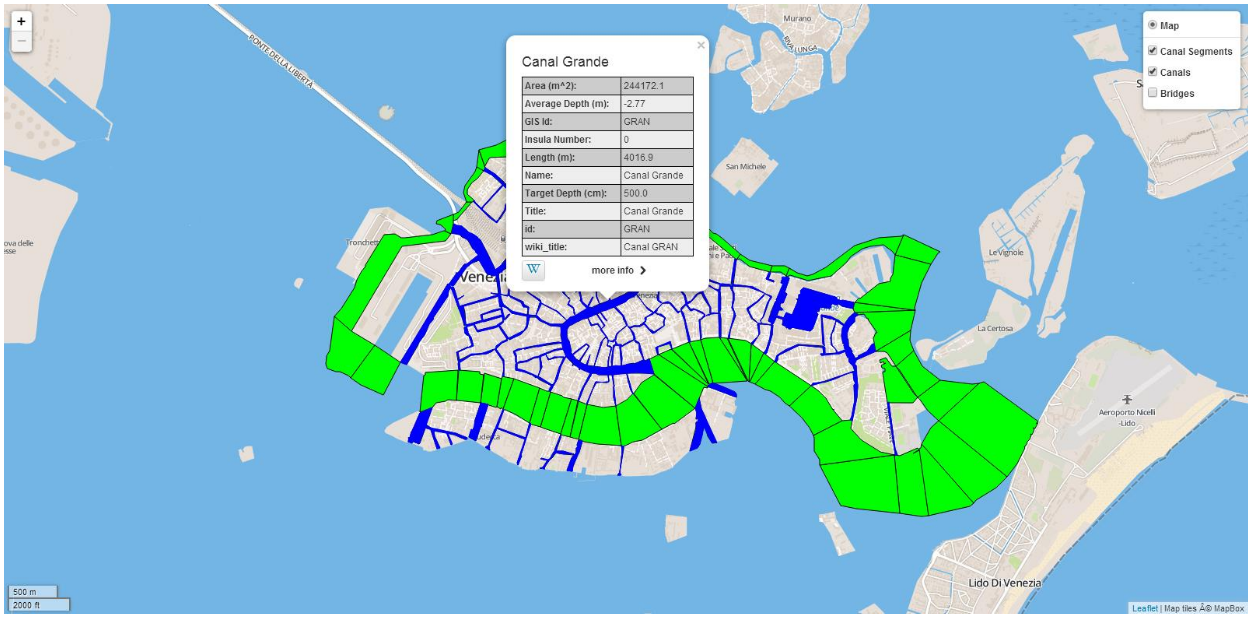


Figure 6: The Canal Infrastructure application with a canal selected

2.7 Canal Hydrodynamics Visualization

Using the canal hydrodynamics model and data provided by ISMAR (Institute of Marine Science), we were able to run the model for a more recent period. Using the output of the model, which includes details such as water depth, salinity, and water velocity, a visualization, was created to allow the information to be more easily interpreted. The visualization (shown below) indicated the direction and intensity of flow in the inner canals of Venice. A slider at the bottom right indicates the current time in the visualization. The slider automatically advances, but can also be manually moved by the user to adjust the current time.

Figure 7: A visualization of the water flow in the canals

2.8 Conclusion & Recommendation

The canals of Venice are essential to the survival of the city, providing the entire transportation infrastructure in the city for vehicular traffic, as well as acting as the sewers of the city. Providing an up to date online repository of this information that is easily accessible to everyone stimulates interest in Venice's canals and ensures that the public is aware of the continued maintenance that is needed to keep the canals usable. Future WPI students should work to update information on the Venipedia pages as it becomes available in addition to expanding the current applications and pages. Canal segment pages have been created for the 475 canal segments of which we have information, but these are in need of further information and mapping.

Several past WPI projects have studied the hydrodynamics of Venice's waterways, but continued study is needed as the construction of the MOSE floodgates wraps up. Sedimentation rates should also be studied as a change in the hydrodynamics of the lagoon could potentially affect other aspects of the lagoon.

3 BRIDGES

There are currently 435 bridges located within the City of Venice and Giudecca seen in Figure 8, all of which vital to pedestrian movement between the 182 islands in the city. While the original bridges of Venice were made out of wood, over time the majority of them have come to be Masonry bridges, constructed out of Istria stone and brick. Bridges also serve another purpose as in many cases they also transport utilities over the canals and between islands. Large boats are sometimes prevented from travelling through certain canal segments due to some bridges being too low for them to pass through. As such during high tides bridges are not normally, an issue can impede boat traffic making important to have an up-to-date record of them.

Figure 8: The 435 Bridges of Venice

3.1 Gathering Bridge Data

To gather data on bridges we looked towards data collected by previous projects as well as data gathered by maintenance groups within Venice. There were two main spreadsheets that we focused on, one from 1998 project titled[28] and another from Insula's Bridge data from 2000, which is part of their program called "Easy Bridge da Insula." The Insula spreadsheet had very

---

[28] Ceriana,Stefano Dan Nashold, Joan Olender, Matthew Poisson Inventory and Analysis of the Bridges and Pedestrian Traffic in the Dorsoduro, San Polo, and Santa Croce Sestieri of Venice" (1998)

comprehensive data regarding many bridges. By using the Insula spreadsheet as a basis, we were able to identify any bridges that had crucial data missing from them. We were able to obtain this data using three different methods:

1. One method was to look at the bridge data provided both within the QGIS Layers of different projects, and the raw bridge data provided by past projects. Using these sources we were generally able to obtain a figure and cross-reference it with another source before adding it to the spreadsheet. This method was particularly useful for bridges that were known to have been previously measured yet missing from the master spreadsheet.

2. Another method was to look for communications with the architect of the bridge. Occasionally it would be possible to find a record of communication with the designer of the bridge that would contain the missing pieces of information. This method was most successful for obtaining information of recently constructed bridges such as The Constituzione.

3. Finally, we could obtain missing information by visiting the bridges with measuring devices provided by the Venice Project Center. We had the basic tape measure and a laser pointer. We could use the tape measure to get a feel for the water height as well as most straight parts of a bridge. The laser pointer allowed us to measure things that were particularly far away such as the width of a canal or the span of a bridge. This method was good for measuring bridges without much traffic but was particularly more difficult for bridges that were heavily traveled.

In order to determine the location of the bridges and add that data to the spreadsheet we converted a QGIS map to the correct coordinate system using a program called conVE. Using formulas included in QGIS to create centroids for each of the bridges, we were able to attach real world longitude and latitude data to each centroid, and therefore, each bridge. By inspecting the attribute table attached to the resulting map, we were able to match the bridge code to the matching bridge code in our spreadsheet proving location data for most of the bridges. Unfortunately, not all of the bridges we had data for were listed in the QGIS layer. Therefore, after the conversion they did not yield longitude and latitude data. This meant two things, if we were able to obtain coordinates for the bridges we should be able to add them to the layer since it was converted and that we could not simply copy and paste the coordinates within the attribute list into our data sheet so each bridge would need to be matched by hand.

