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Quantification of Sediment Sources in the City of Venice, Italy

An Interactive Qualifying Project

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The opinions expressed in this report do not necessarily represent those of the sponsors.

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1 INTRODUCTION

The goal of our project was to contribute to the effort by Insula S.p.A to maintain the canals and thus help the citizens of Venice lead a better life, by providing accurate estimates of the amounts of sediment entering each canal which will be used by a model that is prepared by UNESCO on the sedimentation of the canals. We also contributed to the preservation of the historic city of Venice by investigating damage on the canal walls.

The following chapters of this report are organized as follows. An Executive Summary, which outlines the entire project, is contained in Chapter Two. Chapter Three of this report is the Background chapter. The first part is a description of the sponsors and the goals of our project. The next part contains a description of the Venetian sewer system and of the canal wall damage that Venice must deal with. The Literature Review for this report can be found in Chapter Four. It contains descriptions of the references we found useful in writing this IQP. Each work cited is followed by a short paragraph briefly describing its contents and the sections we found useful. Chapter Five is our Methodology section, which covers the goals and objectives of the project. It contains detailed descriptions of the procedures used to collect our data.

The Results are described in Chapter Six, which chapter contains the raw data obtained from our visual surveys of the canals and the masonry debris. The types of graphs, tables, and maps used to interpret and analyze our data are also explained here. Chapter Seven is the Analysis section, which contains details regarding the processes we utilized to manipulate our data and present our correlations. Finally, Chapter 8, Conclusions summarizes the results and explains the conclusions we drew from these results. All raw data and database structure listings can be found in the Appendices.

In order to fulfill our first goal, we located and counted active sewer outlets around 23 islands in *Sestiere di Cannaregio* to calculate the sewage output into the canals and also estimated the amount of masonry debris flaking off the walls of buildings by visually surveying an island in Cannaregio and extrapolating the results for the whole city. Both the sewage and the quantities of eroding material from walls contribute to the rising sedimentation levels in the canals, and thus were both determined and documented in order to reach our goal of helping Insula perfect its future schedule for the removal of accumulated sediment through dredging. A good canal dredging[1] schedule would help the citizens of Venice live a better life by reducing the inconvenience resulting from the maintenance interventions.

Our work in Venice was heavily dependent on the tides. The tides were low enough for us to inspect the sewer outlets on every other week with very small windows of opportunity. Appendix C contains a detailed schedule of the tides for the months June and July 1999.

Our first objective was to attempt to determine the amount of effluents going into the canals. Since it is impossible to actually measure the amount of effluents, we attempted to estimate it using several factors. Two of these factors were the water consumption per island, which was obtained from ASPIV (the Venetian water company) and the number of active sewer outlets per canal segment. These data are indicative of the rate of sediment inflow in the given canals and they will be useful tools for UNESCO to build their sedimentation model. However these data are not precise variables.

Our second objective was to determine the quantity of masonry debris that flakes off of buildings and enters the canals. This was estimated by visually surveying an island in Venice and extrapolating the data for the entire city.

Shown below is a flowchart that clearly portrays our contribution in the efforts of both UNESCO and Insula S.p.A. As explained previously, we are directly contributing data to the model that is prepared by UNESCO which will simulate the sedimentation in the canals of Venice. The documented damage on the canal walls will also be helpful for Insula S.p.A. to determine the canals that need maintenance the most and prepare their dredging schedule accordingly.

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[1] A way of maintaining the canals in Venice where the canal is closed off from two ends and the water is drained off from the area to be maintained

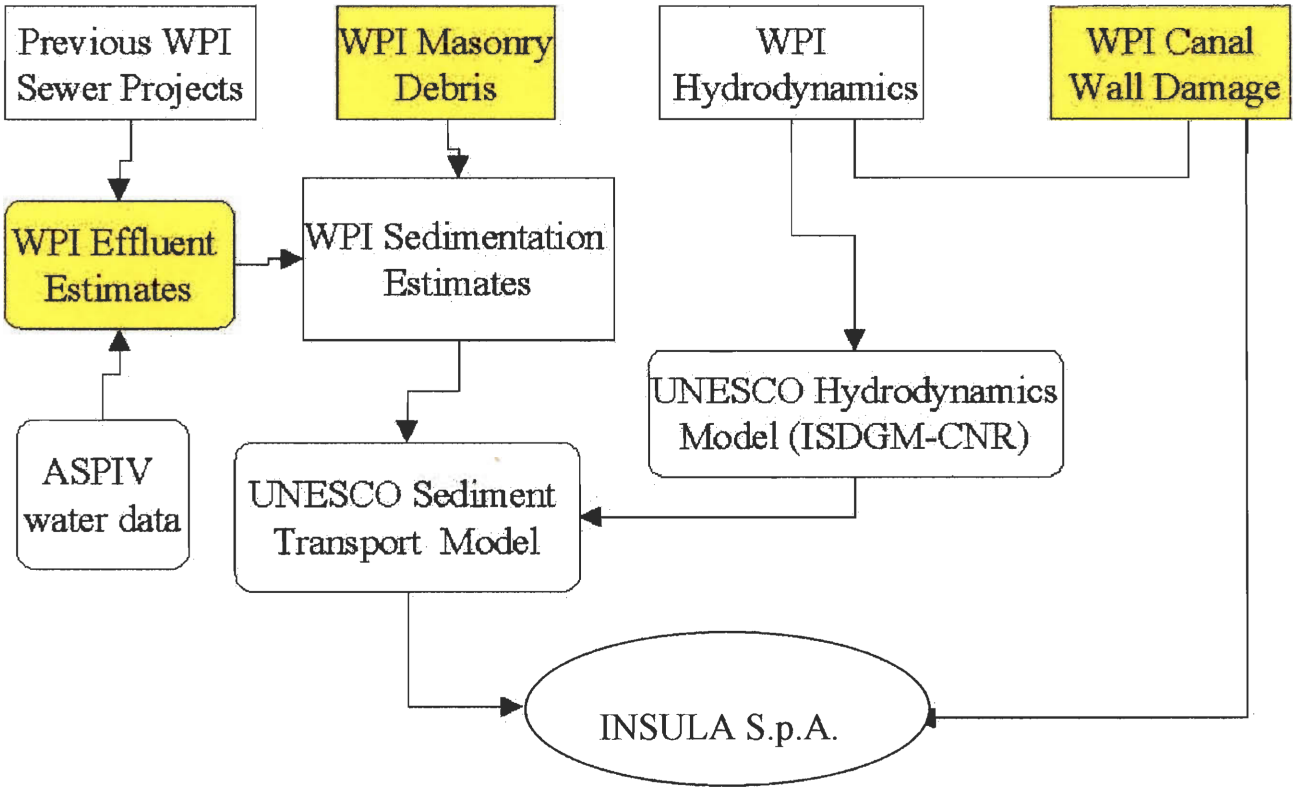

Figure 1-1 Flowchart showing the way our project will contribute to Insula S.p.A. and UNESCO 's efforts

This project entails many operations that could have a dramatic effect on the citizens of Venice. Venetians depend on the canals for daily transportation, delivery of necessities, and of particular importance to this project, sewage removal. The canals are threatened, however, by factors like pollution and rising sediment levels. For decades, this sewage system, as old as the city itself, has been taking care of the waste; however, the effects of lack of maintenance of the waste-carrying pipes and of rising sediment levels are clearly seen today. Venice's sewage pipes that are damaged or clogged cause the deterioration of the masonry in the surrounding structure because of the erosion caused by leaking wastewater. We also contributed to the conservation of the city by cataloging damage on the canal walls and determining the relation between the magnitude of the structural damage and the number of inactive outlets in the canals that were surveyed.

The main consequences of our project will ideally be an increase in the ease of traffic flow in the canals and an increase in the quality of life among Venetian citizens once the new dredging schedule is put in use. Without periodic dredging of the canals, the sedimentation levels would render the canals impossible to navigate by boats. Also, a good dredging schedule will minimize the inconvenience caused by the maintenance, which is one of the goals of Insula S.p.A, the company that has been responsible for such maintenance since 1996.

This project will benefit the tourism as well as the citizens of Venice. If the canal wall damage and the sewers are repaired properly, the canals of Venice will be both structurally and aesthetically sound. This will project a better image of the city to the people who come to see it. Even at the risk of offending tourists, Oliviero Toscani has recently produced several controversial works of art, at the suggestion of the Mayor Massimo Cacciari, to try to alert Venice's citizens and visitors of the troubles it is facing.[2]

If these problems are not addressed, serious consequences could ensue. Health problems could arise from these canals. Another problem, as mentioned before, is that the flow of traffic, especially the operation of the emergency vessels can be restricted by buildup of sediment levels. Also wall deterioration and structural failures around sewage pipes if not repaired can render buildings uninhabitable due to safety problems.

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[2] Emsden, Christopher, International Herald Tribune, *Venice Tries to Solve Its Image Problems*, July 20, 1999, p 1.

2 EXECUTIVE SUMMARY

Our overall goal for this project was to contribute to the effort by Insula S.p.A. to maintain the canals of Venice. Our particular contribution was to collaborate in the validation of the sediment transport model being developed by UNESCO. The aim of this model, once it is combined with a separate hydrodynamics model, is to predict where sediment flows and settles so that Insula S.p.A. can develop an accurate and efficient dredging schedule for the canals of Venice. Such an agenda could then be created that would minimize the inconveniences experienced by the inhabitants of Venice when canals are closed for dredging.

We developed three core objectives to achieve this goal. Our first objective was to determine the location and activity of unrecorded sewer outlets in the canals of the sestiere di Cannaregio. The second objective was to perform a visual survey of plaster deterioration to determine if the volume of plaster entering the canals is a significant component of sediment. Lastly, our third and final objective was to inspect and document the wall damage along these same canals and compare these data with that previously collected.

The canal system of Venice is similar in importance to the infrastructure of any city. Venetians rely on the canals for daily transportation, delivery of necessities, and, somewhat unique to Venice, for sewage removal. Rising sediment levels, pollution, and the resulting deterioration from these factors have taken their toll on this system, and constant maintenance is required to keep it in working order.

The sewer system itself, or *fognature*, is nearly as old as the city itself. It is comprised of a series of troughs, holding and settling tanks, and pipes that direct the effluent from the individual buildings to the canals, where it is removed by tidal flux. The exact underground routing of this system is largely unknown due to its age. The level at which the sewer outlets enter the canal was at one time strictly regulated to a maximum height of 120 cm below mean sea level. Due to rising sediment levels that have clogged low-lying outlets, new holes have been created above the older, inactive outlets. In many cases these new outlets are not properly lined up with the existing system, causing further problems and damage. Our visual survey determined how many outlets were actively discharging sewage, and therefore contributing sediment.

When sediment rises to the point where an outlet becomes obstructed, the pressure of the built up sewage can cause the pipe to rupture, allowing the effluent to permeate the canal walls and exit through any crevice available. This flow of sewage will erode the canal wall and building foundation, greatly diminishing the structural integrity of the structure. This damaged area, along with damage from other causes such as boat impact, was documented during the course of this project so that Insula S.p.A. can identify problem areas and coordinate wall repairs with their dredging schedule accordingly.

The canal survey aspect of our project in which we documented sewer outlets and canal wall damage took place during low tides due to the low placement of the sewer outlets. This work could only be done at or near low tide during the new and full phases of the moon. We were able to perform this survey on 19 separate occasions for a total of about 67 hours in the field. During the course of this fieldwork 15.3 kilometers of canal were documented and 23 islands were completely surveyed. 928 sewer outlets and over 1,000 instances of wall damage were observed and catalogued for entry into the multimedia database we compiled.

Once we had recorded the location and status of all the sewer outlets, we could then calculate the yearly contribution of sewage effluent to sedimentation in the canals by segment, based on an estimate of the volume of sewage discharge for all of Venice. Our calculations determined that 2,217 cubic meters of solids from sewage settle in the canals of Venice each year. Of the outlets surveyed, 83% were active and 15% were inactive. One-third of the inactive outlets was damaged, while only 17% of the active outlets suffered any damage.

Over half of the damaged inactive outlets inspected were found to be in close proximity to structural damage. This supports our hypothesis that when outlets become obstructed by sediment, the built up pressure inside causes them to rupture and flood the foundation of the structure with raw sewage. This sewage escapes through crevices in the canal walls, erodes the mortar and surrounding material, and diminishes structural integrity. Thus we would expect to find such a large percentage of damaged inactive outlets near this damage.

The masonry debris assessment we performed was an attempt to ascertain whether or not plaster is a significant contributor to sedimentation. A device for the collection of debris from buildings was designed and a prototype was constructed in the United States prior to the start of the project. Unfortunately, due to several factors we were unable to employ this device, and had to devise an alternative method of quantifying the plaster volume entering the canals. A visual survey was executed in which each building on a typical island was catalogued and its surface area of plaster was calculated. These measurements were used to estimate plaster volume and ultimately compute the volume of plaster entering the canals of Venice under several scenarios.

This assessment was a previously unresearched topic. Our findings were the first of their kind and proved conclusively that building deterioration is, in fact, a significant factor in the levels of sediment in the Venetian canal network. We estimated that at least 1,120 cubic meters of plaster enter the canals each year, about one-half the amount contributed by precipitating solids from sewage. This represents the average of five scenarios representing different hypotheses about the rate and the extent of plaster decay. Although not entirely accurate, due to several assumptions made, the magnitude of the estimate clearly shows that plaster is a significant component of sediment that accumulates in Venetian canals.

Armed with data on plaster and sewage contribution to sedimentation, we went on to determine the amount of sediment, if any, that is unaccounted for. Information on the levels of sediment in the canals in Venice was obtained from Insula S.p.A. and compiled with other bathymetric measurements from previous WPI projects to quantify the amount of sediment in all of Venice's canal system. When this knowledge was combined with the plaster and masonry debris figures, we discovered that there is an extremely large portion of sediment, nearly 85%, that is as of yet unidentified.

Experts on sediment transport have theorized that sand from the Lagoon and Adriatic Sea may play a major role in the sedimentation in Venice's canal network. This sand is brought into the city by tidal flux and settles in the canals. Our data supports this hypothesis and gives strong backing to the continuation of an efficient dredging schedule, as there is no effective way to prevent sand from entering the canal system. Therefore, the only way to maintain the accessibility of all canals is to physically remove this sediment periodically by dredging.

This information also rises a question on the practicality of installing a new sewerage system in Venice. If the primary motivation behind this endeavor were to decrease the sediment level in the canals, then such a project would be futile considering the figures we have arrived at. It would be a great inconvenience with little reward for the city of Venice, not to mention a sizeable financial burden. At the very least, more research has to be done to determine the extent to which various sources contribute to sedimentation, and identify these sources before any money is invested in such costly ventures.

3 BACKGROUND

This chapter contains general information about some important problems Venice is facing today and introduces our sponsors, who are trying to address these problems. The problems include public health hazards created by increased exposure to raw sewage, continuing damage to the canal walls, and increasing sediment levels in the canals.

3.1 PROJECT SPONSORS

This section gives information about our sponsors, UNESCO-ROSTE (United Nations Educational, Scientific, and Cultural Organization; Regional Office for Scientific Technology in Europe), and Insula S.p.A, a company that devotes itself to maintaining the canals of Venice.

3.1.1 UNESCO

The primary sponsor for our project is one of the Venetian offices of UNESCO, the United Nations Educational, Scientific, and Cultural Organization, whose headquarters are located in Paris, France. Our project is conducted through the Regional Office for Scientific Technology in Europe (ROSTE) in Venice. UNESCO's main objective is to encourage collaboration among the nations of the world in order to promote security and peace. They do so by using education, science, and culture to promote joint ventures and cooperation among nations. Through this cooperation a respect for human rights and the fundamental freedoms of all individuals can be built.

UNESCO was created by a unification of several other organizations that had similar goals under the United Nations. The three main predecessors of UNESCO were the International Committee of Intellectual Cooperation, the International Institute of Intellectual Cooperation, and the International Bureau of Education. UNESCO was founded on November 4, 1946 after the 20th ratification of its constitution. In order to accomplish its goals UNESCO engages in five central activities. The first is prospective studies. This endeavor attempts to determine what forms of education and communication will be most beneficial in tomorrow's world. The second activity is the advancement, transfer, and sharing of knowledge. This goal is accomplished primarily through promoting research, training, and teaching. UNESCO's third key activity is setting standards for action. This includes the preparation and adoption of international instruments and projects and research proposals that have been approved. This function serves to coordinate the scientific research efforts of member nations. The fourth activity is the providing of technical expertise to member nations. UNESCO's fifth activity is aiding in the exchange of specialized information among member nations.[3]

3.1.2 INSULA S.p.A

Insula S.p.A is an organization that was constituted in Venice on July 10th, 1997 and which deals with the maintenance of the city. The municipality of Venice owns 52% of the corporation while 48% of it is divided among ASPIV (The Venetian Water Company), ISMES (Electric Company), ITALGAS and Telecom Italy. The company has three main objectives in fulfilling its mission of coordinating and reducing the conflicts between the municipal public works department and the main public utilities. The first is to plan and carry out the maintenance of the canals while reducing the negative effects of city maintenance on Venetian residents. The second is the planning, realization, and management of an information system for city maintenance (SIMU), and the third objective is the coordination and monitoring of the jobs carried out by public utility companies of Venice.

