Streamlining Canal Hydrodynamic Measurements in Venice

Developing methods for future data collection and validating models with updated measurements

Venice Project Center

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

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

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Abstract

This project investigated new methods for taking extensive hydrodynamic measurements in the inner canals of Venice. The team developed and tested new devices for measuring water level and current velocity, and assessed their feasibility for future implementation. To address speculations of water flow changes within the canals—prompted by relative sea level rise and recent lagoon construction—this project continued past WPI studies of the canals' hydrodynamic behavior to determine if changes have occurred since the 1990s. Water level and current velocity data were collected and compared to hydrodynamic models of the canals and data collected by past studies. The team also updated page templates and uploaded hydrodynamic data to Venipedia, a Wiki-based site focused on the city of Venice.

Executive Summary

Monitoring water movement within Venice's canals is essential to the everyday life of its people: however, there is a general lack of understanding about how water flows through the canals. Recent studies show that there have been changes in the motion of water within some of the canals (Wolf et al., 2012). Although it is possible that these changes can simply be a result of an overall rise in sea level and increase in land subsidence, there are alternative theories about the contribution of floodgates and dredging of the lagoon (Ghezzo et al., 2010).

The *Istituzione Centro Previsioni e Segnalazioni Maree*, or *Centro Maree*, was established in Venice in the late 1970s to provide "maximum information on tide and an efficient and immediate alerting service in case of high tide." To forecast the most accurate tide levels, Centro Maree collects meteorological data from the lagoon, the Adriatic Sea and other surrounding areas ("Il Centro Maree", 2010). Past studies by students from Worcester Polytechnic Institute (Interactive Qualifying Projects - IQP), starting in 1990, have taken measurements of tide levels, water velocity and direction and have compared their data to past data, modeling their findings with the help of the Institute of Marine Sciences (ISMAR), an organization headquartered in Venice that collects and models data on marine environments.

Previous research on canal hydrodynamics in Venice has provided valuable data on tide levels and water speed and direction (Scully et al., 2011). Centro Maree is capable of producing highly accurate water level forecasts using sophisticated modeling techniques for the city of Venice. However, this information is not specific to the individual canals. Instead, this data is collected from locations within the lagoon and other areas surrounding Venice. Therefore this data cannot be used to predict the hydrodynamic conditions in the inner canals. Past IQPs have recorded data within individual canals in order to better understand how they work. This information is accurate on a small scale, but does not allow conclusions to be made about the overall canal network. The current methods for collecting measurements are simple and effective, but they are limited by the amount of manpower available to them, which makes the repeated collection of data laborious and impractical.

The goal of this project was to propose a feasible plan to repeatedly collect hydrodynamic measurements of Venetian canals that can be used to monitor the canals and produce models that can more accurately represent them. With these models, erosion rates and sediment displacement can be predicted and maintenance plans can become more efficient. To develop this plan, various methods for obtaining hydrodynamic data were tested and assessed for accuracy, efficiency, repeatability, and ease of use. Some methods that were investigated are: releasing GPS devices into the canals and implementing measuring sticks that can be easily read via photographs. Data was also collected in order to compare with previously recorded data from the 1990's and to determine if and to what extent there has been change within the canals. The data collected, along with previously recorded data, was furthermore made available online to the public through Venipedia, a website based on Wikipedia that contains information specifically about Venice. The data can then be used for research, modeling, forecasting, and more. The plan should lead to a solution for collecting comparable hydrodynamic data on Venice's canals that can be built upon and someday implemented within the canal system. In order to accomplish these goals, the following objectives have been established:

- To develop and test measuring devices that can be incorporated into an easily repeatable plan for collecting full tide-cycle data
- To measure the existing hydrodynamic status of the canals by collecting water level and water velocity data
- To determine if and to what extent the currents in the canals have changed since the 1990s using ISMAR models
- To make hydrodynamic data available to the public through Venipedia

A capsule containing a cell phone with GPS capabilities was tested as a device for water velocity and flow. The device was tested against previously used flotation devices as well as a propeller device lent to us by our sponsors IPROS. A measuring stick apparatus was constructed to measure water level and it was tested against Venice's actual tide level gauges for accuracy. These devices are shown in Figure 1.

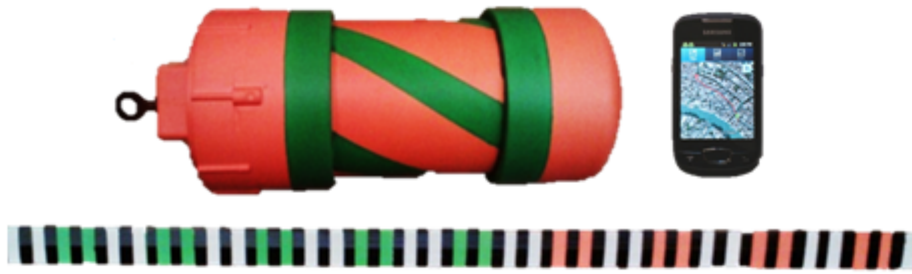

Figure 1. Innovative Hydrodynamic Measurement Devices

Using a combination of these devices, data was collected on three separate days, at five times during a tide cycle (incoming tide, high tide, outgoing tide, low tide, and incoming tide) in four regions to characterize present hydrodynamic conditions in the respective regions. The tide level device was lowered into the water and three pictures were taken at each location. The average of these results will be used to account for boat wake or any other abnormalities in the water level. The propeller device will be lowered off of bridges into the desired canal segments and again three measurements will be taken at each location to ensure accuracy. The GPS device will was used on two separate occasions to track the overall water flow. This data was then compared to models given to us by our sponsors ISMAR as well as the data that was collected in the 1990s. To gain the most accurate results from the model, we updated ISMAR's bathymetry database using INUSLA's online published GIS map with the most recent bathymetries (2005). The locations that were measured, shown in Figure 2, were chosen based on previous project recommendations, liability to change, and accessibility.

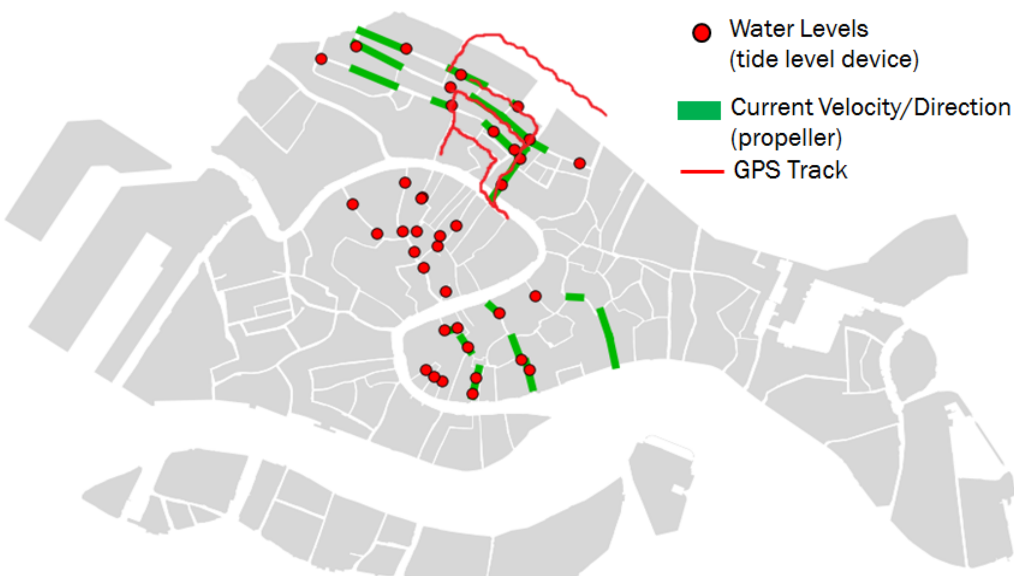

Figure 2. 2012 Area of Study Map

Finally, using the City Knowledge Console, all of the data and model results that we have accumulated were uploaded to the wiki based website, Venipedia.

During the course of our studies we have taken a total of 211 measurements in four different regions in 51 different locations. We took 85 measurements in Cannaregio (59 water level and 26 velocity), 67 measurements in San Marco (50 water level and 17 velocity) and 59 measurements within the regions of Santa Croce and San Polo (59 water levels). Figure 3, below, shows samples of the collected data.

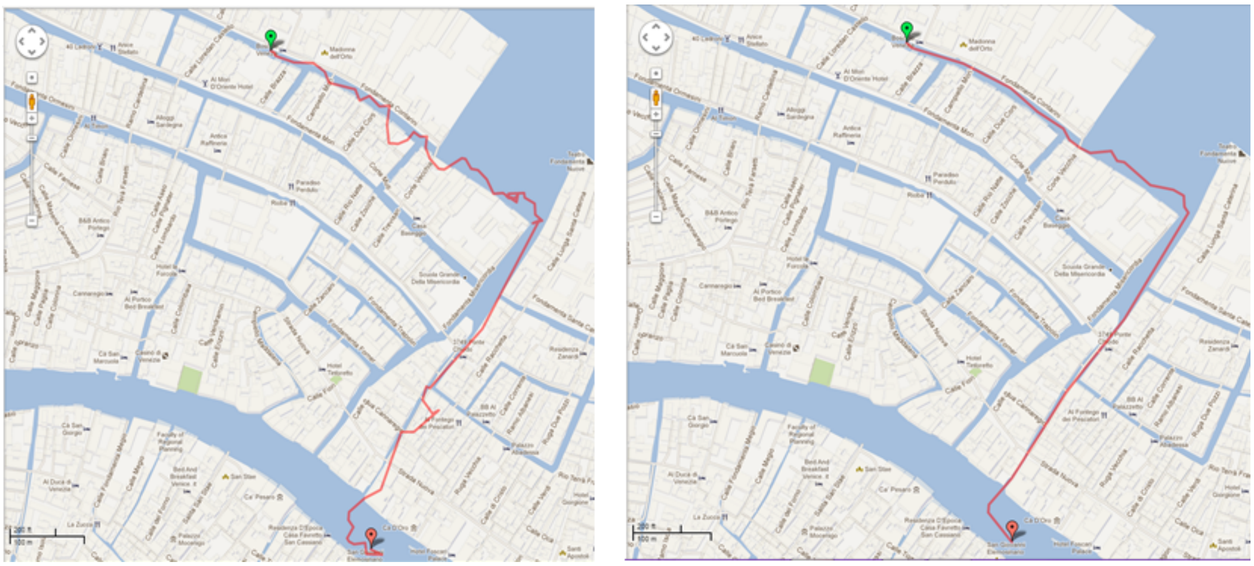

Figure 3. GPS Device Tracks: Original Data (left) and Corrected (right)

The image, on the left, displays the raw data from the GPS capsule. The innaccuracy of the GPS causes a skewed distance and thus an incorrect velocity reading. As seen in the juxtaposed image, on the right, the tracks can be corrected for more accurate readings.

Figure 4, below, is a sample of our water level measurements during high tide in Cannaregio. The measurements were taken slightly before, during, and slightly after hightide which can be observed from left to right as the water levels increase, then decrease as time increases.

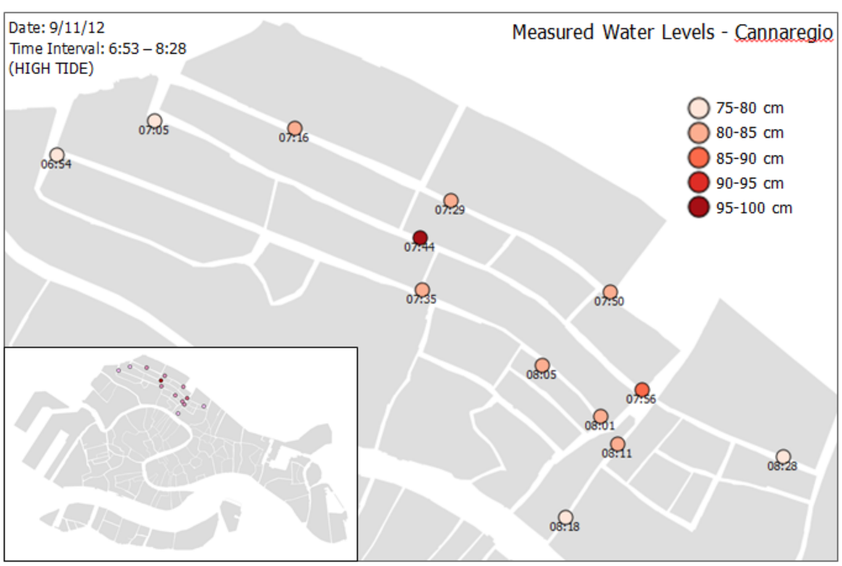

Figure 4. Water Level Measurements - Cannaregio High Tide

The current velocity results collected using the propeller device are shown below in Figure 5. This data represents the outgoing tide in the Cannaregio region.

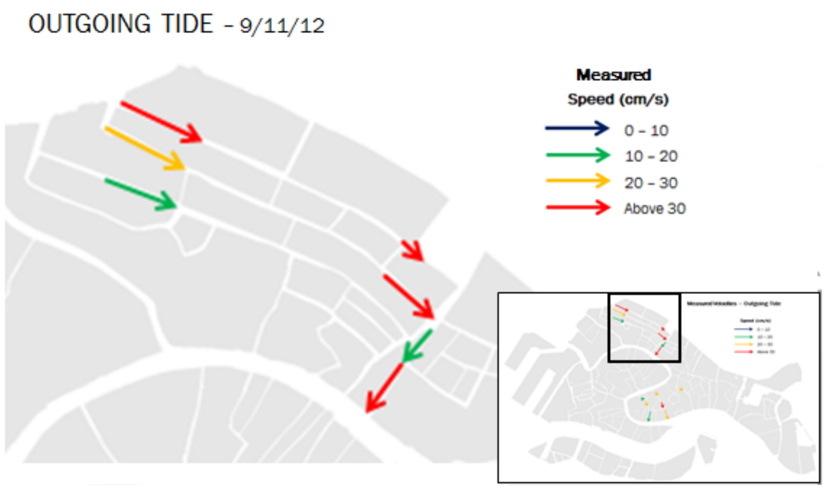

Figure 5. Current Velocity Measurements - Cannaregio Outgoing Tide

We also received the results for four different model simulations from our sponsors at ISMAR for the same day that data was collected in Cannaregio. The models included: the bathymetry data from before 2005 both with and without the MOSE flood gates and the new bathymetries both with and without the MOSE flood gates.

After correcting all of the tracks from the GPS device and comparing them to previous measurements, we had seen some interesting movement along the *Rio de la Misericordia*. In previous studies of the outgoing tide, the currents would flow out into the lagoon, however, in our studies we found that it tends to flow towards the Grand Canal. This difference is highlighted in Figure 6.

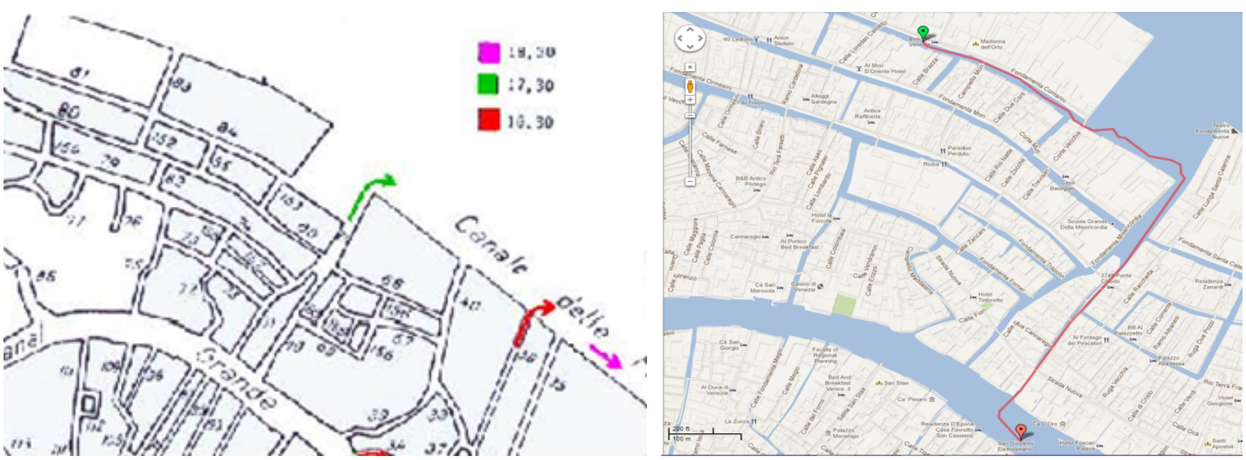

Figure 6. Past and Present Studies - Cannaregio Outgoing Tide

When comparing our water level data from Cannaregio to the Misericordia tide gauge level, we found that we were able to accurately depict the water levels for the measured segments to within 5% accuracy, as shown in Figure 7.

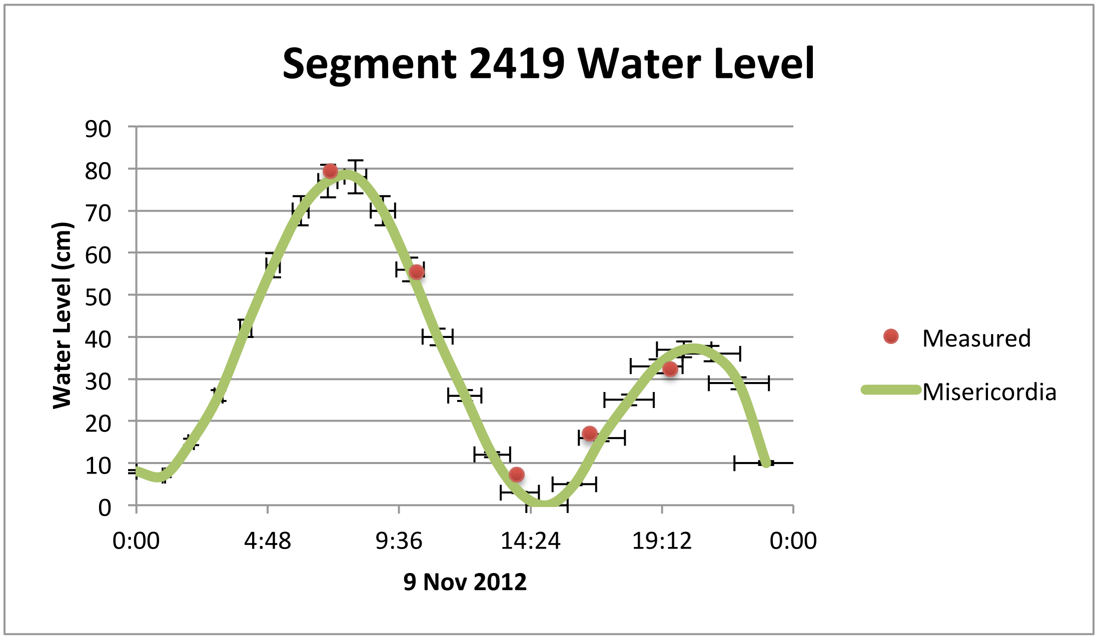

Figure 7. Measured water level compared to Misericordia tide gauge

The water velocity data from each region was also insightful. Many of the canals in the three regions of study had increased in velocity since the 1990's. The most evident increase was found in the Rio di San Felice in Cannaregio. Counter-intuitively, this canal tends to slow down before accelerating to a velocity that is higher than previously recorded, as shown in Figure 8.

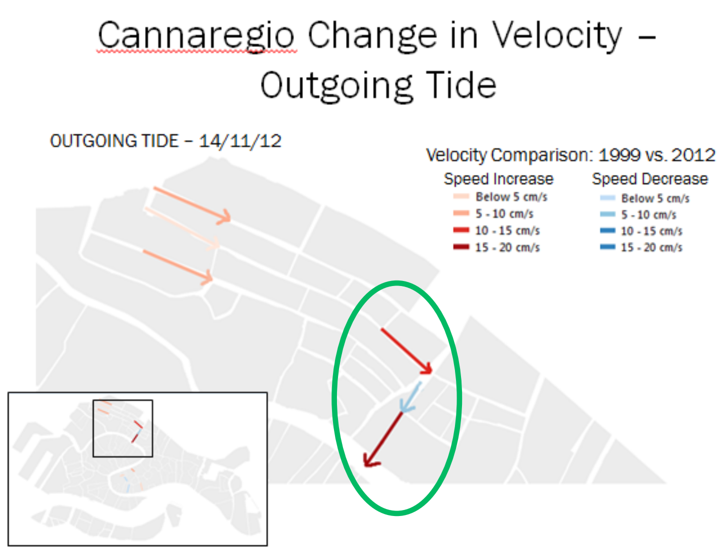

Figure 8. Change in Current Velocity in Cannaregio from 1999 to 2012

The San Marco region also shows trends of change during outgoing tide as seen in Figure 9. Some changes were seen during incoming tide but most of these differences are small enough to be considered insignificant. In general, in the southern region connecting to the lagoon, the velocities seem to be decreasing in speed for both incoming and outgoing tides. In the northern areas, flowing into/out of the Grand Canal, the velocities seem to be increasing for both incoming and outgoing tides.

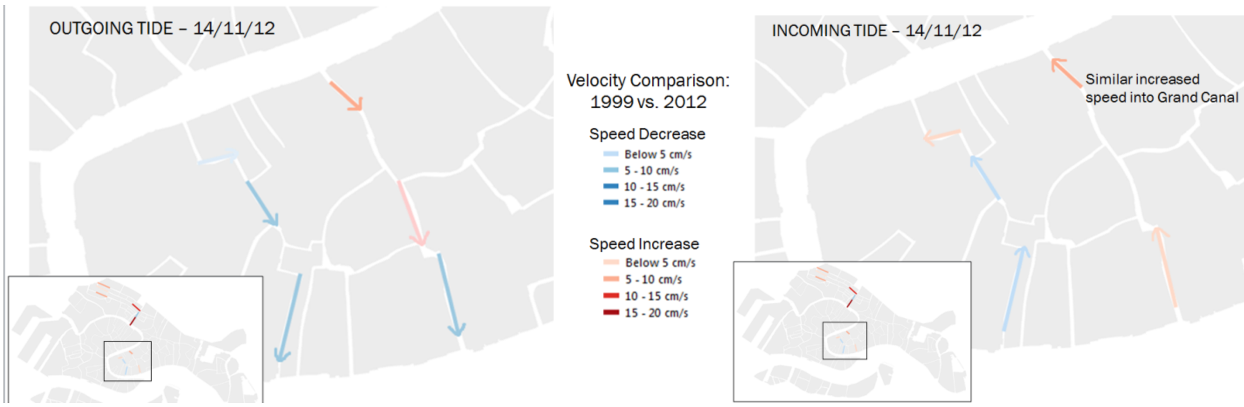

Figure 9. Change in Current Velocity in San Marco from 1999 to 2012

When looking at the data from the models, we can tell that they are producing accurate water level measurements. However, it is difficult to compare the results we measured from the propeller device to the data from the models. Furthermore, when comparing the data from model to model, the change in bathymetries renders very little change. When comparing the models with and without the MOSE flood gates, there seems to be more change but not enough to make a conclusion.

After vigorous testing and analyzing, we have successfully developed two useful and cost efficient devices, the GPS flotation device and the measuring stick device. Although without a more accurate GPS, the GPS flotation device is not able to accurately record velocity data, it can still be used to track general flow over time. If many of these devices were constructed, they could all be used simultaneously to record a network of canals and how they flow into one another. The measuring stick has proven to be very accurate and has potential for simultaneous readings. These devices could be placed in fixed locations and pictures could be taken very quickly. There is also the possibility of creating a smart phone app that could be downloaded by pedestrians; persons with the app could then take pictures at any time and upload them to a database, hereby increasing the amount of measurements. Using the data we collected with these devices we were able to identify a few changes within the canals. From this data we would also recommend that future studies focus in particular on the canals near Rio di San Felice and Misericordia. In accordance with the cause of these changes we were only able to make a few conclusions. The model results suggest that the recent changes in bathymetry have not had much of an effect on the velocities and the addition of the MOSE flood gates has had minimal effects; however, evidence as to the exact cause of the exhibited changes in current velocities is still inconclusive.

Although there is not yet definitive evidence indicating causes for change in some of the inner canals since the 1990s, future studies may be able to use the new measurement devices we developed to continue data collection and further this investigation. Hydrodynamic data, made available to the public through Venipedia, can also be used by sponsors and researchers for future analysis purposes. We hope that our work and this data on Venipedia will help our sponsors to better monitor the hydrodynamics of the canals of Venice so that necessary maintenance can be done in an efficient way, and a healthy, navigable waterway system can be maintained.

Authorship

Each team member contributed equally to this project.

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1. INTRODUCTION

Coastal communities are greatly affected by both human and natural factors and are continuously changing. Sea level rise due to climate change, natural land subsidence, and erosion alter shorelines and land features near bodies of water (Beatley 2009). Over the past 20 years, the sea level has been rising at a rate of 3 mm per year (Rahmstorf, 2012). Humans have been building structures in or near coastal communities in an attempt to counteract some of the negative effects of such changes; other structures are built to harvest water power or fresh water. Many of these attempts can be very effective and can have minimal adverse effects on their surroundings. However, human interference with natural water flow can also cause many unexpected or problematic changes in the hydrodynamics of waterways. According to an article in *Marine Geology*, over 50 years of dredging, jetty construction and other human activities in the entrance to the Columbia River off the coast of Washington and Oregon have caused redirection of sand deposits, "transfer[ring] about 1.5 million m^3 of sand per year out of shallow water into deep water" (Gelfenbaum and Kaminsky, 2010, 7). This loss of sand has caused coastal land erosion in many locations where buildings have been constructed. These effects have put home and business-owners at risk of losing their property. In the Middle East, excessive redirection of fresh water in the upper Jordan River usedto supply homes and agriculture is causing a drop in water flow. The lower Jordan River has experienced serious flow decreases in the past fifty years, slowing from 1.3 billion m^3 to 30 million m^3 per year ("Jordan River"). As a result of this, the lower Jordan is less efficient in removing sewage from its waters, making the river polluted and potentially unusable as a water source or waterway. Human and natural influences are altering the hydrodynamic characteristics of waterways, affecting the communities that rely on them.

The city of Venice, Italy is highly dependent on its waterways. Venice's waterways are relied on for transportation and for the city's sewage removal.. As a result of this, anything that affects the natural water flow through Venice is significant to the lives of its people. The relative sea level rise in the last 100 years "consisting of about 12 cm of land subsidence and 13 cm of sea level rise, has increased the flood frequency by more than seven times" (Carbognin et al., 2010). Changes in canal hydrodynamics can cause delays in transportation, business, and overall Venetian life. Flooding and *acqua alta* (exceptionally high tides) cause damage to building structures, loss of property and merchandise, and traffic backups. For example, currents throughout the canal system keep the waters cleaner by allowing for water re-cycling and sewage drainage; however, rapid currents accelerate the erosion of building foundations. These problems continue to increase in severity as human activity and environmental factors alter waterways (Ravera 2000).

Monitoring the water movement of Venice's canals is essential to the everyday life of its people, but there is a general lack of understanding of how water flows through the canals. Recent studies show that there have been changes in the motion of water within some of the canals (Wolf et al., 2012). Although it is possible that these changes can simply be a result of an overall rise in sea level and increase in land subsidence, there are alternative theories about the contribution of floodgates and the dredging of the lagoon (Ghezzo et al., 2010). There is evidence from other locations outside of Venice that human construction projects have had unintended adverse effects on coastal communities. For example, in New Orleans, Louisiana, the construction of levees intended to prevent flooding of the Mississippi River has redirected sediment-carrying overflow waters that once added sediment to the river's immediate surroundings. This contribution to the loss of sediment supply has added to land subsidence around the levees. In order to avoid similar problems in Venice and to keep the city informed on the behavior of its waters, many organizations have been created in the city to collect information about variations in the city's tides and canal hydrodynamics. The *Instituzione Centro Previsioni e Segnalazioni Maree*, or *Centro Maree*, was established in Venice in the late 1970s to provide "maximum information on tide and an efficient and immediate alerting service in case of high tide." To forecast the most accurate tide levels, Centro Maree collects meteorological data from the lagoon, the Adriatic Sea and other surrounding areas ("Il Centro Maree", 2010). Past IQPs, starting in 1990, have taken measurements of tide levels, water velocity and speed and have compared their data to past data, modeling their findings with the help of the Institute of Marine Sciences (ISMAR), an organization headquartered in Venice that collects and models data on marine environments.