Finally, to add our own data to the bridges we utilized a large amount of information regarding to most historical names in Venice. By searching through the data and picking out the ones that involved bridges, we were able to generate a general history for many of the bridges. Some of the bridges were harder to link than others. Generally, the method of determining whether the history was pertinent to the bridges with reading through all of the provided history was to link it based on the number of mentions of the world “bridge”. These exerts were included in the data under a history column which is intended to only include text. For some nonessential data, such as a list of the decorations on the bridge, information was not gathered in interest of completing other tasks. Bridges missing nonessential data such as this are documented so that they can be measured later. Bridges that we added also needed to be added to the QGIS layer, to accomplish this we used MapInfo and traced out the polygons, specified a centroid and labeled them on their maps. Once we were sure the data was formatted to our liking and that, we had filled essential holes in the data we converted it to a CSV and uploaded it to The City Knowledge Console.

3.2 Formatting Data

After the data was compiled, a main goal was to format the data in such a way that it provided a framework for future data collection and was easily readable by people and easily accessible for future processing. The first step was to assign units to all of the fields in a manner that was acceptable for the comma separated value format. We chose to make the standard that units were listed at the end of the field label text within parenthesis. The next step was reformat some of the text. Fields that contained both numbers and text were interpreted by Excel to be completely text. Any functions within Excel, which called these fields, would return an error or incorrect results. By separating the text and numbers into two different fields and then reformation the numbers, this issue was avoided. Afterwards, Excel stores dates, times and occasionally years as an integer. When large amounts of data from an older version of excel is copied to a newer version or the formation of the original cell and the destination cell are different, the integer can be displayed rather than the date in a recognizable format. By formatting the column rather than the individual cells, the problem was mostly solved. The issue still exists for dates copied from particularly old spreadsheets. Once this was completed, the text needed to be formatted correctly. To solve most of the issues with the text, the text needed to be trimmed (any spaces, as the beginning or end of the text left over from pervious formatting needed to be deleted) and accented characters not recognized by The City Knowledge Console needed to be removed. The trimming was done using an excel function (=TRIM()) and the accented characters were removed by hand. By fixing the data like this, it both further established a standard for data collection and made it available for use in many Excel formulas and other data manipulation tools.

3.3 Displaying Bridge Information

3.3.1 Bridge Venipedia Pages

Using the data in the City Knowledge Console 467 individual bridge Venipedia, pages were created. The pages are directly tied to the data and will update to reflect any changes made to the data. The main bridge page provides the information we deemed most useful or interesting so that it can be viewed at a glance. The rest of the information makes up the body of the text along with any history present in the spreadsheet. The pages have been created in such a manner that they read like a paragraph rather than a list seen in Figure 9. This was accomplished by using the if/then functionality of Venipedia. One method of getting to these pages is to search for the individual bridge, another is to use the navigation box present on any bridge page, and a third is to access the “bridge” category. The creation of the page is uniform as it is based on a template created by members of this project. The addition of new pages including new information or new bridges is very simple as it only needs to be added to the current data and the page will make itself. The intention of these pages is to help simplify the process of obtaining any and all bridge data.

Figure 9: Example Venipedia Bridge Page

3.3.2 Bridge Application

The information on bridges was compiled into a useful web application for boat drivers that allows them to determine which bridges are passable at a given tide level. The application first initializes with the current tide height in Venice and then the user is able to adjust the height of the tide. As the tide, level is changed the color of the bridges changes so that passable bridges are in green and impassable bridges are in red. The height of the boat used in the calculation can also be adjusted using a second slider making the application.

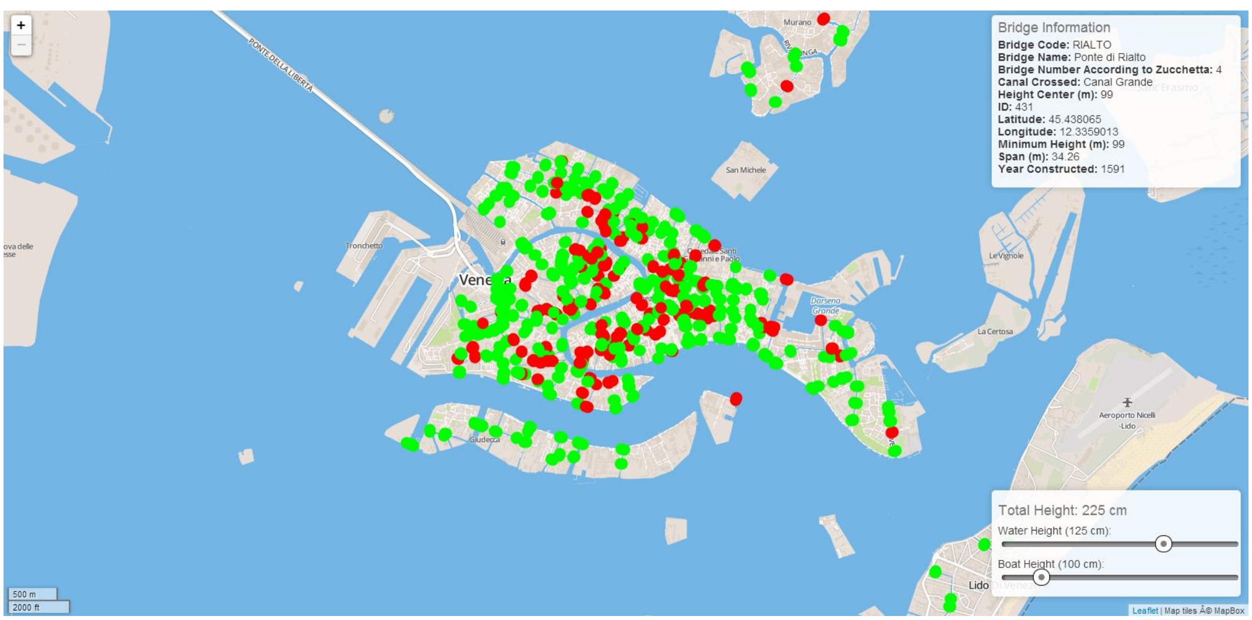


Figure 10: The bridge height application in action

3.4 How to Improve the Data

In order to improve the data two main tasks must accomplished. First of which the data for heavily traveled bridges needs to be recorded. The constant traffic makes obtaining measurements with a surveying tool nearly impossible. The format to turn most of the data into Venipedia already exists so all that is required is adding it to the console. This is the priority as currently the missing data is all related to prominent bridges such as The Rialto.

Second, some bridge photos exist and this project attempted to update a section of them to demonstrate they can be improved. Many of the pictures are dark or blurry which detracts from their usefulness. Our group took pictures of all the bridges around the Ft. Nove location and provided one possible format. The format we used was taking a picture of the arch and of the ramp and then taking a picture of the view from either side. Since we had access to a strong camera, we were able to take very clear images. We believe using these pictures over the previous ones will improve the quality of the Venipidea pages.

In order to improve our method of displaying the data, the text generating the individual bridge pages from the console need to be organized. Due to the method, that it was requested we display the information in the text is very cluttered and difficult to add or subtract from. While it creates the Venipedia pages in a nice format, this is in no way a long-term solution.