Since its formation Insula has been mainly restoring damaged buildings, repairing canal walls and dredging the canals that get shallow over the years due to sediment buildup. Sediment buildup in the canals prevents boats from passing and clogs up sewer holes, so canals have to be dredged regularly. Figure 3-1 shows the area of sediment dredged from the canals (blue) from the year 1901 to 1996 and the area of sediment that is planned to be removed in the future (red) from the year 1996 to 2020. Some of the planned dredging from year 1996 to 2000 indicated by the first red bar has already been

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[3] www.UNESCO.org

accomplished. By looking at this graph we can see that over the last three decades there has not been significant activity in dredging, but the predictions for the future show that Insula is planning to increase the effort put into the maintenance of the canals.[4]

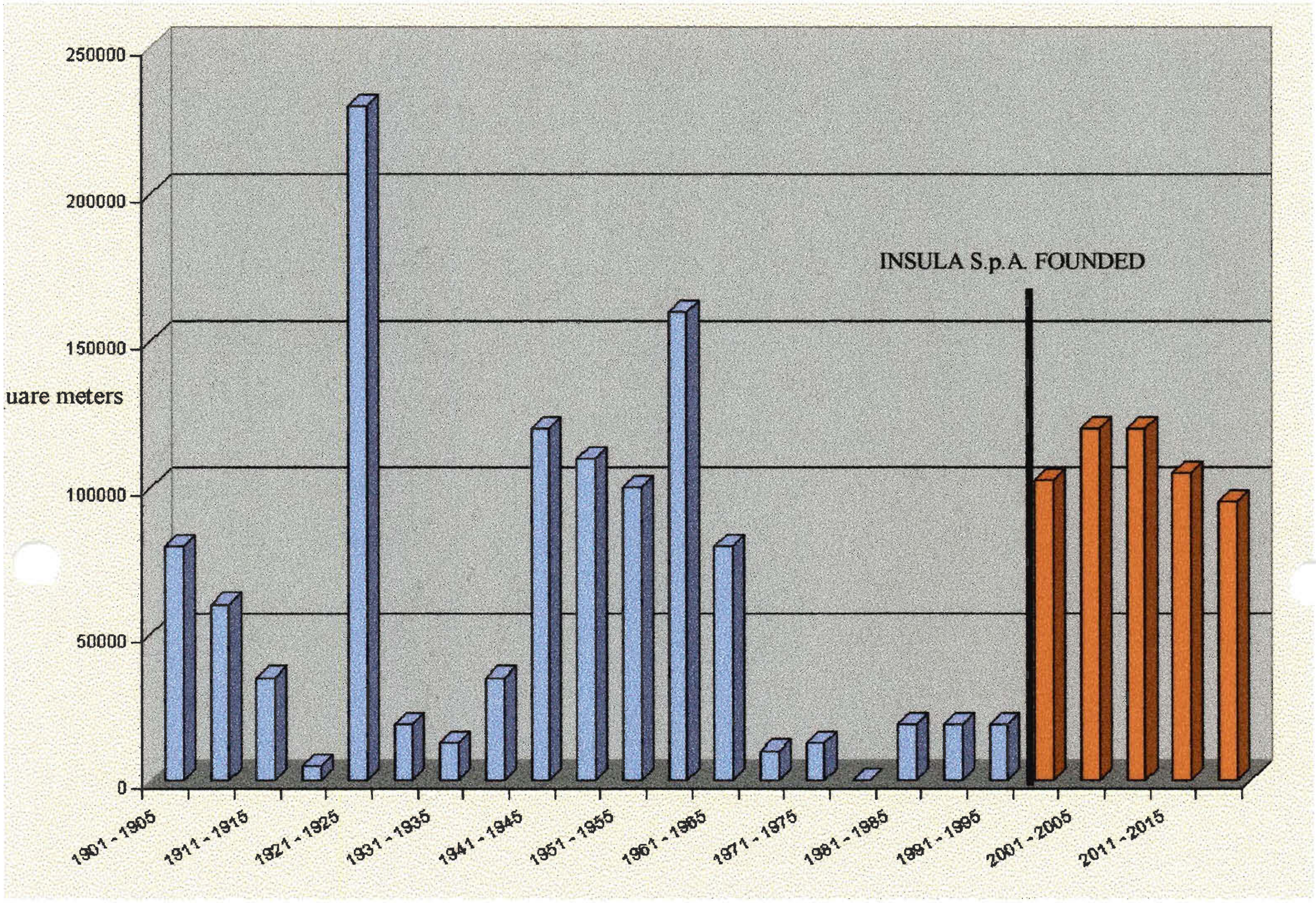

Figure 3-1 Dredging activity from the beginning of the century until present and planned up to the year 2020

3.2 THE SEWAGE SYSTEM

Venice's current sewer system, a gravity-type system called the *fognature,* has remained basically the same since the time of the Republic. It consists of three main components: the *sbocco,* the *collettore,* and the *fossa settica*. The basic function of the *fognature* is to separate heavy sewage from

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[4] www.Insula-SpA.com

lighter sewage so the material that finally enters the canals is of relatively low density. This material is then effectively flushed out to sea by the tides. Lack of maintenance has caused the *fognature* to fail and has also allowed sediment levels to increase, thus creating more pollution, degradation of canal walls, and has in some cases caused some canals to become impassable by emergency boats.

The exact underground layout of the majority of the pipes of Venice's sewer system is unknown due to its age, but the basic arrangement is as follows. Most houses not bordering a canal have their own *vasca*, a simple collection tank in the foundation of the house where the waste is deposited, which allows the heavier sewage to settle to the bottom while lighter material remains near the top and is flushed into the canals. These collection tanks need to be periodically cleaned to remove sediment, which primarily consists of organic materials.[5]

A newer type of tank is beginning to be used due to a recent law that is intended to curb pollution in Venice (Figure 3-1). This tank has three compartments that act as settling tanks to filter out the heavy waste more effectively, making it more like a *fossa settica* (septic tank). New tanks pass only five percent of the original solid sewage into the canals. These changes are part of a 23-year renovation plan proposed to prevent future problems with Venice's sewers. Installation of a vacuum sewerage system as proposed by a 1997 WPI project (see Literature Review) might also be included in this plan.

After the sewage leaves individual houses that do not directly border a canal, it enters a *collettore*, which is usually a brick trough. The *collettori* then carry the sewage to a canal through a *sbocco*, which is a circular or square outlet that deposits the sewage directly into the canals. Houses that directly border a canal deposit their waste straight into that canal through a *sbocco* without a *collettore*. Some existing problems with this system include increased sedimentation in square outlets, outlets that

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[5] Martin Felices, Lauren M. Goodfellow, Jay L. Johnson, Sonali A. Maheshwary. IQP: "A Preliminary Feasibility Study of the Implementation of HIFLO Vacuum Sewerage System Within the City of Venice", July 31, 1997.

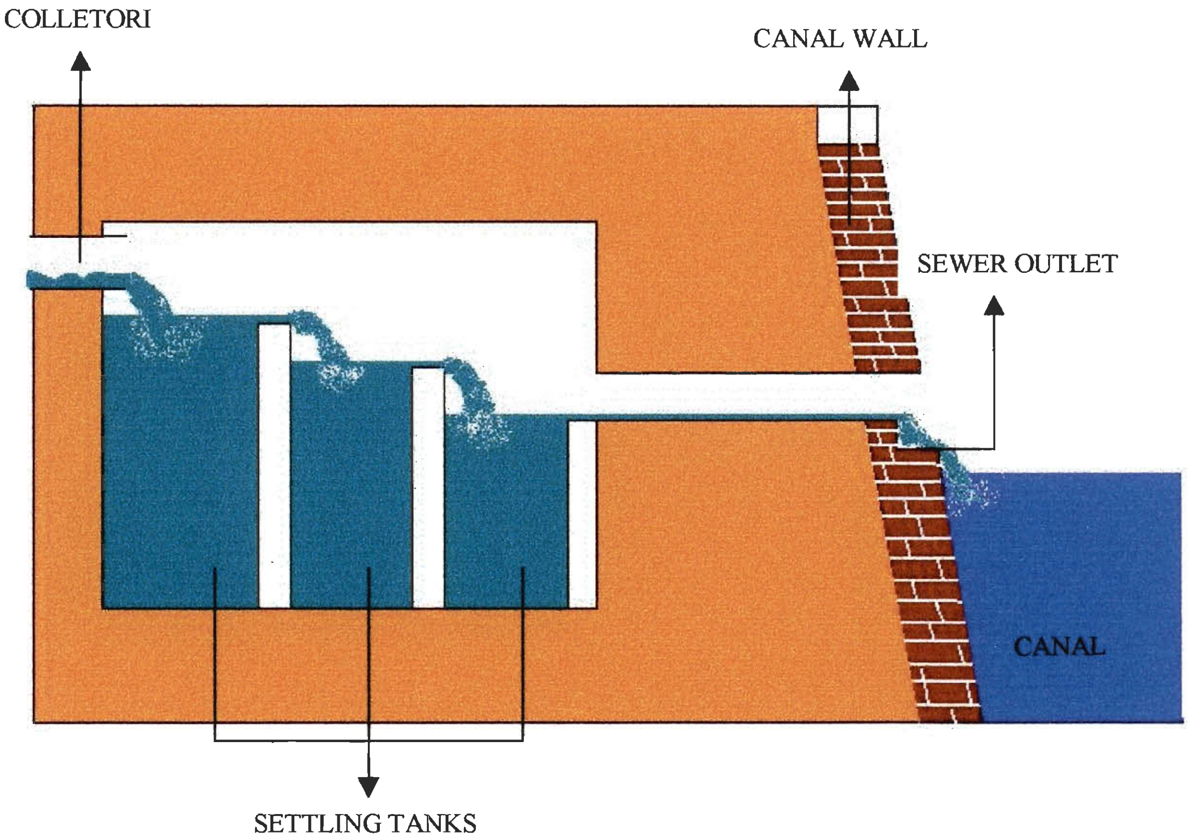

Figure 3-1 Settling tanks as shown in figure pass only 5% of solids into the canals

are not aligned with the rest of the system and do not work at all, and simple lack of knowledge about the actual hidden layout of the sewer network.[6]

3.3 CANAL WALLS

The canal walls are composed of two chief materials: Istrian stone and brick. The Istrian stone forms the foundation of the buildings because it is non-porous and therefore will not allow water to penetrate into and degrade it. The majority of the buildings are built using brick above the Istrian stone due to its availability and relatively inexpensive cost. The brick is porous, however, and can be easily corroded by contact with the salt water of the lagoon.

The water level in Venice has been slowly rising over the past several years, and this is beginning to cause structural problems in many areas. The buildings in Venice were constructed hundreds of years ago when the water level was much lower, and now the water is beginning to rise above the

Istrian stone foundation and erode the brick above. The rising water is not the only factor affecting the integrity of Venetian buildings and canals. An increase in motorized boat traffic has also caused significant wall damage. The high wakes made by such boats create turbulence that significantly amplifies the erosive effects of the salt water. Boats can also damage the canal walls through collision with the walls, which breaks the brick or stone that form the wall. This is a common occurrence at intersections and docking areas as demonstrated by a 1998 WPI project.[7]

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[6] Ibid.

[7] Christopher Babic, Michael Borek, Grant Leeds, Stylianos Sidiroglou. IQP: "Analysis of Sewer Holes and Canal Wall Damage in Venice, Italy," July 29, 1998.

4 LITERATURE REVIEW

4.1 INTRODUCTION

This section contains the references to the books, articles, previous project reports, and many other resources we used to obtain background information for our project in a more in depth manner.

4.2 RESOURCES

Christopher Babic, Michael Borek, Grant Leeds, Stylianos Sidiroglou IQP"Analysis of Sewer Holes and Canal Wall Damage in Venice, Italy", July 29, 1998.

This IQP provided information about wall damage patterns in Venice. It was also useful for general information about the sewer system of Venice.

Berry, Michael, et al. "Suggested guidelines for remediation of damage from sewage backflow into buildings." ***Journal of Environmental Health*****, National Environmental Health Association, 1994.**

This document was useful because it provided a list of pathogenic organisms that live in sewage. It also listed the effects that some of these organisms can have when they infect a person. It also contains very thorough discussions of procedures for containing and cleaning sewage spills in buildings.

Martin Felices, Lauren M. Goodfellow, Jay L. Johnston, Sonali A. Maheshwary IQP"A Preliminary Feasibility Study of the Implementation of HIFLO Vacuum Sewerage System Within the City of Venice", July 31, 1997.

This IQP provided information on the history and current state of the fognature, or sewerage system, in place in Venice. This data was useful in developing an understanding of how the sewers operate, and of the problems Venice is facing due to their disrepair.

Hammer, Mark J., ***Water and Waste-Water Technology*** **(New York: John Wiley & Sons, 1975.)**

This book is an excellent resource on the analysis of wastewater. It gives valuable information on the types of pollution and substances and organisms that are generally found in wastewater. And most importantly, this book contains information on the estimated daily amount of wastewater output from various kinds of establishments (different types of houses, hotels, restaurants) in terms of gallons per person per day. This information is extremely important for determining the amount of sewage that goes into the canals from islands in Venice. In addition to this, having a better idea about the chemical and biological substances in waste water can give us a better understanding of its effect on the structures surrounding the sewer pipes.

Tchobanoglous, George and Burton, Franklin L., *Wastewater Engineering: Treatment, Disposal and Reuse* (Boston: Irwin/McGraw-Hill, 1991.)

This book details many aspects of water treatment disposal and reuse. Using data collected from areas of the United States, this book explains how to estimate water flow rates. This may be particularly helpful to our group using the percentages given to better estimate the percentage of actual wastewater coming out of each pipe that contains sediment.

Viessman, Warren, Jr. and Hammer, Mark J., *Water Supply and Pollution Control* (New York: HarperCollins, 1993.)

This book examines many different aspects of water pollution and supply. Particularly useful to us is its information regarding water use ratios and forecasting methods. The book also gives techniques for determining these ratios for each specific type of sector, whether it is residential, commercial or otherwise. This book offers some insight as to what percentage of water used is wastewater.

Zucchetta, Gianpietro, *Canali e Rii di Venezia, Stato attuale dell'inquinamento.* (Ateneo Veneto, 1983).

This book provided us with useful information on the sewage system of Venice. Many of our calculations were based on figures from this book such as sewage density, average water consumption, and sediment composition.

“Previsioni delle altezze di marea per il bacino di San Marco e delle velocità di corrente per il Canal Porto di Lido – Laguna di Venezia, Valori Astronomici (Forecasts of the tide heights for the river basin of Saint Mark’s and of the water current for the Canal Porto di Lido - Lagoon of Venice: Astronomical values)”, Comune di Venezia, Roma Instituto Poligrafico dello Stato Libreria, Consiglio Nazionale delle Richerche, 1999.

This is a collection of charts that give forecasts about the tide heights and the speeds of currents in the Venetian lagoon. Tide heights are very important in our project because collecting data on the sewage pipes can only be done at low tide when the pipes are not under water. This booklet will help us in scheduling our tasks.

Publication of the CDC on Salmonella spp., http://vm.cfsan.fda.gov/~mow/chap1.html

This document was useful for obtaining general information about the Salmonella bacteria. It provided information such as where it is found, the incubation period, and the symptoms experienced once contracted. The document also provided a brief listing of selected outbreaks of Salmonella in the United States.

Publication of the Nemours Foundation,
http://philly.kidshealth.org/parent/common/toxocariasis.html

This document provided information on the larvae of Toxocara and how they affect children once they enter their bodies. It listed all major data on the worm such as incubation period, contiguousness, prevention, and a variety of other facts.

http://www.Insula-SpA.com **Website of Insula S.p.A**

This website provided background on Insula S.p.A and their goals to preserve the city of Venice.

http://www.unesco.org **Website of UNESCO**

This website provided background on UNESCO. It outlined the organization’s goals and purpose. This URL also gave detailed history about UNESCO.

5 METHODOLOGY

This chapter explains in detail the tasks undertaken to fulfill our objectives and reach our goals. As mentioned earlier in Chapter 1, the primary goal of this project was to contribute to the effort by Insula S.p.A. to maintain the canals and hence to help the citizens of Venice lead a safer and more comfortable life. Our contribution consisted of predicting the amount of sediment entering the various canal segments.

Our project had three objectives. The first one was to estimate the amount of sewage output from pipes emptying into the canals. Our second objective involved quantifying the amount of plaster that erodes off walls and falls into the canals. Our third objective, not directly connected with sedimentation albeit complementary, was to inspect and document the wall damage along these same canals and compare these data with that previously collected. A corollary of this third objective was to look for a correlation between sewer outlet activity and wall damage.

5.1 SOURCES OF SEDIMENT

Sediment in Venetian canals comes from three primary sources: sewage effluents, masonry debris, and the sea. Sewage effluents contain solid, organic material generated by the permanent or temporary population of the city. Masonry debris includes plaster or mortar originating from erosion of building materials due to weather factors and to capillary movement of salt through the structure. Another component of masonry debris is material contributed by the deterioration of the canal walls due to influences such as the destructive effects of motor boat wakes. This phenomenon is referred to as the "siphoning effect", which occurs when water penetrates behind a canal wall and "siphons" out the earth behind it.[8]

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[8] Phillipe Pypaert, UNESCO, Venice Office, personal communication

Sea sediment is mainly sand carried into the lagoon from the sea by the tides. The amount of sea sediment can be determined directly by:

1. Sampling water in the lagoon and inside canals,
2. Quantify & qualify suspended solids both with incoming and outgoing tide,
3. Possibly trap solids at canal entrances,
4. Analyze everything and see if there is a net input.[9]

5.2 DOCUMENTATION METHODS (CANAL SURVEY)

Accurate recording of data was an important part of this project and many tools were utilized to minimize the margin of error. Following is a description of equipment used and procedures followed during the course of the canal survey aspect of our project.

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[9] Prof. Fabio Carrera, personal communication

5.2.1 Fieldwork Procedures

To document both the sewer outlets and canal wall damage, we had to perform a visual survey of the canals. This survey, which took place mostly at night due to the schedule of low tides, required several different devices. We used a boat provided by UNESCO to navigate the canals and collect our data. Another important tool was a digital camera that allowed us to document our work and insert pictures into documents without the need for scanning. Other useful equipment included a powerful light projector (500,000 candle power) to illuminate the area that was going to be photographed and to aid in focusing, a flashlight to help us see the navigation maps and data tables, and a ruler to measure the dimensions of the damaged sections.

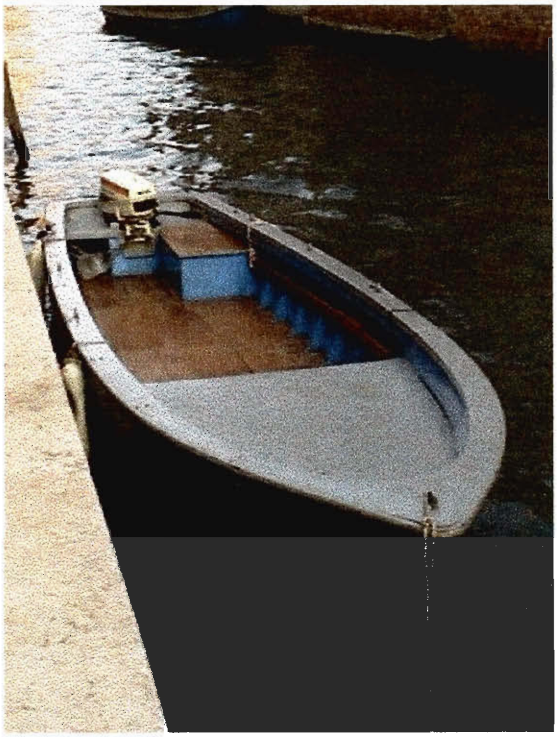


Figure 5-1 UNESCO Boat for navigating canals

The successful navigation of the boat during this survey was critical in assuring accurate results. Computer -generated maps were utilized at different zoom levels to aid in navigation and to pinpoint the location of the sewer outlets and canal wall damage. We needed a moderate-sized zoom map for navigating on the canals and finding our way to a general region, and more detailed maps to help us recognize the outlines of the buildings in order to accurately record the data points. The best way to match up the actual buildings with the map outlines was by visually following the silhouettes of rooflines.