Previous research on canal hydrodynamics in Venice has provided valuable data on tide levels and water speed and direction (Scully et al., 2011). Centro Maree is capable of producing highly accurate water level forecasts using sophisticated modeling techniques for the city of Venice. However, this information is not specific to the individual canals. Instead, this data is collected from locations within the lagoon and other areas surrounding Venice. Therefore this data cannot be used to predict the hydrodynamic conditions within the canals. Past studies by students from Worcester Polytechnic Institute (Interactive Qualifying Projects - IQP) have recorded data within individual canals in order to better understand how they work. Methods such as measuring the time it takes for a floating device to travel a set distance can be used to calculate the water velocity which provides a good concept of how water flow within the canal segments can be derived. This information is accurate on a small scale, but does not allow conclusions to be made about the overall canal network. The current methods for collecting measurements are simple and effective, but they are limited by the amount of manpower available to them, which makes the repeated collection of data laborious and infeasible.

The goal of this project is to propose a feasible plan to repeatedly collect hydrodynamic measurements of Venetian canals that can be used to monitor the canals and produce models that more accurately represent them. With these models, erosion rates and sediment displacement can be predicted and maintenance plans can become more efficient. Canals that have been identified to possess a high rate of sediment accumulation will be dredged more often than canals with less sedimentation. To develop this plan, various methods for obtaining hydrodynamic data will be tested and assessed for accuracy, efficiency, repeatability, and ease of use. Some methods that are going to be investigated are: releasing GPS devices into the canals and implementing measuring sticks that can be easily read via photographs. The data collected, along with previously recorded data, will be made available online to the public through Venipedia, a website based on Wikipedia that contains information specifically about Venice. The data can then be used for research, modeling, forecasting, and more. The plan should lead to a solution for collecting comparable hydrodynamic data on Venice's canals that can be built upon and someday implemented within the canal system.

2. BACKGROUND

This chapter includes background on the Venice Lagoon, the canal system in Venice, factors influencing canal hydrodynamics, and previous and contemporary work on collecting hydrodynamic data.

2.1 Venice Lagoon

Venice is situated in a shallow lagoon, protected from the Adriatic Sea by a string of barrier islands. Water flow through the lagoon influences flow into and out of the canal network of the city. This section provides a background on the Venice Lagoon – specifically, its three inlets, watersheds, hydrodynamic information regarding water flow through the lagoon, and lagoon construction projects: the Malamocco-Marghera channel and Project MOSE floodgates.

2.1.1 Lagoon Hydrodynamics

Water flow through the inlets to the Venice Lagoon is largely influenced by tides. Over 90% of the water level and current variations between the lagoon and the Adriatic Sea are due to tides, while other influencing factors include winds and barometric pressure (Gačić, 2004). The consistent recurrence of tides particularly impacts the transit times (time required for water to travel from its current position in the lagoon out into the Adriatic Sea) for water in the inner lagoon. Water that is further from the lagoon's three inlets is prevented from leaving the lagoon by incoming tides, causing the transit times of some areas to be over 80 days. The average time required for a sample of water to reach the sea is 47 days whereas water in very close proximity to the inlets can exit the lagoon in 6 hours ("Atlas of the Lagoon").

Studying the transit times for water in the lagoon is one way to comprehend how water flows through the lagoon and, in turn, through Venice. Water that first needs to pass through the city's canals before reaching the sea can stay in the canals and the lagoon for a significantly longer amount of time compared to water that does not travel through the city. This delay is relevant to understanding the movement of waste and sediment in the canals.

2.1.2 Watersheds

The Venice Lagoon is divided to create three main sub-basins: the northern, central and southern sub-basins, as shown in Figure 10. The northern sub-basin can be further broken down into the north and central north (Apitz et al., 2007). The City of Venice is located in the central north sub-basin. The Lido inlet connects the Adriatic Sea to the northern sub-basin. The second inlet to the Venice Lagoon, the Malamocco inlet, opens into the central sub-basin. Hydrodynamic and tidal effects are enhanced in this sub-basin due in part to the Malamocco Marghera Channel that allows tankers to pass more easily in the lagoon. The Chioggia inlet creates a pathway between the Adriatic and the southernmost sub-basin of the Venice Lagoon. This sub-basin has the lowest inflow of freshwater in the lagoon (Franco et al., 2006).

Figure 10. Watersheds of the Venice Lagoon (Borin et al., 2009)

2.1.3 Malamocco-Marghera Channel

Maritime trade has been vital to the economy of Venice and the coastal communities of the Venice Lagoon for centuries. Over time, cargo ships entering the lagoon have grown larger, placing physical constraints on ship navigation in the lagoon since the average depth of the water is only about 1 meter (Ravera, 2000). To allow for large ships and oil tankers to pass through the lagoon, deep channels have been dredged from lagoon inlets to major ports on the mainland. A prominent example of this was the construction of the Malamocco-Marghera channel in 1968, which was built to connect the Malamocco inlet to the Marghera port and measures 11 meters deep ("Access to the Sea," 2010).

Figure 11 shows water depths in the Venice Lagoon. The Malamocco-Marghera channel is clearly seen as the dark blue "canal" extending westwards from the Porto di Malamocco and then hugging the mainland as it runs north to Marghera. The model illustrates the drastic difference in water depth between the Malamocco-Marghera channel (and other man-made channels) and the rest of the lagoon colored lighter blue. The dark blue color shown on the map emphasizes the deepest water in the Venice Lagoon.

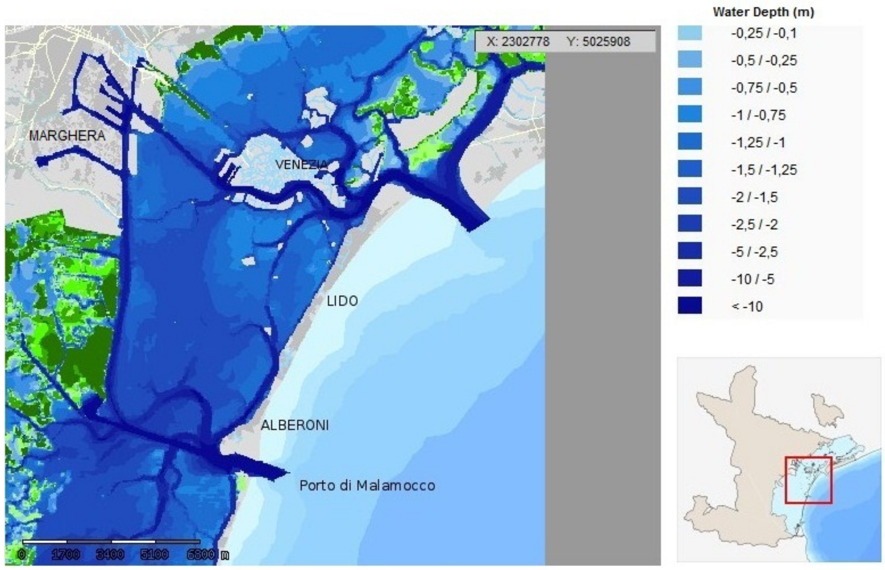


Figure 11. Bathymetric model of the Venice Lagoon, showing the Malamocco-Marghera Channel

The Malamocco-Marghera channel allows access to the Marghera port, therefore permitting an expansion in business. However, various research studies have shown that "excavation of navigation channels through the seaward inlets and across the lagoon, carried out mainly in the 1960s, significantly altered water circulation within the lagoon" (Molinaroli et al., 2009, 121). The greater depth of the channel relative to the rest of the lagoon bed, and repeated dredging, causes currents to flow more rapidly through, contributing to erosion of the lagoon bed around the channel. Figure 12 illustrates this bathymetric change to the lagoon; the map shows that between 1970 and 2000, strong erosion (more than 0.5 meters lost) occurred primarily surrounding the Malamocco-Marghera channel, and deposition of sediments were recorded in the channel. This study confirms that since the construction of the channel, a noticeable amount of sediment-carrying water has redirected to flow through the channel, and that the channel's presence has caused increased erosion in its immediate surroundings.

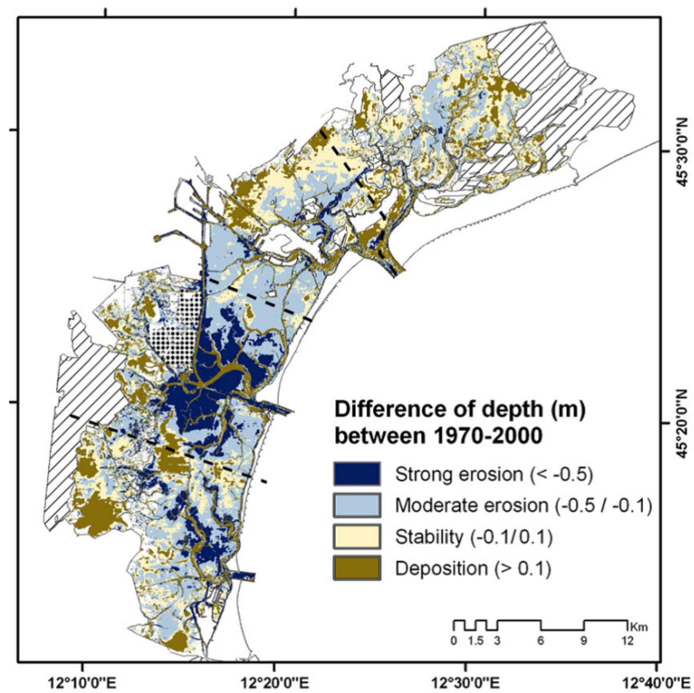


Figure 12. The change in depth of the lagoon from 1970 to 2000. As Shown, the greatest depth difference occured in the region surrounding the Malamocco-Marghera Channel

2.1.4 MOSE Floodgates

The MOSE project, or *Modulo Sperimentale Elettromeccanico*, is a controversial engineering project executed by the *Consorzio Venezia Nuova* and the Venice Water Authority ("Sal.Ve") that began in 2003 and is expected to complete in 2014. The plan is to construct mobile floodgates at the three inlets to the Venice lagoon. The gates are intended to protect the City from flooding by closing them when exceptionally high tides and storm surges are forecasted, preventing the flow of water into the lagoon (Thomas, 2010). Figure 13 below illustrates the mechanical design of the floodgates: when the gates are not in use, they are filled with water and lie flat on the lagoon bed. Pumping air into the gates displaces the water and makes them rise to create a barrier for high tides as high as 3 meters.

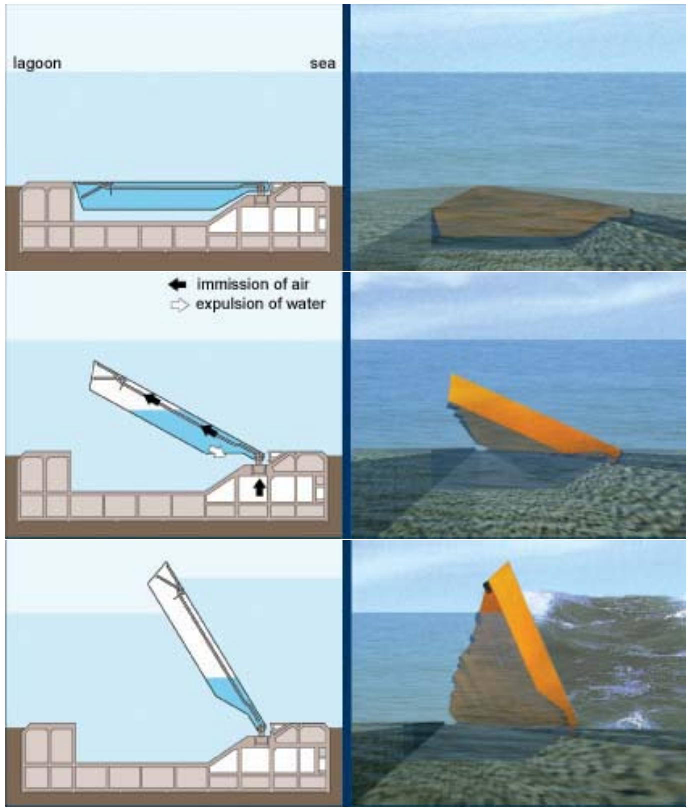


Figure 13. Drawings and realistic renderings of the mobile flood barriers currently under construction as Project MOSE in the Venice Lagoon inlets. In closed position (top), the gates are filled with water; pumping air through the gates makes them rise and block tides up to 3 meters high ("Sal.Ve")

The construction project was approved to address the increasing frequency of flooding and resulting adverse effects on the city's infrastructure and inhabitants. The gates are also a precautionary measure, in the case of another extreme flood like the Great Flood in 1966, during which Venice's waters reached a historic level of 194 cm (Thomas, 2010). Although the gates may be successful in preventing high waters from reaching the city, the project is raising concern among some citizens and conservation groups regarding the effects the gates will have on the lagoon's ecosystem and hydrodynamics. Conservation groups such as Italia Nostra fear that the gates could cause negative environmental effects, such as reduced water circulation as result of blocking off the lagoon from the sea (Standish, 2004). The gates are designed to rise and block the sea only when tide levels are forecasted to reach 110 cm or higher, and are predicted to be used between 3 and 5 times per year ("Sal.Ve") - but many skeptics of the project claim that if relative sea level continues to rise, the gates' frequency of use will also increase. In addition to environmentalist opposition, disapproval also stems from political groups and residents who believe that less expensive alternatives with a lower risk of adverse environmental effects should be implemented (Thomas, 2010).

Project MOSE is currently under construction and not yet operational, and the scope and degree of positive and negative impacts that the gates may have on Venice have yet to be fully determined. Although it is agreed that the presence of the barriers will yield some change to the natural water flow between the lagoon and the sea, it is still disputed whether or not significant environmental benefits of this natural flow will be forfeited in exchange for the protective service the gates will provide.

2.2 Venice Canal System

Venice relies heavily on its complex system of canals. An intricate network of about 160 canals also known as *rii,* connect the islands of the City of Venice. The largest and most frequently traveled canal is the Grand Canal. This canal can be easily identified as the large S body of water in Venice. In total, the canals span about 40 km in length and take up approximately ten percent of Venice's living area. Figure 14 shows a map of the canals of Venice. Knowledge of the functions of the canals and their structure is important to understanding some of the factors that influence canal hydrodynamics.

Figure 14. Map showing the canal network of Venice

2.2.1 Uses of Canals

The canals are to Venice like streets are to New York City; anything that influences their flow dramatically affects the lives of the city's people. The canals are essential to everyday life, for Venetians and tourists alike, as a main source of transportation and waste removal. One way this is exemplified is in Venice's extensive water taxi service system. The company of Motoscafi alone has over 100 water taxis that run 24 hours a day ("Consorzio Motoscafi Venezia"). The canal system is also used to transport supplies around the city to the large variety of small shops and businesses. Although the canals are essential to life for the Venetian people, they have also become a symbol of Venice and attract thousands of tourists and visitors from around the world each year.

2.2.2 Canal Structure

Although the canals of Venice vary in size they share the same general structure. The canals range from a few to tens of meters in width and between 1 to 5 meters in depth. The longest canal in Venice, the Grand Canal, spans approximately 4000 meters. The shortest canal in the City is Rio Amalteo, which is 25.7 meters in length. The canal walls are generally constructed using one of two different materials, brick or Istria stone. Although Istria stone is more durable and fares better in salt water, brick is still often used because of its low cost and availability (Shevlin, 2006). Figure 15 shows the structure of a canal.

Figure 15. Canal Structure

2.2.3 Dredging and Canal Maintenance

In order for the canals of Venice to remain useful, they must be maintained regularly.. The maintenance process, known as dredging, consists of removing sediments that have settled to the canal floor and built up to dangerous levels. The sediment consists of natural sediment brought in by the tides, waste, and materials that have fallen off buildings and canal walls. There are two types of dredging: deep-water dredging and dry-bottom dredging. In deep water dredging, shown in Figure 16, excess sediment is removed from the bottom of the canals, while the canals are full. In dry-bottom dredging, most of the water is drained from the canal and then sediment is removed. Typically deep-water dredging is performed before dry-bottom dredging.

Figure 16. Deep-water dredging in a canal

Insula maintains the canals of Venice. In the early 1990s, this company cleared more than 380,000 cubic meters of sediment out of the canals. The dredging process is unavoidable and ongoing due to continuous of sediment build up from the constant flow of water throughout the ("Venice Urban Maintenance", 2009).

2.3 Canal Hydrodynamics

Tides are a major factor influencing the hydrodynamics of Venice's canals. This section includes a general overview of why tides occur, the phases of tides, and background on one of our project sponsors, Centro Maree the tide-forecasting center in Venice. Although tides are the dominant driving force, there are also other influences on canal hydrodynamics that include cruise ships, boat traffic, filled in canals and weather conditions (pressure gradients and wind).

2.3.1 Tides

As the moon rotates about the earth, it imposes a gravitational force. The force is strong enough to influence the water in the earth's oceans. The water is pulled in the direction of the moon, and the opposite side is pushed out to counter act this force (Figure 17). The gravitational effects of the sun also come into play and cause what is called "spring tide" and "Neap tide," which occur when the sun and the moon are aligned to create the strongest possible force. These are particularly high and low tides, respectively ("Tides and Water Levels", 2012). Between every high and low tide cycle, there is slack tide. Slack tide is the tide that occurs right as the water starts changing direction and causes the water to be momentarily stagnant. This stagnation is similar to a ball being thrown into the air and having a velocity of zero at its peak. Current velocity measurements are not useful at these times because there will be no flow.

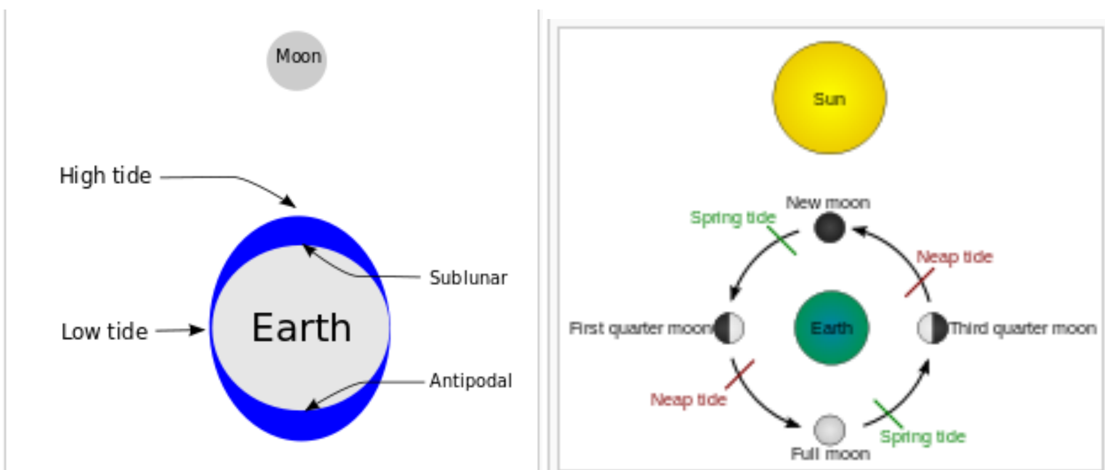


Figure 17. Gravitational pull from the moon and sun cause tides on Earth

In accordance with Venice's location, the middle of a lagoon in the northeast corner of the Adriatic Sea, the tides play a major role in the city's functionality. When large tides are expected to come and flood the city, the Centro Maree is in charge of warning the people in Venice by means of sirens. In the case of high tides, people must properly dock their boats and prepare their shelter. Boats need to be tightly secured and items on the ground that may get wet need to be elevated. When the tides are extremely high, bigger boats will not be able to pass under bridges, public transportation boats cannot run as often, and some of the streets are unusable. During the winter season high tides occur more frequently. This phenomenon is called *acqua alta* or "high waters." Along with the normal tidal influences, this portion of the Adriatic has its own tidal resonance with a frequency of about 22 hours, known as seiche. Strong winds called *Sirocco*, from the southeast, and *Bora*, from the northeast force water to one side of the Adriatic and cause the resonance by holding the water there and then releasing it. As the northern areas start to cool off during the winters, the warm air masses cause higher-pressure gradients and add to the irregular high tides. As shown in Figure 18, the pressure differences and strong winds cause a great water displacement that is forced into the lagoon ("Il Centro Maree", 2010).

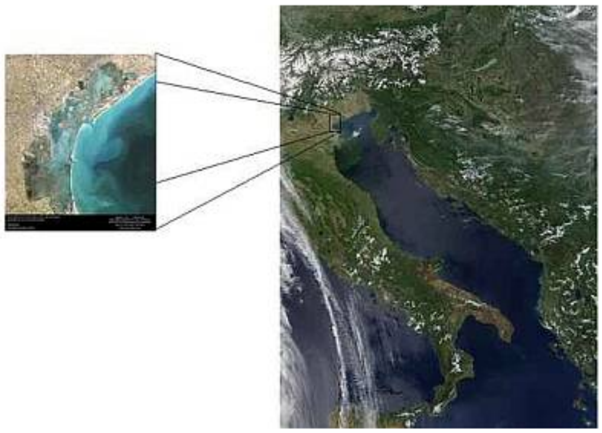


Image of NASA, www.visibleearth.nesa.gov - Image of the lagoon from CVN www.istitutoveneto.it

Standard model of atmospheric depression which can cause high water in the Lagoon of Venice (NASA image, www.visibleearth.nasa.gov)

Figure 18. Winds and pressure differences

2.3.1.1 Centro Maree Forecasting

The Istituzione Centro Previsioni e Segnalazioni Maree, or Centro Maree, is an organization that dedicates its work to forecasting tide levels and sounding flood warnings in the city of Venice. The tide levels in the canals are forecasted and monitored so the residents of the City can be warned as early as possible of an incoming flood. When Centro Maree is aware that a flood is approaching, they sound the alarms located on various bell towers in order to provide residents and visitors time to prepare for the floods. Although the tides move in slowly, it is still essential to sound the warning. This siren has become a part of Venice and is something that is regularly listened for while in Venice to take action to avoid the damaging effects of floods. ("Città di Venezia")

In order to make the most accurate predictions of incoming tide levels, the Centro Maree uses what they call the "Frankenstein Model." The Centro Maree employs many different models and the Frankenstein model is essentially a combination of every method Centro Maree has. This model therefore takes advantage of both statistical and deterministic predictions. Statistical predictions are based off of a large database of previously recorded situations and their effects on the tides. This method will predict what is likely to happen based on what has happened in the past but conditions are never exactly the same. The deterministic models use meteorological models to predict what should happen in theory, but as in any model, there are unknown factors that are not, or cannot be accounted for which leads to inaccuracies. The results of Centro Maree's Frankenstein model are usually accurate to five centimeters.

2.3.2 Factors that Influence Canal Hydrodynamics

There are many different factors that influence the hydrodynamics of the canals. The friction of the walls and bottom of the canal affect the water flow. The maximum water velocity in a canal occurs in the middle of the canal and one third of the depth, where friction is at a minimum. Cruise ships affect the hydrodynamics of nearby canals. When a cruise ship is going by, the water levels in surrounding canals decrease and the water velocity increases. Although it is known that cruise ships affect the hydrodynamics of the canals, the extent is unknown (Saari et al., 2011). The increased use of motorboats in the Venetian canals also disturbs the natural flow of water. A motorboat creates two different waves; the wash is created by the front of the boat and the propeller at the back of the boat produces the wake. These waves interrupt the natural flow of water and increase the force felt by the canal walls. The materials used to build the canal walls are more susceptible to damage because they are unable to withstand the increased force from motorboat wakes. The increased use of motorboats in recent years has intensified the rate of erosion and breakdown of the canal walls, which contributes to the increase in the amount of sediment on the bottom of the canals (Nodine, Jagannath and Chiu, 2002).

2.3.3.1 Rii Tera

The term *rii terà* is used to refer to canals in Venice have been filled in. There are two types of *rii terà.* Some canals have been completely filled in and are referred to as *rii terà tombatti*. When a canal is filled and removed from the canal network, there is an initial change in hydrodynamics. After this initial change, *rii terà tombatti* no longer affects the flow of the surrounding canals. Other canals are covered over and referred to as *rii terà con volti*. These canals act like regular canals but there is a limit as to how far the tides can rise because they are covered. These canals are constantly affecting the flow of surrounding canals, especially when the water level is high. Water flow through a *rii terà con volti*, is restricted and if too much water tries to go through, it can cause the water level to rise in other canals (Zsofka et al., 1999). A map of rii tera is shown in Figure 19.

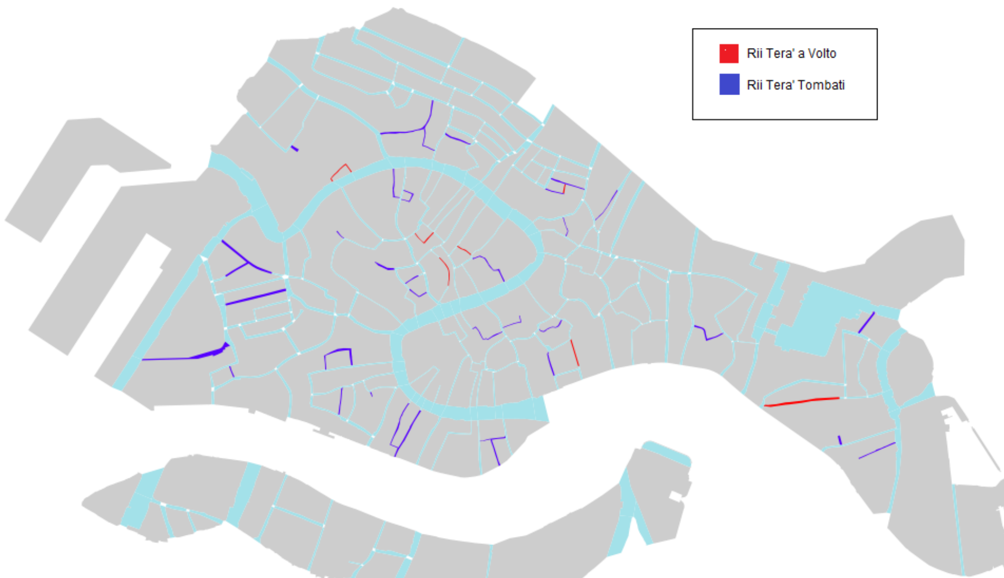


Figure 19. Map of rii tera

2.4 Past Hydrodynamic Studies of the Canals of Venice

Over time, many hydrodynamic studies have been performed on the canals of Venice. Early studies collected data pertaining to the direction of flow in the canals. More recent hydrodynamic studies have collected quantitative data about the canals. The following sections highlight some of the most important studies that have been performed on the canals of Venice.

2.4.1 Early Studies of the Canals of Venice

Early hydrodynamic studies in the Venetian canals collected only qualitative data. Carlo Paluello conducted the very first study of the canals of Venice in 1900. His goal was to determine the direction of current in all of the interior canals. However, he only documented direction either during the incoming or outgoing tide. Although this study did not collect a complete data set, it marked the beginning of studying the canals of Venice and set a benchmark for future studies.

The next recorded study of the canals, *Ufficio Idrografico Magistrato alle Acque,* began in 1914 was performed over a span of about 40 years. This was essentially a repeat of Paluello's study performed over a larger period of time to gain a better understanding of the flow of the canals. These observations and determination of direction occurred 10 times and in 7 different years. The dates include 3/9/1914, 5/19/1914, 5/26/1917, 3/8/1920, 10/2/1921, 3/22/1932 – 3/23/1932, 6/22/1932 – 6/23/1932, 7/22/1933 – 7/23/1933, 12/12/1951, 1/11/1952 – 1/12/1952. These studies show almost identical results to Paluello's findings, showing the flow of water through the canals didn't change much over the course of 60 years. However, some different results showed first signs of the direction of current changing, which was probably caused by tides.

Additional research was conducted during the *Ufficio Idrografico Magistrato alle Acque*. In 1937, Fabris conducted another observational study to determine the direction of the canals. However, this project included the canals in Giudecca in its area of study for the first time.

Figure 20 shows a time line of past hydrodynamic studies performed in Venice. A larger version can be found in Appendix A.