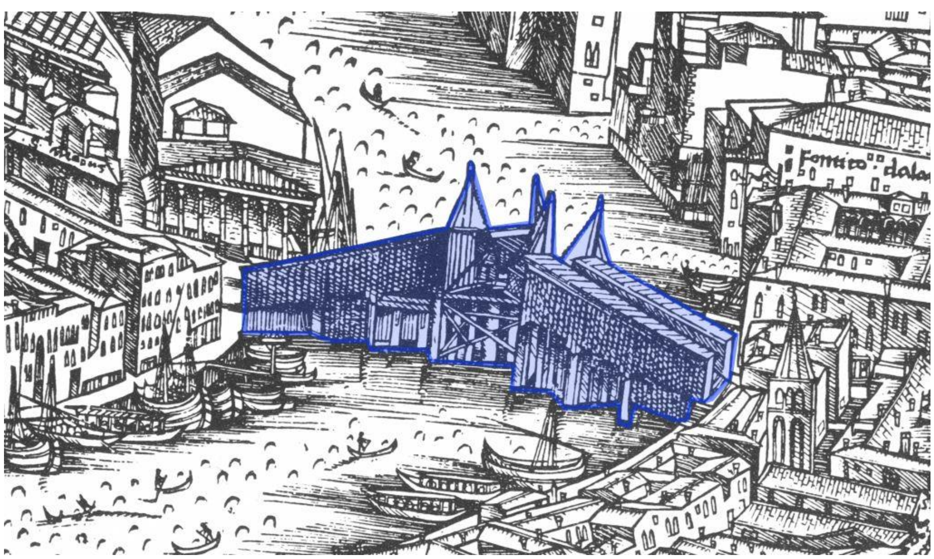


Figure 11: Highlighted Bridge on D'barbari Map

4 URBAN MAINTENANCE

The canal walls of Venice are under constant assault from the very water that they keep at bay. The motion from the tides, as well as the wakes caused by passing boats, leads to significant erosion along the canal walls. In the past erosion was more manageable, although it has become a larger issue since the sea levels have risen. When Venice was established, the water flowing through the canals washed along Istrian Stone, a non-porous marble mined on the Istrian Peninsula in present day Croatia. Due to rising global sea levels, the water level in the Venetian lagoon have risen 23 centimeters since the end of the 19^{th} century[29]. This means that the current height of the Istrian stone is no longer sufficient to protect the more vulnerable parts of the buildings. Brick, as a significantly more porous material than Istrian stone, is easily damaged by the corrosive canal flows as shown in. As the bricks and mortar of the walls fall apart, they wash away, allowing water to penetrate even farther into the buildings, causing further damage to the outer walls, as well as causing the land upon which the city was built to wash away.

Canal walls can also be damaged by the backing up of waste inside sewage outlets due to blockages such as sedimentation. This problem can lead to the piping bursting and the creation large holes in the walls[30]. Most sediment washes in to the canals from unknown sources[31], but some of it can be attributed to manmade waste such as sewage and masonry debris. Canals must have their sediment levels properly monitored so that the sediment can be removed before it becomes an issue. Venice spends millions of euros a year on the upkeep and repairs of canal walls, spending around 35 million Euros on maintenance in 2006 alone[32].

[29] David Chiu, Anand Jagannath, and Emily Nodine, "The Moto Ondoso Index: Assessing the Effects of Boat Traffic in the Canals of Venice," (Worcester Polytechnic Institute, 2002).
[30] Randy Astaiza, "You Might Think These People Are Crazy For Swimming In Venice's Flooded Streets Once You See How Their Sewer System Works," *Business Insider* (2012).
[31] Alexander Borrelli et al., "Quantification of Sediment Sources in the City of Venice, Italy," (1999).
[32] Black et al., "Urban Maintenance And Venetian Accessibility ".

Figure 12: A damaged canal wall[33]

4.1 History of sewage disposal

Managing sewage has been an important aspect of human development. Some of the earliest forms of sewage disposal were advanced for their time and similar to Venice's current method. The Harappan civilization had a system of troughs and ducts that ran into a nearby river. The Minoans featured a system with running water in about 1700 B.C. In Italy, the Romans constructed a large canal that allowed sewage to run into a nearby river, otherwise known as the Cloaca Maxima. Each of these methods are similar to the Venetian sewer system, however these methods are also ancient.

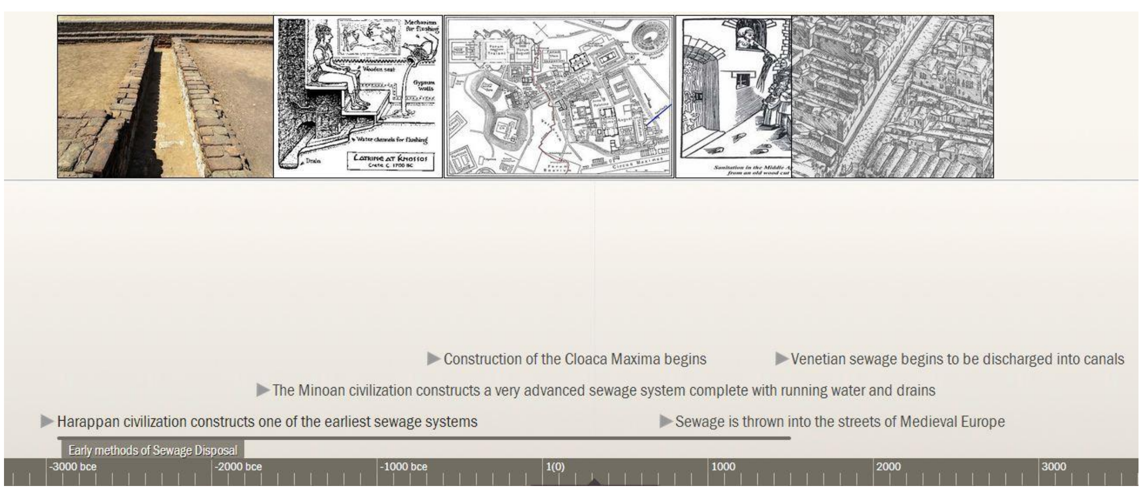


Figure 13: Methods of sewage disposal dating back to 3000 B.C.

[33] http://www.venipedia.org/wiki/index.php?title=Sewage_disposal

The first documented use of canals as sewers began in the 15th century[34]. At the time, Venetians would fling raw sewage into the canals, using the channels of water to sweep the waste out into the lagoon. Compared to other methods of sewage disposal at the time, this method was very effective in removing waste and kept the city healthier than other places where sewage was left to build up in the streets. The system evolved in the 16th century, as a series of underground tunnels and drainage systems was built to transfer wastewater from homes into the canals. These systems are known as Fognatura . Fognatura are made up of underground tunnels called Gatoli that carry the wastewater out into the canals through an opening in the canal wall, known as Sboccho.

Figure 14: The Sboccho portion of a Fognatura system

[34] Robert C. Davis and Garry R. Marvin (2004). *Venice, the Tourist Maze*

Merli Law[35] outlines sewage treatment and disposal throughout Italy. Those who do not comply with those regulations are subjected to a fine. At the time of the law, Venice did not comply with the outlined regulations, especially as their main method of sewage disposal involved discharging raw sewage directly into canals. However, Venice was given an indefinite exemption. As outlined in the Special Law for Venice[36], the city would be able to put the funds generated by the fines of Merli Law towards implementing a method of sewage disposal that complied with the law.