5.2.2 Outlet and Wall Damage Documentation and Archival

We had to develop an organized and efficient method of recording our data for accuracy and also because of the limited amount of time available to perform our fieldwork. Our field notebooks were the first place in which data on outlets and canal wall damage were recorded. An excerpt of the field form used can be seen in Figure 5-1. For a complete form, refer to Appendix B.

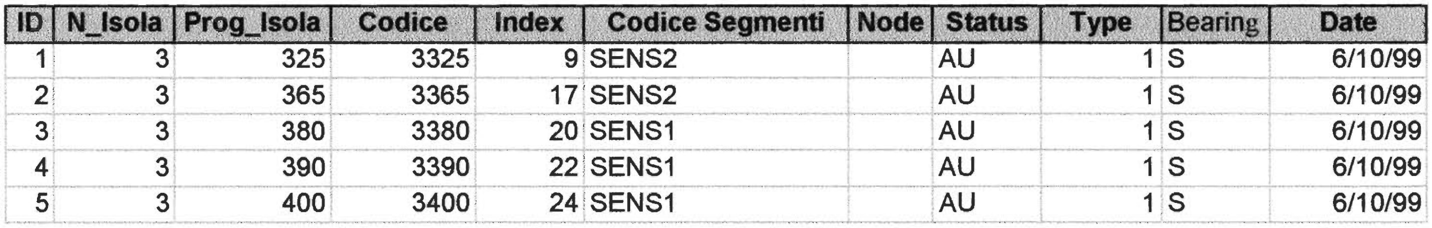
					Type:		Hole Status:				Damage Type		
Index#	Disk	Frame	Island#	Bearing	H	D	AU	AD	HU	HD	Impact	Structural	Comments
1328													
1329													
1330													
1331													
1332													

Figure 5-1 Fieldwork datasheet (excerpt)

From here we transferred the data into two separate Access databases, one for the sewer outlets and one for the wall damage, that were our primary means of data storage.

5.2.2.1 Sewer Outlet Database

The main Access database for sewer outlets was organized according to the following fields: *numero_isola, prog_isola, codice, index number, codice segmenti, node, status, type number, bearing,* and *date.* Table 5-1 shows an example of a group of entries in the database for some of the sewer outlets found during our fieldwork. Following is a brief description of the fields.



ID	N_Isola	Prog_Isola	Codice	Index	Codice Segmenti	Node	Status	Type	Bearing	Date
1	3	325	3325	9	SENS2		AU	1	S	6/10/99
2	3	365	3365	17	SENS2		AU	1	S	6/10/99
3	3	380	3380	20	SENS1		AU	1	S	6/10/99
4	3	390	3390	22	SENS1		AU	1	S	6/10/99
5	3	400	3400	24	SENS1		AU	1	S	6/10/99

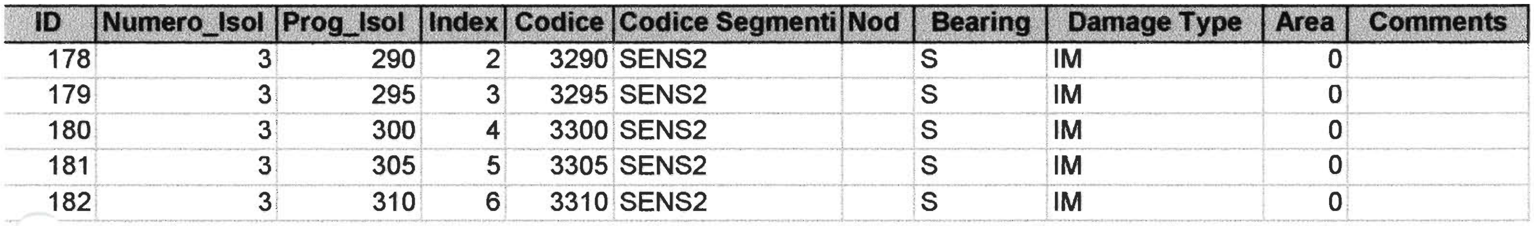
Table 5-1 Excerpt of the main sewer outlets database

- *Prog_isola* is the number of the outlet according to a specific numbering system developed by a previous project team. The system functions by starting at the northernmost point of the island and then numbering the data points in a clockwise direction in multiples of five. This format makes addition of future information easier. When a new sewer outlet or damaged area is discovered, it is given a code that is between the preceding and the following outlet or damaged section so renumbering the whole island is avoided.
- *Codice* contains the *Numero_Isola* and the *Prog_Isola* entries in an integer format. For example, a sewer outlet on island number 3 with a code number of 45 is shown as 3,045 in the *codice* field. The sole purpose of this field is to create a link between the database and the MapInfo layer created to show the locations of the sewer outlets and the canal wall damage. Because MapInfo cannot geocode tables using character fields, it was necessary to make the *codice* field an integer field.
- *Index number* is the number of the picture of the sewer outlet and also indicates the order in which the outlets were discovered.
- *Codice_Segmenti* is the code of the segment where the outlet is located.
- *Node* is used for points that occur at a T intersection and are not on a segment.
- S*tatus* of sewer outlets has been broken down into four categories: active undamaged, active damaged, inactive undamaged, and inactive damaged.
- *Type number* is also for the use of MapInfo and allowed us to generate the thematic maps displaying the various types of outlets.
- *Bearing* is the compass direction in which the outlet is facing.
- *Date* is when the picture was taken.

A structure documentation of the Sewer Outlet database structure can be found in Appendix E.

5.2.2.2 Wall Damage Database

The Access database used for recording canal wall damage was similar to that used for sewer outlets. The following fields are common to both the sewer outlet and canal wall damage databases: *numero_isola, prog_isola, index number, codice, codice segmenti, node, bearing,* and *date*, (section 5.2.2.1). Two fields are unique to this database: *damage type* and *area*. *Damage type* consists of two categories: *impact* and *structural*, (section 5.6.1). The *area* field contains the surface area of the damaged section. It was used as part of a correlation involving width and the amount of damaged surface area in a canal. For a description of the calculation method, consult section 5.6.2. Table 5-1 shows a group of entries for canal wall damage occurrences found during our fieldwork.



ID	Numero_Isol	Prog_Isol	Index	Codice	Codice Segmenti	Nod	Bearing	Damage Type	Area	Comments
178	3	290	2	3290	SENS2		S	IM	0	
179	3	295	3	3295	SENS2		S	IM	0	
180	3	300	4	3300	SENS2		S	IM	0	
181	3	305	5	3305	SENS2		S	IM	0	
182	3	310	6	3310	SENS2		S	IM	0	

Table 5-1 Excerpt of the main canal wall damage database

The complete database structure documentation can be found in Appendix E.

5.3 ESTIMATION OF SEDIMENT PRODUCED BY SEWER DISCHARGE

It is practically impossible to measure the amount of effluent pouring out of sewage outlets and into canals. However, since Venice is not served by a modern sewage system, we can assume that all of the water consumed within the confines of each island must flow out of the island and into one of the perimeter canals. So, we can base our estimates of sewage output on water consumption data, as explained in section 5.3.5.1.

To arrive at a reasonable estimate of the amount of sediment contributed by the sewer system, which was believed to be the largest contributor to sedimentation, we needed to estimate the quantity of sewer discharge into the canal network. Our project contributed to the larger UNESCO-Insula project by surveying the canals in the Cannaregio borough. To estimate the sediment entering each canal segment, we needed to know how many outlets are still actively being used to discharge sewage from each island in Cannaregio. A large part of our fieldwork was dedicated to determining precisely the number of active sewer outlets along our target canals.

Knowing the yearly water consumption for an island and having surveyed all of the surrounding canals to identify active outlets, we were able to estimate the water discharged, on average, by each outlet over the course of a year for the various islands.

maybe

5.3.1 Study Area

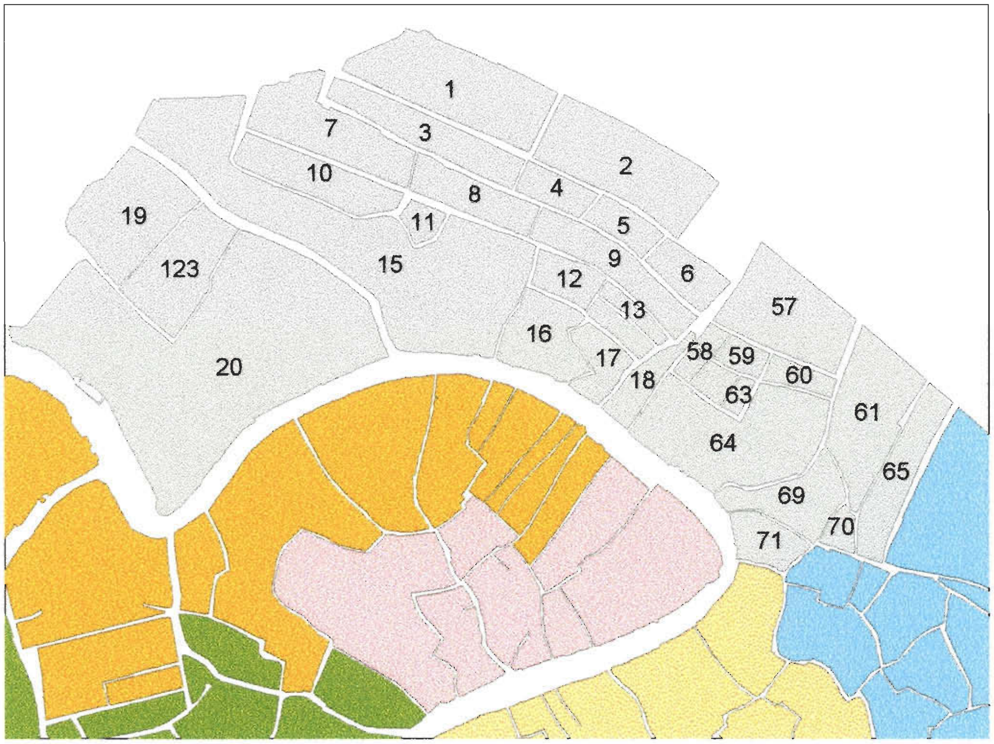


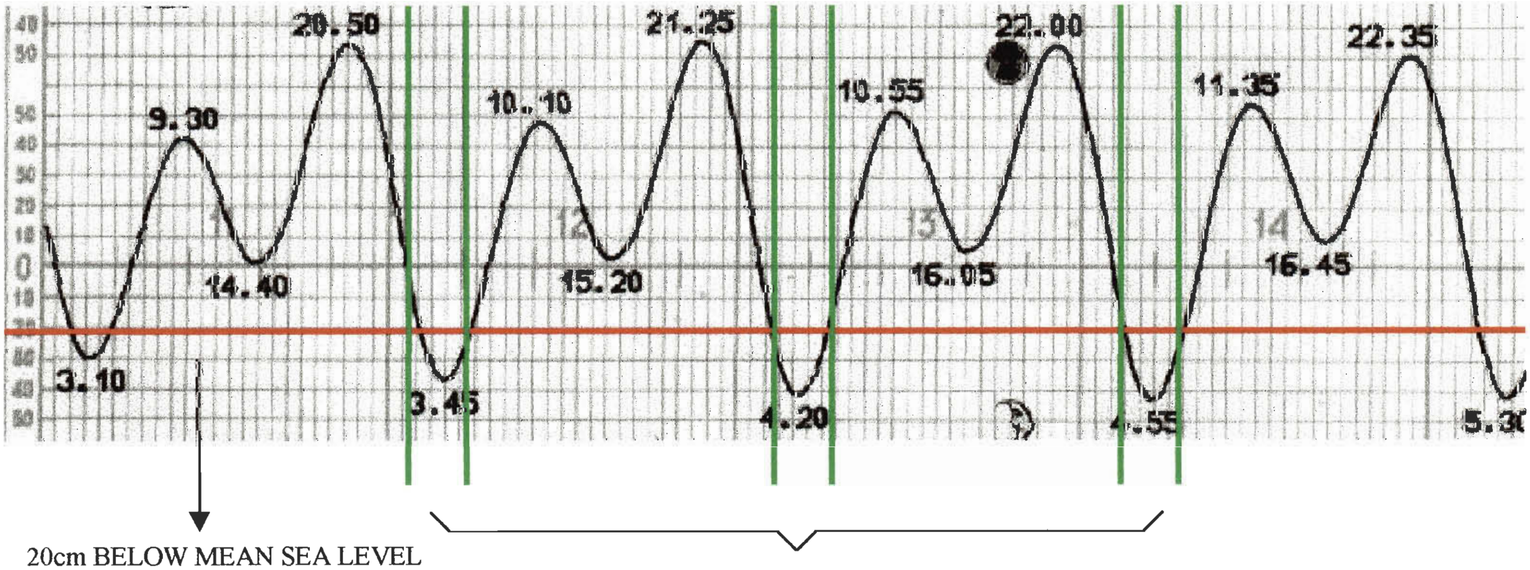
Figure 5-1 Sestiere di Cannaregio showing the numbers of all targeted islands

As mentioned, our fieldwork took place in the sestiere of Cannaregio, which is situated in the north of the city and shown in light gray in the following map (Figure 5-1). In particular, we visually surveyed the perimeters of the islands numbered 1 through 14, 57 through 63, 65, and 70 in Figure 5-1. All islands were assigned a unique number by the city of Venice and by past WPI-UNESCO projects.

5.3.2 Field Work Schedule

Sewer outlets are usually located well below mean sea level, therefore, in order to detect the sewage outlets, we had to go out when the tides were low (at least 20 cm below mean sea level) as shown in (Figure 5-1).

Figure 5-2 shows days that are unsuitable for fieldwork because the lowest points of the tides either do not go below 20cm limit line or go below for a very short time. According to the tide forecast charts for the months of June and July, 1999, most of our fieldwork was performed at night or in the early morning in most cases.



20cm BELOW MEAN SEA LEVEL
(FIELDWORK LIMIT)

WINDOWS OF OPPORTUNITY

Figure 5-1 Detail of the tide chart showing windows of opportunity for fieldwork

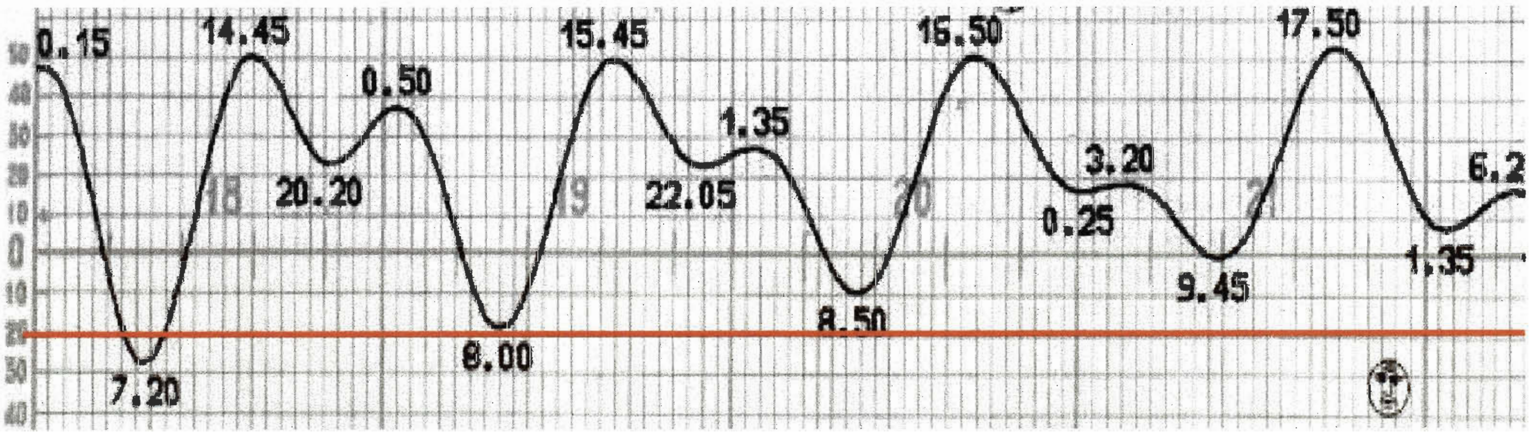


Figure 5-2 Detail of tide chart showing days that are not suitable for fieldwork

5.3.3 Documentation Of Sewer Outlet Locations

Sewage pipes in the canals were documented according to type, location, activity, and structural condition. These data were entered into a database and the location of the pipes was pinpointed on electronic maps. Outlets were also documented photographically using a digital camera, and a software program called Photo Impact was used to enhance picture quality.

5.3.4 Determination of Sewage Pipe Activity

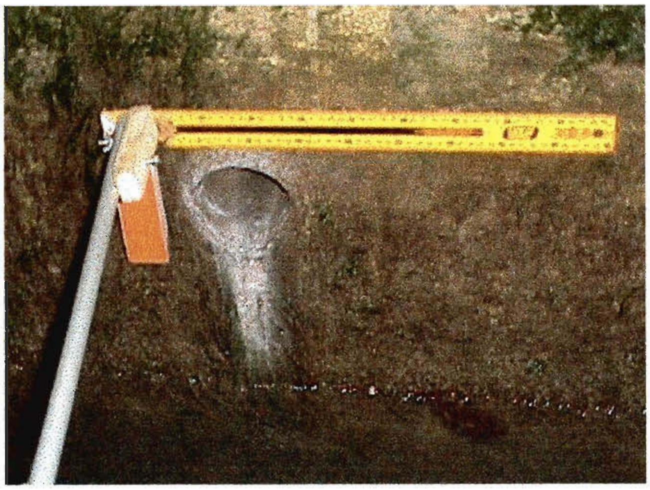


Figure 5-1 Sewer outlet with primary signs of activity

Figure 5-2 Sewage outlet with seaweed inside, a sign that it is inactive

The identification of most of the sewer pipes was straightforward, but determination of their state of activity was not so trivial. Water discharge, undesirable odors, and the absence of seaweed, moss, and algae that can grow only in salt water but not in fresh water discharges are indications of an active sewer pipe (Figure 5-1) whereas presence of seaweed inside the outlet indicated its inactive status (Figure 5-2).