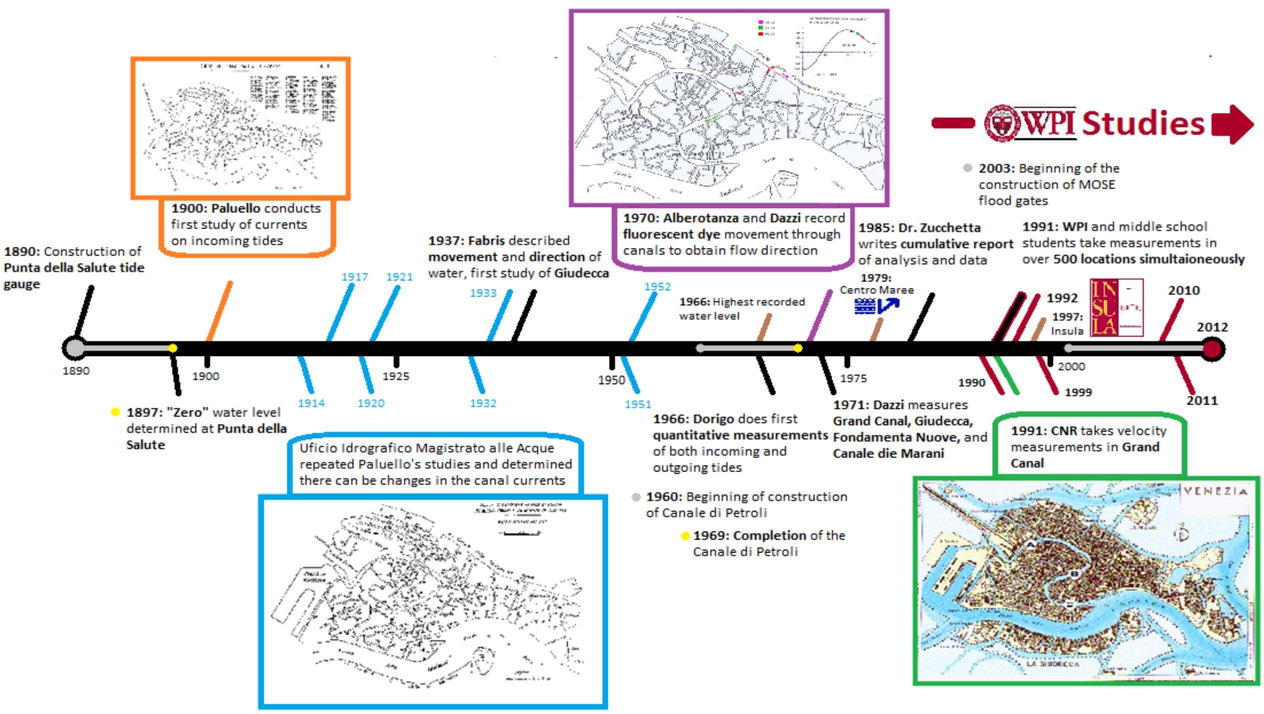


Figure 20. Past Hydrodynamic Studies in Venice

2.4.2 Studies of the Canals of Venice - the Last 50 Years

The canals of Venice were first studied quantitatively in 1966 by Dorigo. This study collected current data at 4 fixed locations in each of 36 interior canals of Venice. This marked the beginning of gaining real data on the canals marking the projects true significance to the future.

One of the most famous studies performed on the canals was when a florescent dye was dumped into the water and was followed around to see how the water moved throughout the city. It took place on June 23, 1970 and was organized by two men named Alberotanza and Dazzi. Furthering his work in 1971, Dazzi did another study where he measured four major locations. He measured the Grand Canal, Giudecca, Fundamente Nuove, and Canale dei Marani.

Giampietro Zucchetta's I *Rii di Venezia* (1985) is a paper that amasses all of the information collected in the previous studies in an attempt to validate their results. The studies by Dorigo and

Paluello were used to verify those of Alberotonza and Dazzi. This paper also emphasizes the difficulties and lack of representative statistics about the behavior of the canals, conditions of the tides, and maintenance of the canals.

In 1991, a group of researchers from CNR Comune took continuous hydrodynamic measurements of the Grand Canal at three locations. The researchers measured the minimum and maximum water velocities of the tides during different phases for a significant number of cycles. The velocity of the current one-meter below the surface was measured along with an entire profile of the canal (from bottom to top). The goal of this research was to establish a tolerance as to which the speed of a vessel undergoes due to the velocity of the current. This research also provided evidence of a watershed at the western end of the Grand Canal that had yet to be recorded.

One of the largest efforts to collect quantitative data pertaining to the canals was conducted in 1991 and involved Club UNESCO collaborating with the middle school children of Venice. Velocity and direction of the currents were simultaneously measured at 105 different locations and spanned the city of Venice and the islands of Giudecca, Murano, Burano, Lido and Malamocco. This example of "citizen science" along with other organized events in the past and present have proven that crowd sourcing and community involvement are effective forms of man power and data collection. Past efforts in other scientific fields have gathered useful data, including Waterloo's SnowTweet; Canada has set up a system where the world was asked to tweet the snow level from their current location. This is a simple and effective way to collect data to map the snow levels around the world and actually provides a visualization to show your current location's snow level compared to the rest of the world (SnowTweet 2012). Another example of a community-involved effort is the Community Collaborative Rain network. This involves the citizens of the United States taking the amount of precipitation they record in a day and posting it on the website. It allows people to get involved and report the weather but also provides useful information that weather centers can use to model future weather. The more data they have the more informed and mathematically accurate the models can be (Community Collaborative Rain). Previous efforts involving citizen science have proven successful and in the future community involvement could be a great way to obtain the necessary amount of people needed to collect hydrodynamic measurements successfully.

Previously conducted studies conducted by students from Worcester Polytechnic Institute (USA), performed in 1999, 2010 and 2011, used a simple floating device that was placed in the middle of a canal and allowed to move freely with the current. The time it took to travel a predetermined distance was recorded. These measurements can be used to calculate the speed of the device and thus the approximate current velocity. The direction of the current is simply observed from watching and timing the device as it moves in the water. The floating devices consisted of a floating bottle on top of the water connected by fishing line to a weighted blade hung one third of the average depth of a canal below the surface. This location is the point where water in a channel moves the fastest. This blade would then glide through the water dragging the bottle with it, allowing a known distance to be timed and velocity to be calculated (Zsofka et. al 2009). Students on this current WPI project continued these measurements and compared them to more modern methods and technology. The contributions of WPI to the study of hydrodynamics in Venice are shown in Figure 21. A larger version can be found in Appendix B.

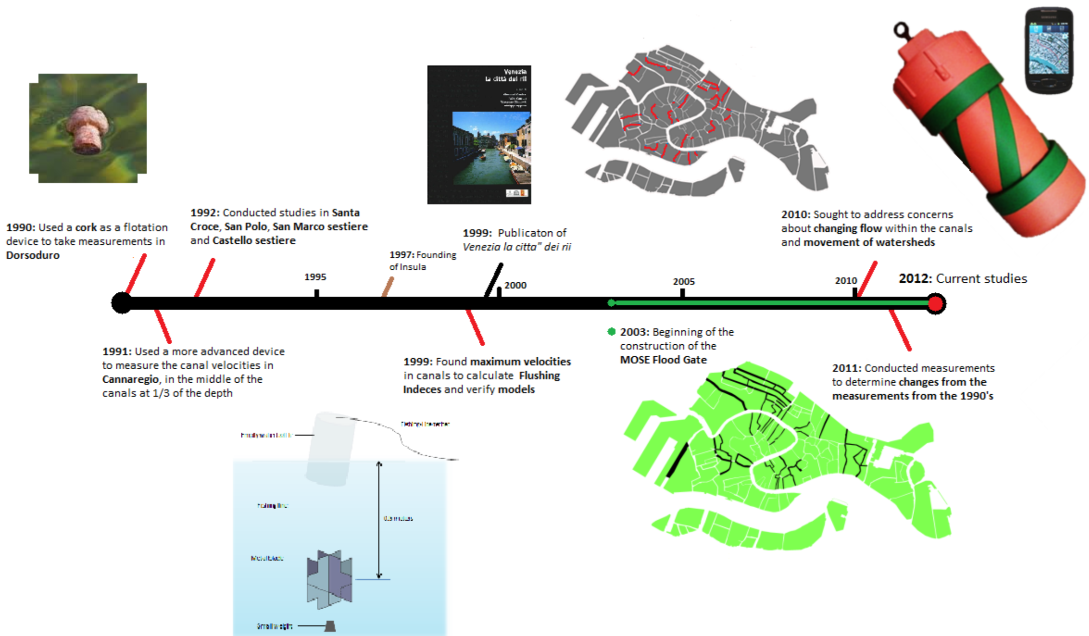


Figure 21. WPI contributions to hydrodynamic studies in Venice

2.5 Hydrodynamic Modeling of Venice

Mathematical models of Venice's lagoon and canals are used to simulate hydrodynamics and sediment transport. Models are based on and validated by data collected in the field. Sediment and flow models can be used to assist in creating maintenance plans by predicting which canals will have the quickest buildup of sediment (Zsofka et. al, 1999). One of the sponsors, ISMAR, creates mathematical models of the lagoon, canals and inlets and their water flow behaviors. Their work is essential to the city of Venice because it aids in forecasting the tides and predicting future water flow patterns through the canals.

2.5.1 Makeup of ISMAR Model

Models are mathematical representations of some aspect of study that requires further analysis beyond what can normally be acquired through field tests and actual measured data. ISMAR's model is mainly made up of two major components. The first is a 2-D finite element shallow-water model (SHYFEM) of the lagoon that has been applied to calculate the water level around the city of Venice (Figure 22). This will be used as an input for the model used for the inner canals.

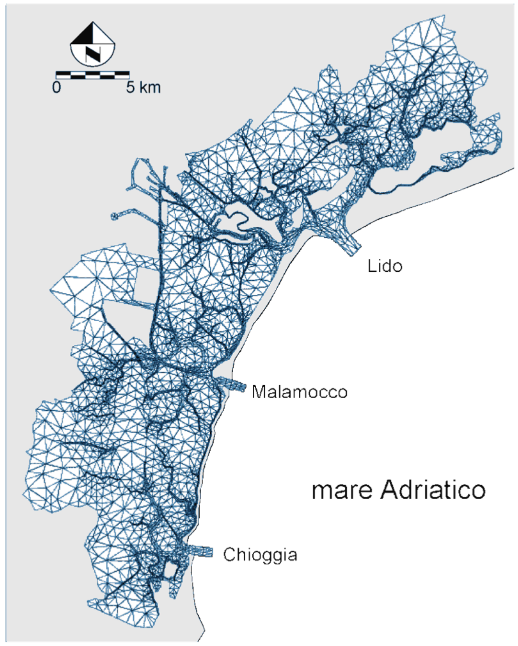


Figure 22. Finite element lagoon model (SHYFEM) used by ISMAR

The water levels surrounding Venice are important because water level directly affects the currents through the inner city's canals. Even slight variation in the water level from one end of the city to the other will create some form of a current in the direction of the lower water level. The second component is a hydrodynamic link-node model that has been used to calculate the water level, current velocity, and sediment transport in the inner canals of Venice, as shown in Figure 23. The model utilizes what is referred to as link nodes, or segments that are smaller than existing physical segments, to get a more accurate view of what is going on. The combination of these two elements allows the model to present a vertical layered structure that simulates and shows sediment transport through the canals as well as erosion and deposition. These models can then be analyzed and used in a number of different ways to determine important information relevant to the city.

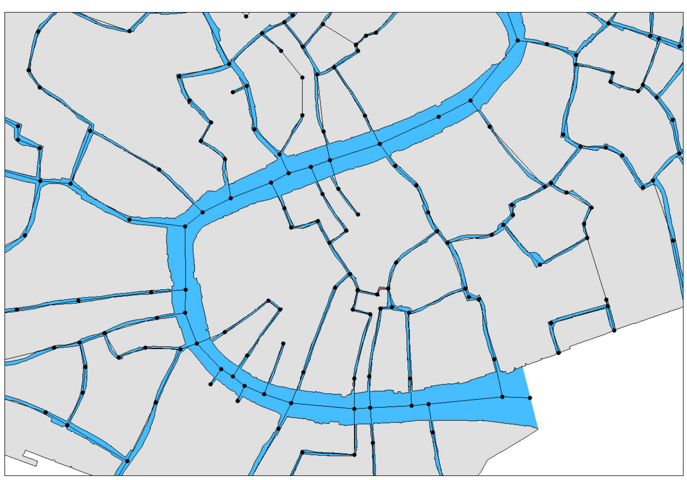


Figure 23. Link-node model used by ISMAR

2.5.2 Application of ISMAR Models in Venice

Understanding the circulation in the channel network of Venice is important for the life of the city because it constitutes the principal way of transportation for people and public services. The primary use of the model is to gain a full understanding of how the water flows through the intricate network of canals. With this knowledge, things such as sediment transportation, erosion and deposition can be calculated and then be used to determine which canals are likely to fill with sediment faster. Canals are natural collectors of pollutants, most commonly human waste, which can lead to be a serious health concern for the people living in the city. As the canals continue to collect sediments, also known as silting up, they tend to collect pollutants such as this at a much quicker rate. By running models, dredging schedules can be accurately assessed and planned so that canals filling much quicker can be targeted first. By targeting these canals, the level of risk due to built-up waste will be decreased significantly. Another way these models can be used is to determine change in the hydrodynamic properties of the canals and possibly aim to prove the cause. These models are run and analyzed and the information gathered from each run is saved for future use. As aspects of the models are updated and the models rerun, any changes in the canal properties can easily be seen. If there is change, informed decisions can be made on why the changes may have occurred by comparing to past model results.

The models that ISMAR has created provide imperative data and analysis that has led to the city being an overall healthier and safer place to live. However, one issue concerning models is proof that they are accurate. In 2004, the first proof of the models was performed showing promising results of how they were representing the currents in the canals. However, as Venice and its surrounding areas continue to change, the models are updated and further proof is needed. Examples of change are dredging of the canals, other bathymetry changes, like the creation of the Malamocco-Marghera channel, and construction of the flood gates including the addition of a small island added in the middle of one of the Lido inlet. All of these things will cause hydrodynamic changes in the lagoon as well as the inner canals of the city and more measurements will need to be taken to prove the accuracy of the models.

3. METHODOLOGY

There are many socioeconomic and health reasons to monitor the canals. At low tide, the water levels can drop so drastically that transportation issues arise. In 2008, the water level dropped by 80 centimeters, causing gondolas to get stuck in the sediments on the canal floors. *Vaporetti*, or waterbuses, were forced to change their routes to avoid grounding ("Venice's gondolas stuck in low-tide mud", 2008). The build-up of sediments at the bottom of the canals contributes to the problems at low tide and makes it difficult for boats, including emergency boats, to pass in many locations. This interrupts daily life for Venetians and tourists. Water velocity is directly related to sediment build-up on the canal floors. A high-velocity canal is able to carry sediments whereas in a slow moving canal, sediments more easily settle to the canal floor. Maximum velocity measurements can be used in models to estimate sediment buildup in the canals and determine where sediment will build up the fastest (Zsofka et. al, 1999).

Additionally, measuring the flow of the canals is essential to the health of all who visit Venice. Much of the city does not have a sewer system and human waste is released directly into the canals. Venice relies on the movement of water in the canals to flush this waste out of the canal system and out with the tides. If water flow through a canal slows over time until it is stagnant, this is a major health concern because this can form what is essentially an open sewer. Poor sanitation is linked to many different diseases, bacteria and viruses including diarrhea, cholera and typhoid ("Tearfund and WaterAid"). Monitoring the canals of Venice to identify if such changes are occurring can allow them to address such health issues, and is crucial to the livelihood and welfare of Venetians and those who visit Venice.

This project was intended to help our sponsors better understand and monitor the canals of Venice by developing a sustainable plan to collect accurate hydrodynamic data over an extended time period, taking and analyzing our own hydrodynamic measurements, determining changes using models, and making all of this data accessible to the world through Venipedia. A component of the plan includes prototyping and validating new devices for collecting hydrodynamic data in the canals, and developing recommendations for implementing the devices for future data collection.

The objectives for the project are:

1. To develop and test measuring devices that can be incorporated into an easily repeatable plan for collecting full tide-cycle data
2. To measure the existing hydrodynamic status of the canals by collecting water level and water velocity data
3. To determine if and to what extent the currents in the canals have changed since the 1990s using ISMAR models
4. To make hydrodynamic data available to the public through Venipedia

The project requires the group to take repeated measurements of canals across the city. To be most efficient with our time, we have identified specific canal locations to take measurements. These locations were strategically selected based on interest (many of the chosen canals are connected to the Grand Canal and the lagoon). Canals were also only selected if they were not undergoing maintenance. See Figure 24 for the map of measurement locations.

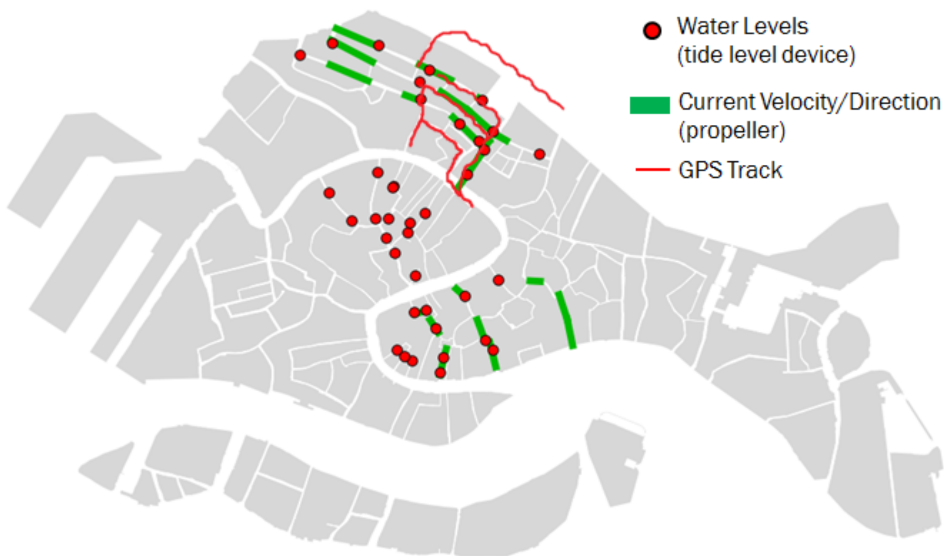


Figure 24. Field map of measurement locations for water levels and current velocities

Times for collecting data will depend in part on tide forecasts from Centro Maree. Water level measurements cannot be taken if flooding over the canal walls occurs. We must also be aware of outside influences such as wind and boat traffic. Measurements of water level and current speed should be taken together when possible, and the same measurement locations will be revisited several times over a 12-hour period to obtain data from complete tide cycles (Figure 25). Ideally, data collected at each location will include measurements close to the peak of high tide and trough of low tide, and around the midpoint between high and low tide (when current will reach maximum velocity). It is important for modeling purposes for us to carefully record the date and time at which all of our measurements are collected. The schedule and tide forecasts for measurements is shown in Appendix C.

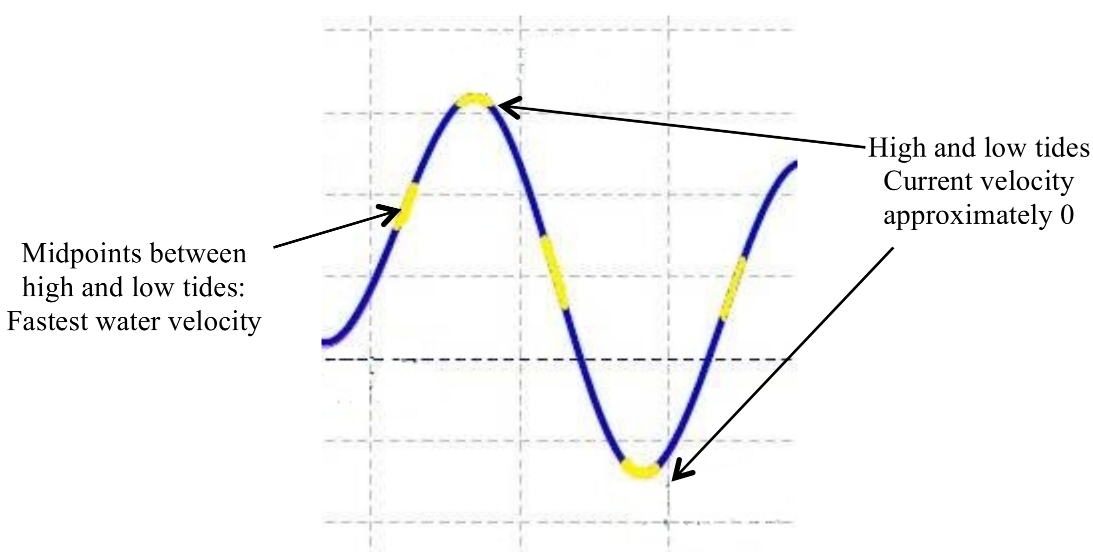


Figure 25. Tide cycle with example measurement periods

The team will be developing and testing a new method for collecting hydrodynamic data in the inner canals of Venice. We will be collecting measurements of water levels and current velocities. The new device for measuring current velocity will concurrently collect data with the timed float used by past groups and the data collected by each method will be compared to determine if the new method is valid and accurate.

3.1. Developing a Plan for Repeatable Measurements

The plan for extensive, repeatable measurements contains three major components: the floating GPS device, measuring sticks, and community involvement. The following sections highlight the design of these components, their validity, and how their functionality and accuracy were assessed.

3.1.1 Designing and Testing Floating GPS Measurement Device

Floating measuring devices can be used to collect hydrodynamic data, such as current velocity and direction. Instruments can be used that employ the Doppler effect of sonar waves in water to calculate the speed and direction of current. The faster the currents are, the closer together the sonar signals will be when the receiver detects them ("Products"). Currents can also be measured with a device that is similar to a turbine. As the water flows through the turbine, an electrical voltage is created. The faster the current, the higher the resulting voltage reading will be. Global Positioning Satellite (GPS) technology is a viable way to read currents. By releasing a floating GPS device into the water, it will move with the current. The position of the device can be recorded, and the distance it traveled and time it took to travel this distance can be used to calculate the speed and direction of the current of the device. This method is very similar to the more mundane approach of manually calculating the speed of current by marking a pre-designated distance and measuring the time it takes for a float to get from the beginning mark to the finishing mark. The same calculation can be made and the current speed can be interpolated (Tides and Water Levels, 2012).

An example of a device that can be used to collect hydrodynamic data is the floating sensor being created at The University of California, Berkeley. "The Floating Sensor Network is a water monitoring system that can be deployed in estuarine environments and rivers, and can be integrated into existing water-monitoring infrastructure." These devices are deployed into waterways to take various measurements including water movement, salinity, temperature and GPS location. They are unique in that they are released into the water and will go with the natural water flow in order to get the best readings. Devices such as these would be a great solution to help monitoring the canals in Venice granted there is a release system to release them all at the same time (Floating Sensor Network, 2012). However, these devices are expensive, and using several of them would not be cost effective if any were lost or damaged in the field.

Venice would benefit from the ability to take repeated measurements of the current velocity and direction in multiple locations. A key problem is the lack of an inexpensive measurement device that can be easily reproduced. There are over 100 canals in Venice and placing expensive precision instruments in all of the canals at one time is not feasible due to the cost and the risk of damaging instruments. A major part of developing this plan is creating an inexpensive device that we can test in Venice in order to start the process for the long-term goal of implementing new measurement methods.

As a part of the overall plan, the GPS device will be used to collect many measurements of current velocity and direction in the canals in order to determine thefeasibility of its use in the future. There are a lot of considerations that go into making the device that will affect the overall accuracy and efficiency of the device that will be discussed below.

3.1.1.1 Constructing the Floating GPS Device

The first step towards producing this device was an investigation of technology that can be used to implement the device. In an effort to make the device technologically up-to-date, we decided to use a smart phone with GPS capabilities. The use of updated technology could lead to more accurate and reliable data collection. With the smartphone, we can use the Android/Google app My Tracks to gain the information necessary to determine the phone's velocity. This program uses the GPS in the phone to track the phone's location. In addition, the app takes time stamps every second to record how long the trip took. With this information, we can conclude the current direction and speed because we have the distance traveled and how long it takes. The calculation is as follows: Velocity of current = Distance traveled/Time. Our next challenge was finding something that could encapsulate the phone and keep it dry and on the surface of the water.

We considered two different ways to safely encapsulate the phone – a Nalgene bottle, and a capsule constructed from PVC. Due its durability and cost efficiency, PVC was selected. A Nalgene bottle costs $10 and we estimated the PVC to be slightly under $5. The PVC pipe construction is as follows: one end was sealed and one end had a cap with threads where we can put the phone in and seal it by tightening the cap. The pipe was cut to about 1 foot long to try to keep it small to avoid boats but long enough to have a substantial amount of air in it to keep it afloat. The capsule was then spray-painted fluorescent colors for visibility (Figure 26).

Figure 26. PVC capsule that houses the smartphone

3.1.1.2 Testing Feasibility of Floating GPS Device

Our initial testing started with simple accuracy trials of the app My Tracks; this was essential to our project due to the need for the measurements to be as precise as possible. Our test was simple: walk a known distance, in this case the length of a football field, while running My Tracks and holding the device in our hands. The distance of a football field is 300yds and after a few trials we calibrated the error to be about a 15yds – 20yds diameter. After construction, tests proved that the capsule floated and didn't affect the GPS signal of the phone inside. The device successfully recorded tracking data after simulating canal conditions in a local pond in Worcester. To simulate the conditions, the device was dragged across the pond as if it was being pulled by a current.

3.1.1.3 Verifying the Phone GPS and Capsule

To verify that the GPS tracking collected by the MyTracks app is accurate, we compared the data it collected against data concurrently collected from a GPS device given to us by one of our sponsors, Dr. Paolo Peretti of IPROS. The two devices were run concurrently down the Grand Canal while rowing in a boat. This allowed us to gain, in theory, the exact same data collection in order to show that the phone being used was accurate or at least efficient enough to be used in a real measurement scenario. The tracks recorded are shown below in Figure 27.

Figure 27. GPS device comparison tracks

However, after analysis from the data, the phone proved to be extremely inaccurate and unreliable. The data from the GPS tracker showed a nice consistent stream of data providing a final average speed of around 3 m/s while the phone was showing about half of that. Since the distance we traveled was the same, we concluded something in the phone needed to be adjusted or the phone would no longer be a viable device to track GPS. We further analyzed the GPS and Phone CSV files and came across one major difference in the way each device operated. The GPS device took a time stamp no less than every five seconds while the phone tried to take a timestamp every second. This meant the GPS device allows the user to travel a further distance before trying to take another point allowing to account for the accuracy of the GPS. The phone, due to how quick it was trying to gain data, would record a zero for distance traveled more than half the times it took a measurement. Due to the accuracy of the GPS in the phone, it wouldn't be able to tell that a small distance was traveled. After much thought, we decided that distance was much more important to calibrate the phone to so to fix this problem, instead of a one second time stamp, it was changed to five seconds and the distance shortened to 5m instead of 10m. Essentially this made the phone and the GPS device work exactly the same, and after more tests were run, proof of the phone's accuracy was confirmed.

Another way to confirm the accuracy of the phone and capsule was to test our GPS device against the old timed float-and-weight device used by past projects. Our device, like the old device, consists of a float attached to a weight that travels approximately 0.5 meters below the surface of the water. To compare the data that each method collects, we conducted verification tests in which our device collected data with the MyTracks phone app concurrently with a timed float that we constructed.

3.1.2 Developing and Testing Tide Level Device

Developing a plan for collecting water level data involves researching measurement methods, designing an instrument, testing the instrument and proposing ideas for its implementation. Measuring sticks were concluded to be the most favorable instrument choice for this project. In order to measure the relative water level (relative to the sidewalks) within the canals of Venice, a measuring stick apparatus was constructed. This apparatus was placed in key locations, near the ends of canals, and aided in taking canal measurements quickly and easily. At least three photos of the sticks were taken at each measurement location and later analyzed to obtain the water level data at the time of the photo. Taking photos of the measuring sticks allows data collection to move quickly from one location to the next.

3.1.2.1 Measuring Water Levels

Different techniques for measuring water depths are used in different situations. To measure the water level, a rope with a weight can be dropped into the canal. Once the weight reaches the bottom, the water level is marked and the rope is pulled out of the water and measured. While a fairly accurate method, the device must be pulled out of the water and measured for every measurement. Another option is to use a measuring stick, fixed to the side of the canal. Instead of measuring from the bottom of the canal up, this method involves measuring from a known point down to the water. The known point may be a sidewalk or the top of the canal wall. The tide level in Venice is always measured in reference to the zero point at Punta della Salute. This point represents the average sea level in Venice in 1897. Tide measurements are reported in reference to this point (Sal.Ve, "Problems: High Water"). In order to measure the depth of the ocean, for instance, sonar resonance would be the best.

In the canals of Venice, sonar is not needed. Surveys by Insula has provided us with an updated altimetry map of the heights of Venice's sidewalks, or *fondamente*, measured relative to the average zero sea level at Punta della Salute in 1897 (Insula). Since the depths of the canals with respect to the edge of the canals are known from these surveys, the simplest way to take water level readings is to measure from the edge of the canal to the water, as opposed to from the bottom of the canal to the top of the water. By holding a measuring stick upright against the canal wall, with one of its increments lined up with the sidewalk edge, several photos (each with automatically-recorded timestamp) can be taken of the stick and the water level can later be easily extracted. The number of centimeter-increments from the sidewalk edge to the water's surface is counted in each photo; this value is subtracted from the known sidewalk height at that location to obtain the water level (see Figure 28). An average water level is calculated from all the photos at a specific location and time.