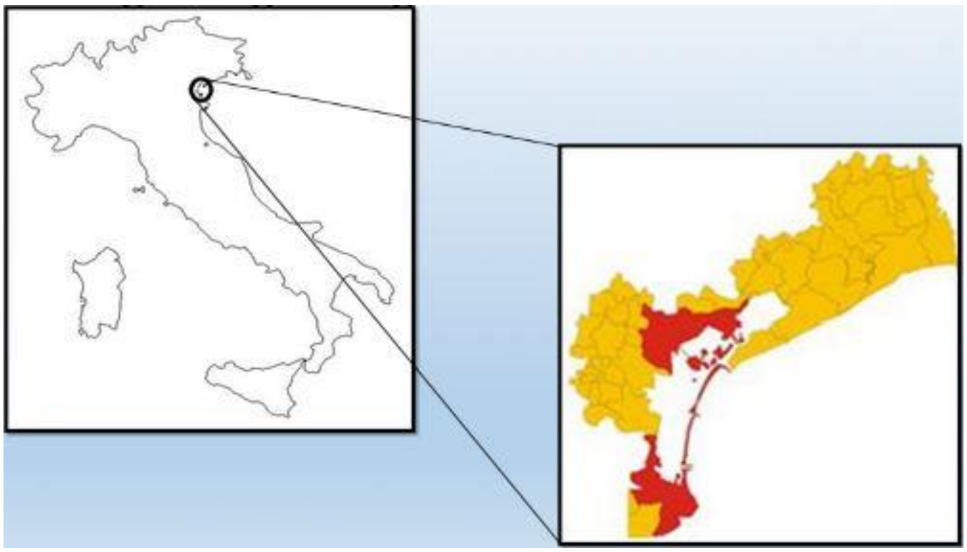


Figure 15: The citiies of Venice and Chioggia

4.2 Documenting and Assessing Improvements

There are over 6000 septic tanks installed throughout the city. These tanks provide an anaerobic environment that breaks down sewage found in wastewater[37]. Most septic tanks then have the remaining wastewater run-off into a leach field. Due to the inability to construct leach fields, modifications must be made to the conventional system. Unfortunately, that involves allowing wastewater to run off into the canals. Some septic tanks function as the holding tanks in gravity systems, while others are used as a form of storage.

[35] Origoni, Gianni "Italy: Recent Developments in Italian Environmental Law" (1995)
[36] Venezia Commune "Fee Pursuant to Law 206/95" (2013)
[37] American Ground Water Trust "Septic Systems for Waste Water Disposal"

Figure 16: Septic tank

Additionally, treatment centers are located throughout Venice, and are important in reducing the amount of sewage that would otherwise discharge into canals. Treatment centers are often located inland, where residences do not have the luxury of discharging sewage directly into the canals. They also treat the waste recovered from septic tanks. While most sewage treatment centers are just a result of a heavily-populated area being far from a body of water, some centers have been recently been used to treat vacuum sewage systems and reduce the waste discharged by gravity sewage systems.

The gravity sewage system is the most common sewage system found throughout Venice. It uses gravity to transport wastewater either into the canals or to a sewage treatment center. Some systems only use Fognatura to move waste directly from a residence into the canals with no treatment depicted in Figure 17. These, however, only make up about 30% of gravity sewage systems[38] and can only be found on properties that sit directly on canals. These systems contribute to almost all of the sediment accumulation caused by sewage outflow. Other gravity sewage systems use settling tanks to filter wastewater before the remaining waste is discharged. This method of treatment is effective for removing up to 95% of suspended solids from the

[38] Alexander Borrelli et al. "Quantification of Sediment Sources in the City of Venice, Italy" (1999)

wastewater. Systems that are not near a canal have waste stored in septic tanks, or transported to sewage treatment centers.

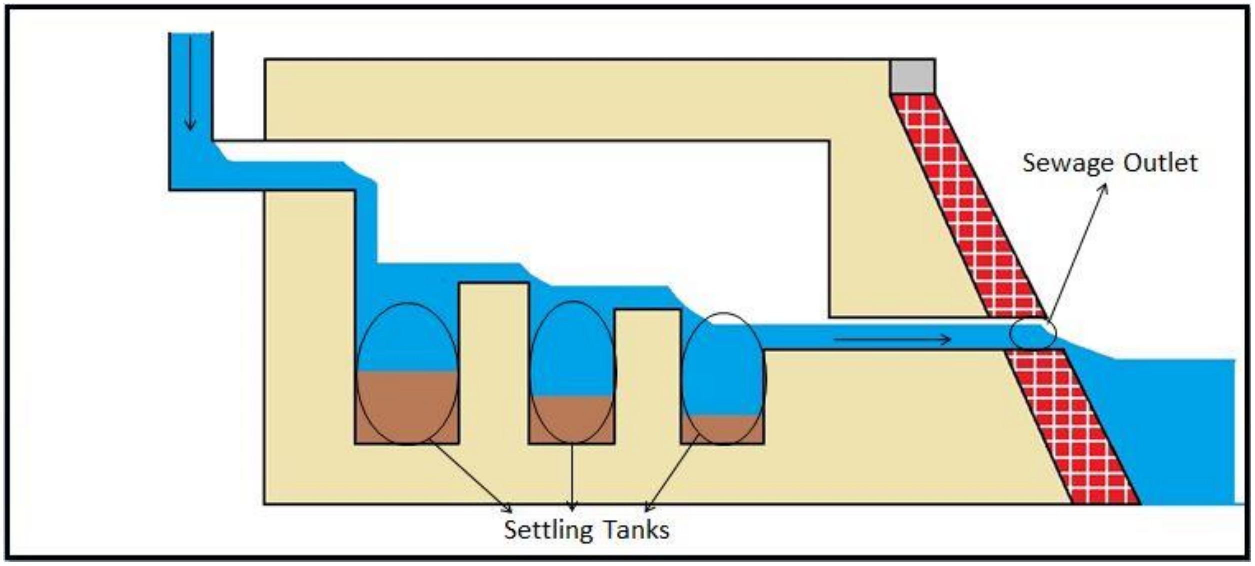


Figure 17: Example of Gravity Sewage System

Vacuum sewage systems are another option that the city of Venice has used to dispose of sewage. Although not nearly as abundant as gravity systems, the island of Sacca Fisola is an example of a location that has installed a vacuum sewage system. Vacuum sewers create a pressure differential in order to move wastewater, unlike the gravity system which uses gravity[39]. Systems usually have one valve that shares responsibilities for air intake and liquid intake, which help create the vacuum and move the wastewater. The wastewater is held in a tank until it reaches a predetermined level; in which case the vacuum is created and liquid helps flush the wastewater out. This system is inexpensive to install and maintain compared to other systems. If vacuum systems malfunction sewage does not spill into the canal.

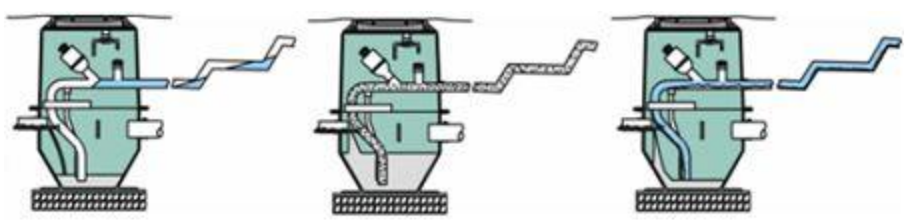


Figure 18: A conventional vacuum sewage system[40]

[39] Felices et al. "A Preliminary Feasibility Study of the Implementation of HIFLO Vacuum Sewerage System Within the City of Venice" (1997)
[40] Sivac vacuum sewer systems "Vacuum chamber package"

4.3 Calculations

In order to assess sewage output of the islands of Venice, calculations were made using the water consumption data from the 1997 project and the suspended solids formula from the 1999 project. The data from the 1997 project measures water consumption by island, in cubic meters per year. The formula given by the 1999 project multiplies cubic meters of wastewater by the average amount of suspended solids produced by each person by the average density of the sediment in canals. The resulting number shows the amount of suspended solids produced by an individual island in a year. Since the values for suspended solids produced per person and average density of sediment stayed constant, we were able to simplify the equation by multiplying water consumption per year by (0.3/1440). Since both values used similar units, the unit for suspended solids remained cubic meters. The majority of the remaining data was organized from pictures and accompanying Word documents. Some data was also organized using QGIS, a Geographical Information System.