A damaged outlet can be readily identified by increased occurrences of structural damage around it because the pipe is clogged or cracked. When a pipe bursts or cracks, the escaping sewage deteriorates the surrounding structure (On several occasions the sewage from an inactive, damaged sewer outlet was observed to exit through small crevices in the canal wall nearby (Figure 5-3 & Figure 5-4). This process greatly diminishes the integrity of the canal wall and eventually causes structural failure.

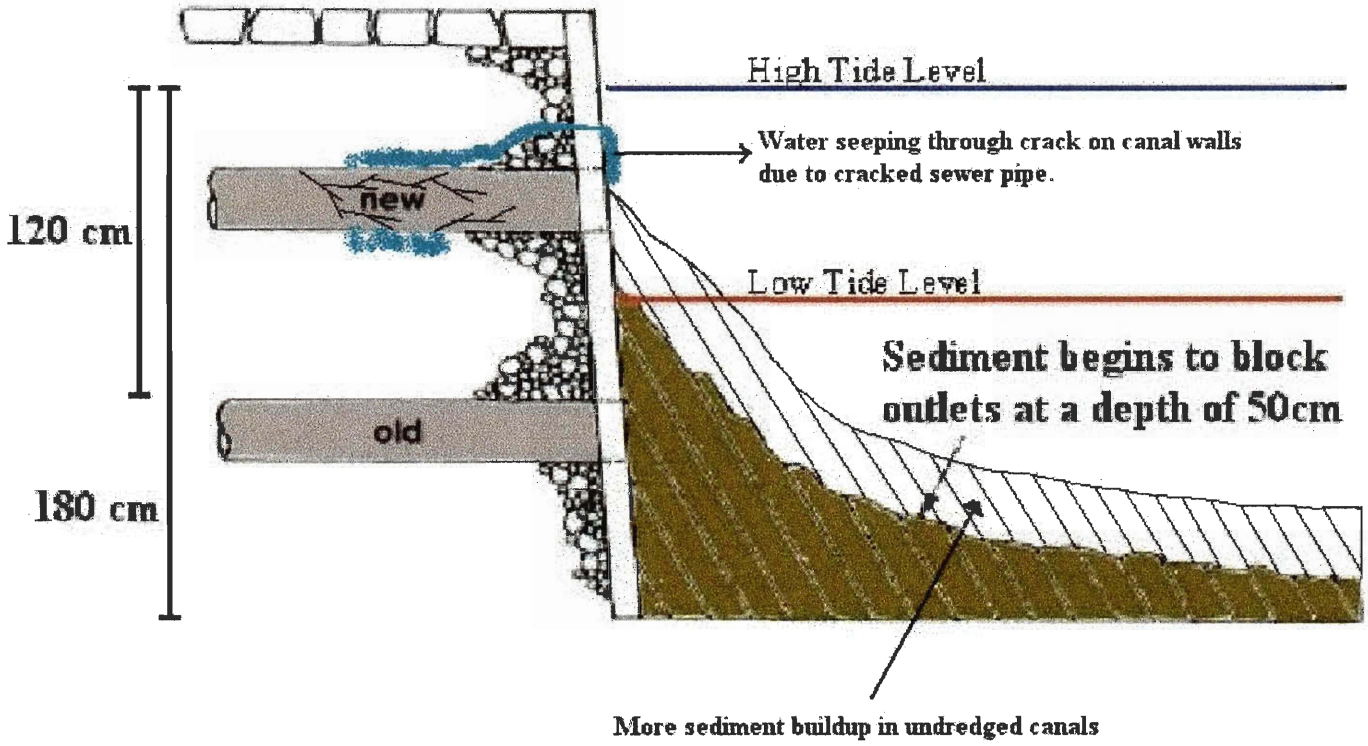


Figure 5-3 Diagram showing the formation of structural damage caused by ruptured sewage outlets

Figure 5-4 Beginning of a structural damage caused by leaking sewage pipes

5.3.5 Estimation Of Sewer Discharge

Following our field surveys, we were able to calculate the total number of active sewers (Figure 5-1) on each canal segment with the help of MapInfo, a Geographical Information System (GIS). Using this tool along with data obtained from Insula S.p.A. we were able to determine the total amount of raw sewage flowing into a given canal segment in the following way. We acquired water consumption figures for 1997/1998 from Insula and derived the average amount of precipitating solids in domestic wastewater, obtained from figures given in the literature[10], to calculate the yearly discharge per outlet. From these data we calculated the total sediment deposited into the surveyed canal segments.

5.3.5.1 Water Consumption Data

The water consumption of each island in our study area was an essential parameter for estimating sewage outflow. We obtained the data from ASPIV in the form of average monthly water consumption per billing address. With appropriate manipulations to the water database, and using spatial queries in MapInfo on a street address layer, we associated an island number to each water consumption record. These data were then used to determine the total yearly water consumption per island in cubic meters, for use in further calculations.

5.3.5.2 Estimation of Sewage Discharge per Active Outlet

The quantity of wastewater discharged from a single active pipe can be found by dividing the amount of wastewater output from one island (i.e. the yearly water consumption of the island) by the number of active pipes along the island's perimeter.

5.3.5.3 Total Sewer Outflow into a Canal Segment

Two islands border each canal segment and the wastewater output from individual islands is generally different. We multiplied waste water output per outlet on one side of the canal segment by the number of active sewer holes on that side to find the total discharge from one island into the given segment. The same procedure was then followed to find the wastewater flowing out of the island on the opposite side of the same segment. Adding these two values gave us the total amount of wastewater entering the segment in one year.

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[10] Zucchetta, Gianpietro, *Canali e Rii di Venezia, Stato attuale dell'inquinamento* (Ateneo Veneto, II Semestre 1983)

5.4 ESTIMATION OF SEDIMENT PRODUCED BY SEWER DISCHARGE

Once the total volume of raw sewage going into a canal segment was calculated, we could then determine the quantity of sedimentary matter entering the canals.

5.4.1 Obtaining the Mass of Sediment Entering the Canals

From the existing literature[11] we found that the average inhabitant of Venice consumes $0.2 m^3$ of water per day and contributes 60 grams per day of suspended solids, which will eventually settle as sediment. This gives a density of $300 g/m^3$ for precipitating solids in Venetian wastewater. We multiplied the total volume of wastewater entering a canal segment yearly by this number to get the total mass of sediment entering that segment per year as a result of sewer discharge.

5.4.2 Volume of Sediment Entering the Canals

This value then had to be divided by the average density of sediment to obtain a volume of sediment. The average density was determined to be $1440 kg/m^3$ from measurements given in the aforementioned literature.

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[11] Zucchetta, Gianpietro, *Canali e Rii di Venezia, Stato attuale dell'inquinamento* (Ateneo Veneto, II Semestre 1983)

5.5 ESTIMATION OF SEDIMENT CONTRIBUTED BY MASONRY DEBRIS

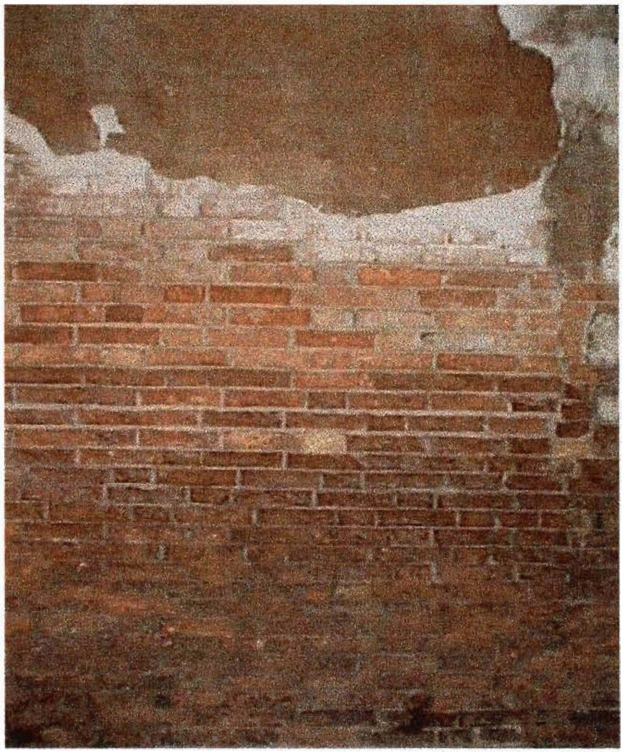

Figure 5-1 Wall segment showing partial plaster erosion

In addition to sewer discharge, it was believed that some significant amount of sediment is contributed by masonry deterioration from buildings on each island (Figure 5-1). We considered two approaches to the problem of estimating the quantity of plaster entering the canals. The first was to build a device that would be mounted on the side of a building to catch the debris, and then extrapolate the measured quantity to the entire building, to the island, and then to the whole city of Venice. Although we had designed and built a prototype of such a device in the United States, its installation proved not to be feasible for two primary reasons that will be discussed in section 5.5.1.

Our second approach involved a visual survey in which we would estimate the quantity of plaster on each of the buildings for a test island. These data could then be extrapolated to the rest of the city to approximate the amount of plaster that settles as sediment in the canals. This is the method that proved to be feasible, and is described further in section 5.5.2.

5.5.1 Quantification of Masonry Debris (Masonry Debris Device)

During the planning process in the United States, we designed and built a masonry debris-collecting device to hang on buildings. This device consisted of a trough made of tarpaulin in the shape of an asymmetrical triangular prism that would lead the masonry debris falling from walls to an inclined aluminum pipe set at an angle of 30° with respect to the ground. The masonry debris would then collect in a canvas bag at the end of the aluminum pipe (Figure 5-1). The upper part of the trough was held open by a frame made from ½ inch PVC piping. Canvas was selected for the filter bag because of its ability to hold the masonry content while filtering out rainwater.

This device could have been useful in our efforts to measure the actual masonry debris. It also would have established a time factor with which we could more accurately predict the rate of building decay, but proved to be impractical to deploy due to several reasons. Such an application would entail fastening the device to the walls of buildings, which would potentially require the use of screws or nails. This would have to be cleared with building owners and authorities before any work was carried out. Its relatively large size would have interfered with canal and street traffic due to the low level at which it would need to be mounted. The abundance of small children playing on the streets also posed a risk to the device, considering that in order to get good results the device would have to be at a height to be easily tampered with. The concept was abandoned due to all these factors. Detailed information on the Masonry Debris Device, including photographs of the prototype we constructed, can be found in [Appendix G].

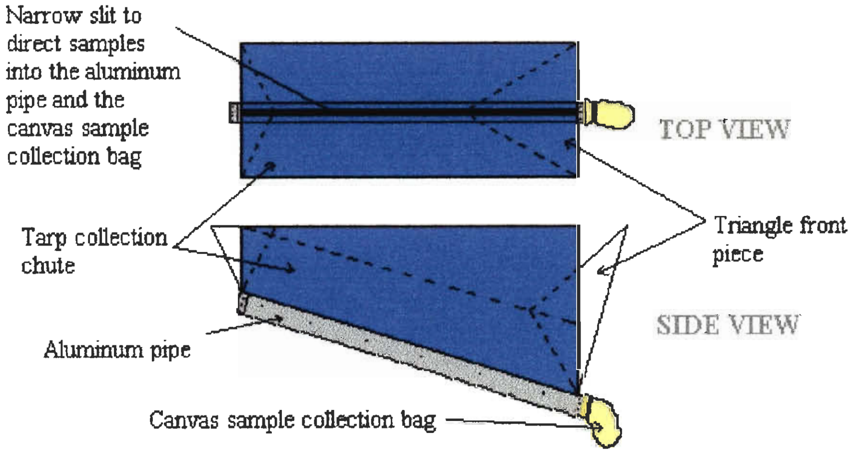

Figure 5-1 Masonry debris collection device

5.5.2 Estimation of Masonry Debris (Building Survey)

The quantity of wall debris that enters the canals was estimated by calculating the amount of plaster on the exterior of an average building, on the assumption that plaster is the primary contributor to masonry sedimentation. We further supposed that all plaster that falls to the ground would eventually find its way into a canal either directly or through street drains. To relate the amount of damage to time, we estimated the elapsed time before the plaster needs replacing with several scenarios. In order to get some real figures, we chose a test island of island 58, which is in the sestiere of Cannaregio where we were already working on the canals. Figure 5-1 shows a map of island 58. Following is a brief outline of the steps taken to complete this estimation, further details can be found in the subsequent sections.

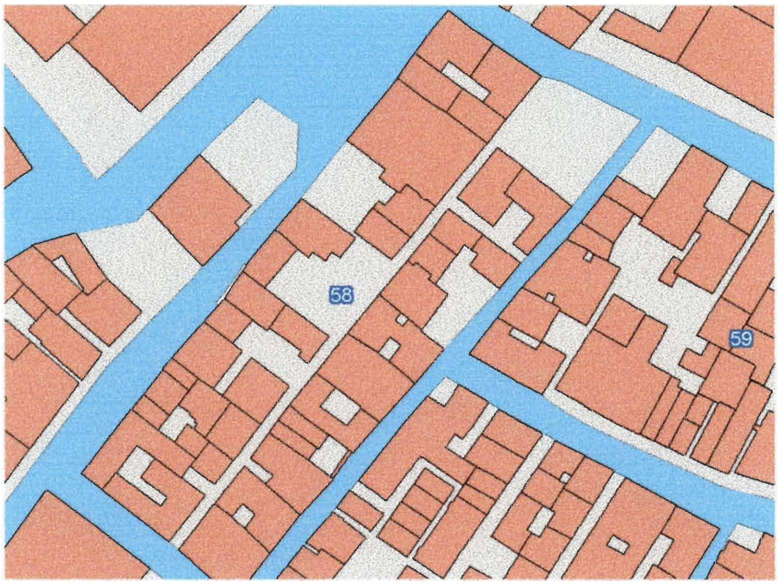

Figure 5-1 Island 58 situated in the Sestiere di Cannaregio

1. Maps were used with the MapInfo "*Edificato Nuovo Con Attributi*[12]" layer that displayed each building on island 58, and its height measurements.
2. A visual survey of each building was performed in which the dimensions of all doors and windows, the height at which plaster starts, the thickness of plaster, and the number of floors were recorded (Figure 5-2).
3. The exposed perimeter of each building was determined by subtracting the length of each building adjoining other structures from the total perimeter given by MapInfo.
4. The total surface area of each building was calculated by multiplying the height by this new perimeter value.

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[12] A layer in MapInfo that shows the outlines of all buildings in Venice, and contains several attributes related to each building, such as height, footprint area, and perimeter.

5. The plaster surface area, or façade surface area, was determined by subtracting the area of all doors and windows, as well as the area of the lower part of the ground floor not covered by plaster, from the total surface area.
6. The plaster volume was computed by multiplying plaster surface area by thickness of the plaster.
7. The plaster volumes for each building on island 58 were added together, and divided by the total building footprint area on the island (obtained from the "*Edificato Nuovo Con Attributi layer*") to give average volume of plaster per square meter of building footprint.
8. This value was multiplied by total building footprint area for the city of Venice to arrive at an estimate of total quantity of plaster for the entire city.

Figure 5-2 Diagram showing parameters for calculating quantity of plaster and estimated rate of deterioration

5.5.2.1 Calculating the Surface Area of Plaster (Island 58)

Figure 5-1 Detail of island 58 showing the perimeters of buildings

To find the surface area that is covered by plaster for each building, we first extracted the perimeter length of each building from MapInfo (Figure 5-1). We then measured and subtracted the lengths of these walls in contact with other buildings from the total perimeter. The remaining perimeter length was multiplied by the height to give the total exposed surface area. The area for windows, doors and the unplastered space at the ground floor was surveyed and subtracted from the total wall surface area to give façade surface area.

5.5.2.2 Calculating the Total Volume of Plaster

Using the façade surface area that was determined (Section 5.5.2.1) we were able to calculate the total volume of plaster for each building by multiplying this area by the thickness of the plaster.

5.5.2.3 Estimation of Plaster decay over time

Due to the fact that a comparison of plaster decay over time was not known we had to find a method to estimating it. Five rates of deterioration were considered to better estimate the quantity of plaster entering the canals of Venice per year.

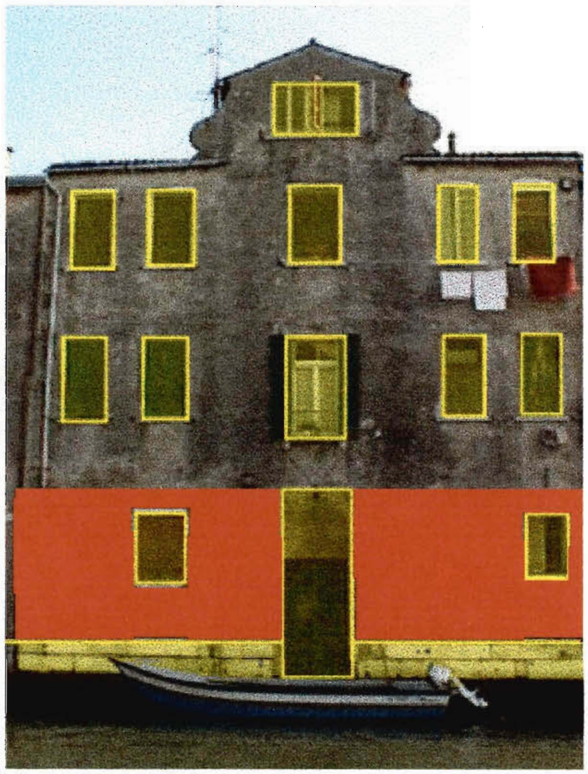


Figure 5-1 Scenario 1: 33% of the plaster off the building deteriorates in 20 years

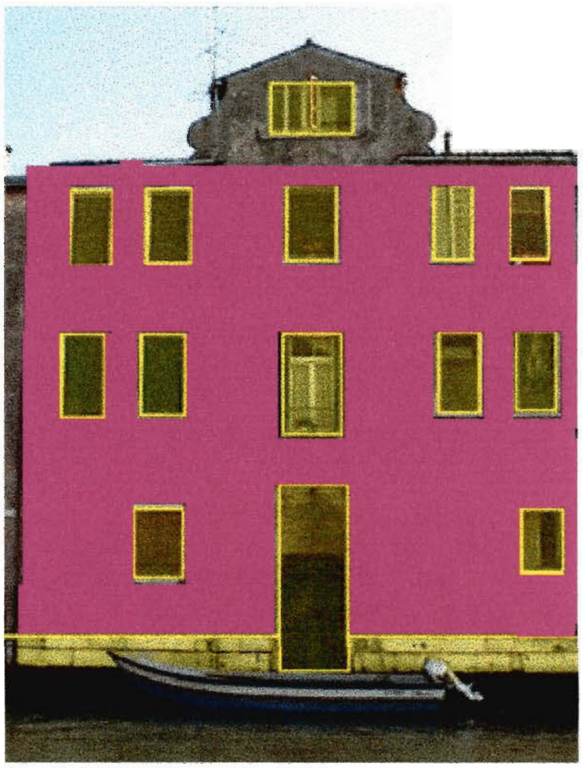


Figure 5-2 Scenario 2: 100% of the plaster off the building deteriorates in 50 years

In Scenario 1, we predicted that 33% of the plaster would deteriorate off of the building in 20 years. This area is shown in red in Figure 5-1.