Figure 28. Left: The measuring stick is placed vertically into the canal against the sidewalk, typically near a physical landmark such as a bridge, and at least 3 photos (right) are taken for later analysis. Center: Known sidewalk height obtained from Insula. Right: Water level calculated by subtracting counted increments (24cm) from known sidewalk height

In order to effectively compare water levels at a certain location from different trials, we must ensure that the measuring stick is always placed at the same point along the canal wall. This is particularly important since the sticks are not stationary and will be removed after each trial. To do this, we selected locations at visual landmarks and other distinctive physical features, such as bridges, sidewalk corners and stairs. These features appear on the Insula map that has the surveyed sidewalk heights.

3.1.2.2 Developing the Design of Measuring Sticks

The measuring stick that was constructed in Venice is made from a length of white fiberglass that is 2 meters long, 3 centimeters wide and approximately 2 millimeters thick. The strip was originally intended for use as a strap for a boat cover, so the material is flexible but resistant to salt water.

Centimeter-wide black stripes were spray-painted at 1-cm intervals, and every 4 centimeters the pattern alternates between black-and-white stripes and black-and-color stripes as seen in Figure 29.

This color pattern and increment design was intended to allow water level readings to have centimeter accuracy. In the case that the photo from which the water level is being taken is difficult to read (due to poor photo quality or far distance from the stick), the alternating colors will allow an approximation of within 4 centimeters.

Figure 29. Painted measuring stick

3.1.2.3 Verifying Water Level Data Collected by Measuring Sticks

To verify the precision of the water level data collected with our measuring sticks, data was collected with the device in several locations within close proximity of each other around the forecasted time for low tide. At this time, water levels should be approximately the same in locations that are close together. The precision of the collected water level data was determined by how similar the data at each point was to one another, with small time differences between the measurements considered.

The accuracy of the measuring stick data was assessed by comparing water level data collected for one segment in Cannaregio over a 12-hour cycle against water levels measured on the same day and time period at the Misericordia tide gauge.

3.2 Measuring Current Velocity and Level in the Inner Canals

In addition to developing and testing new methods for collecting measurements, up-to-date data was collected on current velocity and direction for comparison to measurements made in the 1990s, to determine if changes have occurred in the canals. A propeller device borrowed from one of our sponsors, Dr. Paolo Peretti from IPROS, was used to collect current velocity data in the inner canals because it was the fastest method available to us. Updated water level data was also collected with our measuring sticks to help verify models run by ISMAR. This updated data collection and analysis involved identifying which canal segments to measure while in Venice, collecting water direction and velocity data as well as water level data, and comparing our data to past data.

3.2.1. Identifying Measurement Locations

During our seven weeks in Venice, as much usable hydrodynamic data as possible was collected for analysis against past data and to contribute to hydrodynamic modeling for sponsors, while new measurement methods were also created. With these commitments, we needed to be strategic in selecting canals to measure to ensure efficiency in collection and use of resources to provide the most data as possible.

3.2.1.1. Selecting Canal Segments for Velocity Measurements

For our data on water velocity and direction to be useful, the data must be accurate, comparable to past data and representative of potential trends in the area it is in. To ensure this, we used selection criteria that consider the desired analysis from the updated data, as well as the physical conditions required for hydrodynamic data collection.

Specifically, we looked at recommendations from the 2011 hydrodynamics IQP team, our advisors, and sponsors. Last year's team suggested canal segments that have not been measured since the 1990s. Many of the canals were also of interest because they are adjacent to the Grand Canal (updated measurements could shed light on how the Grand Canal affects smaller canals). Past data from the 1990s must be available for canals we measure so that comparisons can be made and analyzed for notable changes. We consulted with our sponsors at IPROS and ISMAR to confirm our planned measurement locations. Discussing areas of interest with our sponsors and advisors identified regions – such as Cannaregio - and specific canals within them that may provide insight on overall hydrodynamic behavior of the canal network, and any possible changes.

Once we narrowed down a set of canals that would be useful to measure, we determined which would be practical and plausible during our time in Venice. The propeller device we used required a bridge from which it could be lowered into the canal, so selected segments needed to have an accessible bridge over it. If a boat was not available, taking any measurements with the floating GPS device required a relatively long length of canal with a bridge for dropping the device into the water, or unobstructed sidewalk to avoid tether entanglement. The segments must also not be undergoing maintenance and must be far enough away from maintenance occurring in other canals such that water flow through them is unaffected.

3.2.1.2. Selecting Locations for Tide Level Device

The location of the measuring stick must allow photographs to be taken of it that are to the desired resolution. The accuracy accounted for by Venice's monitoring system is accurate to 1 cm; ideally, this will be the accuracy obtained in most pictures taken of the device. Therefore the photos should be taken from a close distance so that the increments are visible, and not angled to show as much of the flat face of the stick as possible. Locations such as corners of bridges and other physical landmarks (see Section 3.1.2.3.) were identified as good locations for the sticks because they can be easily pinpointed on a map. Ideally, the location would also not have constant boat traffic or parked boats that could block the view of a photographer.

To provide the most beneficial data to our sponsors, the measuring stick was used in multiple city districts to represent large areas of the canal network. Many of the stick locations were chosen to coincide with locations for current velocity measurements, since we took both measurement types concurrently. Several other locations were selected due to their proximity to the Grand Canal –water levels in such canals can be directly correlated to the water level of the Grand Canal, where boat traffic inhibits data collection.

3.2.2. Collecting Current Velocity and Direction Data

Our procedure for collecting current velocity and direction data with the floating GPS device is as follows:

1. Mark out known distance to be measured
    a. This can be a strip of sidewalk or distance between two distinct features along the canal, such as posts or bridges
2. Attach tether line to the PVC capsule
3. Place phone in enclosed water tight capsule in the canal running My Tracks App. Ensure that the phone has successfully obtained GPS signal
4. Check for boat traffic and place GPS device in canal before the start of the marked distance
    a. This is to allow the devices to pick up speed so the acceleration isn't part of the time
5. Record the time when the GPS device reaches the start of the known marked area.
    a. Recording time stamps at the beginning and end of the useful data collection aids in analyzing the output data from the app. Timing the device as it travels also serves to compare speed data collected through the GPS app against data collected from the distance-time calculation method used by past projects

6. Record the time when the device reaches the end of the marked area
7. Remove device from the water; remove phone to stop recording the track and begin a new track.
8. Repeat steps 3-7 twice more for a total of 3 trials
9. Remove phone from capsule and extract data

To collect current velocity data for comparison to 1990s data and to the velocity outputs of the ISMAR models, we used a propeller device (Figure 30) lent to us by IPROS. The propeller device is lowered into the canal from a bridge, and a counter records the number of rotations made by the propeller blades in the selected time interval (Figure 31).

Figure 30. Head of propeller device and rotation counter from IPROS

Figure 31. Left: Lowering the propeller device (with attached stabilizing pole) into a canal from a bridge. Right: The propeller device in a canal, oriented parallel to current direction

The procedure for collecting current speed data with the propeller device is as follows:

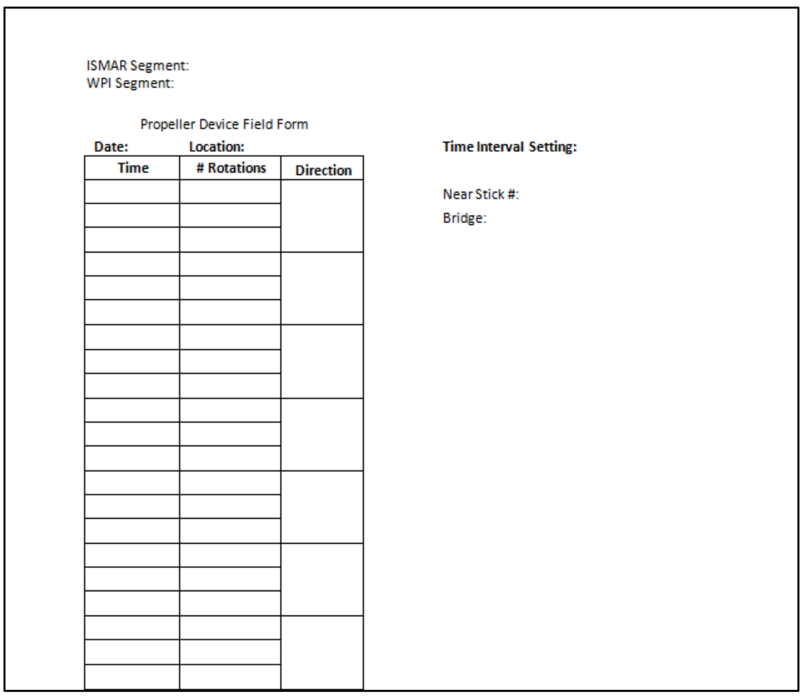
1. Attach the stabilizing pole and 5-meter rope to the propeller

2. Set the counter to record number of rotations for a selected time interval
3. Check for boat traffic and lower the propeller in the water from a bridge until it is approximately 0.5 meters below the water surface (use marking on rope)
4. Collect at least three rotation-counts
5. Remove the propeller and disassemble. Rinse all parts with fresh water and oil the propeller for future use

The propeller was tested to verify that the data collected was not influenced by the selected time interval for rotation counting. We conducted trials measuring the current velocity of a canal using both the 30-second and 60-second time intervals and found that the two data sets are not significantly different from each other. Therefore, the 30-second time interval was used in the field so that faster measurements could be taken.

To verify the accuracy of the propeller device, we compared the velocities it collected against those measured concurrently by a timed float. The results of this verification test are given in Section 4.2.1.1.

The field form used to record data collected with the propeller device is shown in Figure 32.


ISMAR Segment:
WPI Segment:

Propeller Device Field Form

Date: **Location:** **Time Interval Setting:**

Near Stick #:
Bridge:

Time	# Rotations	Direction

Figure 32. Field Form used to record water velocity

3.2.3. Collecting Water Level Data

Our procedure for collecting water level with the measuring stick is as follows:

1. Place measuring stick in the water at location
   a. Make sure that one of the centimeter markers is lined up with the top of the sidewalk
2. Take a trial of the measuring stick by taking at least 3 photos of the stick
3. Calculate the average measurement of the trial
4. Find the height of the sidewalk from the zero point on the INSULA website (in cm)

5. Count the number of centimeter increments from the edge of the sidewalk to water's surface(in cm)
6. Take the height of the sidewalk and subtract the distance from the sidewalk to the water to obtain the water level in that location. Record the timestamp of the photo.

Definitions:

"Trial" = set of 3 photos/measurements

"Measurement" = data from a photo

"average measurement" = data average from a trial – overall water level

3.3 Quantifying Change in Canals using ISMAR Models

In order to quantify change within the canals, we were assisted by our sponsors ISMAR and their models. The following sections highlight the contributions that the team made to the modeling process and how the model results were analyzed. These contributions were crucial in ensuring the model's accuracy and ability to determine change.

3.3.1 Contributing to Modeling Process

The team made two major contributions to the process of modeling the inner canals of Venice. First, before any models could be run, an updated model input database of the canal segments was created. The average depth of each canal segment was calculated using an online map published by Insula in 2005, shown in Figure 33.

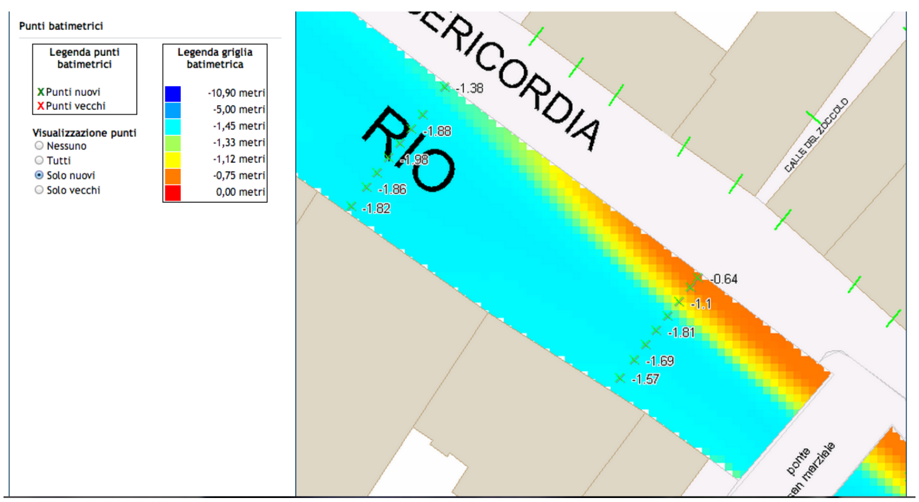


Figure 33. Online bathymetry map published by Insula

The model input database also includes other necessary information about a canal segment like segment length and width, if it is a rii tera, the friction coefficient (mann), if the segment has a cement bottom and the node numbers for each end of the segment. A sample of the model input database is shown in the Table 1.

Table 1. Sample model input database created for ISMAR

Segment ID	Length (m)	Width (m)	Depth (m)	rii tera	mann	cem	n1	n2
2001	187.35	52.43960502	-5.96	0	0.035	0	195	224
2002	75.93	12.55998946	-1.33	0	0.035	0	225	238
2003	119.34	11.34607005	-1.003076923	0	0.035	0	214	225
2004	136.12	12.061196	-1.699090909	0	0.035	0	193	207
2005	145.08	12.24751861	-1.267857143	0	0.035	0	175	193

To indicate the presence of rii tera in a canal segment, a 1 was placed in the rii tera column, while a lack of rii tera was specified with a zero in the column. Indication for cement canal floors follows a similar scheme where a 1 represents a cement bottom and a 0 designated a natural canal floor. This database was updated for all canal segments. For very few canal segments, updated bathymetry data was not available from Insula so the depths in the database, reflect the depth from before 2005. Once this input database was complete, our sponsors at ISMAR were able to run the models.

Second, field data was shared with ISMAR to enable them to run the model in hindsight for the specific dates that data was collected. This field data was compared with the results of the model to determine changes in canals. Field data is shared in the format shown in Table 2.

Table 2. Sample data spreadsheet for collected current velocity data

ISMAR Segment: 2426

Date	**Median Time of Counter Reading***	**Average Current Speed* (cm/s)**		**All Recorded Current Speeds* (cm/s)**			

3.3.2 Analyzing Model Outputs

In order to quantify the change of the currents in the canals, the model outputs were compared to the data collected in the field. Change can also be determined by comparing the results of the old model, which uses the old model of the Venice lagoon, and the new model, which accounts for recent bathymetric and other changes attributed to the MOSE flood gate project. Comparing the results of the models and field measurements allowed the changes in the currents of the canals to be quantified.

3.4 Making Hydrodynamic Data Available to the Public

Part of the mission of this project is making the data collected available to the world through Venipedia. Venipedia is a wiki-based website that focuses on sharing information about the city of

Venice. The data collected in this project and from previous projects will be uploaded to Venipedia and made available to anybody who desires it.

3.4.1 Uploading Data through CK Console

CK Console is a web uploading system that reads CSV files and puts them into a wiki based website. The first step is to upload data or a CSV file into CK Console through the data+ button. The CSV file must be formatted in a specific way such that the CK Console's coded protocol can read through it and store the information to be later put into the template. The general outline of this file is the first column is the title of every page while the first row is all the headings the user wants to appear on the page. This allows identical pages of different titles to be created instantly instead of creating each page individually. Upon clicking the data+ button, CK Console will ask the user to name the data; this name should be specific to the type of data being uploaded, for example: Canals. After completing the upload, a group is automatically created and named according to the data which was just uploaded and later used for the generation of a template.

3.4.2 Creating a Venipedia Page Template

After successfully uploading data, creating the page template is as easy as clicking the wiki button. This displays what CK Console thinks the page should look like in code; which can be visually previewed by hitting the preview button. After viewing the sample page, the template must be rearranged and information needs to be added to make the pages look the way the user wants them to look. Once the sample page looks the way the user wants, clicking the + button next to the WIKI button will begin the process of creating the actual pages. These pages are automatically generated and information is populated into them according to the CSV file uploaded in the first step.

First a template for an individual canal page was created. This ensured that all canals have the same format and share the same information. Information in this template included canal location, length, and other hydrodynamic data. This template was used for creating new pages for canals that do not have pages. The Venipedia pages allow the world to access the information collected in a visually pleasing way.

3.4.3 Creating Different Page Types

There are three typical pages created to cover all the canals. The first is the plural page *Canals*. This page contains a list of all of the individual canals and links them to their own pages. Any general information about the canal network and any overall conclusions we have made from analysis of all the collected data and models is displayed on this page as well. The second type of page is the singular page called *Canal*; this describes the typical make-up of an average canal and in general what it is used for and how it is important. The final type of page is the individual pages; this is where each canal has its own page where the data we collected is stored. Previously stated, the plural page *Canals* will have links to all these pages to make it easy to navigate to and from each individual canal page so that specific canals can be looked up with ease.

4. DEVELOPMENT OF NEW MEASUREMENT DEVICES

The new measurement devices developed were assessed for accuracy by statistically analyzing the data they collected and the results of the verification tests conducted on them. Their reliability and ease of use in the field were also observed and taken into account when making conclusions about the practicality of the new devices for future data collection.

4.1 Development of Floating GPS Device

The floating GPS device was designed to track current velocity within the inner canals of Venice. It uses the smart phone app MyTracks to record GPS locations of the phone within it. The following results and analysis are from our studies with the device.

4.1.1 GPS Tracks and Extracting Data from MyTracks Application

After adjusting the parameters of the phone's GPS functionality, tracks (Figure 34) were recorded in Cannaregio during outgoing tide and corrected for analysis. The average accuracy of the GPS signal for the original tracks was approximately 16.5 meters, and the most frequent accuracy reading for all of these tracks was 15 meters. The accuracy readings range from 5 meters to 50 meters, with a standard deviation of 9.27 meters. This indicates that the "raw" data outputted by the MyTracks phone GPS may not be a reliable method for obtaining accurate data on the device's speed and exact location at a given time.

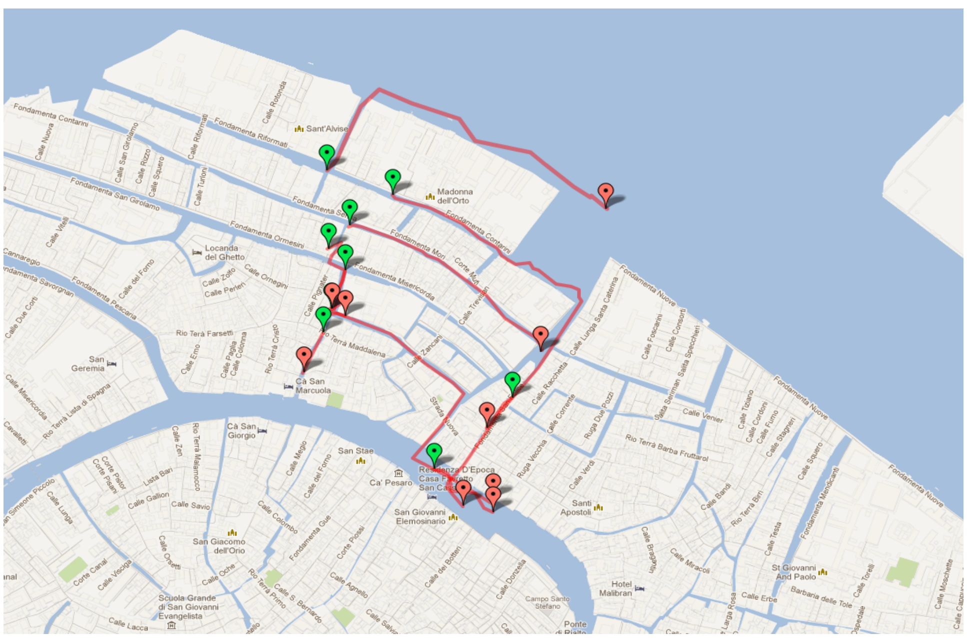


Figure 34. GPS tracks recorded by MyTracks

The original tracks recorded by the phone's GPS were manually corrected in the outputted .csv file to remove unwanted sections of data (such as at the beginning, when time is allowed before the desired data collection for signal to be obtained, and at the end, when the device is being retrieved), as well as clearly inaccurate readings of the device's location. After correction, the track better depicts the actual path the GPS device traveled (Figure 35) and the current velocity results are much more accurate and consistent, as shown in Figure 36. The uncorrected GPS track records a velocity approximately three times the corrected velocity.

Original My Tracks Data   Corrected My Tracks Data

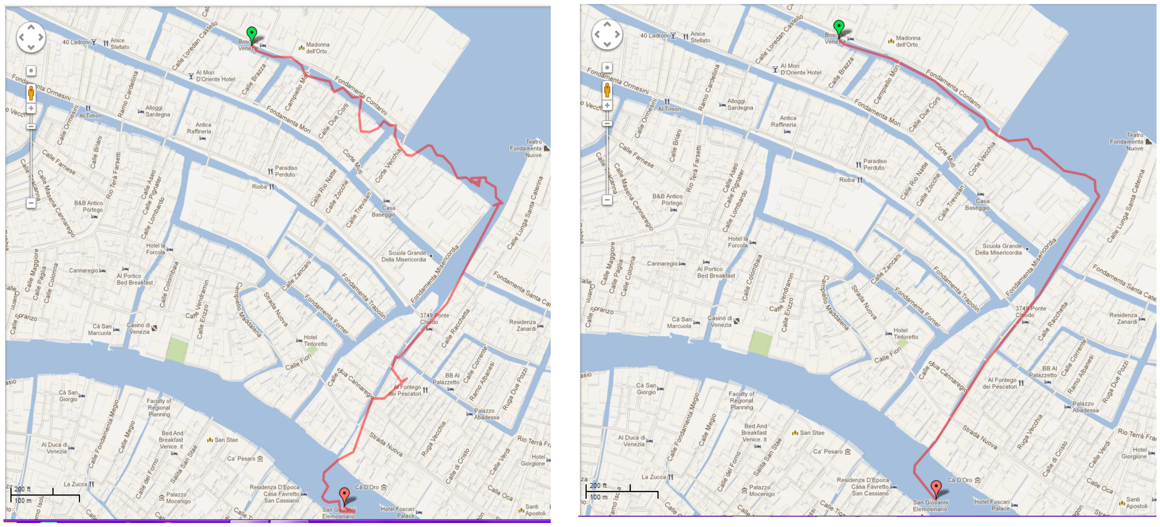


Figure 35. Original MyTracks data (left) and Corrected tracks (right)

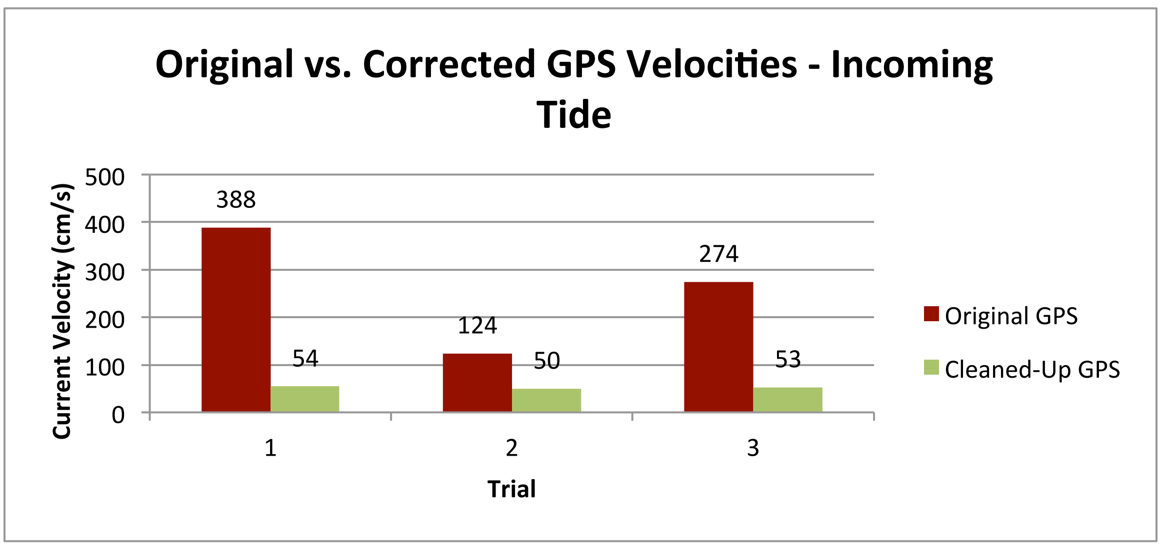


Figure 36. Current velocities from original and correct tracks

4.1.2 GPS Device vs. Timed Float Comparison

The capsule was also tested to determine if it accurately depicts the current velocity of the water. If the capsule is not moving at the same rate as the water, the GPS accuracy is irrelevant because it will be recording false velocities. The capsule was tested adjacent to the previously used flotation device. The current velocity comparison between the float and the capsule is shown below in Figure 37.

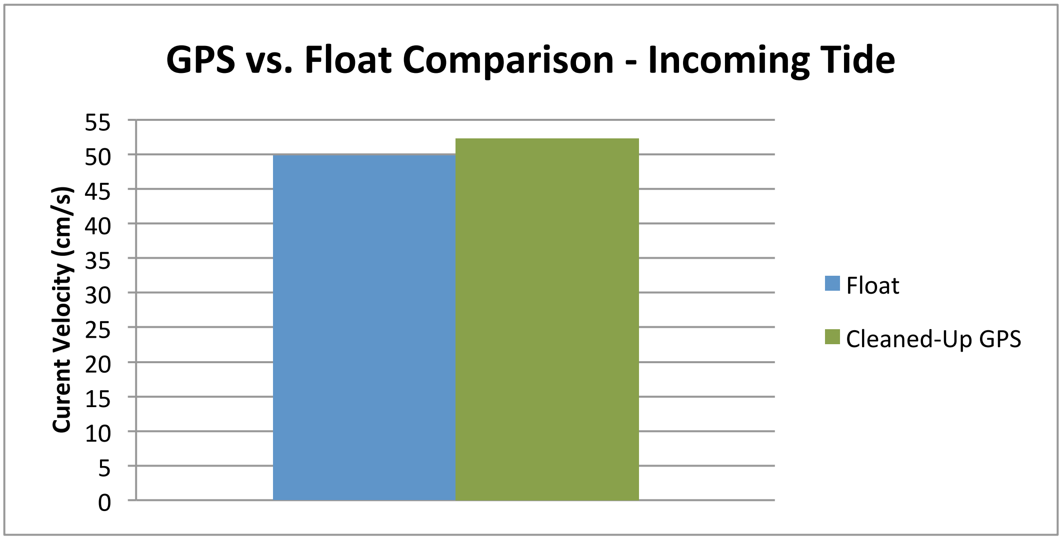


Figure 37. GPS device versus float current velocity comparison

The results of the comparison testing of the GPS device against the timed float also showed that the GPS tracks outputted by the MyTracks app need to be corrected for the current velocity data to be useable. The tracks recorded by the app show some erratic paths and distances that are not actually travelled by the device due to positioning inaccuracies and loss of GPS signal. The actual distance travelled by the devices for the verification test was 16.2 meters – for the test during outgoing tide, the average travelled distance reported by the phone app was 56.66 meters. After cleaning-up the data, the new reported distance was 19.04 meters. The corrected distance of 19.04 is 17.5% greater than 16.2 meters (as opposed to the originally recorded GPS distance, which is 250% greater than 16.2 meters). For the tests conducted during incoming tide, the average originally recorded GPS distance was 94.17 meters (481% greater than the actual travelled distance).

When comparing the corrected GPS data against the timed float, we found that the average difference in recorded speed was 5.94 cm/s for the tests during outgoing tide, and 2.54 cm/s during incoming tide. Since the GPS velocities for each trial of the two tests exceeded the corresponding velocities measured with the timed float, a one-tailed t-test was performed on the two groups of data for each test to determine whether or not the GPS data was significantly different from the timed float data. For the outgoing tide data, a p-value of 0.054 was obtained, placing it slightly above the 0.05 significance level, meaning that statistically the GPS velocities were not necessarily significantly faster than the timed float data. The p-value for the incoming tide data was 0.112, more conclusively above the 0.05 significance level. These comparisons suggest that the corrected GPS velocity data is not consistently similar to the timed float data. The incoming tide test shows that the data sets are statistically similar enough to suggest that the GPS does not measure velocities greater than those measured with the timed float. However, the t-test result for the outgoing tide data shows that the current velocity in the GPS dataset is on the border of being considered significantly greater than the current velocity measured by the timed float. Therefore, the results show a slight significant difference. There is a possibility that the data is a result of chance although there is also the possibility of correlation.