ID	NOME	CODICE	NUM_INS	POPULATI	WATER_C	per capita	Suspended Solids per island
279			0	0	0		0
648	Rio del Du	DUCA	11	0	0	0	0
649	S. Stefano	STEFAN	11	1377	0	0	0
650	Ca' Corner	CORNER	35	110	0	0	0
651	S. Angelo	ANGELO	35	645	0	0	0
652	S. Fantin	FANTIN	1	185	0	0	0
653	S. M. Zobe	ZOBENI	1	106	0	0	0
654	S. Maurizi	MAURIZ	11	1377	0	0	0
655	Rio Malati	MALATI	1	125	0	0	0
656	Madonna	SALUTE	20	10	0	0	0
657	S. Marco	MARCO	10	0	0	0	0
658	Bacino Or:	ORSEOL	10	428	0	0	0
659	S. Luca	LUCA	35	588	0	0	0
661	Calle larga	MARZO	1	182	0	0	0
663	S. Giovanr	GRISOS	2	318	60312	189.6604	12.565
664	S. Marina	MARINA	3	375	57637	153.6987	12.00771
665	Borgolocc	BORGOL	3	77	6545	85	1.363542
666	S. Maria F	FORMOS	3	475	64218	135.1958	13.37875
667	S. Lio	LIO	3	968	132263	136.6353	27.55479
668	SS. Filippc	FILIPP	4	0	235724	0	49.10917
669	Calle Ruga	GIUFFA	4	454	47559	104.7555	9.908125
670	S. Severo	SEVERO	4	476	52510	110.3151	10.93958
671	Calle Capp	CAPPEL	3	106	7022	66.24528	1.462917

Figure 19: A sample of sewage output values

4.4 Compiling Existing Information

The majority of the data in this portion of our project was gathered from the projects A Preliminary Feasibility Study of the Implementation of HIFLO Vacuum Sewerage System within the City of Venice, Quantification of Sediment Sources in the City of Venice, Italy, and from Insula Spa. This data includes the location of septic tanks and sewage treatment centers in the city, progress made in the restoration and installation of sewage systems throughout Venice, wastewater consumption data, calculations used to find suspended solids, and other information and data.

Additionally, since the implementation of Merli Law, and the subsequent Special Law for Venice, a lot of progress has been made in the city. This map, provided by Insula, shows where major renovations and renewal have either taken place, or are currently scheduled.

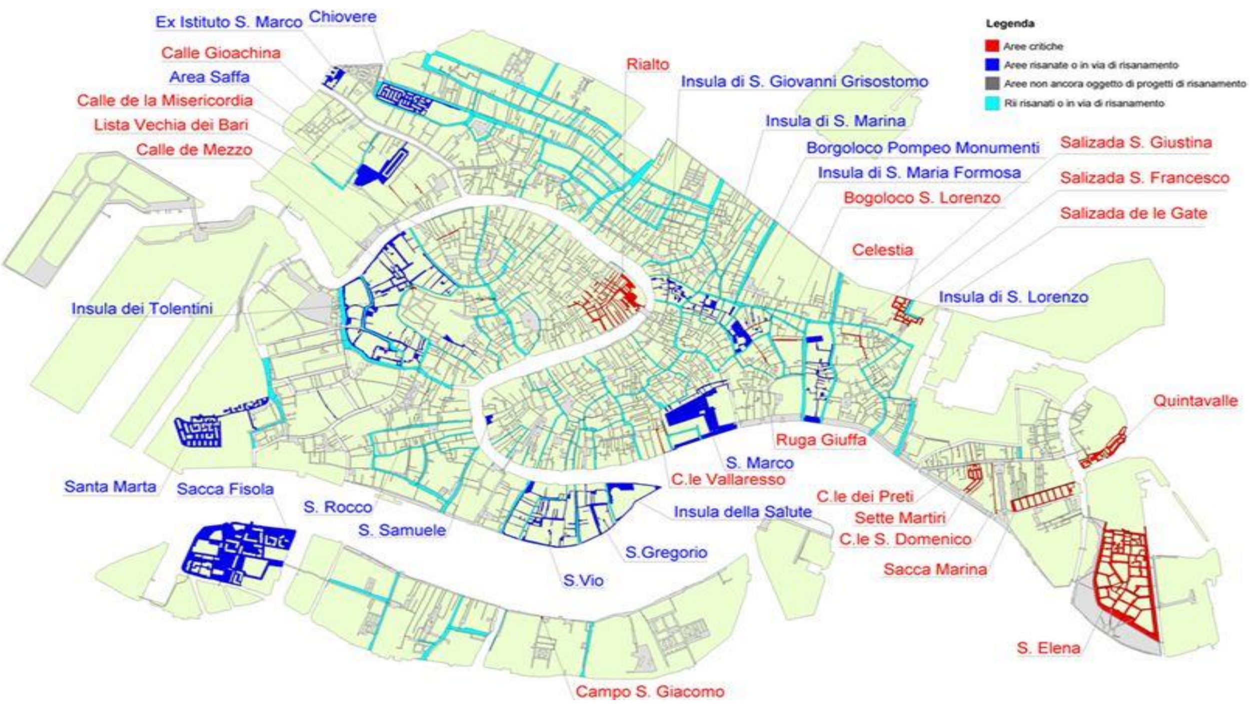


Figure 20: Insula Projects

The areas on the map in red show where renewal of the sewage system is critical. The San Marco area still needs extensive renovations done to its sewage system. The areas in dark blue show where renovations have been completed, these areas (and others not included in this map) were also completed after the exemption given by the Special Law for Venice. The areas in light blue show canals that have been dredged.