For Scenario 2 we predicted that all of the plaster would eventually fall off of the buildings after 50 years, assuming that the buildings are not repaired. In this case we used the entire amount of plaster-covered surface area to determine the volume of plaster deposited in the canal. In Figure 5-2 this area is represented by the magenta.

Scenario 3 assumes that 33% of the bottom two floors deteriorates in 10 years, while Scenario 4 assumes that same area but in 5 years. These two scenarios are represented in Figure 5-3and Figure 5-4 respectably.

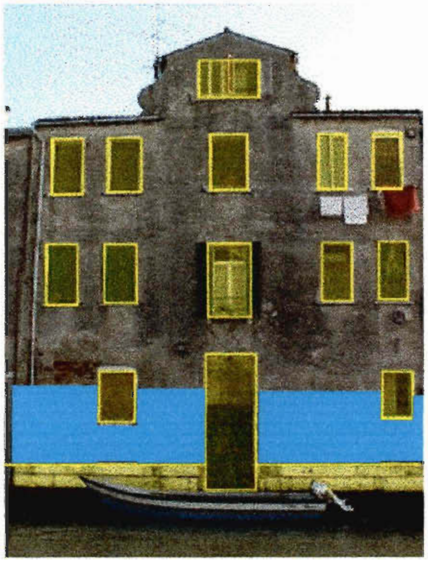


Figure 5-3 Scenario 3: 33% of the bottom 2 floors decay in 10 years

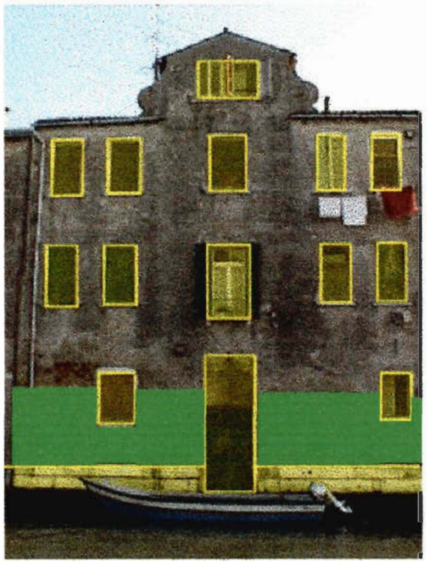


Figure 5-4 Scenario 4: 33% of the bottom 2 floors decays in 5 years

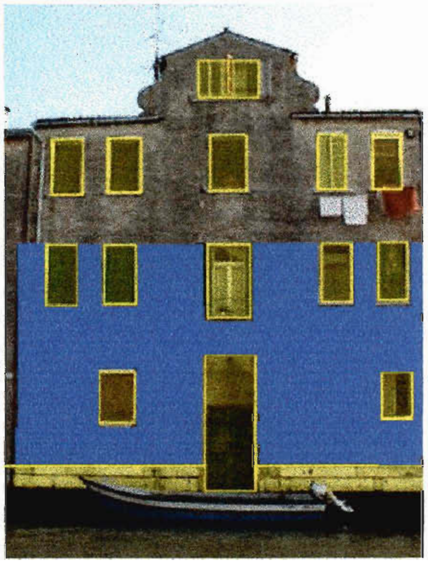


Figure 5-5 Scenario 5: 100% of the bottom 2 floors deteriorates in 10 years

In Scenario 5, Figure 5-5, 100% of the bottom two floors is assumed to deteriorate in 10 years and is shaded in blue.

Scenarios 1, 3, 4, and 5 are more representative of what actually occurs: plaster deterioration begins at the ground floor and continues up the building and is usually repaired before the entire building is affected. But on occasion it is actually left to deteriorate for the entire building such as in Scenario 2.

Once the volume was calculated for each building on island 58, we could then add these figures together to get the total volume of plaster entering the canals from the test island for both best- and worst-case scenarios. An assumption had to be made to extrapolate these results to the entire city of Venice, namely, that the total volume of plaster that makes its way into the canals as a function of the total surface area covered by building footprints as well is the same for all the islands of Venice as it is on island 58. We had to use the MapInfo "*Edificato Nuovo Con Attributi*" layer once again to find the total surface area that was covered by buildings on island 58 (Figure 1-1). This same layer was then used to determine the surface area covered by buildings on all other islands in Venice using the same proportion of footprint surface area to volume of plaster. Again assuming a homogenous behavior of all the islands that make up the city, we extrapolated our results to all of Venice.

Figure 5-6 Part of island 58 with areas of buildings shown

5.6 DOCUMENTING CANAL WALL DAMAGE

Figure 5-1 Image showing canal dredging in progress

This portion of our project did not deal directly with sedimentation but concerns another aspect of canal maintenance, the restoration of canal walls (Figure 5-1). The repair on most types of canal wall damage can only be done by draining the canal segment where the damage is present. Our purpose in documenting canal wall damage is to provide supplemental data to Insula S.p.A. for the canal-dredging schedule they are preparing.

5.6.1 Photographic Documentation of the Canal Wall Damage.

The documentation of the canal wall damage was done simultaneously with the survey of the sewer outlets and in a similar manner (Section 0). A 50-cm ruler was used to measure the damaged section. In the photographs taken by the digital camera, the ruler could be used as a reference for measuring the size of the damage, thus allowing future groups to compare our data with any new information they collect (Figure 5-1).

The observed damage was divided up into two categories: impact (Figure 5-2) and structural (Figure 5-1). Impact damage occurs most frequently at loading docks and corners. As its name suggests it is due to an object, most likely a boat, colliding with the area. Such a collision can cause cracking and displacement of the stone. Structural damage occurs in the middle of canal segments and may be due to ruptured sewer pipes or the effects of motorboat wakes.

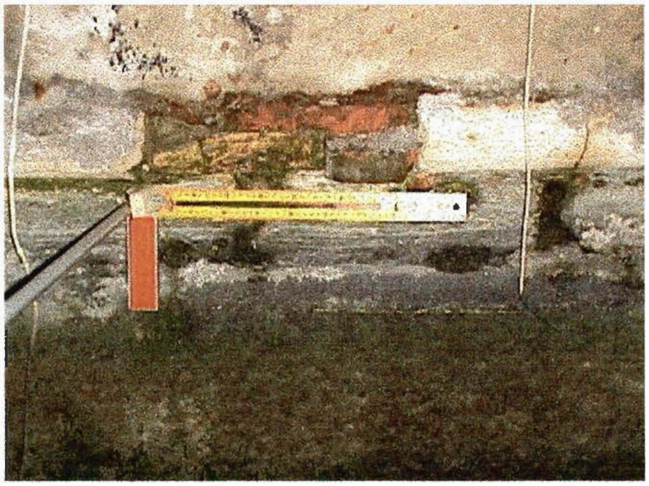


Figure 5-1 Image showing damage to istrian stone which is structural in origin and ruler used for reference

The information on the size and number of occurrences of structural wall damage was used along with the sewer outlet activity data in order to establish a correlation between the area and number of occurrences of wall damage and the number of inactive sewage pipes.

Figure 5-2 Picture showing impact damage on stairs

5.6.2 Calculation of Canal Wall Damage Area

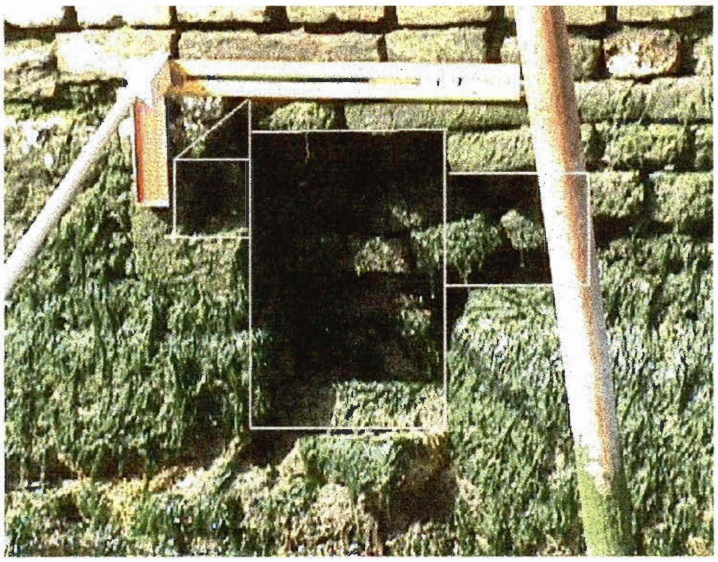


Figure 5-1 Damage on canal wall partitioned into basic geometric shapes for area calculation

Once the damage was documented we then proceeded to calculate the surface area for each occurrence that was found. We did so by first superimposing simple geometric shapes on the damage image and then calculating the area of these shapes. Figure 5-1 shows an example of the way the geometric shapes are fitted onto the damaged area. We calculated the area of each individual shape and added them together to find the total surface area of the damage image. The known length of the ruler, 500mm, was then used to calculate the actual surface area of the damage. Below is the actual formula that is used to calculate the area of the canal wall damage.

$$Area = \left[\sum_{\text{Rectangle}} (Length * Width) + \sum_{Triangle} (Base * Height) \right] * \frac{500\hat{}2}{Ruler\_Length\_In\_Picture\hat{}2} * 0.001\hat{}2$$

The last part of the equation where the actual ruler length is divided by the ruler length in picture converts the area on the picture frame to the actual area of the wall damage. The result is in square millimeters however, so the area is multiplied by the square of 0.001 to convert it to square meters.

6 RESULTS

This section presents the raw data obtained from our fieldwork. The organization of our tables and various means of data storage are also explained.

6.1 Results of Sewer Outlet Survey

The following subheadings contain the data from our study of the sewer outlets in Cannaregio. Table 6-1 lists the number of outlets found on islands that have been surveyed and gives percentages for each type. As can be seen from this table, 84.1% of the sewer outlets surveyed are active. Of these, 82.8% are also undamaged. Inactive outlets accounted for 15.9% of those documented. Of these outlets 64.1% are damaged as well as inactive. The majority of the outlets surveyed have been found to be in working order. Figure 6-1 shows a map with the positions of all documented sewer outlets in Cannaregio.

	Occurrences	% of total
Active Undamaged	635	69.7%
Active Damaged	131	14.3%
Inactive Damaged	93	10.2%
Inactive Undamaged	52	5.7%
Total Number of Outlets	911	100%

Table 6-1 Number and condition of sewage outlets surveyed in Cannaregio

Figure 6-2 displays a more detailed map with the locations of all the outlets for island 3. On this map all sewer outlets, regardless of condition, have been given the same symbol. In MapInfo one can simply click on the marker to get information about a particular outlet because each object is geocoded to the main databases for sewer outlets.

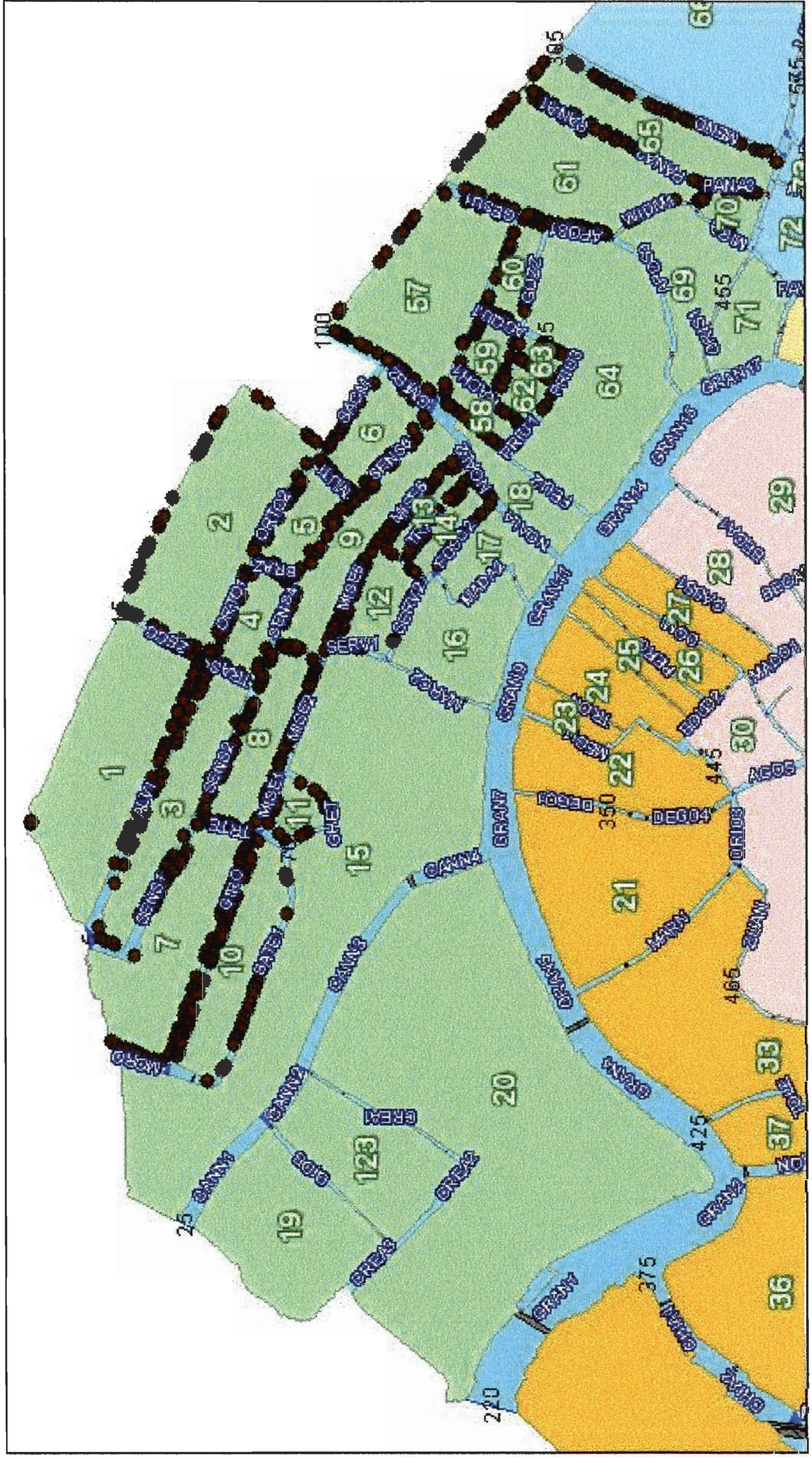


Figure 6-1 Map showing the positions of recorded sewer outlets in Cannaregio

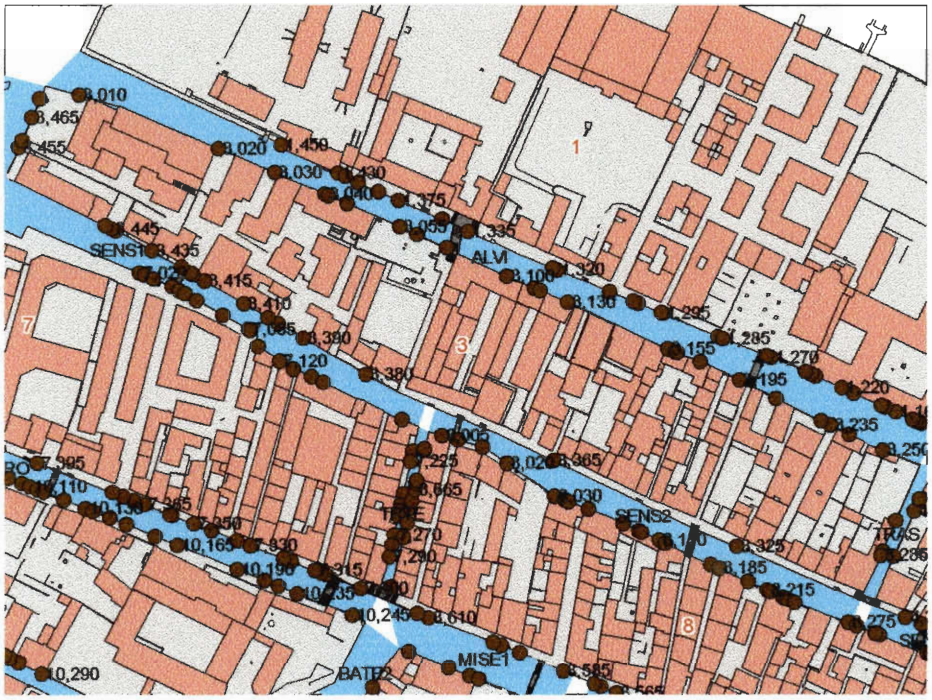


Figure 6-2 Example of sewage outlets located around island 3

Table 6-2 shows a breakdown of the data for island three. As can be seen, 55.6% of the outlets on island three are active and undamaged while 4.4% of them are active but damaged. Of all the outlets 60% are active. The inactive outlets are almost equally divided between damaged and undamaged.

	Occurrences on Island 3	% of total
Active Undamaged	25	55.56%
Active Damaged	2	4.44%
Inactive Damaged	10	22.22%
Inactive Undamaged	8	17.78%
Total Number of Outlets	45	100%

Table 6-2 Number and condition of sewage outlets for island 3

6.2 Comparison of Old and New Data for Misericordia Canal

During our fieldwork we had an opportunity to recheck data taken by a previous IQP team in 1992 along the Misericordia canal (segments MISE 1 – MISE 6 in Figure 6-1). We found that, for the most part, these previous data are correct and reliable for the sewer outlets. However, the data for island 11, the "Ghetto" of Venice (Figure 6-2), showed major discrepancies. All of the outlets recorded by the 1992 team are not currently visible. This may be due to the fact that the Misericordia canal was recently dredged. During that process the holes may have been closed off during wall repairs. This supposition is rendered very probable by the observation that seven of the ten holes on the side of the island bordering canal segment MISE 1 were blocked at the time of dredging as found by a previous WPI team. The canal wall damage data showed major inconsistencies as well. This is also most likely due to the fact that the canal walls were repaired during the recent dredging.