4.1.3 GPS Device Effectiveness in Water Flow Study

Overall, the accuracy of the data collected by the GPS device for current velocity appears to be inconsistent. In part, this is due to the variable GPS signal strength in the city, as well as the amount of corrections that need to be made to each track to better characterize its actual travelled path. However, the GPS device is effective for recording the direction and general flow of the canal, especially over long distances. For example, Figure 38 shows two corrected tracks recorded when the GPS device was released from a boat during outgoing tide. Track A starts at the intersection of Rio della Madonna dell'Orto and Rio degli Zecchini, moves north toward the upper lagoon on Rio degli Zecchini, then travels in a south-east direction. Track B starts on and travels south-east on Rio della Madonna dell'Orto, but when the GPS devices reaches the opening to the lagoon at Sacca della Misericordia, the device behaves differently from what would be expected from Track A and moves *away* from the lagoon towards the Grand Canal, travelling south-west on Canale della Misericordia and Rio di San Felice. This behavior contradicts one of the findings in a 1970 study in which Dazzi documented the movement of fluorescent dye through Venice's inner canals (Figure 39). In the 1970 study, the current direction at Sacca della Misericordia during outgoing tide was *towards* the lagoon, where it was then directed south-east. These canals, and other nearby canals should be studied more in depth to determine flow patterns in the area and to identify the cause of this change.

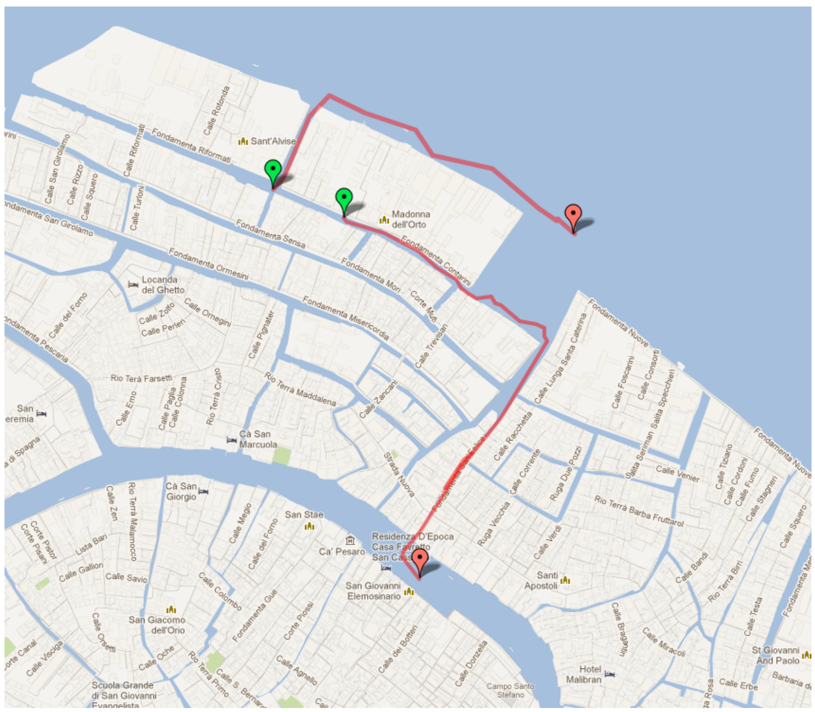
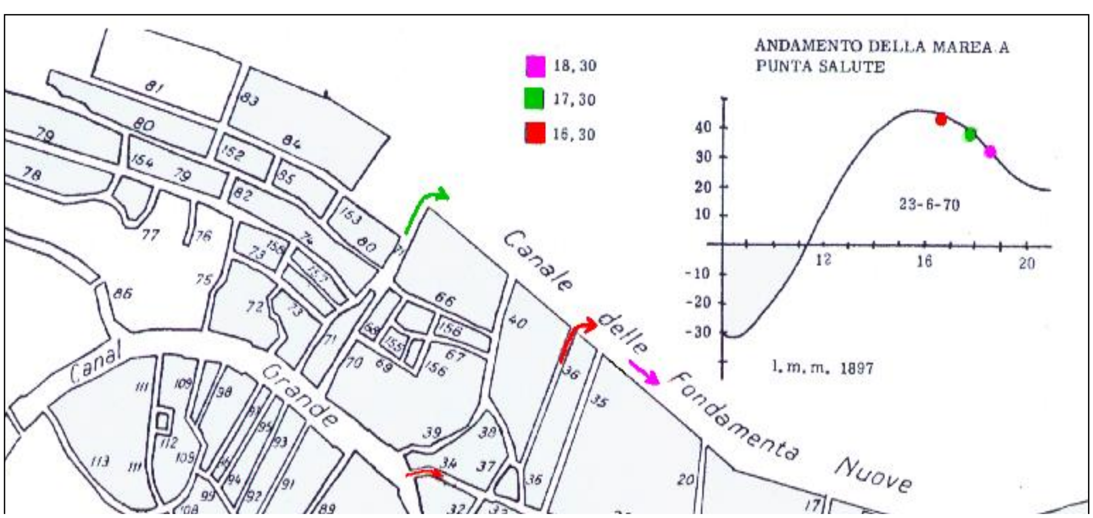


Figure 38. Corrected GPS tracks during outgoing tide that display interesting behavior



The GPS device proved to be useful for determining the flow direction of the canals. When allowed to float freely in a canal, the GPS tracks can show the direction that water tends to flow at canal or lagoon intersections. Additionally, because of the capsules durability, the GPS device was also used successfully in places where the timed float would not be as effective, such as the lagoon and Grand Canal.

For the floating GPS device, it is highly recommended to obtain a more accurate and reliable GPS device than a cell phone. The device should also have remote capabilities including a start, stop, waypoint marker, signal strength reading and location reading. This will allow the user to put the device in the water and start the tracks when it is up to speed, mark when it enters another canal, check to make sure it is functioning, find the device at the end of a run and stop it when it reaches the end of a canal. If a device such as this cannot be acquired, this can also be implemented through the use of two smart phones running an app that could link the two phones and have a client and server mode.

4.2 Development of Tide Level Device

The tide level device is used to measure the water level at locations of known "sidewalk" height. It was designed to be quick, cost efficient, and reliable. The device should uphold an accuracy of 1 cm.

4.2.1 Tide Level Device Verification

Table 3 and Figure 40 show the data collected to verify the precision of the measuring sticks. Measurements were taken during low tide (approximately at 1:30 pm) on November 8th, in the Cannaregio district.

Table 3. Data for Tide Level Device Precision Test

Median Time	Stick #	ISMAR segment	WPI segment	Sidewalk height (cm)	Photo Distances (cm) - Water to Sidewalk				Average Distance (cm)	Water Level (cm)
13:26	3	2039	MISE6	182.5	157	158	157	159	157.75	24.75
13:29	4	2039	MISE6	127	101	104	103	102.5	102.625	24.375
13:33	5	2024	LUST	112	86.5	85	87	87	86.375	25.625
13:37	10	2028	ORTO1	110	82	84	84.5	--	83.5	26.5
13:40	9	2025	SENS3	95	70	70	70	--	70	25
13:54	11	2034	ORTO3	104	79	79	80	--	79.333333	24.66666667

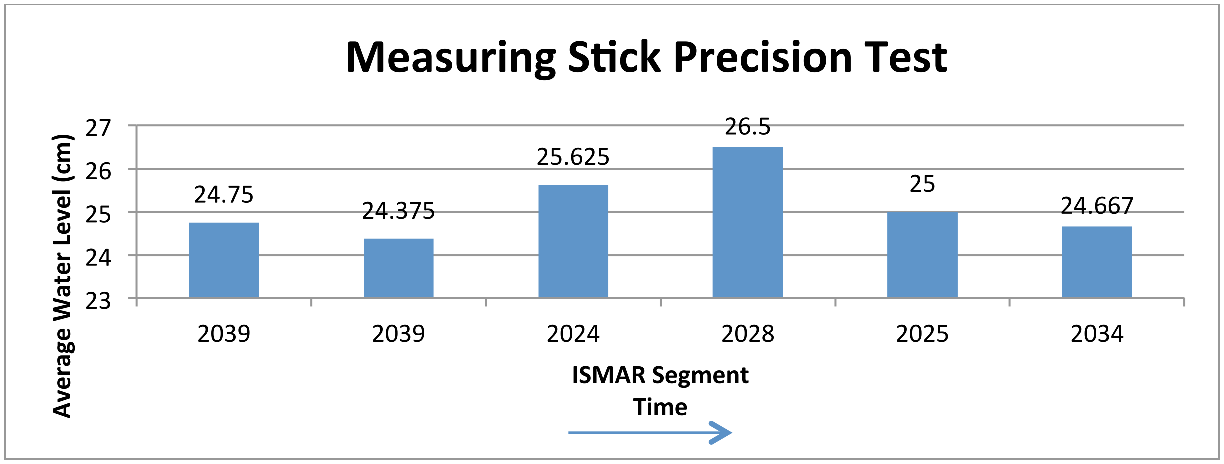


Figure 40. Water levels measured for precision test of measuring stick near low tide

4.2.2 Analysis and Conclusions

Data collected by the measuring stick was compared to the actual water levels recorded at the Misericordia tide gauge to evaluate the accuracy of our data. A graph showing this comparison for a] segment 2419 in Cannaregio is shown in Figure 41.

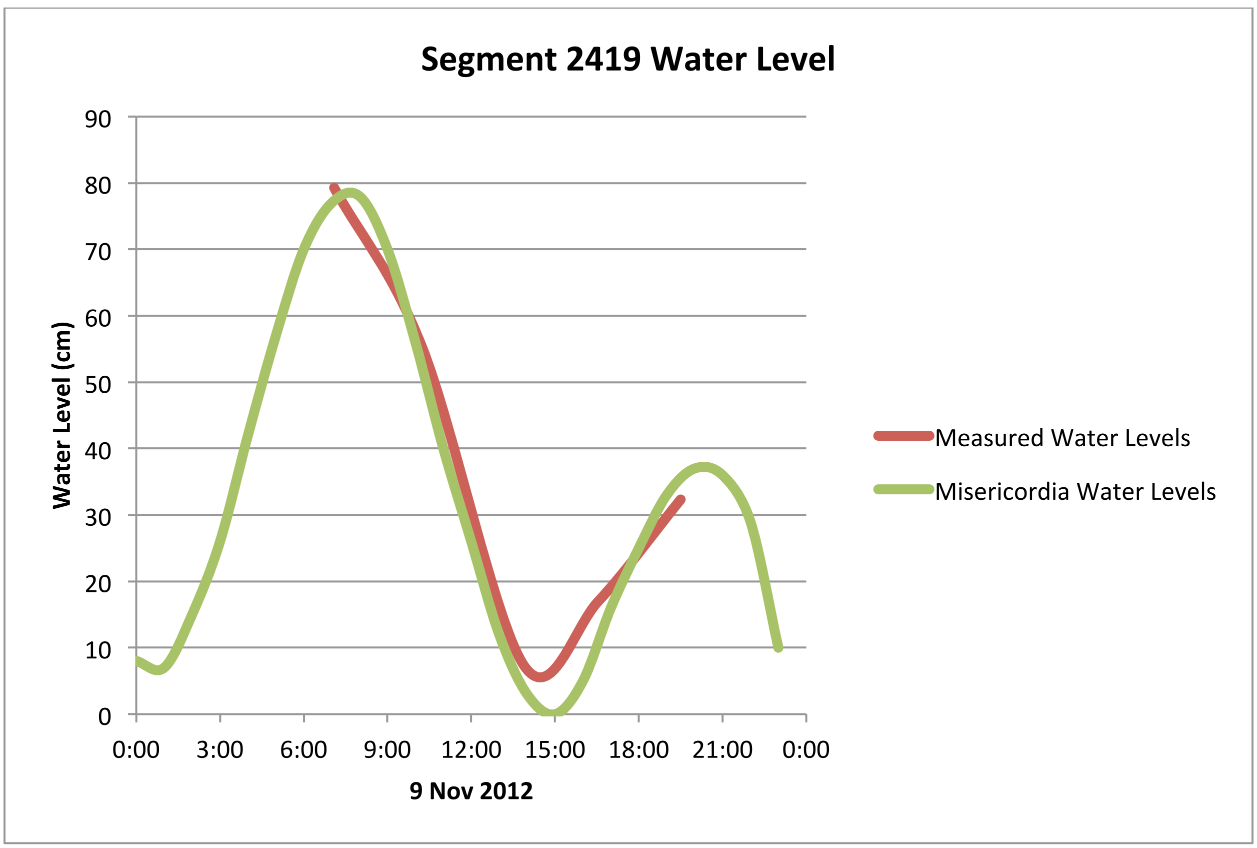


Figure 41. Measured water levels compared to Misericorida tide gauge water levels

The measured water levels match very closely to the water levels recorded at the Misericordia tide gauge. In the verification test, all points collected were within five percent of the actual tide level at Misericordia, as seen in Figure 42 below.

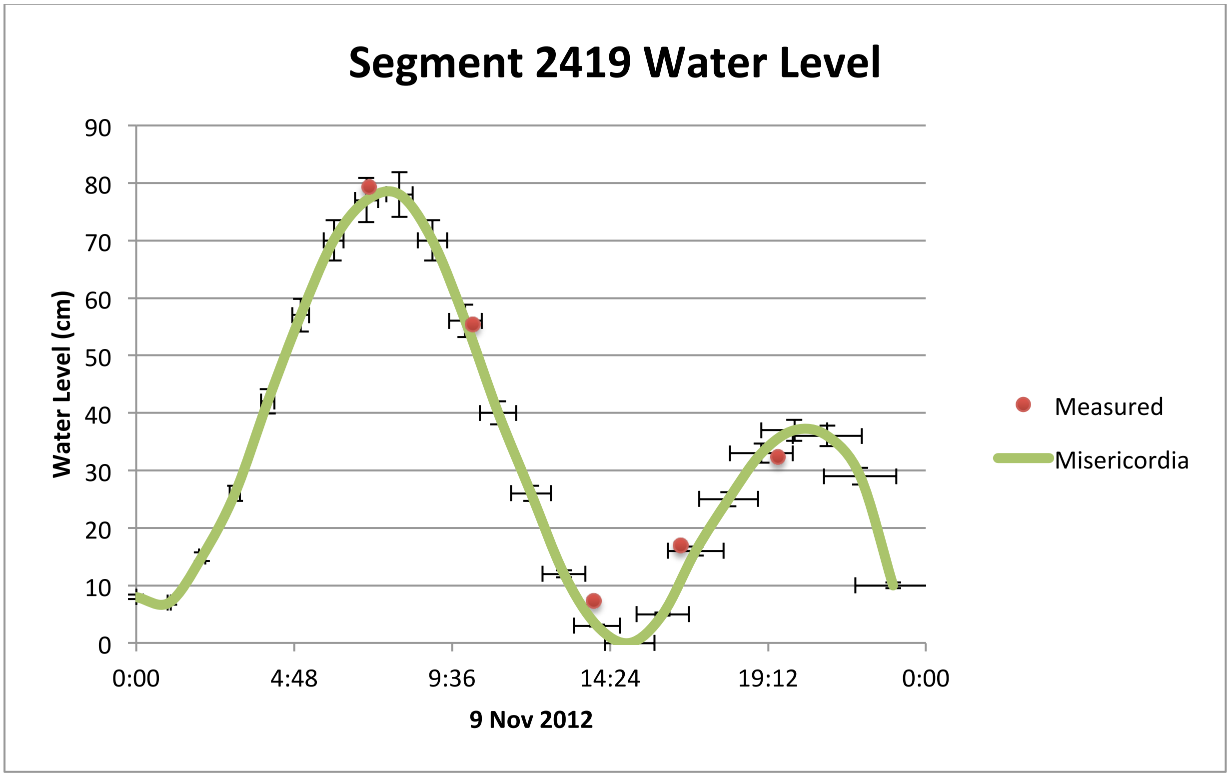


Figure 42. Measured water levels are within 5% of the water level at the Misericordia tide gauge

This information proves that the measuring stick is accurate to within five percent of the actual water level.

Using the measuring stick to collect measurements in the canals proved to be an effective method. The process in the field is very simple and fast, typically requiring only one minute to take three photos of the measuring stick.

There are a few changes that could be made to the implementation of our devices in order to increase its efficiency. The measuring stick should be implemented as a stationary device. By setting them in fixed locations, it will only require one person to take water level measurements and the process will be much quicker. It would also be useful to implement a smart phone app for people to download. Persons with the app could take pictures with their phone and upload them to a database that will decipher the measuring sticks location, time and water level.

5. MEASUREMENTS COLLECTED IN THE INNER CANALS

Throughout the seven weeks in Venice, three twelve-hour cycles of hydrodynamic measurements were taken in four different regions. Hydrodynamic measurements were collected for 41 canal segments throughout Venice.

5.1 Current Velocities Measured with Propeller

Current velocity measurements were collected using the propeller device in nineteen segments (Figure 43) Data during incoming tide was collected in San Marco, and data during outgoing tide was collected in both San Marco and Cannaregio.

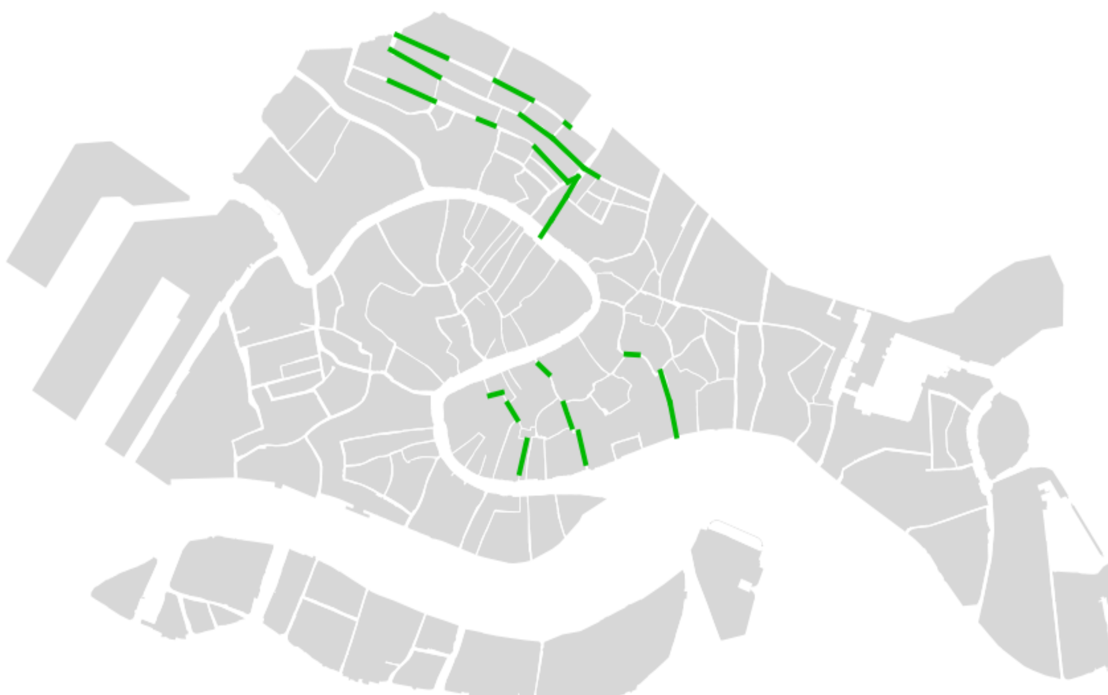


Figure 43. Measurement locations for current velocity measurements with the propeller

5.1.1 Propeller Verification vs. Timed Float

Further verification had to be done to ensure that the propeller device would record comparable data to that of the GPS Capsule. This was accomplished by lowering the propeller device into the same canal as the capsule, and calculating the velocity of the capsule (using distance and time travelled) and recording the readings from the propeller device. The results are shown below in Figure 44.

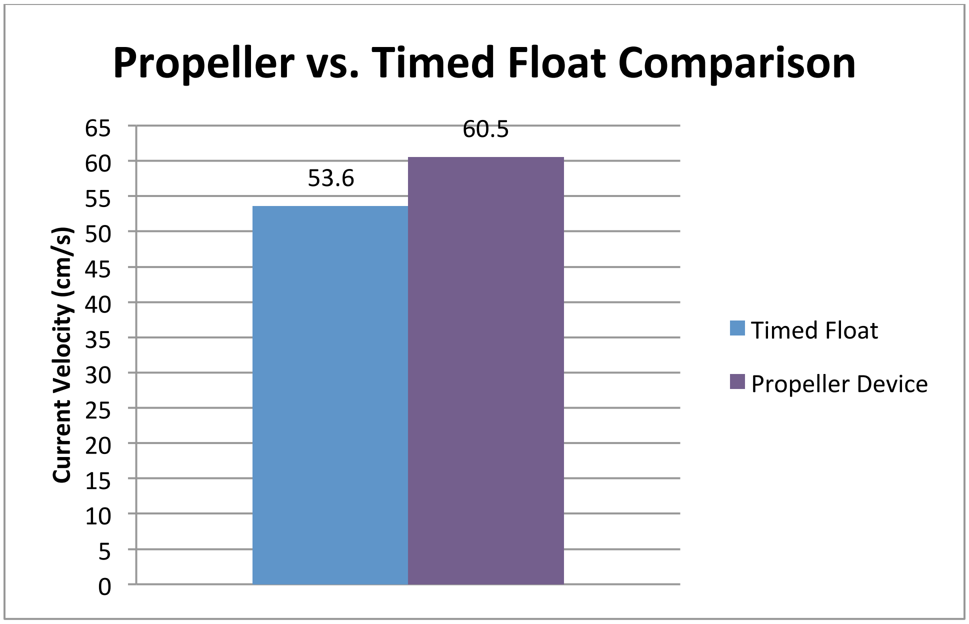


Figure 44. The propeller device is on average approximately 7 cm/s faster than the timed float

The results of the comparison tests conducted on the propeller device were analyzed to verify the device's accuracy. The current velocity data that was collected with the propeller was then analyzed to determine general trends. It was also compared to data collected in 1999 to determine change.

To compare the velocity data collected concurrently by the propeller device and the timed float, a two-tailed t-test was performed to assess whether or not the two data sets were significantly different from each other. A p-value of 0.065 was obtained, supporting the hypothesis that any differences between the data sets are not statistically significant (at the 5% significance level). The average difference between the propeller velocities and the timed float velocities was 6.95 cm/s.

Statistically, the propeller device appears to collect individual values similar to the timed float method, but the overall data set for the propeller is higher than the timed float for the verification test we conducted. The average difference was considered low enough to make the propeller an adequate measurement device for current velocity, but more verification tests should be conducted to confirm this. Although the propeller is a faster method than the timed float for collecting velocity data, we experienced technical difficulties with the device's cable and the counting mechanism inside the propeller. The device needed to be fixed on several occasions, sometimes causing rounds of measurements during 12-hour cycles to be missed.

5.1.2 Current Velocity Data

The current velocities measured during outgoing and incoming tides (when currents move at maximum speed) were classified as follows:

Below 5 cm/s = Below Propeller Threshold

5 – 10 cm/s = Lazy

10 – 20 cm/s = Mid-Ranged

20 – 30 cm/s = Fast

Above 30 cm/s = Very Fast

The propeller device used is only accurate above a threshold of 4 rotations over a 30-second time interval, which converts to a current velocity of approximately 5 cm/s. Current velocities under this threshold are not guaranteed to spin the propeller blades consistently; therefore, the “Below Propeller Threshold” category includes canals moving at very low speeds and stagnant canals.

Figures 45 and 46 show the current velocities measured during outgoing and incoming tides, respectively.

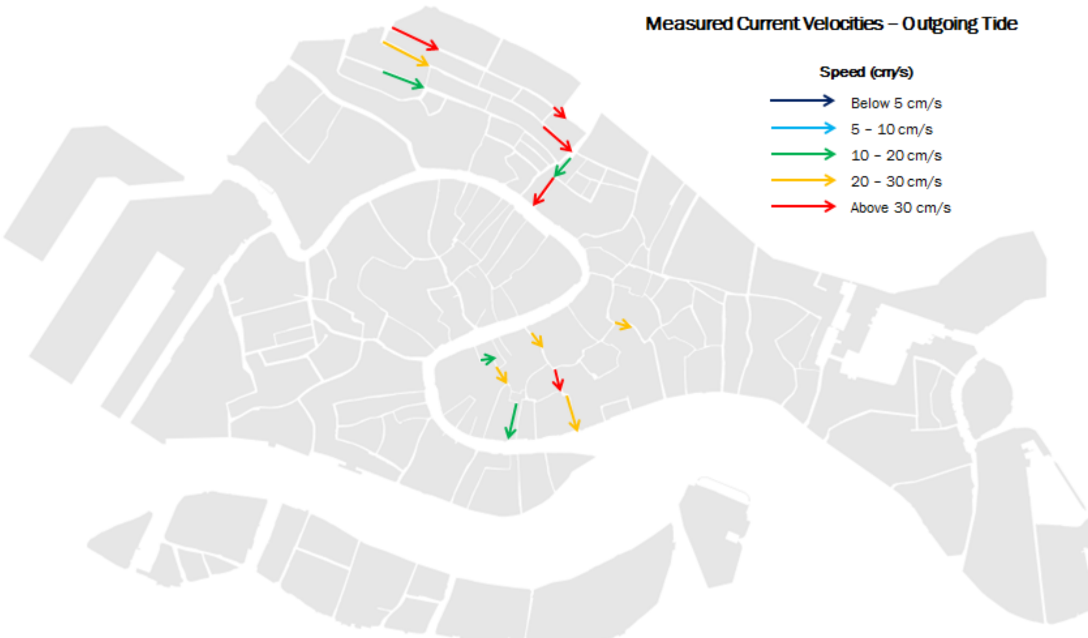


Figure 45. Current velocities measured during outgoing tide

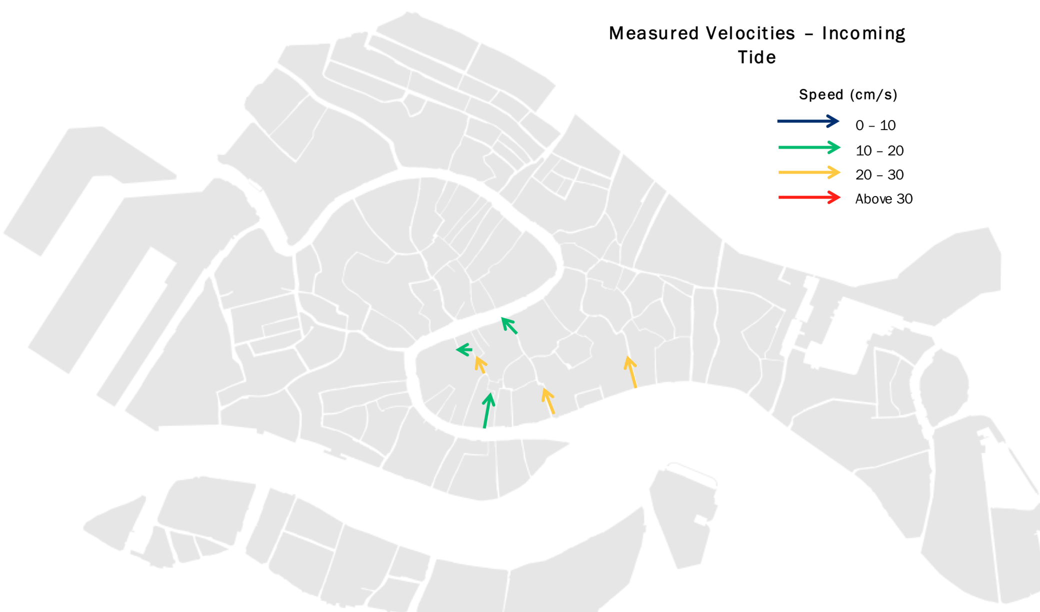


Figure 46. Current Velocities measured during incoming tide

Seven canal segments were measured for current velocity in both Cannaregio and San Marco during outgoing tide. None of the velocities were below 10 cm/s.

The full set of current velocity data collected with the propeller during our 12-hour cycles in Cannaregio and San Marco can be found in Appendix D.

Of the seven measured canal segments in Cannaregio, two were travelling between 10 and 20 cm/s and placed in the "Mid-Ranged" category; one was categorized as "Fast;" and four were "Very Fast." In general, the canals in Cannaregio move quickly and flow in the southeast direction during outgoing tide, which is expected.