Our project also charted sewage output. This calculation was measured in suspended solids produced in cubic meters per year. Islands in white did not have sewage output data readily available to them, but it is clear to see from the islands that do have data that there is a large range of output values. The smallest measured output was San Bartolomio at approximately 0.8 cubic meters per year, and the largest output was Via Garibaldi at more than 55 cubic meters per year

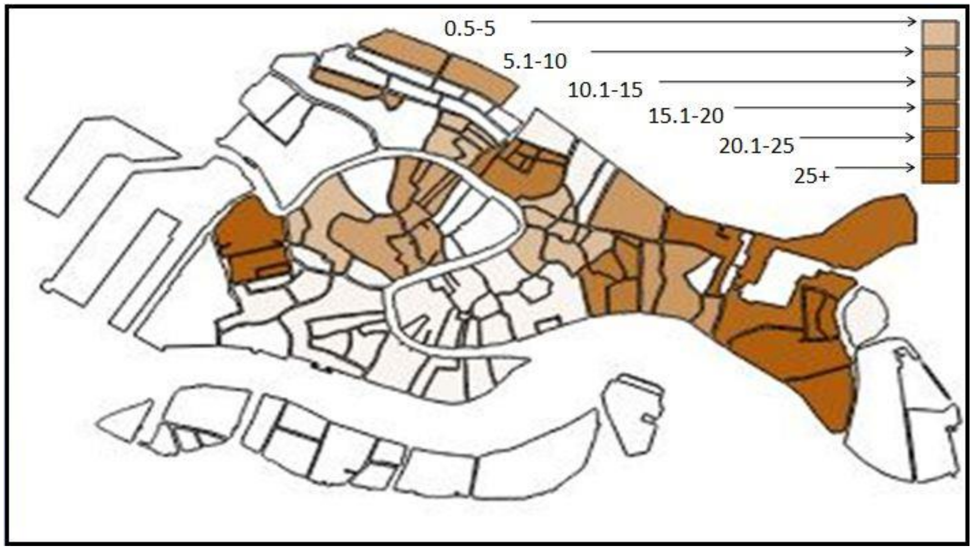


Figure 21: Sewage output by islands

Our project also obtained information about the locations of treatment centers. Venice has also made strides in its sewage treatment, and now has over 100 centers throughout the city.

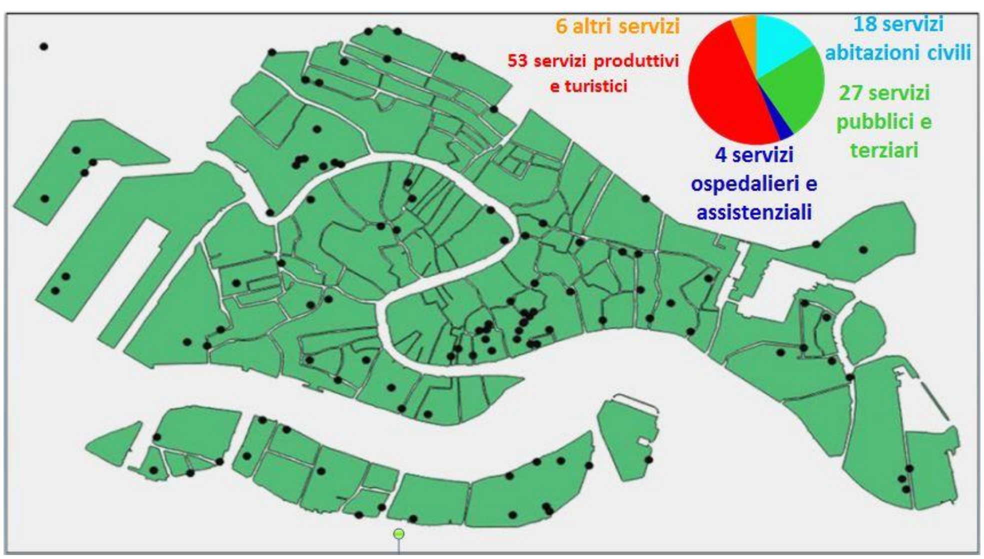


Figure 22: Sewage treatment center locations

This map, provided by Insula, shows 108 treatment centers that service a variety of locations. 53 centers serve tourists and businesses, 27 serve the public, 18 serve private citizens, 6 serve other locations, and 4 serve hospitals and health centers.

Finally, we cataloged a map provided by Insula regarding septic tanks. There are over 6000 septic tanks throughout the city that service a variety of locations.

Figure 23: Septic tank locations

4.5 Canal Maintenance Application

All of the canal maintenance information was collected into an interactive timeline of canal maintenance. A user can drag a slider to adjust the date and then all past maintenance is displayed on an interactive map. Canal segments that have had maintenance done on them in the past and are undergoing maintenance at the time on the slider are displayed. Segments that have not had maintenance done on them are also highlighted. More information is also available on maintenance by hovering over a segment.

Figure 24: The interactive maintenance timelines

4.6 Results

Although Venice has made great strides since the enactment of The Special Law for Venice, the city still has a long way to go. For instance, the Rialto, San Marco, and San Elena area are in dire need of renovations. Considering how important the Rialto and the San Marco area are to tourism, it is vital that these areas are renewed as quickly as possible. The San Elena area is just as important to shipping and industry, so the city cannot be complacent with the progress it has made. It is also worth noting that these outdated sewage systems could lead to increased sewage output. For instance, the map showing the progress the city has made contains areas in need of renovation that also produce a large amount of sewage. Some of these areas include Celestia, San Marina, Sette Martiti, Ruga Giuffa, C. le dei Preti, C le S. Domenico, and Bogolocco S. Lorenzo. This is something future projects need to continue to study and refine, as having data for the Rialto, San Marco, and San Elena areas in particular would go a long way in proving or disproving the assertion that outdated sewage systems lead to greater sewage output. Overall, the city of Venice produced over 200 cubic meters of suspended solids per year. This would be enough to fill over 70 minimally sized septic tanks[41].

Installing septic tanks and updating gravity sewage systems would go a long way towards reducing the amount of sediment in the canals; however, it still may leave them susceptible to

[41] A-1 Cesspool "Typical Septic Tank"

fines under Merli Law. Not only that, but sewage can accumulate near the sewage outlet creating blockages. If severe enough, these blockages can begin to erode away at canal walls and cause structural damage. Installing pressure sewage systems throughout the city is another option for wide-scale sewage treatment. These systems use grinder pumps to grind wastewater into a fine slurry. This wastewater makes it easier to transport and treat the sewage, while also helping prevent outlet blockages. Unfortunately, these pumps would have to be emptied often, and the extensive excavation required makes it an unsuitable option for Venice. The extensive electrical power required at each outlet location makes pressure sewage systems a non-starter. Vacuum sewers are the final and perhaps best option. Vacuum sewers can be further broken down into two options: conventional and HIFLO™. Conventional systems have already been installed in Venice, with the most notable one being in Sacca Fisola. These systems have had extensive issues, such as valves being stuck open. After discussing the matter with Alan Hassett, the inventor of the HIFLO system, it becomes clear why the conventional systems have valves that become stuck. Conventional vacuum sewers have one valve that shares responsibility for both air intake and liquid intake. Since the valves operate on a timer, a large load can disrupt the liquid intake required to flush out sewage, creating a valve stuck open or closed. These valves have required extensive maintenance on Sacca Fisola. Fortunately, the HIFLO™ system does not have this problem. The HIFLO™ system has separate valves for air intake and liquid intake, allowing it to treat a highly populated area such as Venice.