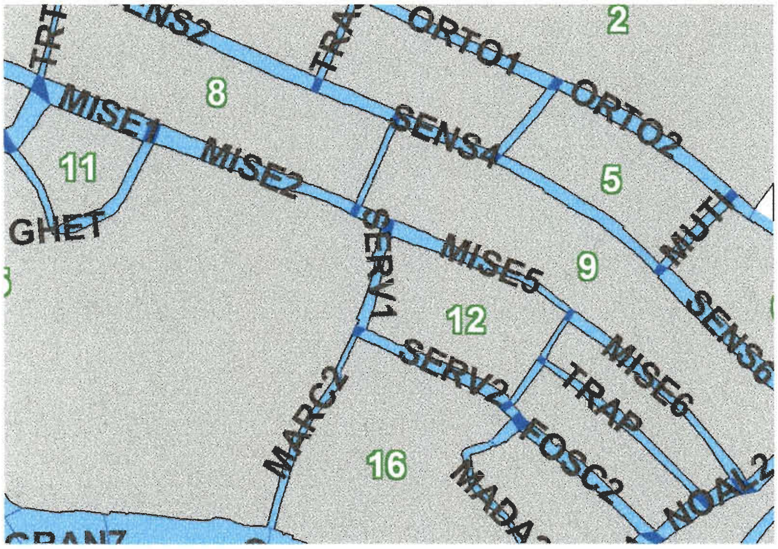


Figure 6-1 Map showing the "Misericordia" canal which is bordered by islands 8 and 9 on the north and by 11, 12, 13 and 15 on the south

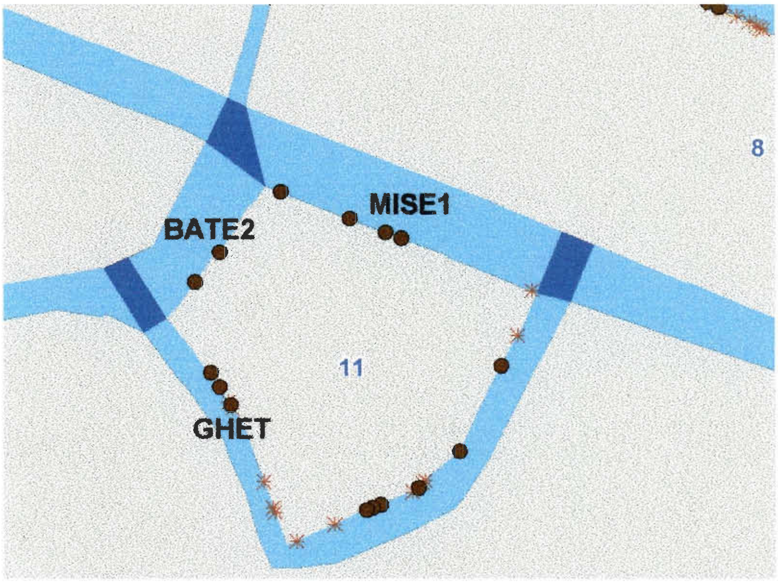


Figure 6-2 Island 11 with the position of current sewer outlets and canal wall damage

6.3 Results from Our Calculations on Sewer Discharge

This section contains samples of data from the series of calculations necessary to ultimately determine how much solid effluent actually enters the canals. Descriptions of the calculations used to generate these numbers can be found in section 5.4 of the methodology.

Island Number	Total Water Consumption (m^3)
1	62232
2	87216
3	51000
4	13860
5	21924
6	12060
7	56652
8	52464
9	44880
10	57744
11	12960
12	1176
13	8208
14	9744
15	444600
16	77580
17	28740
18	27024
19	42984
20	321204
57	69456
58	10284
59	9996
60	16380
61	113184
62	16536
63	5868
64	175116
65	63936
69	79164
70	8640
71	49464
123	32328

Table 6-1 Water consumption for all islands in Cannaregio

6.3.1 Water Consumption

The water consumption data was given to us in the form of consumption in cubic meters per billing address per month. The numbers are an average for the years 1997 and 1998. Table 6-1 displays the total water consumption per year for every island in Cannaregio. The highest consumption occurred on island 15, with 444.600 cubic meters. Island 12 consumed the least amount of water, only 1.176 cubic meters. Figure 6-1 is a thematic map showing monthly water consumption for Cannaregio. The scale on the map ranges from zero to 57.700 cubic meters. Shades of blue define the amount of water consumed, a darker shade indicating higher water consumption.

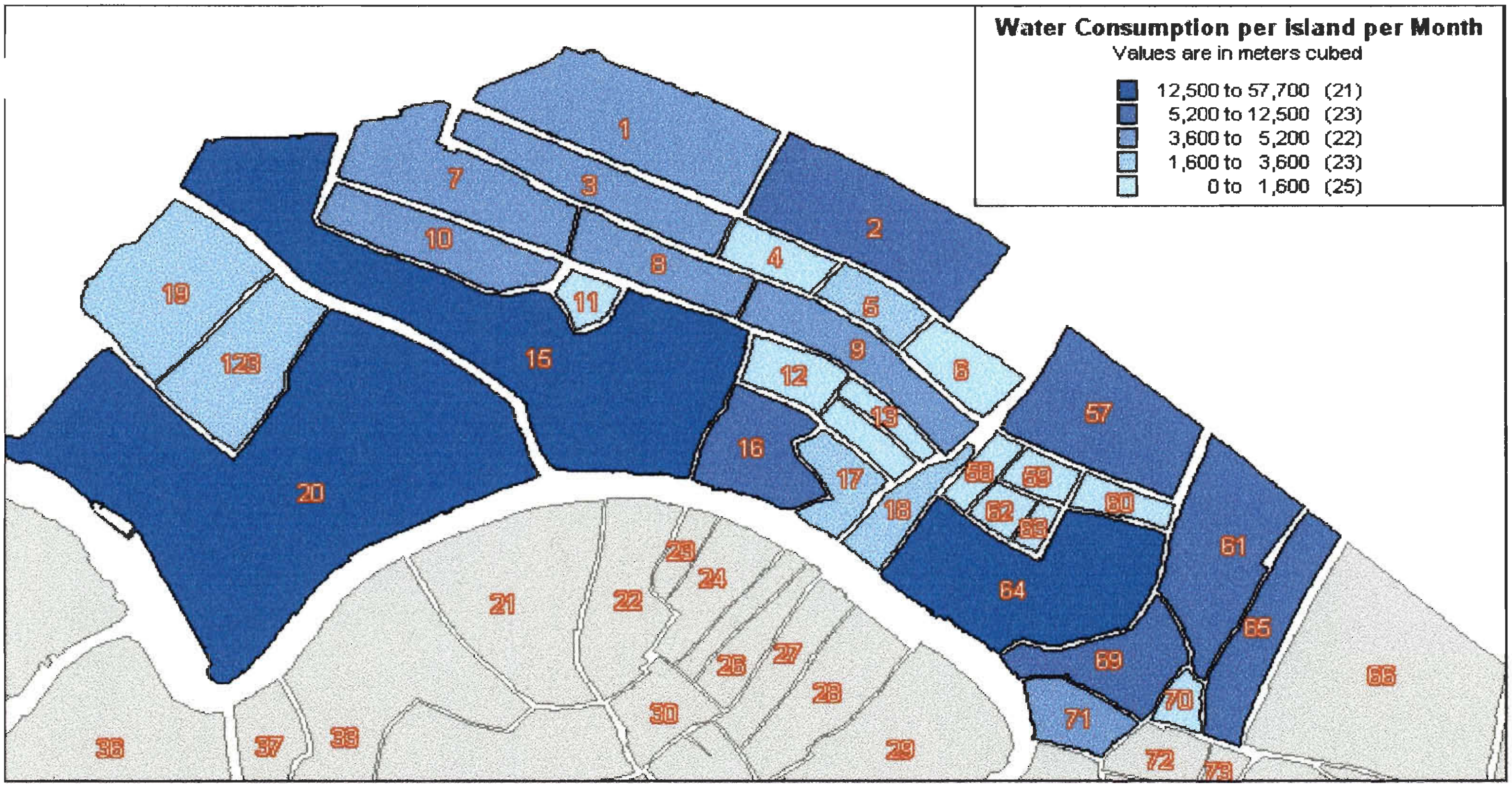


Figure 6-1 Map of water consumption for the islands of Cannaregio

6.3.2 Sewer Discharge per Outlet

Discharge per outlet was calculated by dividing the water consumption for an island by the number of active outlets around that island. With these data we were then able to compute the total discharge into adjoining canal segments. Table 6-1 gives the discharge per outlet for all surveyed islands.

Numero Isola	Yearly Water Consumption (m^3)	Active Outlets	Yearly Discharge per Outlet (m^3)
1	62232	32	1944
2	87216	47	2725
3	51000	27	1085
4	13860	20	513
5	21924	18	1096
6	12060	22	670
7	56652	64	2575
8	52464	71	819
9	44880	56	632
10	57744	58	1031
11	12960	14	223
12	1176	23	84
13	8208	39	356
14	9744	23	249
57	69456	34	3019
58	10284	24	302
59	9996	21	416
60	16380	31	780
61	113184	54	3651
62	16536	13	306
63	5868	21	451
65	63936	47	3044
70	8640	6	183

Table 6-1 Table showing calculations for yearly sewer discharge per outlet for surveyed islands

6.3.3 Total Discharge into a Given Canal Segment

Once we had the discharge per outlet for all documented active outlets we were able to calculate the total discharge into each of the surrounding canal segments. This was done by multiplying the number of active outlets along one side of a segment by the discharge per outlet for the bordering island. The same procedure was followed for the other side of the segment and then the two quantities were added. Figure 6-1 displays a canal segment, TRAS, for which we will illustrate the calculation.

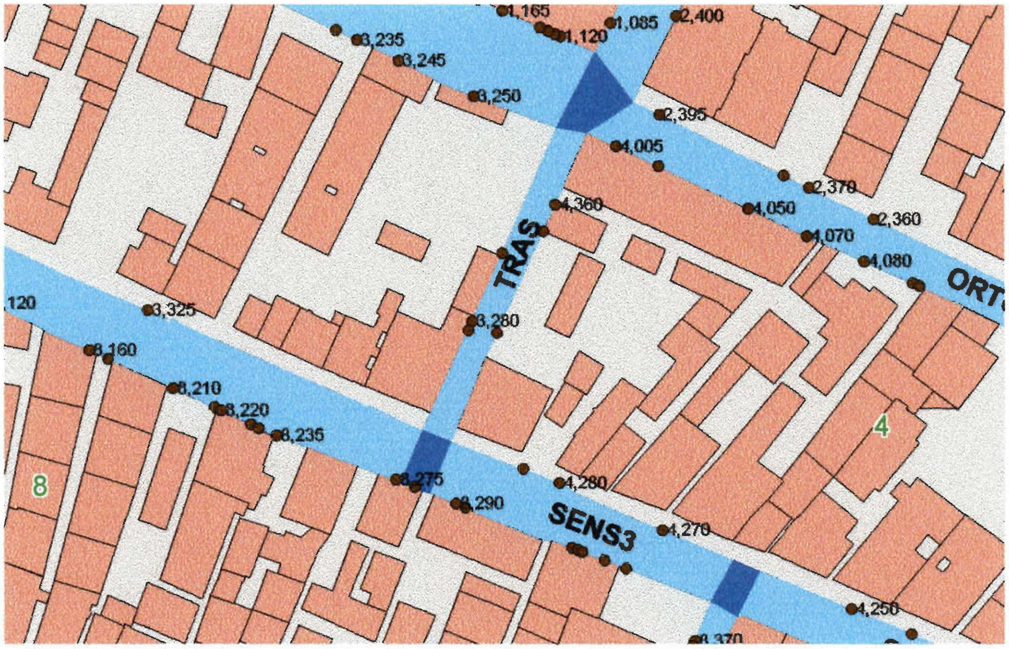


Figure 6-1 Canal segment (TRAS) with sewage outlets located on two bordering islands

Segment TRAS is situated between islands 3 and 4. Table 6-1 shows the calculations necessary for determining the total yearly inflow of sewage into this segment. As can be seen from this table, TRAS receives an annual input of 3274 m^3 of sewage every year.

Table 6-2 lists the raw sewage output into all the canal segments in Cannaregio. A certain percentage of this material consists of suspended solids that will eventually settle to the bottom of the canal to become sediment. The next section shows how the volume of those solids is calculated.

Numero Isola	Discharge per Outlet m^3	Number of Active Outlets along TRAS	Discharge from Islands m^3
3	1888	1	1888
4	693	2	1386
		Total discharge into Segment =	3274

Table 6-1 A representative calculation for finding yearly sewage discharge per individual canal segment

Codice Segmenti	Sum of Raw Sewage Output per year (m3)	Codice Segmenti	Sum of Raw Sewage Output per year (m3)
ACQU1	6183	MISE3	8128
ACQU2	559	MISE4	801
ACQU3	2235	MISE5	18398
ALVI	77008	MISE6	16482
ANDR1	5400	MORO	5311
ANDR2	1511	MUTI	7370
APOS1	12576	NOAL1	1659
APOS2	14672	NOAL2	1062
BATE1	24890	NOAL3	1271
BATE2	1728	ORTO1	18310
BRAZ	8505	ORTO2	30156
CATE1	2900	PANA1	19378
CATE2	10075	PANA2	38755
CATE3	4755	PANA3	7041
CMIS1	18385	PRIU1	857
CMIS2	17439	PRIU2	3816
CMIS3	1286	PRIU3	279
FELI1	2571	RACH1	4142
FOSC2	5084	RACH2	4687
GESU1	18704	SACM	2741
GESU2	9969	SENS1	33937
GHET	6912	SENS2	18556
GIRO	60295	SENS3	5774
GOZZ	5284	SENS4	5285
GRIM1	421	SENS5	10097
GRIM2	51	SENS6	8899
GUER	9867	SERV1	102
LUST	7577	SERV2	256
MARI1	10020	TRAP	5915
MARI2	1616	TRAS	3275
MARI3	1360	TRTE	14617
MEND	35369	WIDM1	6288
MIRA	1440	WIDM2	2096
MISE1	7890	WIDM3	7072
MISE2	8128	ZECC	24658

Table 6-2 Sewage input for all the studied canal segments of Cannaregio

6.3.4 Quantification of Suspended Solids

Once we had the total volume of raw sewage flowing into a segment we were able to estimate the quantity of suspended solids that flows into each segment on a yearly basis. The figure we used for our calculations was 300 g of suspended solids per cubic meter of sewage (see section 5.4). We also had to utilize the average density of canal sediment, which is 1.440 kg/m^3, to convert the amount of sediment from units of mass to volume. For example, the amount of suspended solids going into the canal segment TRAS is 0.68 m^3 per year (see calculation below).

$$\frac{(3275m \wedge 3)(.3kg/m \wedge 3)}{1440\text{kg/m\^{}3}} = \mathbf{.68m^3}$$

The following table shows the results from the preceding equation for all the surveyed canals in Cannaregio (Table 6-1).

Codice Segmenti	Volume Of Sediment per year(m3)	Codice Segmenti	Volume Of Sediment per year(m3)
ACQU1	1.3	MISE3	3.6
ACQU2	0.9	MISE4	0.8
ACQU3	1.5	MISE5	3.8
ALVI	16.0	MISE6	3.4
ANDR1	1.1	MORO	3.0
ANDR2	0.3	MUTI	1.5
APOS1	3.6	NOAL2	0.2
APOS2	4.0	NOAL1	0.3
BATE1	17.6	NOAL3	0.7
BATE2	0.4	ORTO1	3.8
BRAZ	1.8	ORTO2	6.3
CATE1	0.6	PANA1	4.0
CATE2	2.1	PANA2	8.1
CATE3	1.0	PANA3	1.5
CMIS1	3.8	PRIU1	1.1
CMIS2	3.6	PRIU2	2.4
CMIS3	0.3	PRIU3	0.9
FELI1	1.4	RACH1	0.9
FOSC2	2.4	RACH2	1.0
GESU1	3.9	SACM	0.6
GESU2	2.1	SENS1	7.1
GHET	6.6	SENS2	3.9
GIRO	12.6	SENS3	1.2
GOZZ	4.2	SENS4	1.1
GRIM1	0.1	SENS5	2.1
GRIM2	0.0	SENS6	1.9
GUER	2.1	SERV1	2.4
LUST	1.6	SERV2	2.2
MARI1	2.1	TRAP	1.2
MARI2	0.3	TRAS	0.7
MARI3	0.6	TRTE	3.0
MEND	16.8	WIDM1	1.5
MIRA	0.3	WIDM2	0.8
MISE1	1.6	WIDM3	1.5
MISE2	4.4	ZECC	5.1

Table 6-1 Quantity of suspended solids entering the Cannareggio canal segments surveyed

6.4 MASONRY DEBRIS ASSESSMENT

One of the primary objectives of this project was to determine whether or not plaster is a significant contributor to sedimentation in the canal system of Venice. This section contains the results from early order of magnitude estimates and subsequent methods for refining these estimates are discussed here.

6.4.1 Preliminary Estimate

Before starting any intensive fieldwork, we utilized existing data to calculate a rough estimate of the degree to which masonry debris contributes to sedimentation. This calculation used the known perimeter and height of buildings in all of Venice to establish an estimate of the overall volume of plaster in the city. An average thickness of one centimeter was assumed and the average height was used due to the lack of sufficient measurements for the entire city. The rough estimate equation was written as follows:

$$RE = \sum (perimeter) * (avg.height) * (0.01m)$$

We arrived at a value of 85,810 m^3 of plaster in all of Venice. When compared to the total volume of recorded sediment in the canals, approximately 118,000 m^3, it was clear that masonry debris could be a major contributor to sediment in the canals. Although this was a very rough estimate, it provided us with an order of magnitude that made this topic worthy of further, more accurate investigation.

6.4.2 Visual Survey and Refined Estimate on Test Island

Now that the sediment contribution of masonry debris had been show to warrant further investigation, it was necessary to refine our measurement methods to minimize the margin of error in our survey. Our visual survey approach involved selection of a test island, island 58, on which we inspected every building. The main flaws with the preliminary estimate were that it did not account for unplastered areas such as doors and windows, and the perimeter included lengths of building that are connected and have no exposed surface. During this survey we recorded the area occupied by the windows, doors, and the unplastered area at the base of the building. The thickness of the plaster was also measured. With this information, a more accurate estimate of plaster area could now be calculated by subtracting unplastered areas from the total area. The refined equation was as follows:

$$E_{58} = \sum_{all\_buildings\_in58} \left[(perimeter - connecting\_walls) * (height) \right]$$

$$- \sum_{all\_buildings\_on\_58} \left[(door\_area) + (window\_area) + (area\_w/\_no\_plaster) \right]$$

This equation gave us a refined estimate of the total *area* of plaster (E_{58}) on the buildings on our test island. To arrive at an estimation of *volume* of plaster, this value needed to be multiplied by the thickness of the plaster, approximately 1 cm. Our result was that 64.5 cubic meters of plaster are on the buildings of island 58.