During the outgoing tide in San Marco, the canals were generally flowing mid-range to fast and flowing in the southeast direction, which is normal for outgoing tide. Of the seven measured canal segments,, two were "Mid-Ranged;" four were "Fast;" and one was "Very Fast." Similar to the current velocities measured during outgoing tide in San Marco, the velocities measured during incoming tide were also in the middle range of velocities. As expected, the currents during incoming tide are directed northward, and all of the San Marco segments that were measured during outgoing tide and re-measured during incoming tide switched direction. Six canal segments were measured in San Marco during incoming tide. Of the six, three (50%) were "Mid-Ranged" and three (50%) were "Fast." (Figure 47).

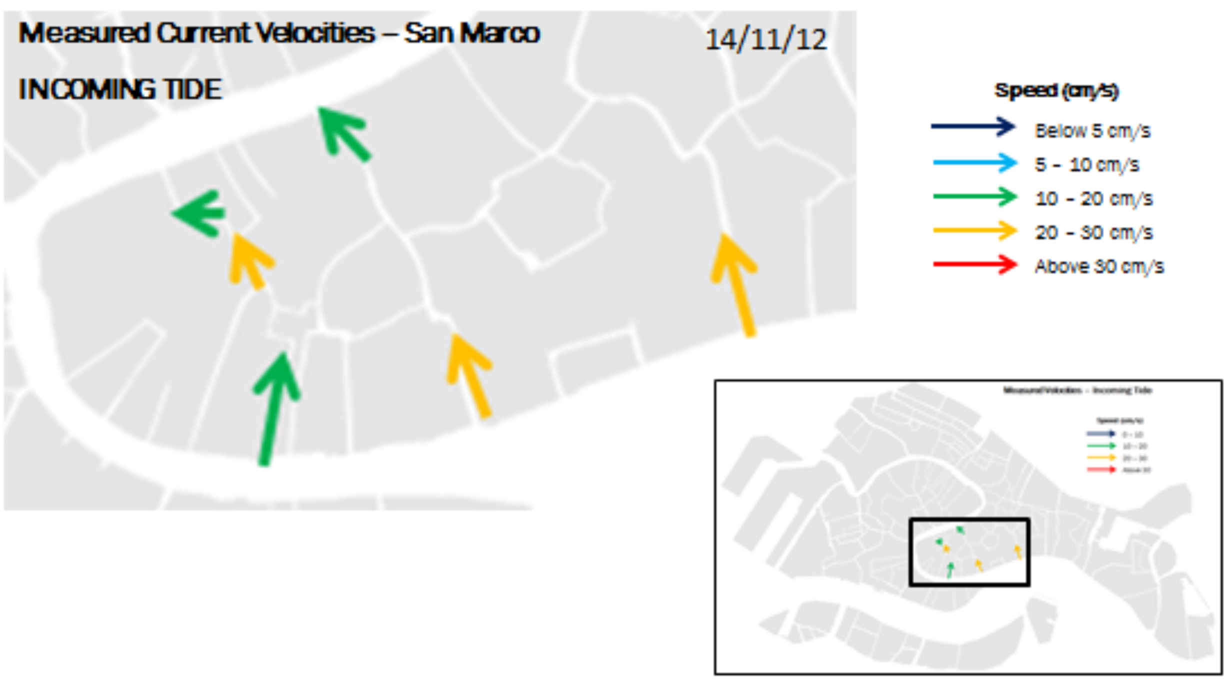


Figure 47. Current velocities in San Marco during incoming tide. Three canals were classified as "Mid-Ranged" and three canals were classified as "Fast"

5.2 Water Level Data

Water level data was collected at high and low tide, as well as incoming and outgoing tide at 38 selected locations in Cannaregio, San Marco, San Polo and Santa Croce. These locations are indicated in Figure 48 below.

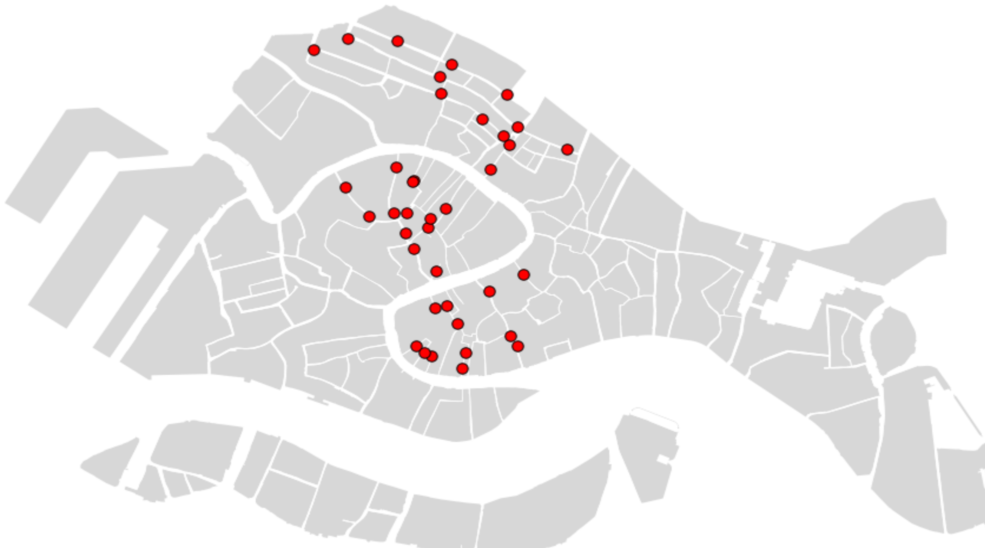


Figure 48. Measuring stick locations measured during 12-hour cycles

Water levels were collected at many points throughout the tide cycle and complied by segment as shown in the table below. All collected water level data is included in Appendix E.

Table 4. Collected Water Level Data for an Example Segment (2034)

ISMAR Segment: 2034

Date	Median Time of Water Level Reading	Tide Cycle	Average Water Level (cm)	All Recorded Water Levels (cm)				
9/11/12	7:50	High Tide	82.66666667	81	84	83		
9/11/12	10:46	Outgoing Tide	44.66666667	47	44	43		
9/11/12	14:21	Low Tide	1.333333333	0	1	3		
9/11/12	17:15	Incoming Tide	17.66666667	18	18	17		
9/11/12	20:10	High Tide	40.33333333	41	40	40		

This water level data in Table 4 was compared to the water level measured at the tide gauge located at Misericordia and is shown in the graph shown in Figure 49.

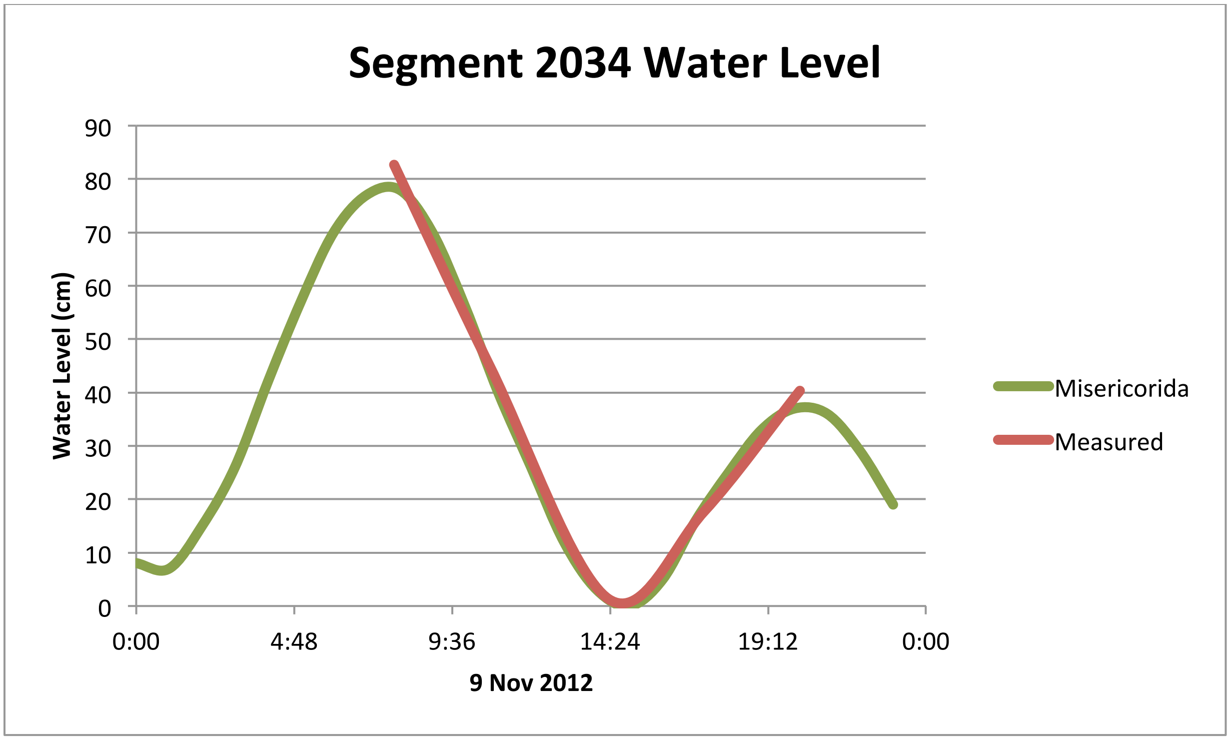


Figure 49. Measured water level for segment 2034 matches Misericordia tide gauge water level

5.3 Making Collected Data Available to the Public

Throughout this project, a total of 186 Venipedia pages were created and updated. Individual pages were created for each canal that include a map, statistics, history and collected hydrodynamic data. Existing pages were also updated including *Canals* (plural page), *Canal* (individual page), *Canal Hydrodynamics* and *Hydrodynamics*. The plural *Canals* page includes information about the history of the canal system as well as statistics and a navigation box to the individual canal pages. The singular *Canal* page includes information about the anatomy of a typical canal as well as how canals are segmented. The *Canal Hydrodynamics* page discusses factors that affect the hydrodynamics of the inner canals of Venice and includes a timeline of past hydrodynamic studies in Venice. The *Venice Lagoon Hydrodynamics* page reviews the main factors that affect the hydrodynamics of the Venice Lagoon. All pages can be viewed at www.venipedia.org. In the future, all previously collected hydrodynamic data should be uploaded to the appropriate individual canal pages in Venipedia.

6. DETERMINING EXTENT AND CAUSE OF CHANGE

There are many hypothesized causes of change within the canals including: the addition of the MOSE flood gates, the overall rise in sea level, and possibly the dredging of the Canale di Petroli. All of these factors may influence the canals in different ways and cause unexpected changes in their hydrodynamics.

6.1 Comparing Collected Data to 1990s Data

The current velocities collected were compared to current velocities collected in the same canal segments in 1999. All of the data for the 1999 versus 2012 comparison can be found in Appendix F. This comparison is shown below in Figure 50.

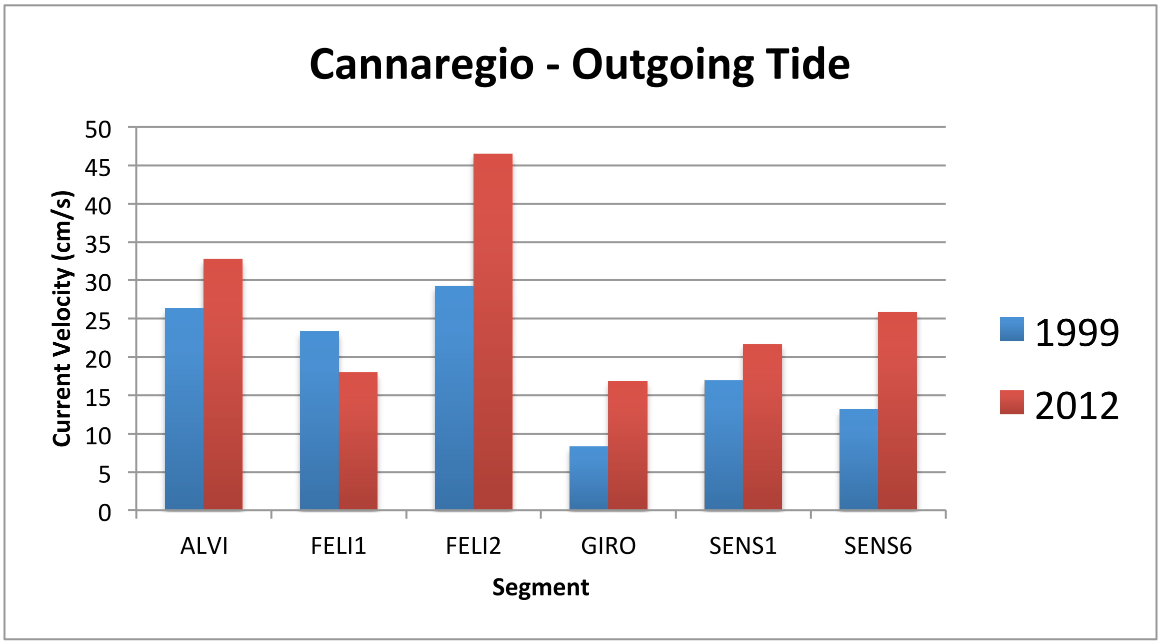


Figure 50. Current velocity comparison between 1999 and 2012 in Cannaregio outgoing tide

The data collected in 2012 overall shows an increase in current velocity compared to 1999. For most canal segments measured, this increase was slight and can be explained by a variety of different reasons. The propeller device used to collect measurements, on average is approximately 7 cm/s faster than the float method used in 1999. This along with human error, are possible explanations for the difference in current velocity and the presence of change cannot be confirmed or denied. However, two canal segments showed a very large current velocity increase, Rio di San Felice (FELI2) and Rio della Sensa (SENS6). These locations are shown as red arrows in Figure 51 below.

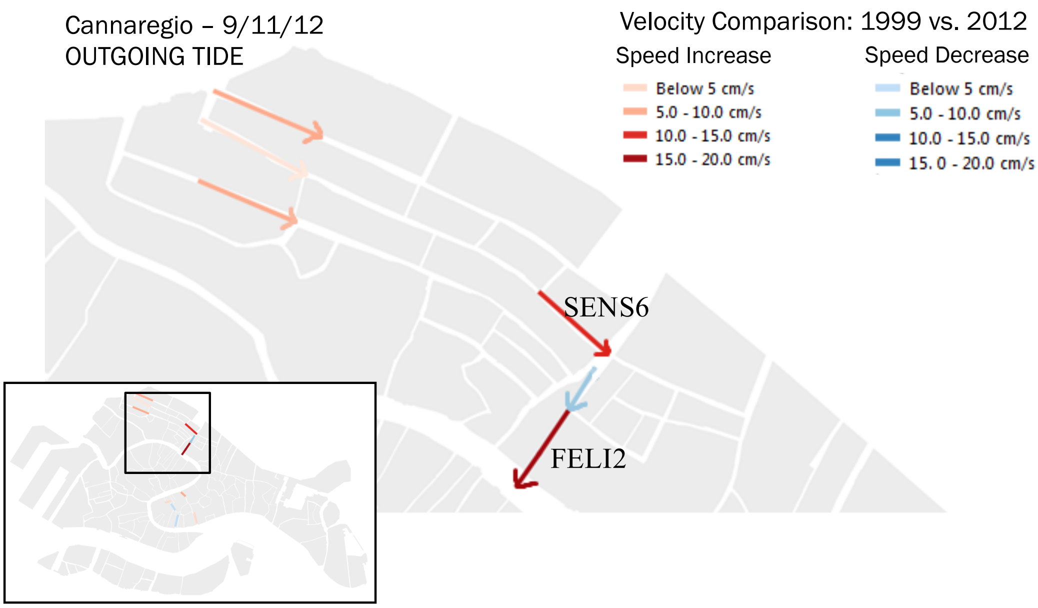


Figure 51. Change in current velocity from 1999 to 2012 in Cannaregio outgoing tide

The increase in velocity of these canal segments is too large to be explained by the previously mentioned factors. Segment FELI2, had an increase in current velocity of 17 cm/s. This leads to the conclusion that the segment has increased in velocity. A possible explanation for this change could be a bathymetry change. Although this canal segment has not been dredged between 1999 and 2012, between 1999 and 2005, when the most recent bathymetry data was collected, the canal became 12 cm shallower. This difference in bathymetry would cause an increase in current velocity but the magnitude of the change is unknown. If the rate of sediment accumulation continued at the same rate, by 2012 the canal segment could be approximately 25 cm shallower. The change in canal depth explains an increase in current velocity; a canal with a higher current velocity would carry more sedimentation and debris and dredge itself. While this change in bathymetry is a possible cause of the current velocity increase, it cannot be identified as the confirmed cause and other factors are likely to have contributed. Another possible cause for this increase involves canals feeding into the segment FELI2. In comparing 1999 to 2012, there was a slight decrease in current velocity in the segment feeding directly into FELI2. The flow of a small network of canals that add to FELI2 from the east are also a possible factor in the velocity increase of FELI2. Further study is needed in this area to gather more information about these canals. See Appendix G for segment identification.

The canal segment SENS6 also had a notable current velocity increase between 1999 and 2012. Between 1999 and 2005, the depth of this canal increased by 20 cm, which alone would indicate a decrease in current velocity. While the bathymetry change in this canal is not a cause of the current velocity increase, it may be a result of increased velocity, as a faster moving canal is able to displace more sedimentation.

Although the cause is mainly unknown, it appears that change is occurring in some canals in Cannaregio during outgoing tide. Future studies are necessary to draw accurate conclusions.

The current velocities collected were also compared to current velocities collected in the same canal segments in 1999 in San Marco. This comparison is shown below in Figure 52.

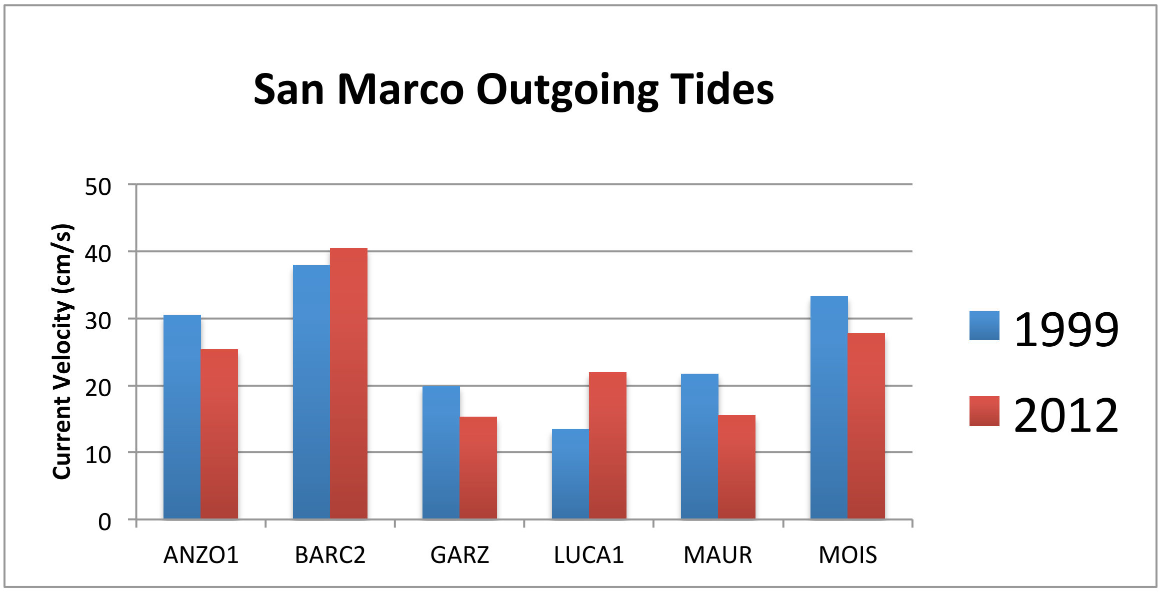


Figure 52. Current velocity comparison between 1999 and 2012 in San Marco outgoing tide

The overall trend of change in San Marco is a small decrease in current velocity, although the change in most canals is not significant and could be explained by error due to the use of different devices, human error and other factors such as weather. This general trend is more pronounced further south in the San Marco region, as shown below in Figure 53.

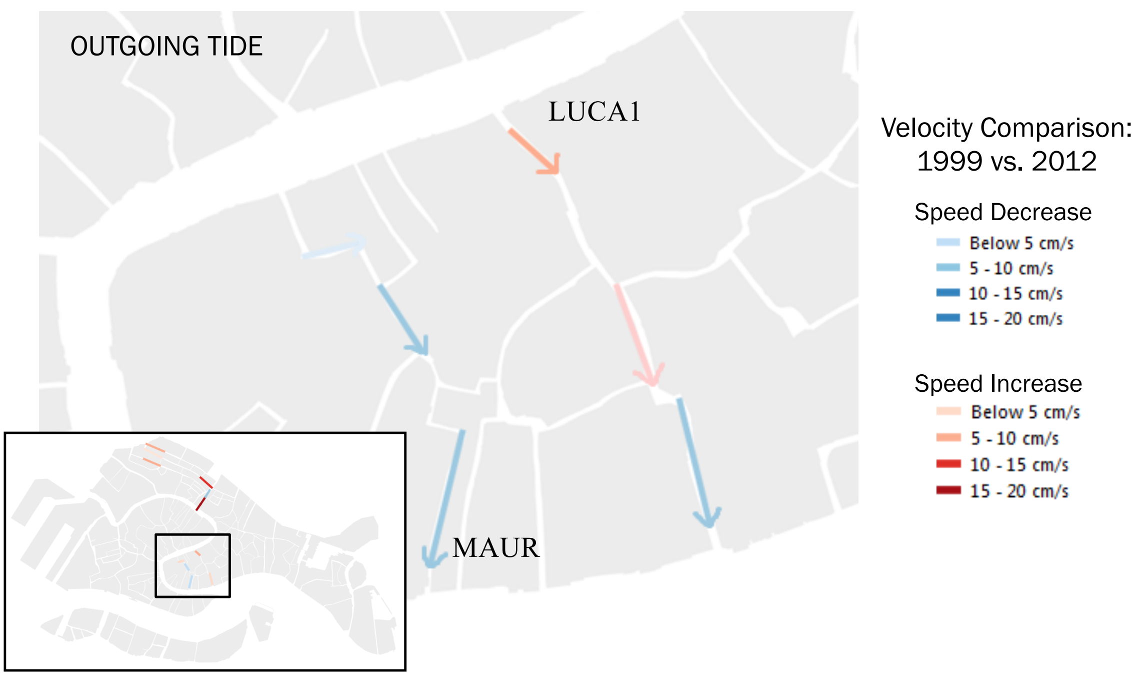


Figure 53. Change in current velocity between 1999 and 2012 in San Marco outgoing tide

One canal segment, LUCA1 did not seem to follow the trend of all of the other canals. Rio de San Luca (LUCA1) increased in current velocity by 8.5 cm/s. Between 1999 and 2005, the canal depth increased by 32 cm, which would predict a decrease in velocity. The increase in velocity may then be due to some cause other than bathymetric change, and the increase in depth may have been a result of the increased velocity. Because of the segment LUCA1's location, the effect of the Grand Canal on its velocity should be studied.

The canal with the largest decrease in speed was MAUR. This canal segment had a depth of 1.3 meters in 2005 compared to 0.98 meters in 1999. This increase in depth is a possible cause for the current velocity decrease.

The current velocities measured in San Marco during incoming tide were compared against incoming tide data collected in 1999 for the same segments (see Figure 54).

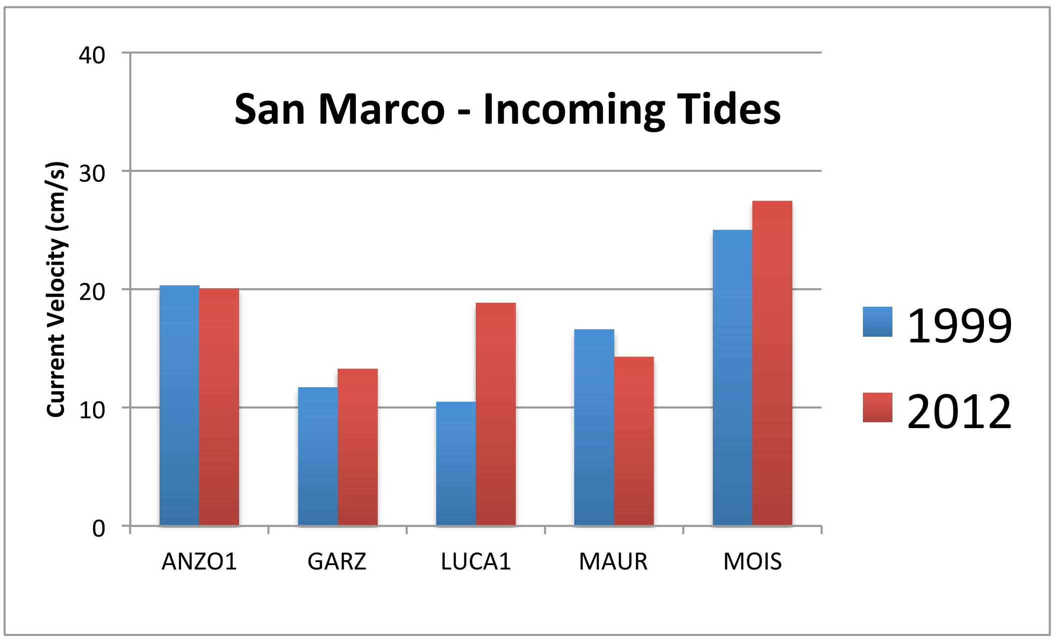


Figure 54. Current velocity comparison between 1999 and 202 San Marco incoming tide

The comparison shows both increases and decreases in velocity since 1999. All but one of the measured segments showed a small amount of change (less than 5 cm/s) and should not be considered indicators of overall change in those segments since 1999 due to possible measurement error (see Figure 55). However, the LUCA1 segment (as in the outgoing tide data) showed a more noticeable increase of 8.40 cm/s. This increase during incoming tide is very similar to the increase of 8.49 cm/s found for LUCA1 during outgoing tide. This consistent change since 1999 in both outgoing and incoming tide for LUCA1 further confirms that an increase in speed has increased in this canal segment directly connected to the Grand Canal.

Figure 55. Change in current velocity between 1999 and 2012 in San Marco incoming tide

6.2 ISMAR Model Analysis

Due to differing tides and other climate conditions (wind, pressure, etc.) from day to day it is crucial to have model results for the days in which we collected our data. Data from different days can lead to false conclusions about that model that are actually due to other factors. We had received model results for November 9th, 2012, the first of our twelve-hour cycle measurements. Four variations of the model were run for this date. The first variation of the model used bathymetry data from before 2005 and did not account for changes in the lagoon due to the MOSE project construction. This model is referred to as "No MOSE, old". Model outputs for water level (Figure 56) and current velocity (Figure 57) are shown below.

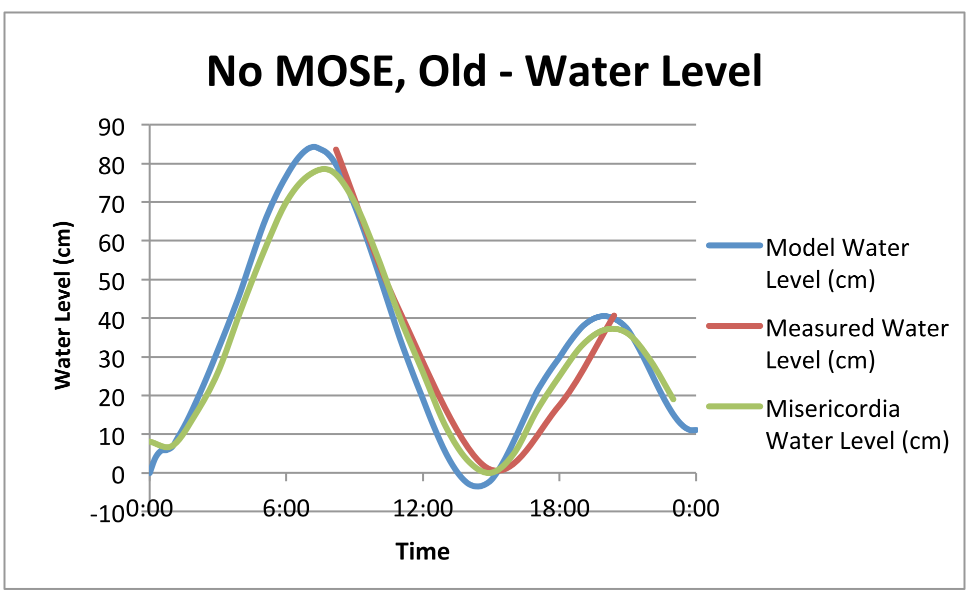


Figure 56.Water level comparison between the model (No MOSE, old), measured water levels and the actual water level at Misericordia tide gauge

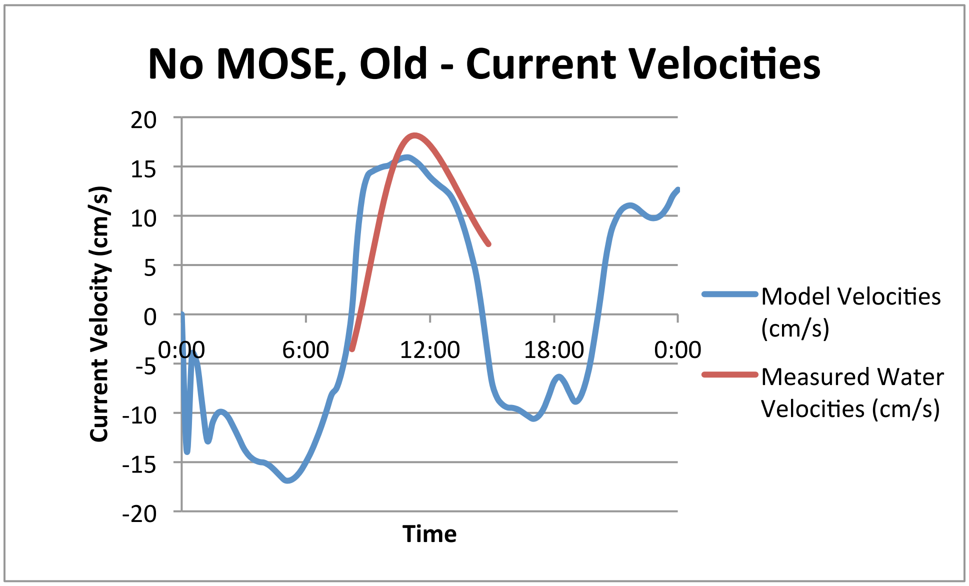


Figure 57. Current velocity comparison between the model (No MOSE, Old) and collected data

The second variation of the model, referred to as "No MOSE, new" used bathymetry data from 2005 and also did not account for lagoon changes due to MOSE. Model outputs for water level (Figure 58) and current velocity (Figure 59) are shown below.