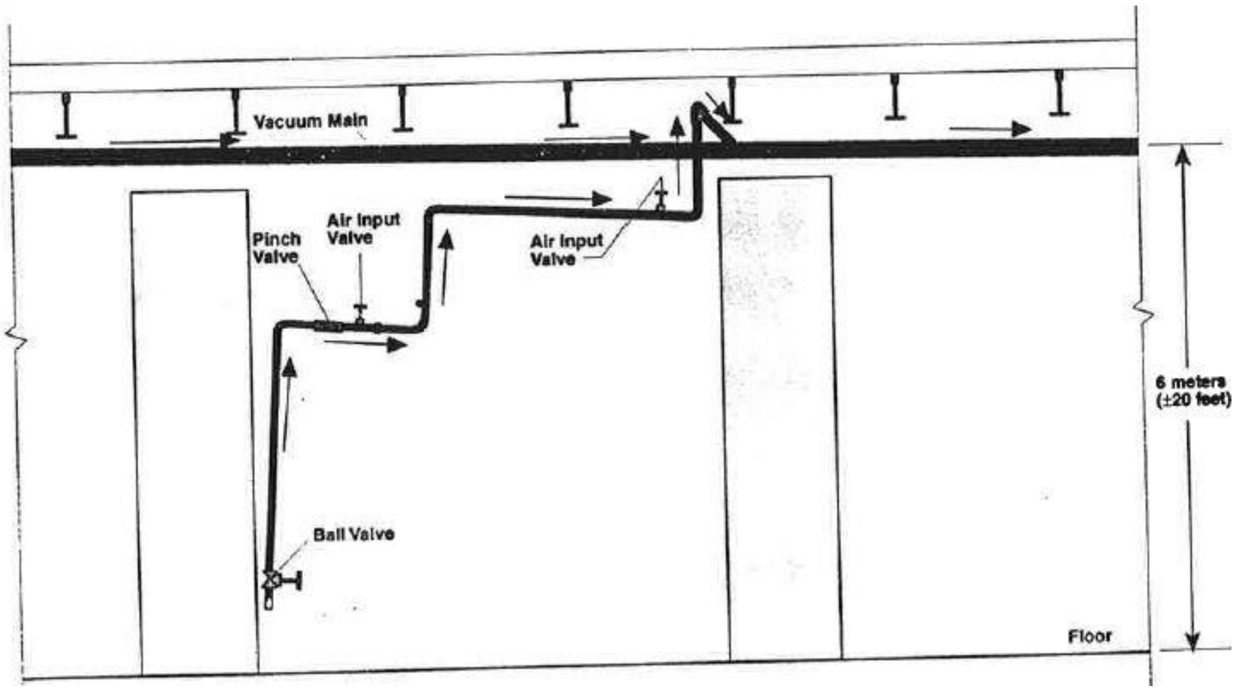


Figure 25: A diagram of a HIFLO™ sewage system.[42]

The 1997 group proposed The HIFLO™ system, but no system has been installed in Venice. This is likely due to the extensive costs of installation and treatment of the sewage. However, much has changed since that project was proposed, such as laying pipes along the bottom of canals. This would eliminate much of the excavation cost.

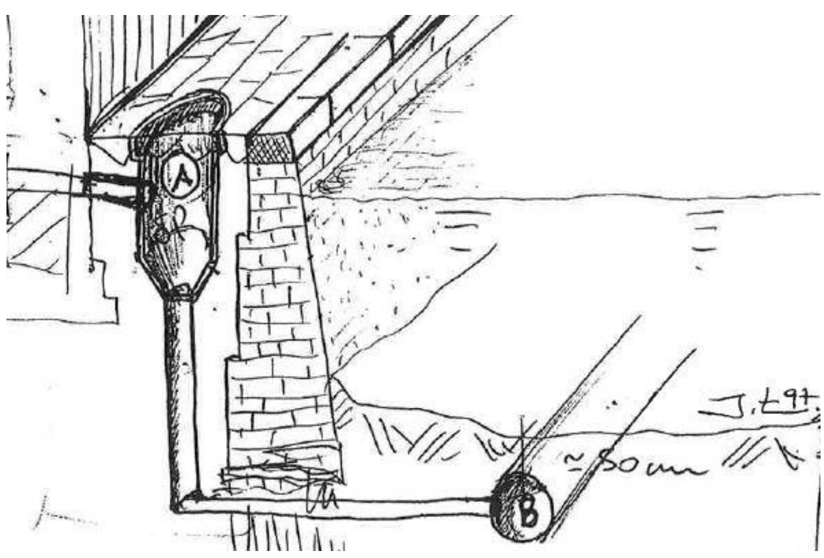


Figure 26: A sketch of what a HIFLO™ sewer system would look like in Venice

[42] Hyatt Regeny Houston "Sewers of the Future" (1995)

Future projects should look into other ways to make implementing a wide-scale sewage system more feasible, and their top priority should be making sure Venice complies with Merli Law. Future teams should look at reducing costs without compromising the somewhat fragile architecture that can be found throughout the city. Teams should revise and expand upon calculations for sewage output by island, and determine if there is any correlation between outdated sewage systems and excessive sewage output. Although compliance with the law is a top priority, reducing the amount of sewage discharged into the canals is vital to the preservation of the city.

5 BIBLIOGRAPHY

"Aqua Alta Oceanographic Tower Â€ ” Ismar." ISMAR, http://www.ismar.cnr.it/infrastructures/piattaforma-acqua-alta?set_language=en&cl=en.

Astaiza, Randy. "You Might Think These People Are Crazy for Swimming in Venice's Flooded Streets Once You See How Their Sewer System Works." *Business Insider* (2012).

Barringer, Felicity. "Both Coasts Watch Closely as San Francisco Faces Erosion." *The New York Times*, 2012/03/25/ 2012, A18(L).

Biscotti, Christine L., Andrea M. Emery, Maxwell Pistilli, and Joseph A. Zsofka. "Hydrodynamics of the Inner Canals of Venice." 1999.

Black, Kevin, Sara Migdal, Michael Morin, Dukens René, and Nick Vitello. "Urban Maintenance and Venetian Accessibility ", 2008.

Borrelli, Alexander, Matthew Crawford, James Horstick, and Izzettin Ozbas. "Quantification of Sediment Sources in the City of Venice, Italy." 1999.

"Canal - Venipedia." http://www.venipedia.org/wiki/index.php?title=Canal.

"Canals - Venipedia." http://www.venipedia.org/wiki/index.php?title=Canals.

Centre, UNESCO World Heritage. "Venice and Its Lagoon - Unesco World Heritage Centre." (sThemes All Cities Cultural Landscape Forest Marine & coastal Earthen Architecture Criteria with only with Cultural Criteria: i ii iii iv v vi Natural Criteria: vii viii ix x).

Chen, Junbo, Anthony DiNino, Zachary Mintz, and Robert Wolf. "An Update on the Hydrodynamics of the Venice Canals ": Worcester Polytechnic Institute 2011.

Chiu, David, Anand Jagannath, and Emily Nodine. "The Moto Ondoso Index: Assessing the Effects of Boat Traffic in the Canals of Venice." Worcester Polytechnic Institute, 2002.

"Citta Di Venezia - La Marea." http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1753.

"City of Venice - Distribuzione Annuale Delle Alte Maree >= +110 Cm." http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/EN/IDPagina/2968.

"City of Venice - High Water in Venice: Frequently Asked Questions (Faq)." http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/22795.

"City of Venice - Monitoring Networks." http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1649.

"City of Venice - the Exceptional High Waters." http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1850.

"City of Venice - the Tides Center." http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1644.

"Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters." The World Bank, 2009.

Company, Oak Hill. "Collection and Treatment Of "Mixed Waters" With Hiflo vacuum Technology." 2003.

"Consorzio Venezia Nuova." http://www.consorziovenezianuova.it/uk/default.htm.

"Consorzio Venezia Nuova - Activity Sectors." http://www.consorziovenezianuova.it/uk/settori_attivit%C3%A0.htm.

"Consorzio Venezia Nuova Nature and Structure." http://www.consorziovenezianuova.it/uk/natura_struttura.htm.