6.4.3 Refined Estimate for all of Venice

To extrapolate our estimate to the entire city of Venice, we calculated the volume of plaster per unit of footprint surface area (VA_{58}). This was done by dividing the volume of plaster on island 58 by the total area of building footprints as displayed in the following equation:

$$VA_{58} = \frac{E58}{\sum (Surface\_area\_of\_island\_58\_building\_footprints)}$$

This formula gave us an average of 0.014m^3 of plaster per square meter of building footprint. Extrapolation of this value simply involved multiplying this number by the total footprint area of all buildings in Venice, obtained from MapInfo. The total volume of plaster in Venice is approximately 34,950 cubic meters.

6.4.4 Calculation of Yearly Sediment Contribution from Plaster

We now had an estimate for the total volume of plaster on all building in the entire city of Venice, but no timeframe to relate the rate of decay to obtain a yearly rate of deterioration. Several scenarios were developed to realistically depict this decay rate by multiplying the total volume of plaster by a percentage of decay over time. They are described in detail in section 5.5.2.3. The average of these scenarios was used to estimate the yearly sediment contribution (Table 6-1).

Description of Scenario	Volume of plaster per year for entire Venice
one-third of plaster falls from entire building in 20 years	582
total deterioration of plaster from entire building in 50 years	699
one-third of plaster lost from bottom two floors in 10 years	595
one-third of plaster lost from bottom two floors in 5 years	1392
total deterioration of plaster from bottom two floors in 10 years	2088
AVERAGE	**1071**

Table 6-1 Scenarios for rate of plaster decay over time

The average rate of plaster decay in the city of Venice was found to be 1,071 cubic meters per year. This is approximately equal to half of the volume of sediment contributed yearly by precipitating solids from sewer discharge.

6.5 Canal Wall Damage Results

This section describes in detail the methods used for recording and organizing data on canal wall damage. The results in this section deal with damage to the walls of the canals themselves and not with the walls of buildings.

6.5.1 Canal Wall Damage Survey Results

Table 6-1 displays the data for wall damage documented thus far. Impact damage has accounted for 6.5% (71 of 1093) of all damage recorded. The remaining 93.5% (1022 of 1093) is accounted for by structural damage.

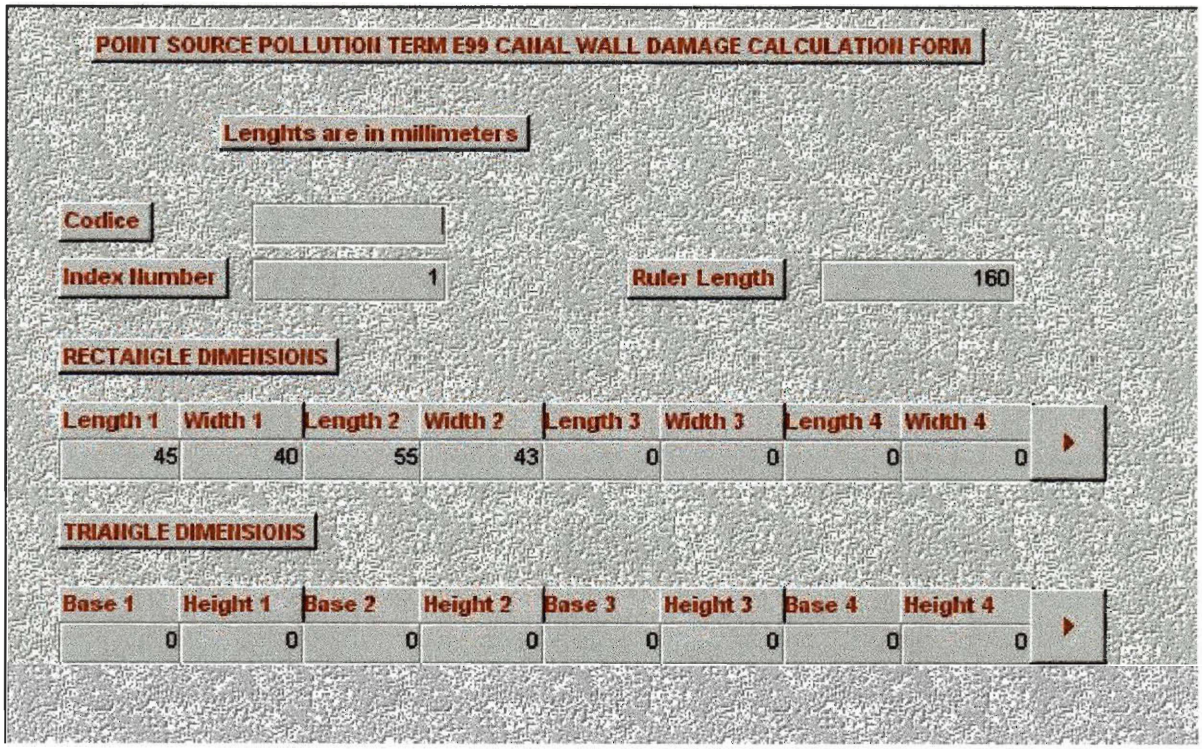
	# of Occurrences	Percentages
Impact Damage	71	6.5%
Structural Damage	1022	93.5%
Totals	1093	100%

Table 6-1 Percentages for the two damage types

A map is shown in Figure 6-2 that relates the positions of all damaged areas documented. Both types of damage have been given the same symbol.

6.5.2 Canal Wall Damage Area Calculations

In order to enter the dimensions of the wall damage accurately and easily into the database, we constructed a form in Microsoft Access that can be seen in Figure 6-1. Fields for the length of the ruler in the picture, the index number, the code of the object in the figure, and the dimensions of rectangles and triangles, which are the primary geometric shapes fitted to the observed damage, compose this form. The top row of the table contains the fields for regular four-sided figures and the bottom row contains the fields for triangle area calculations. These dimensions were then used to calculate the area of the canal wall damage. Consult section 5.6.2 of the Methodology to see the equations used for these calculations.


POINT SOURCE POLLUTION TERM E99 CANAL WALL DAMAGE CALCULATION FORM

Lenghts are in millimeters

Codice:

Index Number: 1

Ruler Length: 160

RECTANGLE DIMENSIONS

Length 1	Width 1	Length 2	Width 2	Length 3	Width 3	Length 4	Width 4
45	40	55	43	0	0	0	0

TRIANGLE DIMENSIONS

Base 1	Height 1	Base 2	Height 2	Base 3	Height 3	Base 4	Height 4
0	0	0	0	0	0	0	0

Figure 6-1 Access entry form for automatic calculation of real dimensions from photo measurement.

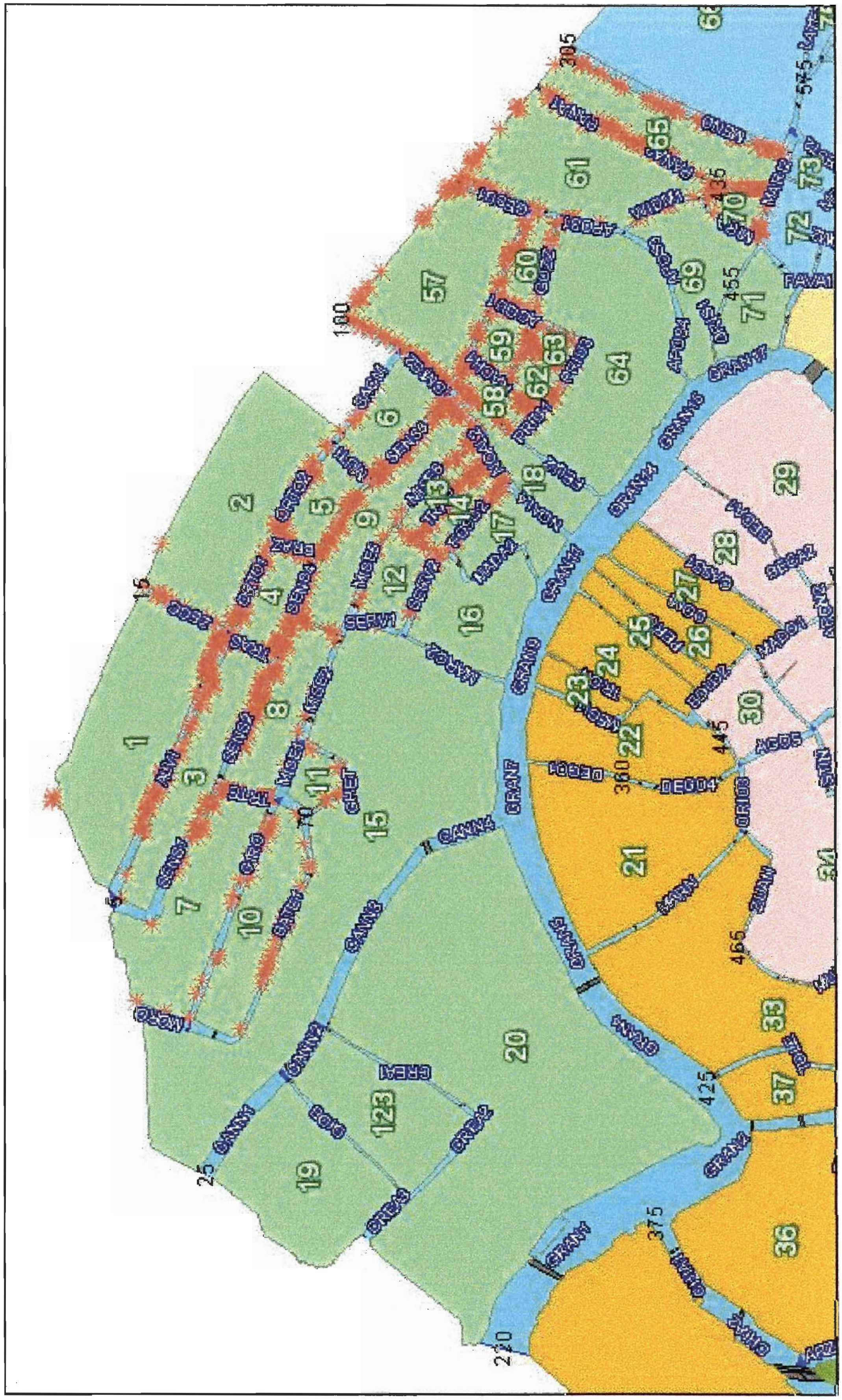


Figure 6-2 Locations of all damage points

7 ANALYSIS

This section contains an in-depth analysis of the data we collected and examines our results to determine if the hypotheses we proposed can be verified. Analytical tools used include Microsoft Access and Excel as well as MapInfo.

7.1 HYPOTHESES ANALYZED

Throughout the course of our project, we formulated several conjectures which are summarized in this section. They are stated here, and analyzed in the subsequent sections of the chapter.

7.1.1 Water Consumption and Sewer Discharge

One of the main objectives of our project was to determine the amount of sewage discharged into the canals we surveyed. We began with the water consumption data for 1997-1998 and were able to calculate the amount of precipitating solids entering the canals surrounding each island using the percentage of solids in wastewater and density of solids information obtained from literature.[13] We could not, however, determine exactly where this material was exiting the islands without a visual survey of the canals to pinpoint the locations of active sewer outlets, which was completed over the course of the project.

The positions of sewer outlets on an island have a direct influence on the water quality and sedimentation levels of the canal segments that surround that island. Our objective was to quantify the wastewater and solids coming out of the active outlets, as well as ascertain whether or not the presence of inactive outlets has an impact on the amount of structural damage in the canal segments surveyed.

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[13] Zucchetta, Gianpietro, *Canali e Rii di Venezia: Stato attuale dell'inquinamento* 1983.

7.1.2 Damage Correlation

Another assumption we made was that there are several factors which affect the frequency of damage in a canal such as canal width, level of sediment, the hydrodynamics of that canal, and the presence of inactive sewer outlets. A narrow canal might have more damage under this presumption partly because of more frequent boat-canal wall collisions due to space limitations. The combination of a slow-moving current and high numbers of active sewer outlets in such a canal would contribute further to the damage by causing sediment levels to increase, as there would be insufficient water flow to remove the sediment. Higher levels of sediment can cover and block sewer outlets, causing them to back up, rupture and create more damage.

7.1.3 Sedimentation Components

There are many sources for sediment in the city of Venice. The primary one was thought to be the sewer outlets. It was our intention to determine what the other major sources are, if any, so that the problem of sedimentation can be better addressed. It could be more economical and efficient to stop or at least minimize the amount of sediment entering the canals than to dredge them every 7-10 years.

Our masonry debris assessment attempted to establish whether or not plaster was one of these significant sediment sources. A visual survey of the buildings on an island of Venice was performed to establish the average volume of plaster per square meter of building footprint, and this value was then extrapolated to all of Venice. Due to the nature of these calculations and the assumptions they are based on, the results may have some margin of error. Nevertheless, the magnitude of the estimate should be an adequate representation of how important plaster is as a contributor to the total amount of sedimentation. We could compare existing known volumes of sediment in the canals of Venice with our estimates of sediment contributed by sewage effluent and plaster to determine what percentage, if any, is unaccounted for.

It has been suggested that tidal flux brings a large amount of sand from the Lagoon into the canal system of Venice. If this is true, there must be a significant portion of sediment besides sewage and plaster that is presently unidentified. Through calculations using the data collected and information from other sources, we attempted to determine if this statement is valid.

7.2 *HOW MUCH DOES MASONRY DEBRIS CONTRIBUTE TO SEDIMENT LEVELS IN THE CANALS OF VENICE?*

Our hypothesis was that the amount of plaster deterioration from buildings in Venice is a significant source of sediment in the canals. After completing a preliminary survey, we were convinced by the magnitude of our rough estimate that this was, in fact, a serious issue to look into. We then performed a thorough visual survey of all the buildings on island 58 and extrapolated our findings to all of Venice as discussed in section 5.5.2. The total volume of plaster entering the canals each year was determined for 5 different scenarios (Table 7-1).

Description of Scenario	**Volume of plaster per year for entire Venice**
(1)one-third of plaster falls from entire building in 20 years	582
(2)total deterioration of plaster from entire building in 50 years	699
(3)one-third of plaster lost from bottom two floors in 10 years	595
(4)one-third of plaster lost from bottom two floors in 5 years	1392
(5)total deterioration of plaster from bottom two floors in 10 years	2088
AVERAGE	**1071.2**

Table 7-1 Sediment produced by various rates of plaster decay

If these average of these values is compared to the total volume of precipitating solids from sewer outlet discharge, 2,217 cubic meters per year, it can clearly be seen that plaster is a significant component of sediment in the canals of Venice when compared with wastewater (Figure 7-1). In the case of scenario 5 the amount of masonry debris, 2,088 cubic meters, nearly equals that of the solid

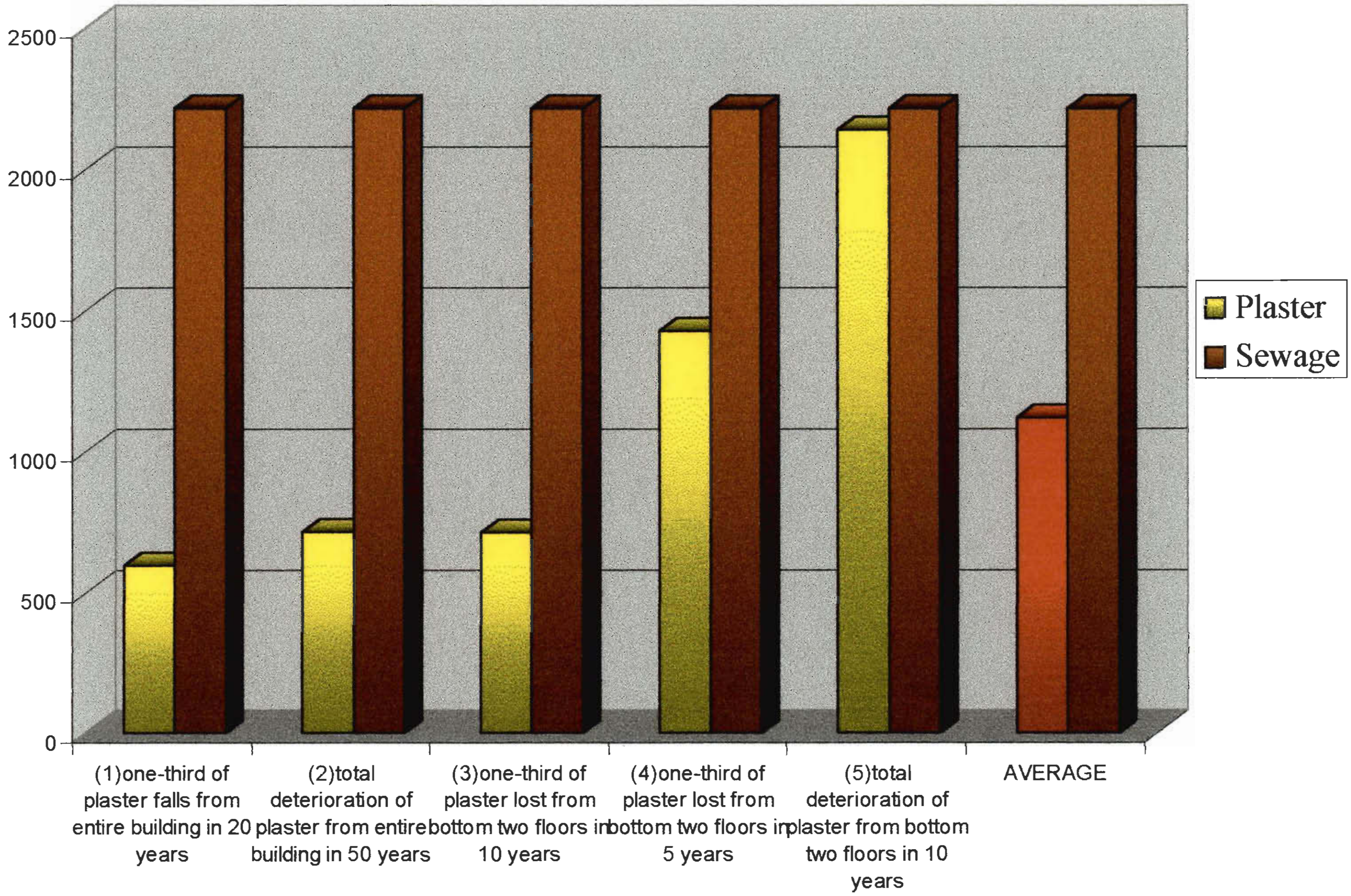

Figure 7-1 Comparison of sediment produced by sewer discharge versus various plaster decay scenarios

discharge from sewer outlets. Even without a measured deterioration rate, these results clearly show that plaster is at the very least as a significant contributor to sediment in the Venetian canal system as sewage and warrants further investigation.