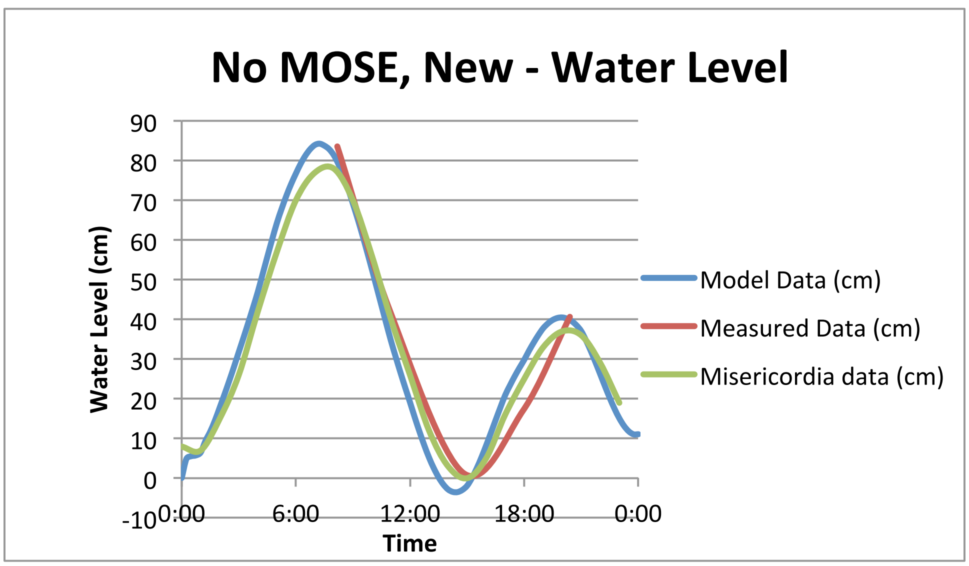


Figure 58. Water level comparison between model (No MOSE, New), collected data and the actual water level at the Misericordia tide gauge

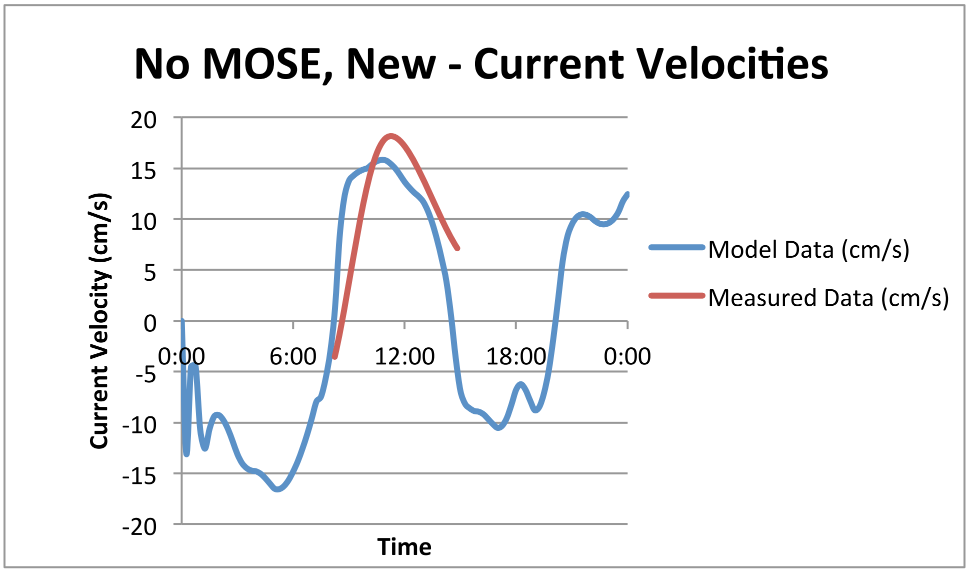


Figure 59. Current velocity comparison between the model (No MOSE, New) and measured current velocity

"MOSE, old" refers to the third variation of the model, which accounts for changes in the lagoon due to the MOSE project and bathymetry data from before 2005. Model outputs for water level (Figure 60) and current velocity (Figure 61) are shown below.

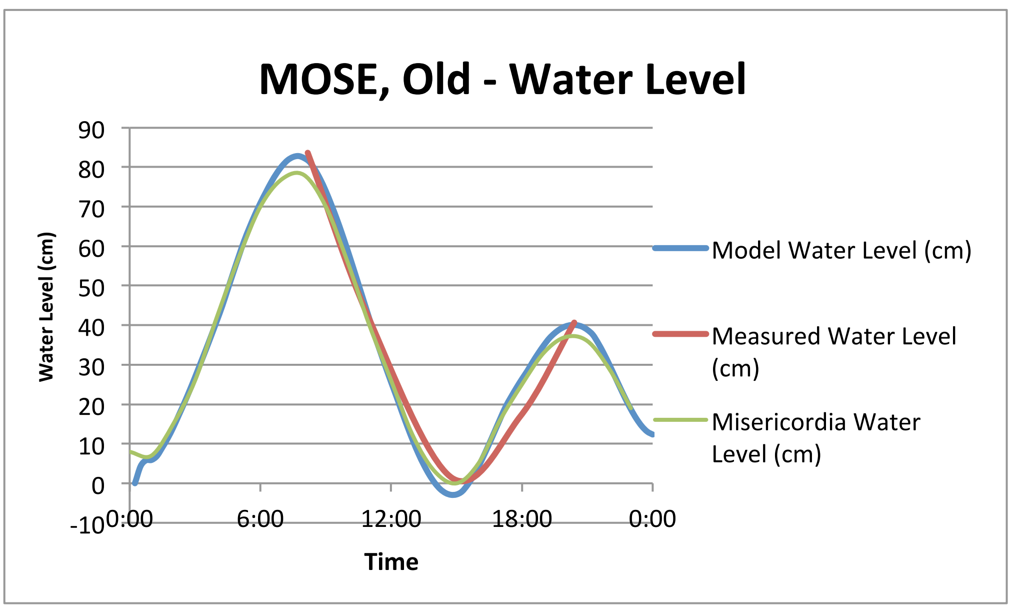


Figure 60. Water level comparison between model (MOSE, Old), collected data and actual water level at Misericordia tide gauge

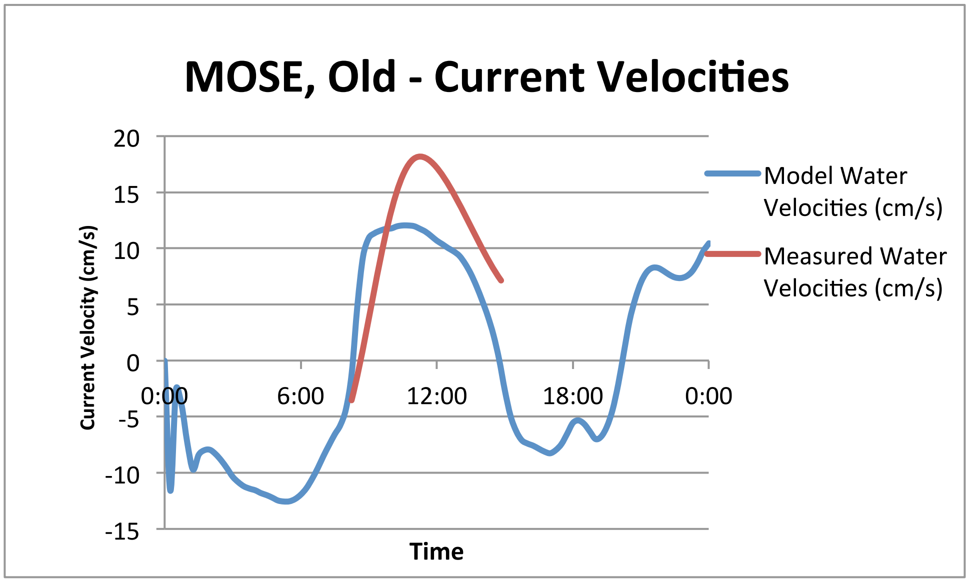


Figure 61. Current Velocity comparison between model (MOSE, Old) and measured current velocity

The last version of the model "MOSE, new" accounts for both the MOSE project and updated bathymetries from 2005. Model outputs for water level (Figure 62) and current velocity (Figure 63) are shown below.

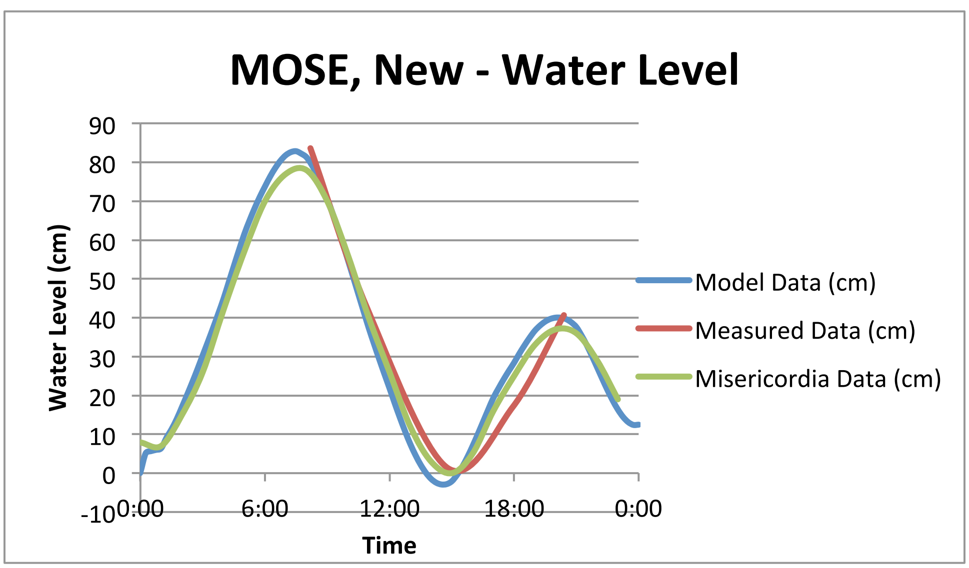


Figure 62. Water level comparison between model (MOSE, New), collected data and actual water level at Misericorida tide gauge

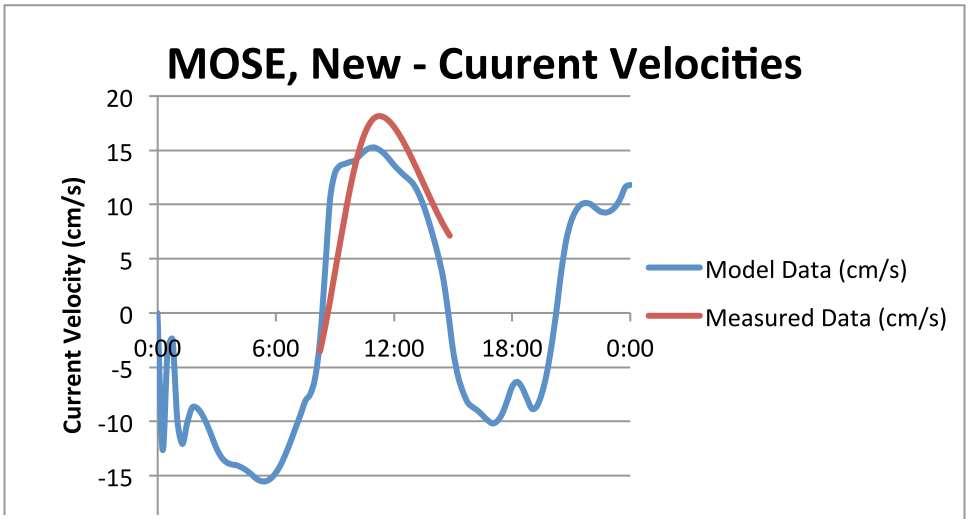


Figure 63. Current Velocity comparison between model (MOSE, New) and measured current velocities

6.2.1 Model vs. Collected Data Comparison

In order to determine if change has occurred using the ISMAR models, they first needed to be compared to the collected data to see if the outputted results were similar to the measurements taken in the field. To conclude the validity of the model, collected data and the outputted results were graphed with error bars to show to what degree of percentage the model deviated from the field measurements. Both water level and current velocities were analyzed in this way.

6.2.1.1 Current Velocity

Seen in 64, the outputted velocities are usually within 35 percent error of the measured ones. This was also common amongst the comparisons made on similar data of different segments, which is a significant increase in error from the water level data. Due to this larger error, we cannot determine whether or not the outputted velocities are correct. More data is needed and other aspects of the models need to be examined in order to get a better representation of the two sets of data being similar. However, even if the model and the measured data are not identical, comparing the models together is still a valid way to conclude or suggest what may be the cause of change within the canals. When comparing model to model, the change in speed is the most significant characteristic.

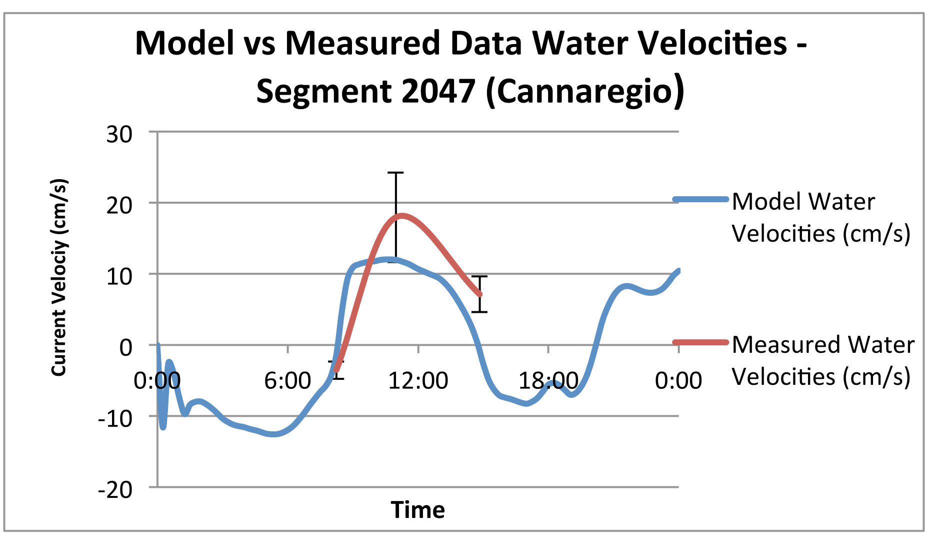


Figure 64. Current velocity model outputs are within approximately 35% error of measured current velocity

6.2.1.2 Water Level

Seen in Figure 65, the water level outputted by the models is always within 5 percent error of the data acquired from the canals. Results such as this were seen throughout the comparisons done of the collected data and the outputs from the models. Due to the small margin of error from the two sets of data, the model's outputs of water level can be determined as accurate and useful for future analysis.

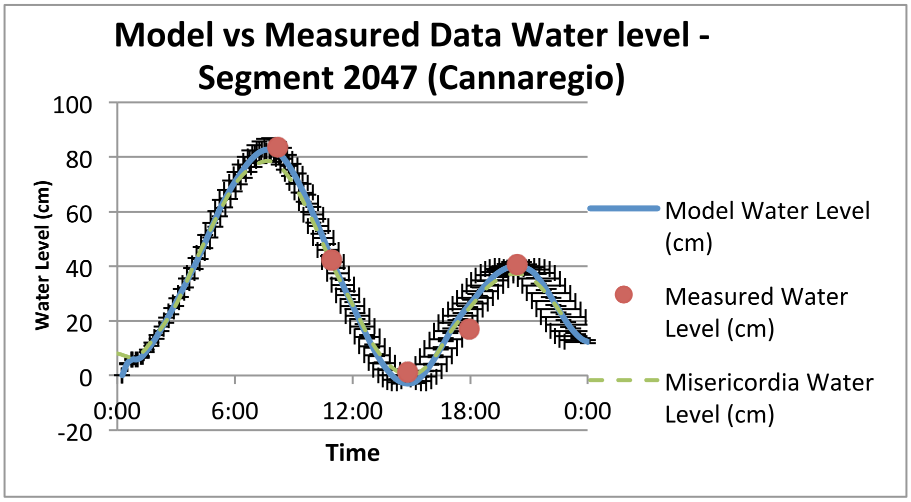


Figure 65. Water level model output is within 5% of Misericordia and measured water levels

6.2.2 Model vs. Model Comparison

The outputs of the different versions of the models were compared to each other to aid in determining the cause of changes in the canal network. The models were compared for the segments of Rio di San Felice (FELI2) and Rio della Sensa (SENS6), located in Cannaregio. These segments displayed notable changes.

For segment FELI2, the different versions of the model outputted both water level and current velocity data. The water level data outputted by all four models is almost identical to the actual water level at Misericordia and the water levels measured during the 12-hour cycle, as shown in Figure 66.

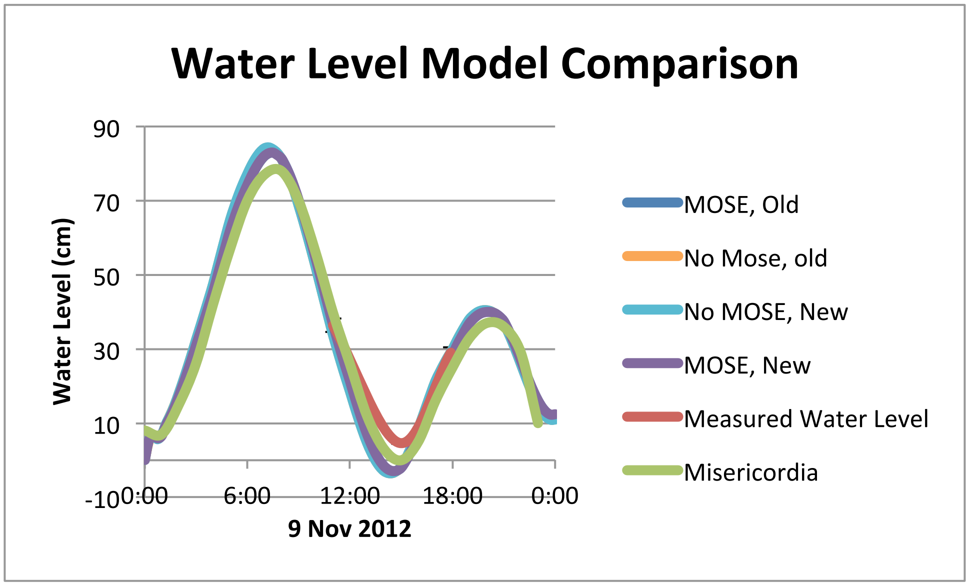


Figure 66. Water level comparison of all model outputs, measured water levels and water level at Misericordia tide gauge

This data shows that the addition of structures associated with the MOSE project and the bathymetry change do not significantly affect the water level.

If the bathymetry change or the addition of MOSE were a cause of the change in the current velocity in FELI2, a comparison of different versions of the model would show this change. As seen in Figure 67 below, the model comparison shows that the updated bathymetries had no affect on the current velocity.

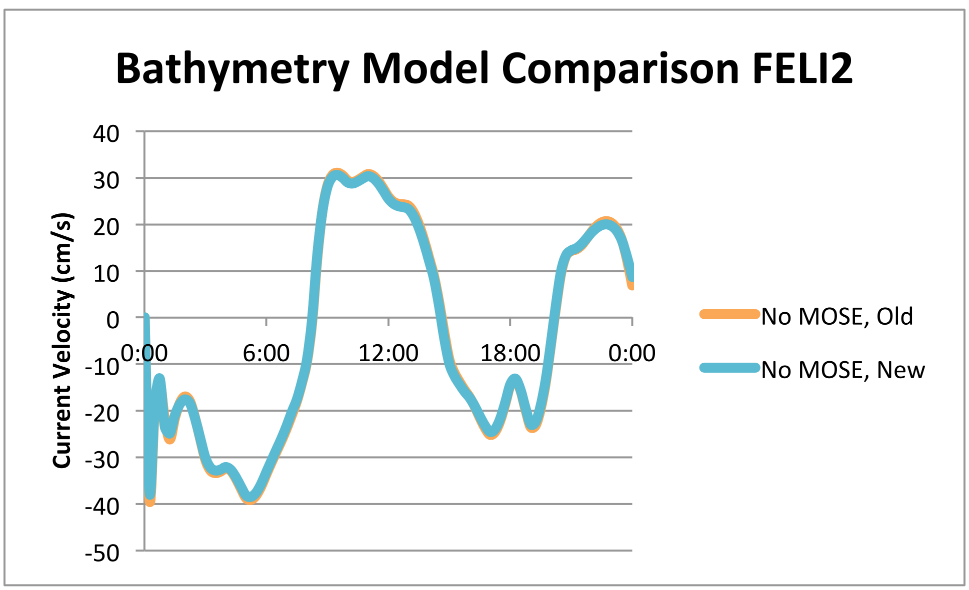


Figure 67. Model comparison to determine the effects of the change in bathymetry on current velocity in FELI2

The comparison between models with updated bathymetry and no MOSE and updated bathymetry and MOSE, show that so far, the effects of the MOSE project are not the cause of the increased current velocity, as shown in Figure 68.

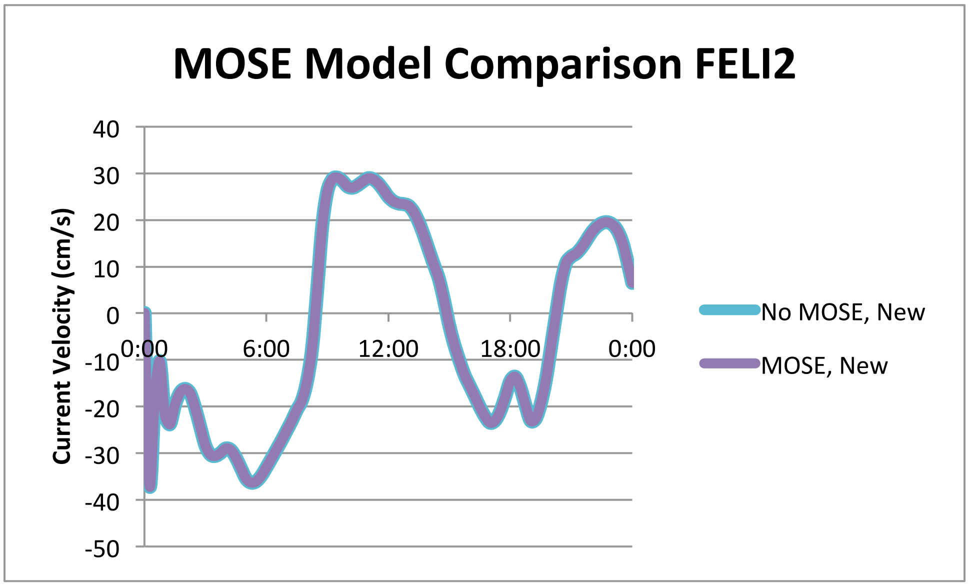


Figure 68. Model comparison to determine the effects of MOSE on current velocity in FELI2

The same comparisons were performed for the segment SENS6. Similar to FELI2, the water levels of all versions of the model output the same water level, which closely matches the measured and Misericordia water level. The model comparisons were also performed for current velocities in canal segment SENS6. The model comparison for updating the bathymetry is shown below in Figure 69.

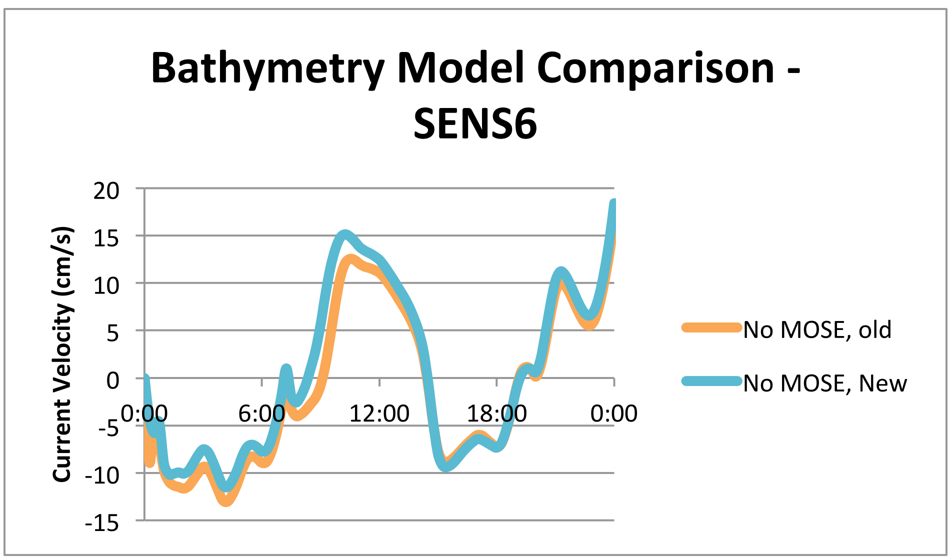


Figure 69. Model comparison to determine the effects of the change in bathymetry on the current velocity of SENS6

In general, the model with new bathymetry data showed an increase in current velocity compared to the old bathymetry. This behavior mirrors the comparison of the field data collected in 1999 and 2012. However, the actual increase in current velocity is more than the increase depicted by the model. This shows that the change in bathymetry of SENS6 is a contributing factor to its increased current velocity. A comparison was performed to determine the effects of the MOSE floodgates on the current velocity of SENS6, with the models outputting almost identical results, shown in Figure 70. According to the most recent model, the MOSE floodgates project does not affect the current velocity in SENS6.

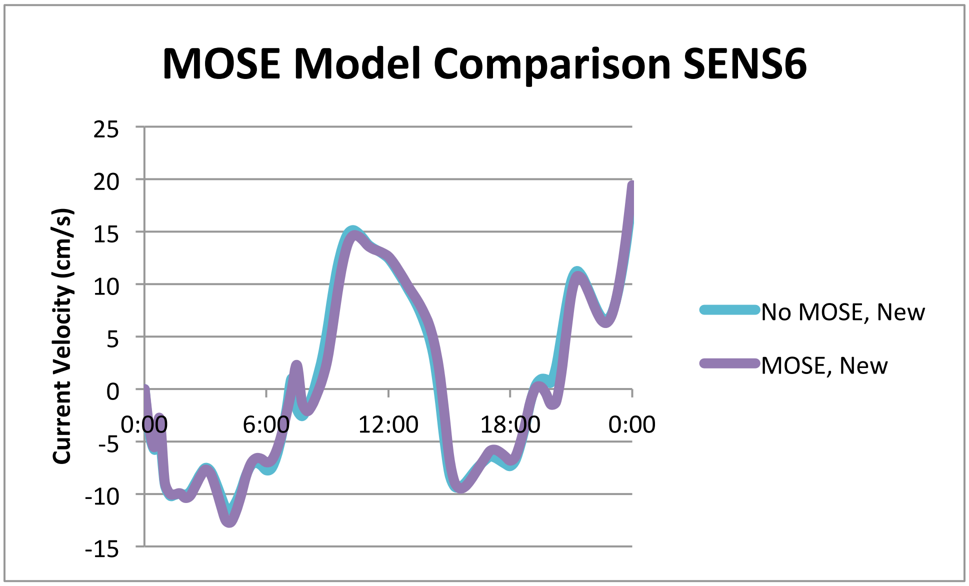


Figure 70. Model comparison to determine the effects of MOSE on the current velocity of SENS6

While the models have shown that the bathymetry change in SENS6 is a factor in the increased current velocity, other factors may need to be taken into account to fully explain the change.