DeMaio, Emanuel, Emily Jones, Louie Mistretta, and Olive Rappoli. "Streamlining Canal Hydrodynamic Measurements in Venice ": Worcester Polytechnic Institute 2012.

"Dry Dredging - Venipedia." http://www.venipedia.org/wiki/index.php?title=Dry_Dredging.

"Ebb Tide (Oceanography) -- Britannica Online Encyclopedia." In *Encyclopedia Britannica*, 2013.

Felices, Martin, Lauren Goodfellow, Jay Johnston, and Sonali Maheshwary. "Preliminary Feasibility Study of the Implementation of a Hiflo Vacuum Sewerage System within the City of Venice." 1997.

Gacic, Miroslav et al. "Temporal Variations of Water Flow between the Venetian Lagoon and the Open Sea." *Journal of Marine Systems* 51, no. Issues 1–4 (2004): 33–47.
Gaul, Gilbert M. "Along the Water, Disasters Waiting for Their Moment Billions of Dollars Are Spent to Sustain Expensive Properties Imperiled by Storms.": The Philadelphia Enquirer, 2000.
"Hydrodynamics - Definition and More from the Free Merriam-Webster Dictionary." http://www.merriam-webster.com/dictionary/hydrodynamics.
Insula. "Adjustment and Upgrading of the Sewerage System." http://www.insula.it/index.php/attivita-servizi/infrastrutture-urbane-e-viabilita/179-adeguamento-e-rinnovo-del-sistema-fognario.
———. "Budget 2010."
"Iwa - Small Water Systems 2011." http://www.iwahq.org/nl/events/iwa-events/2011/small-water-systems-2011.html.
Lin, Liwei. "Introduction to Finite Element Modeling." University of California Berkeley.
M. Affholder, F. Valiron. *Descriptive Physical Oceanography*. India: A.A. Balkema, 2013.
Neumann, James. "Adaptation to Climate Change: Revisiting Infrastructure Norms." *Resources for the Future*, no. 9-15 (2009).
"Nova | Sinking City of Venice | See the Gates in Action | Pbs." PBS, http://www.pbs.org/wgbh/nova/venice/gates.html.
Poggioli, Sylvia. "Mose Project Aims to Part Venice Floods : Npr." (2008).
"Sewage Disposal - Venipedia." http://www.venipedia.org/wiki/index.php?title=Sewage_disposal#cite_ref-OECD_4-0.
Singh, David. "Us$6.7 Billion Floodgates to Protect Venice in 2014 - Unisdr." s:The United Nations Office for Disaster Risk Reduction, http://www.unisdr.org/archive/30174.
"Skills." http://insula.it/index.php/azienda/competenze.
US Department of Commerce, National Oceanic and Atmospheric Administration. "Noaa National Ocean Service Education: Tides and Water Levels: what Are Tides?" http://oceanservice.noaa.gov/education/kits/tides/tides01_intro.html.
———. "Noaa National Ocean Service Education: Tides and Water Levels: what Causes Tides?" http://oceanservice.noaa.gov/education/kits/tides/tides02_cause.html.
"Utilities - Venipedia." http://www.venipedia.org/wiki/index.php?title=Utilities.
"Wet Dredging - Venipedia." http://www.venipedia.org/wiki/index.php?title=Wet_Dredging.
"Who Is Insula." http://insula.it/index.php/azienda/chi-e-insula.

APPENDIX A: USING THE ISMAR CANAL MODEL

The ISMAR Canal Model is an application written in FORTRAN that simulates the flow of water through the inner canals of Venice. The inputs to the model are the depths of the canal segments as well as the tides heights at the boundary canal segments over the period of time that will be simulated. To compile the model you must install a FORTRAN compiler on a Linux system (we used gfortran). Then simply run make in the folder to build the project. We also had success compiling and running the model in Cygwin under Windows. The source code is in the model directory in our CODE folder.

The model simulates the canals as a graph with a number of links and nodes that are all numbered. Links start at 2001 and go to the low 3001 (skipping the upper 2000s), but in some cases they are referenced with 1 being 2001. Nodes start at 1. There is not a 1 to 1 correspondence between the links used in the model and the actual segments, but the links that overlap with a segment have been uploaded to the console. There are also GIS layers the provide locations for all of the model links and nodes. The actual graph is defined in the mygrid05NEW.txt file where the top section is node definitions and the bottom is link definitions. In the mygrid05NEW.txt file, the format is as follows.

The node format is:

Id, ?, ?, ?, is boundary node, number of segments, seg1, seg2, seg3, seg4, seg5, seg6

The link format is:

Id, ?, ?, ?, ?, ?, ?, node 1, node2

To run the model you first must obtain the input depth file. There are three provided in the model folder: zetanew.txt, zetanov7.txt (a week in November 2013), and zeta2012.txt (All of 2012). These files are generated by an ISMAR lagoon model using data from the measurements stations in the lagoon and contain the water levels at all of the boundary nodes in the model. To configure which input is used you must change a line in input.f.

```
open(unit=2,file='zeta2012.txt',status='old',err=902)  !30gg michol
```

Look for a line similar to the one above (there are a lot of them but only one is uncommented). This line dictates which file is loaded as the input. If modified then the model must be recompiled.

When running make 2 executables are built: Venice and date2. Venice will execute the actual model. Date2 is an English version of a tool to configure the model (Date is the Italian version). When you run the tool you will be prompted for a start and end date (with 24-hour time and 1 indexed month) of the input file. The start date is what is considered time 0 in the model output. 3 seconds is a good integration step. The time step for the FEM (Finite element model, the lagoon model) is normally 60 minutes. You can choose the output time step, but 60 minutes is also normally good. If the start date that you entered is at the beginning of the file then you can answer n (no) to having to ignore input lines. Then answer s (yes) to update this configuration file. This file is actually built into the model executable so after running date2 you will have to run make again. Now you can run the Venice executable to run the model. It will prompt you for manning constant, and you can answer either si (yes) or no. If you answer yes then the manning constant used in the calculations will vary by canal segment and if you answer, no then then it will be the same for all. The model will now run. It can take anywhere from a few minutes for a week of simulation to a few hours for a year of simulation. When it completes the output will be in the fort files.

The fort 11 file contains the output information for all of the links. The time step headings are formatted: time, numLinkEntries, ?

Each link row is formatted:

Id, velocity, water elevation, salinity, sediment change from initial, suspended concentration (kg/vol), suspended mass

APPENDIX B: UTILITIES FOR DATA PROCESSING

A number of utilities were created for collecting and processing information. They are all written in java and are in the iqpdataparser directory in our CODE project folder. All tools are located in their own eclipse projects and the libraries they depend on are in the lib folder. All projects are described below.

- canaldepthprocessor
  - Simple program that read canal depth file
- Datamerger
  - Program to merge data from a large collection of sources (also normalizes ids)
- Downloader
  - Program to download layers from ramses.it website
- Geojsonutil
  - Java library for dealing with geojson
- Ismarlayerparser
  - Parser of geographic data from the ismar model
- Ismarsegmentmodelparser
  - Parser for the ismar model input and output
- Maintenanceprocessor
- Marteparser
  - Downloader and parser for data from the marte maintenance site
- org.json
  - java json library
- parserutil
  - utilites for building parsers
- ramsesparser
  - Downloader and parser for data from the ramses.it site
- Storeparser
  - Parser for store data (unrelated to project)