7.3 IS THERE A SIGNIFICANT AMOUNT OF SEDIMENT THAT IS UNACCOUNTED FOR?

It has been hypothesized that Venice is being inundated with large amounts of sand from the Lagoon by means of sediment transport.[14] A large amount of this sand is thought to settle in the canals as sediment. If this were true, it would also be legitimate to assume that there is a large portion of sediment in the canals that is currently unaccounted for.

7.3.1 Calculations Based on Total Volume of Sediment

Using data obtained from previous WPI projects and Insula S.p.A., we were able to compile information on the volume and thickness of sediment in a portion of the canal segments of Venice. Under the assumption that sediment accumulates at a rate of 2 cm per year[15], we could then divide the average sediment thickness by this yearly accumulation and determine that it took roughly 39.3 years for the sediment currently in the canals to accumulate. This is a reasonable estimation considering that canal dredging had nearly stopped after 1965 and has only recently begun to pick up again due to the efforts of Insula.

Using the volume information along with the percentage of canal system area represented, we were able to calculate an approximate volume of sediment accumulated over 39.3 years of 778,675 cubic meters for all of the canals in Venice. This translates to about 19,810 cubic meters per year. When compared to the yearly contribution of sewage effluents and plaster to sediment, which we estimated in 3,336 m^3, it can be plainly seen that a large percentage of the sediment, almost 16,900 cubic meters, is unaccounted for (Figure 7-2). This 85% of unidentified sediment could come from several sources, including sand from the lagoon swept in by the tides.

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[14] "Modeling the Sediment Transport in the Channels of Venice". 28-29 June 1999. UNESCO-ROSTE Venice Office.

[15] Christopher Babic, Michael Borek, Grant Leeds, Stylianos Sidiroglou. IQP: "Analysis of Sewer Holes and Canal Wall Damage in Venice, Italy," July 29, 1998.

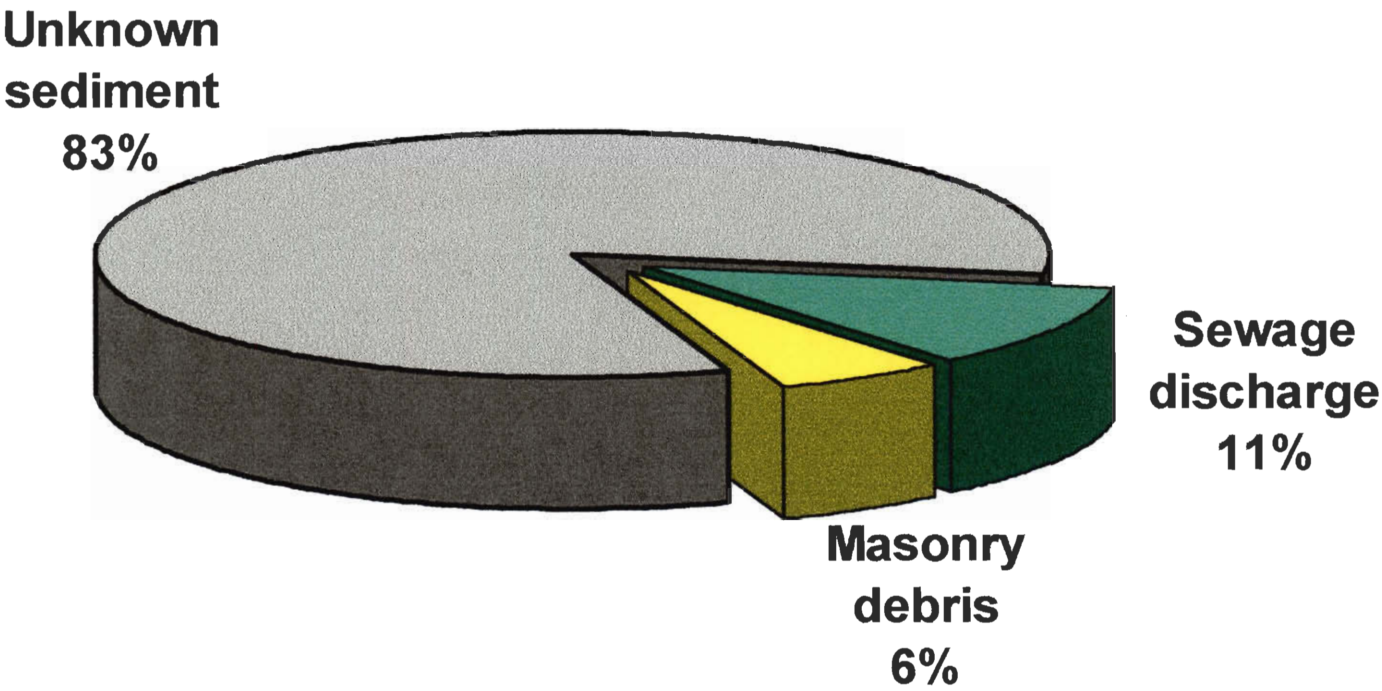

Figure 7-1 Pie chart showing the percentages of sediment types in the Venetian canals

7.3.2 Calculations Based on Canal Surface Area

As a measure of how accurate our calculations were, the results from the preceding method were compared with similar estimations based on canal surface area rather than volume of sediment. The average thickness of sediment contributed each year by masonry debris and sewage discharge per square meter of canal was computed by dividing the volume of these sediment components by the total surface area of canals in Venice. Once again, a total sediment accumulation of 2 cm per year was assumed. We found the percentage in this manner for the average of our aforementioned scenarios and compared the average with results from the method detailed in Section7.3.1(Table 7-1). The two sets of figures are very similar, indicating an unidentified sediment component ranging from 82% to 85%.

	Percentages of total sediment		
Scenario	Sewage discharge	Masonry Debris	Unknown
1	12.0%	3.1%	84.9%
2	12.0%	3.8%	84.2%
3	12.0%	3.8%	84.2%
4	12.0%	7.5%	80.5%
5	12.0%	11.3%	76.7%
Average	12.0%	5.9%	82.1%
Volume Approach	11.2%	3.5%	85.3%

Table 7-1 Comparison of sediment contribution calculation methods

7.4 IS THERE A RELATIONSHIP BETWEEN INACTIVE SEWER OUTLETS AND STRUCTURAL DAMAGE?

Figure 7-1 Image showing wastewater flowing from a crack in the canal wall which will cause further deterioration if not repaired

It was our hypothesis that inactive sewer outlets were a major cause of wall damage due to the inability of sewage to flow from the blocked opening. Instead of leaving the island from the intended outlet, the effluent escapes through crevices in the canal wall, damaging the wall in the process (Figure 7-1 and Section 5.6.1).

Using MapInfo, a proximity analysis was performed by means of the concentric ring buffer tool. This option allows the user to put rings around map objects and calculate how many data points are within a given radius. A query was made to discover how many outlets were within 2.5 meters of damaged wall areas. We assumed that the sewage could travel this distance within the structure before finding a route to the canal. These results were broken down for each type of outlet and can be seen in Table 7-1.

	Total number	Number within 2.5 m of damage	Percent within 2.5 m of damage
Active undamaged	634	167	26%
Active damaged	131	62	47%
Inactive undamaged	94	24	26%
Inactive damaged	51	28	55%
Total	910	281	31%

Table 7-1 Number of outlets within 2.5 m of wall damage (by type)

The results of this query show that only 31% of all the outlets surveyed are within 2.5 meters of damaged areas. However, approximately 55% of the inactive damaged outlets are inside the given range. Relatively high percentages of both inactive <u>and</u> active damaged sewer holes are within 2.5 meters of damaged regions, while the undamaged outlets weren't observed to be a major factor in this damage.

Our assumption was that the inactive outlets, damaged and undamaged, would be the major cause of canal wall damage, and that active damaged outlets would not play a role because the effluent can and does still flow from them. Although not as significant as the inactive damaged outlets, the 47% of active damaged outlets in close proximity to wall damage shows that even when the opening still discharges sewage effluent, serious structural problems may have already begun within the structure. The pipes may have already cracked, causing some of the sewage to escape into the foundation of the buildings and canal walls.

7.5 DOES THE LOCATION AND ACTIVITY OF OUTLETS GREATLY AFFECT THE DISTRIBUTION OF SEDIMENT AROUND AN ISLAND?

I wonder

It has already been established that sewage is a significant component of sediment in the Venetian canal system. Our question was, does the location of sewer outlets around the individual islands considerably affect the distribution of sediment in the canals segments surrounding that island? To answer this question, the current sediment volumes from Insula were entered on the following thematic map along with sewer outlet locations and status (Figure 7-1).

Active outlets are shown in green while inactive outlets are displayed in blue. The darker red segments have higher levels of recorded sedimentation and recently dredged canals were excluded from the calculation. Note that the islands shown in darker gray were not surveyed by this project, therefore there is no existing information on the location of sewer outlets on these islands. The sediment levels in the canal segments bordering them have been estimated by distributing the sewer discharge evenly about their perimeter. As can be easily seen, many of the segments with low sediment levels have significantly higher numbers of active outlets. It can therefore be assumed that the placement and activity of sewer outlets has little effect on the distribution of sediment in the canal segments surrounding an island. This lends support to the assumptions that sewage discharge is not nearly as large a contributor to sedimentation as previously expected and there is a large portion of sediment for which the source is undetermined. or its not significant?

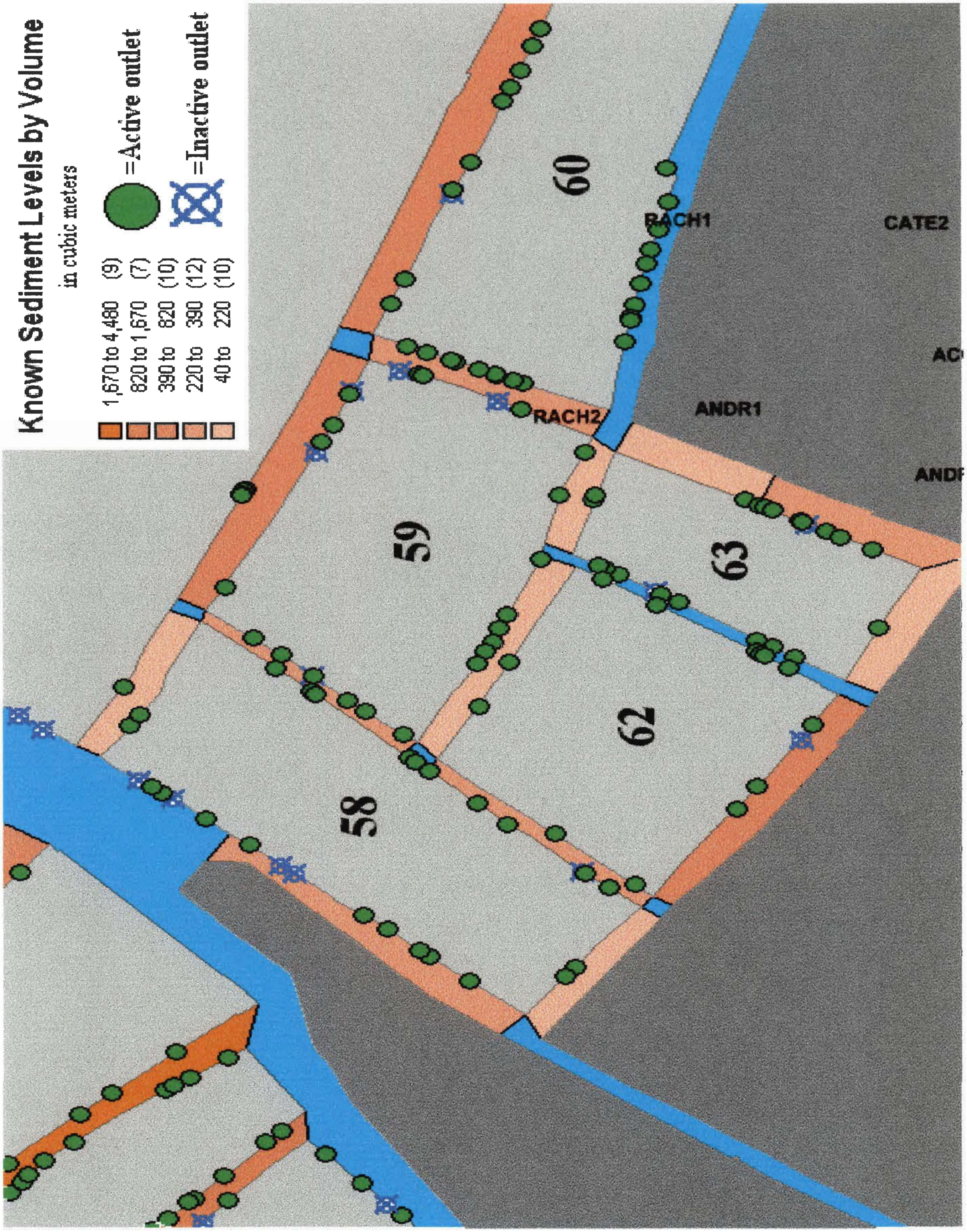

Figure 7-1 Thematic map showing sediment levels and sewer outlet type and location

8 Conclusions

This section presents the conclusions regarding sewer discharge and canal wall damage drawn from our data. These conclusions are based on the analyses in Chapter 7.

8.1 Masonry Debris

From our estimates of the masonry debris volumes we believe that masonry debris contributes notably to sedimentation in the canals. A further study is required in order to more precisely ascertain the decay rate of plaster and determine which of the five scenarios is most probable or if another scenario more accurately fits the data. Even assuming the lowest of our rate estimates, masonry debris still accounts for 25% of sediment when compared with our estimates of wastewater contributions.

8.2 Unknown Sediment Sources

Our two different approaches to the problem of unknown sediment both yielded roughly the same result. Approximately 85% of all sediment is being deposited into the canals by an unknown source. This figure clearly shows that while sewer discharge and masonry debris are contributors to sediment there is also a much larger factor (or factors) at work which have yet to be positively identified. Sediment transport is one such possibility that warrants further investigation. It is especially likely because Venice, with its narrow canals, acts as a natural sinking point for particulate matter that is in the lagoon.

8.3 Inactive Outlets and Canal Wall Damage

Section 7.4 establishes a direct correlation between inactive sewer outlets and structural damage. With this correlation we see that the majority of inactive holes are within 2.5 meters of structurally damaged wall and do indeed contribute to it. It was also discovered that a large number of active damaged outlets were within 2.5 meters of damaged canal walls. From this we can conclude that a fairly large percentage of the sewer outlets in the city can and do contribute to the structural deterioration of the surrounding walls.

8.4 Sewer Outlet Activity and Locations Affect on Sedimentation

With the use of thematic maps we determined that location of active outlets does not significantly effect the distribution of sediment around an island. The map in the Analysis section (**Figure 7-1**) section clearly shows that some canals with lower sediment levels have a large number of active sewer holes. This lends further support to the hypotheses that sewer discharge is not as large a problem as previously thought and that some unknown source is depositing sediment into the canals.

9 RECOMMENDATIONS

This chapter reflects our thoughts on what could be done to improve the current status of the Venetian canals. The suggestions made here reflect what we feel will be beneficial for the canal maintenance system of the city.

9.1 Damage on Canal Walls

As a result of our survey of the canal walls, we saw that most of the canals have large amounts of damage. Furthermore, most of the damage on the canal walls was structural in origin and according to our analyses and regressions the incidence of damage was greater in canals that had not been recently dredged and were narrow with high sediment volume. This result once more raises the point that maintaining low sediment levels in the canals prevents structural damage. As explained in preceding chapters, the most likely cause of structural damage is the blockage of sewer pipes and the resulting leakage. One action that should be taken to prevent wall damage from happening should be dredging the canals more often. Canal dredging is a lengthy process in which sediment removal and fixing canal walls are done simultaneously. This process causes problems to traffic flow and it is also disturbing to citizens living close by to the maintenance area. We recommend that the canals be dredged more often which will lead to formation of less canal wall damage which in turn will greatly reduce the amount of time required for maintenance.

9.2 The Significance of Masonry Debris

One of the most important results we got during this project was that the masonry debris, which was not considered as a significant source of sediment previously, was computed to be close in volume to the sediment contributed by sewage outlets. Although most of the sediment content in the canals is still unknown, decreasing the amount of known sediment will be beneficial for the city in several ways. First of all, less sediment entering the canals will lower the need of canal dredging and thus prevent disturbance to the citizens of Venice. Decreasing the amount of sediment from masonry debris could be achieved by several methods. We think that one of the best ways to do this would be to strip off plaster from all buildings in Venice and leave them as all brick. This will prevent sediment build up from masonry debris but it also could be a time consuming job with high costs in the short term. An alternative to this could be letting all the plaster fall of with time and once it does never plaster the buildings again. We think that not plastering the buildings will not only decrease the amount of sediment from masonry debris but it will also make the city look better than its present condition in which many of the buildings are half covered with plaster which is not an esthetically pleasing sight. As a final alternative to these methods, we recommend that effort should be put on research for developing a new type of plaster that could stick to walls better even when applied in thinner coatings. This approach is more realistic than the other approaches, however, and the expected costs are not known.

Unfortunately, due to time restrictions our analysis of the amount of plaster decay is still a rough estimate. Before action is taken, we recommend that further study be done on the extent of plaster decay. In this study we recommend that future groups follow our basic methodology (Section 5.5.2) with perhaps a greater number of islands analyzed and the most appropriate decay scenario established. Also if in the future our masonry debris collection device could in some way be deployed, the decay compared to time would be easily established as laid out in Appendix G.

9.3 A New Sewage System?

Building a new sewage system in Venice will be beneficial for lowering the sediment levels in the canals but this is not the main reason it is considered. Because of the costs of a project of that magnitude, it would not be feasible to install such a system since most of the sediment in the canals is unknown according to our results. The main reason behind building this new sewage system however is health reasons. The current sewage system in Venice is a health hazard because most of the new sewage outlets are built higher than the older ones and are above water level during low tide. There are even some outlets that are above the high tide level. This is mainly due to rising sediment levels and clogging of the older outlets. We recommend that the new sewage system is built to avoid health problems and bad odors caused by the exposed sewage outlets.

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