The team was able to obtain model results from ISMAR for the day that water levels and current velocities were measured in Cannaregio. If model results could be obtained for the day that the team conducted measurements in San Marco (November 14, 2012), our collected data could be compared to the model and analyzed in the same manner as the data collected in Cannaregio. After receiving model results and validating them, the model should be used to analyze other regions than just where the data was collected. Although conclusions cannot be made from these comparisons, they offer a general idea of other locations to be studied.

7. RECOMMENDATIONS

Unfortunately, seven weeks is not ample time to fully conduct the studies we hoped to complete. We have identified specific recommendations regarding the measurement devices we developed, canals requiring further investigation, model analysis, and Venipedia for future projects to reference when conducting hydrodynamic studies in Venice.

7.1 Recommendations on New Measurement Devices

After working with our devices and analyzing their results we have conjured a list of various suggestions for those hoping to continue our studies. There are a few changes that could be made to the implementation of our devices in order to increase their efficiency. The measuring stick should be implemented as a stationary device. By setting them in fixed locations, it will only require one person to take water level measurements and the process will be much quicker. It would also be useful to implement a smart phone application for people to download. Persons with the app could take pictures with their phone and upload them to a database that will decipher the measuring sticks location, time and water level. Use of the measuring sticks in a crowdsourcing effort requires that the sticks be stationary; feasibility of their use in this way depends therefore on whether or not securing them to canal walls is possible. It is against the city's laws to drill or make any other kind of hole in canal walls or bridges, and most poles in the canals are the property of boat owners. If a way is found to lawfully secure the measuring sticks to canal walls, the measurement increments on the sticks must be readable from a picture taken with the image quality of a typical smartphone camera, possibly requiring alterations to the increment design on the device.

Due to time constraints, we were unable to collect data in all of the locations that we scouted as usable locations for taking measurements with the measuring stick. Figure 71 shows these locations on a QGIS map; the shapefile (SHP) layers for the mapped points are available for use as "Scouted Water Level Locations – Castello.shp", "Scouted Water Level Locations – Dorsoduro.shp" and "Scouted Water Level Locations – SC.shp." For more complete analysis of Venice's canal network, future teams should attempt to measure a wider range of regions, including Dorsoduro and Castello.

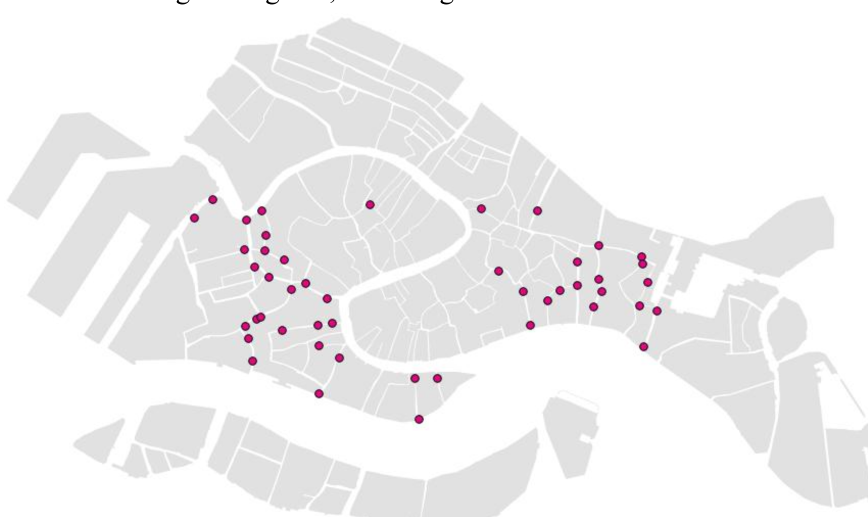


Figure 71. Scouted locations for water level data collection with measuring stick

For the floating GPS device, it is highly recommended to obtain a more accurate and reliable GPS device than the phone. The device should also have remote capabilities including a start, stop, waypoint marker, signal strength reading and location reading. This will allow the user to put the device in the water and start the tracks when it is up to speed, mark when it enters another canal, check to make sure it is functioning, find the device at the end of a run and stop it when it reaches the end of a canal. If a device such as this cannot be acquired, this can also be implemented through the use of two smart phones running an app that could link the two phones and have a client and server mode.

7.2 Recommended Locations for Further Investigation

This type of study should be extended into all other regions of Venice that the team was unable to cover. From our analysis of the data that we collected and compared to the data from the 1990's, we have targeted a few areas that should be looked at more in depth. These canals are highlighted in orange in Figure 73 below:

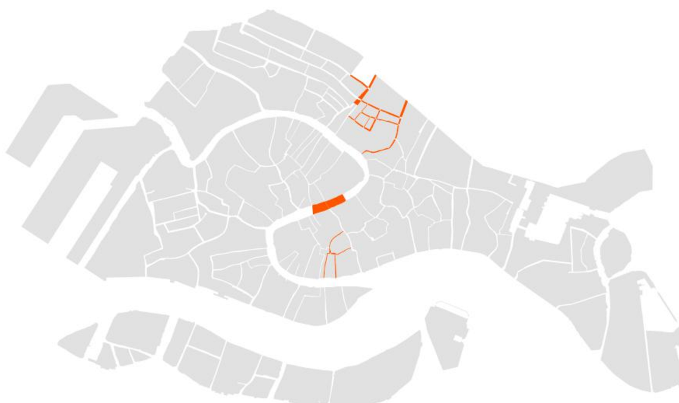


Figure 72. Recommended canal segments for future studies

The first region of significance is in Cannaregio, near the Rio di San Felice (see Figure 73). Two segments of this canal – FELI1 and FELI2 – are separated by another intersecting canal (Rio S. Sofia) that links to network of short canals to the east of Rio di San Felice. The FELI2 segment of the canal moves very quickly and seems to have sped up significantly since 1999; however, FELI1 moves significantly slower than FELI2, and has decreased velocity since the 1999 (in 1999, the velocities of these two segments during outgoing tide were not nearly as different from each other as they are proving to be in 2012). This suggests that the water flowing through the network of short canals and Rio S. Sofia is responsible for this difference between the FELI1 and FELI2 current velocities. We had also recorded interesting data from the GPS that indicated the water flows into the Grand Canal during outgoing tide as opposed to studies done in the 1970's that indicate water flowing out into the lagoon. For these reasons, we feel it is important to look into the network of canals directly to the east and north of the Rio di San Felice to try and come to some conclusions as to how and why these changes have occurred.

Additionally, we were unable to collect data during incoming tide in Cannaregio due to technical difficulties with the propeller device. To make the study of Cannaregio canal segments more complete, current velocity data should be collected in Cannaregio during incoming tide (in the segments we studied in 2012 as well as segments recommended above).

Figure 73. Recommended canal segments in Cannaregio for further investigation

Another area to consider is located in San Marco (see Figure 74). There are also unexplained differences of velocity in areas around the Grand Canal. The water seems to move quicker into the Grand Canal during incoming tide and out of the Grand Canal quicker during outgoing tide. For these reasons, the following canals warrant further investigation:

Figure 74. Recommended canal segments in San Marco for further investigation

7.3 Other Recommendations

The team was able to obtain model results from ISMAR for the day that water levels and current velocities were measured in Cannaregio. If model results could be obtained for the day that the team conducted measurements in San Marco (November 14, 2012), our collected data could be compared to the model and analyzed in the same manner as the data collected in Cannaregio. After receiving model results and validating them, the model should be used to analyze other regions than just where the data was collected. Although conclusions cannot be made from these comparisons, it will give a general idea of other locations to look into.

8. CONCLUSION

As the overall sea level continues to rise and human interventions proceed to interject upon coastal communities, Venice continues to be subjected to alteration. After vigorous tests and analyses, we have successfully developed two useful and cost efficient devices, the GPS flotation device and the measuring stick device, to monitor the changes within the canals. Although without a more accurate GPS, the GPS flotation device is not able to accurately record velocity data, it can still be used to track the general flow over time. If multiple devices were constructed, they could all be used simultaneously to record a network of canals and how they flow into one another. The measuring stick has proven to be very accurate and has potential for simultaneous readings. This device could be placed in fixed locations and pictures can be taken very quickly. There is also the possibility of creating a smart phone app that could be downloaded by pedestrians; persons with the app could then take pictures at any time and upload them to a database, hereby increasing the amount of measurements.

After implementing the aforementioned devices, we were able to identify changes within some canals, most notably, the Rio di San Felice and Misericordia. Compared to previously recorded data, the Rio di San Felice has slowed down in the northern region only to increase in speed in the southern region leading towards the Grand Canal. The Rio di San Girolamo has increased in speed leading toward the Rio di Misericordia during the outgoing tide. In accordance with the cause of these changes we were only able to make few conclusions. The model results suggest that the recent changes in bathymetry have not had much of an effect on the velocities and the addition of the MOSE flood gates have had minimal effects as well; however, evidence as to the exact cause of the exhibited changes in current velocities are still inconclusive.

Although there is not yet definitive evidence indicating causes for change in some of the inner canals since the 1990s, future studies may be able to use the new measurement devices we developed to continue data collection and further this investigation. Data made available to the public through Venipedia can also be used by sponsors and researchers for future analysis purposes. We hope that our work and this data on Venipedia will help our sponsors to better monitor the hydrodynamics of the canals of Venice so that necessary maintenance can be done in an efficient way, and a healthy, navigable waterway system can be maintained.

9. BIBLIOGRAPHY

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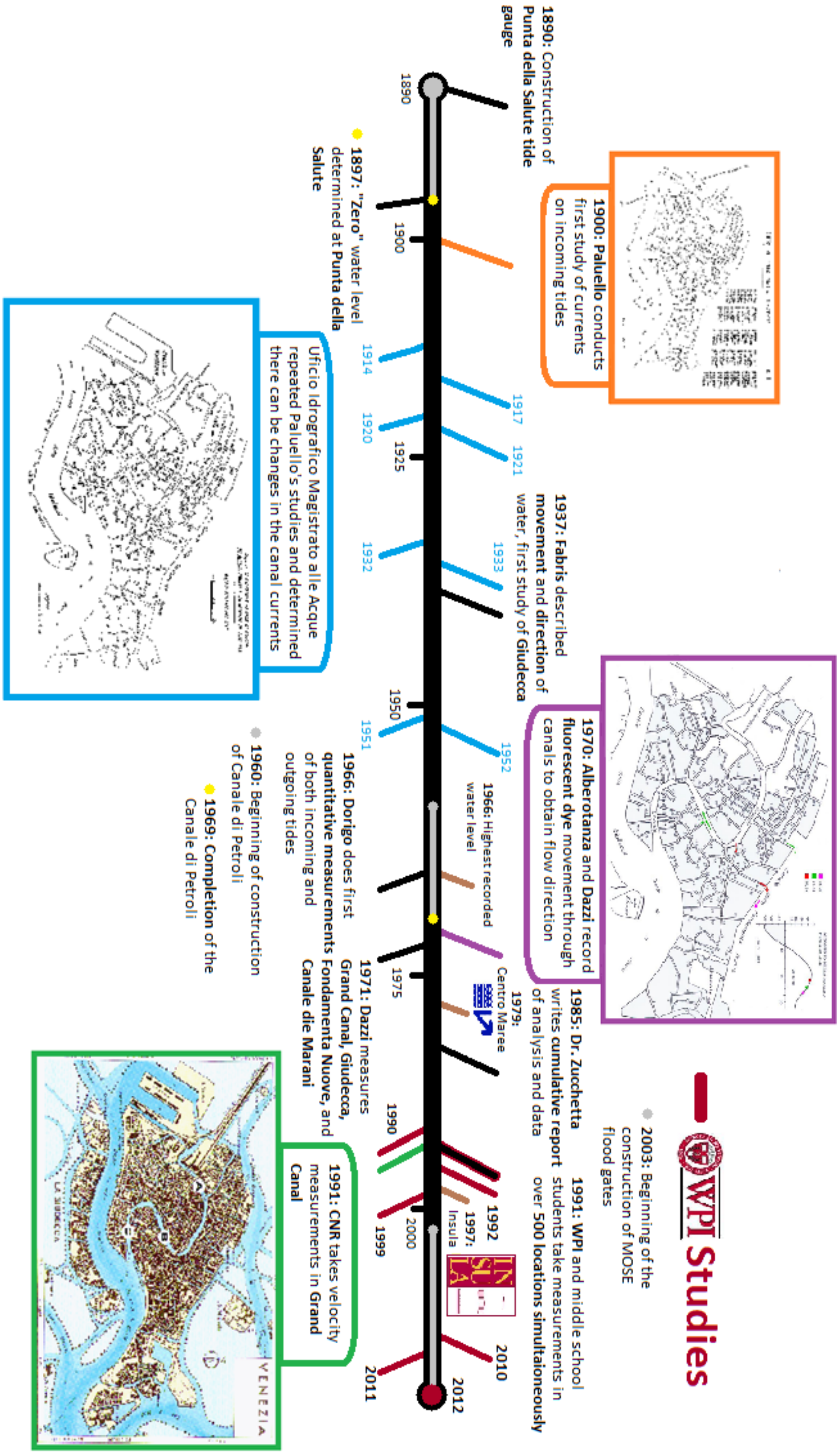
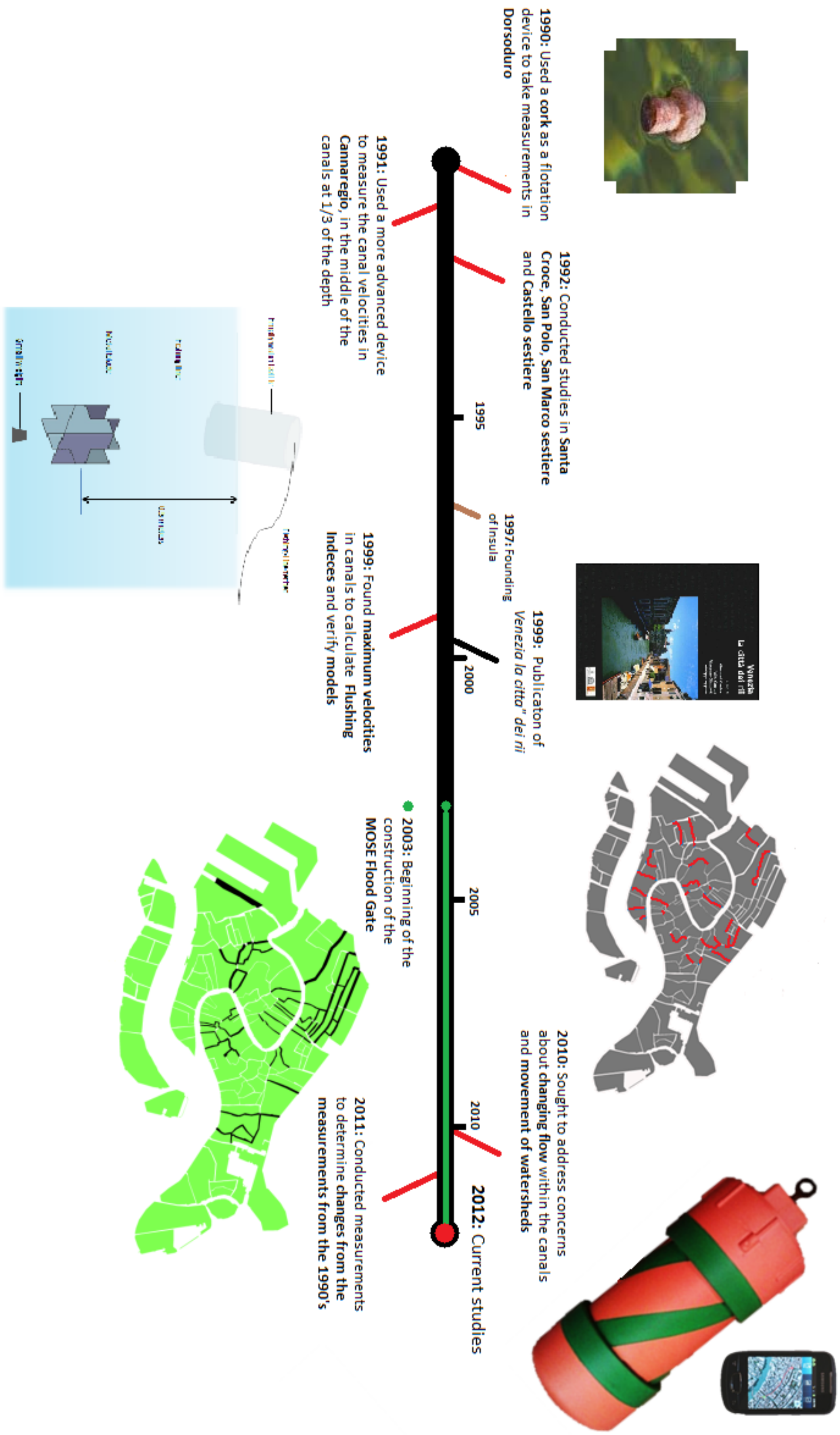
Appendix A: Timeline of Past Hydrodynamic Studies in Venice



Appendix B: Timeline of WPI Hydrodynamic Studies in Venice

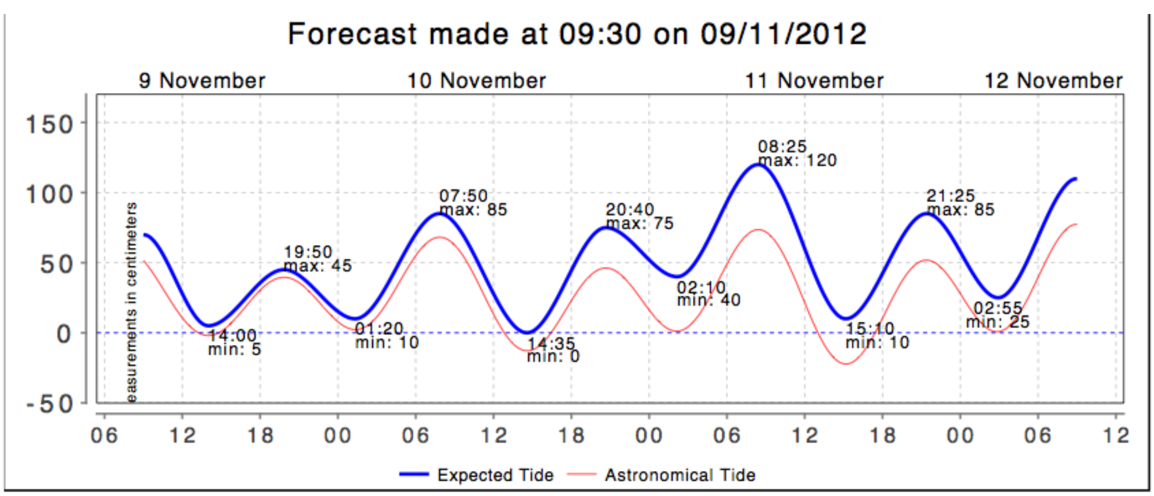


Appendix C: Measurement Schedule and Tide Forecasts

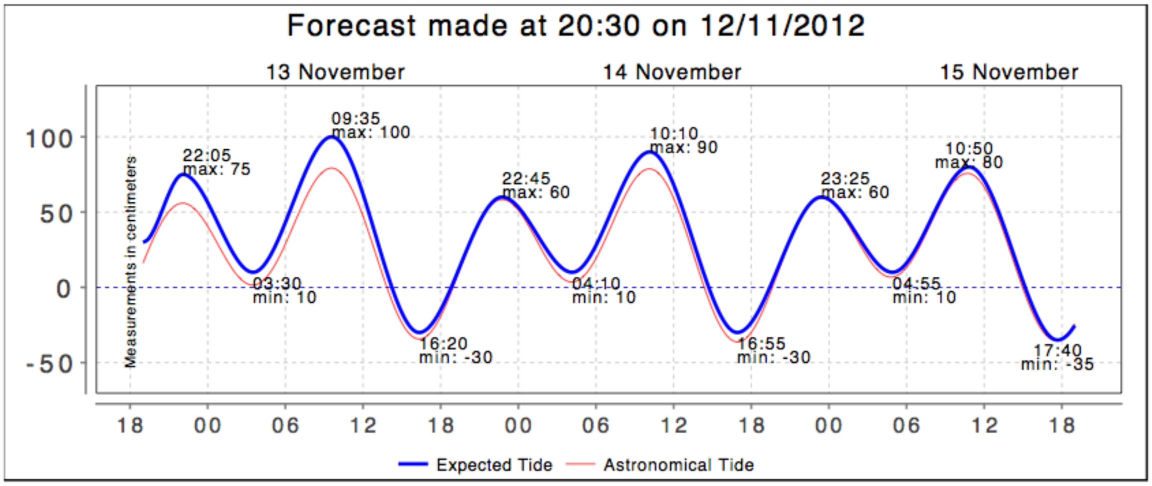
November 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
4	5	6	7	8 Measuring Stick Verification	9 Cannaregio 12 hour cycle	10
11	12	13	New Moon 14 San Marco 12 hour cycle	15	16	17
18	19	20	21	22	23	24
25	26	27 San Polo/ Santa Croce 12 hour cycle	28 Full Moon	29	30 Doppler Measurements	

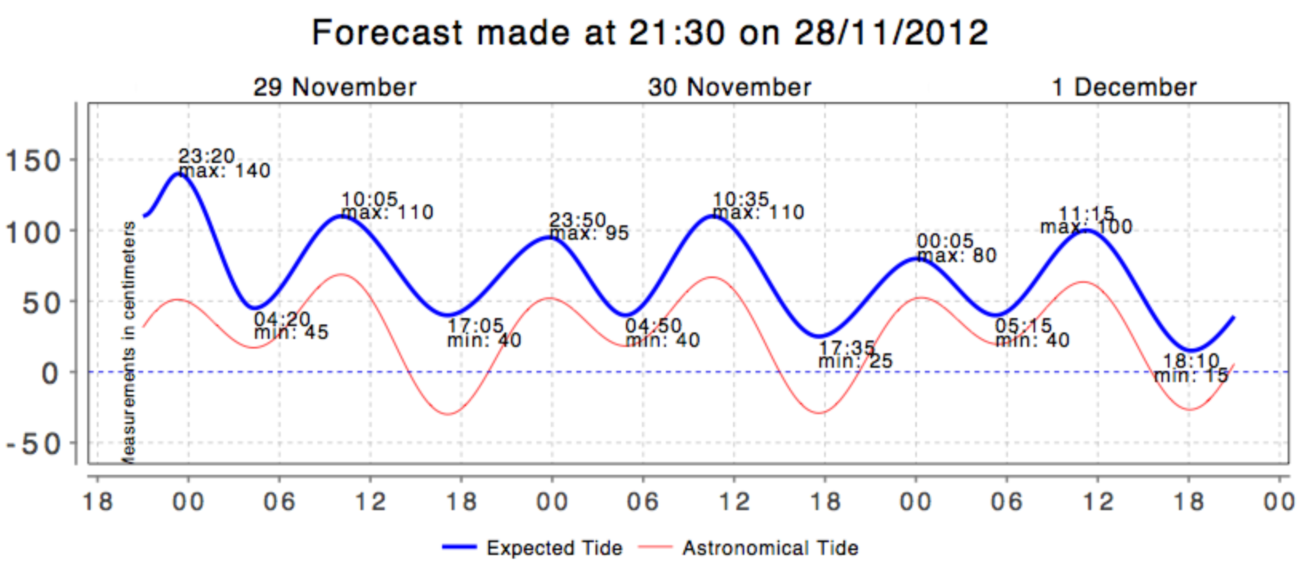
Tide Forecast for November 9, 2012:



Tide Forecast for November 14, 2012:



Tide Forecast for November 30, 2012:



Appendix D: Current Velocity Data

San Marco Current Velocities

ISMAR Segment: 2139

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	14:15	-20.846	Outgoing	-20.052	-20.846	-21.64	
14/11/12							

ISMAR Segment: 2240

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	7:04	-13.27366667	Incoming	-11.488	-13.76	-14.573	
14/11/12	13:12	15.288	Outgoing	15.288	15.288	15.288	

ISMAR Segment: 2267

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	7:20	-14.26933333	Incoming	-13.76	-13.76	-15.288	
14/11/12	13:27	15.55266667	Outgoing	16.082	15.288	15.288	

ISMAR Segment: 2290

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	7:29	-27.46266667	Incoming	-26.404	-27.992	-27.992	
14/11/12	13:35	27.72733333	Outgoing	26.404	27.198	29.58	
14/11/12	17:30		Low tide				
14/11/12	20:33		Incoming				

ISMAR Segment: 2291

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	13:47	40.4975	Outgoing	37.52	42.284	41.49	40.696
14/11/12							

ISMAR Segment: 2375,
2376

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	6:48	17.40533333	Incoming	17.67	16.876	17.67	
14/11/12	12:59	-21.90466667	Outgoing	-21.64	-20.846	-23.228	
14/11/12	19:48	20.31663333	Incoming	20.052	21.64	19.2579	

ISMAR Segment: 2460

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	6:56	-20.052	Incoming	-21.64	-20.052	-18.464	
14/11/12	13:06	25.34533333	Outgoing	24.816	24.816	26.404	
14/11/12	16:51	13.512	Low Tide	15.288	11.488	13.76	

ISMAR Segment: 2463

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	14:00	35.9313	Outgoing	37.52	35.93	34.3439	
14/11/12	17:43	11.99283333	Low Tide	13.0026	10.7306	12.2453	

ISMAR Segment: 2464

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
14/11/12	7:55	29.57996667	Incoming	29.58	31.1679	27.992	

Cannaregio Current Velocities

ISMAR Segment: 2023

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)		All Recorded Current Speeds* (cm/s)			
9/11/2012	7:38	-6.565333333	High Tide	-7.70133	-9.97333	-3.15733	-5.42933
9/11/2012	14:12	26.404	Low Tide	27.198	27.198	24.816	

ISMAR Segment: 2028

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:30	3.157333333	High Tide	3.157333	3.157333		

ISMAR Segment: 2031

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:46	3.662222222	High Tide	3.914667	3.914667	3.157333	

ISMAR Segment: 2034

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:52	6.439111111	High Tide	7.701333	6.944	4.672	
9/11/2012	10:47	24.55133333	Outgoing	24.816	24.816	24.022	
9/11/2012	14:25	9.468444444	Low Tide	10.73067	8.458667	9.216	

ISMAR Segment: 2036

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:59	-3.15733	High Tide	-3.15733			
9/11/2012	10:53	25.87467	Outgoing	24.816	24.816	27.992	
9/11/2012	14:32	10.98311	Low Tide	12.24533	13.00267	7.701333	

ISMAR Segment: 2038

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	14:29	16.876	Low Tide	16.876			

ISMAR Segment: 2039

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)		All Recorded Current Speeds* (cm/s)			
9/11/2012	8:07	3.9146666 67	High Tide	3.157333	3.157333	5.429333	
	14:44	3.6622222 22	Low Tide	4.672	3.157333	3.157333	

ISMAR Segment: 2047

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	8:14	-3.536	High Tide	-3.15733	-3.91467		
9/11/2012	10:58	17.93466667	Outgoing	17.67	18.464	17.67	
9/11/2012	14:50	7.133333333	Low Tide	3.914667	7.701333	8.458667	8.458667

ISMAR Segment: 2402, 2403

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	8:21	-3.662222222	High Tide	-4.672	-3.15733	-3.15733	
9/11/2012	11:05	46.51866667	Outgoing	45.46	47.048	47.048	
9/11/2012	14:56	23.228	Low Tide	20.052	23.228	26.404	

ISMAR Segment: 2416

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:20	3.409777778	High Tide	3.914667	3.157333	3.157333	
9/11/2012	10:29	-32.756	Outgoing	-34.344	-35.138	-28.786	
9/11/2012	14:04	27.46266667	Low Tide	27.992	26.404	27.992	

ISMAR Segment: 2419

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:08	4.924444444	High Tide	5.429333	4.672	4.672	
9/11/2012	10:15	-21.64	Outgoing	-20.846	-21.64	-22.434	
9/11/2012	13:54	-22.16933333	Low Tide	-20.846	-22.434	-23.228	

ISMAR Segment: 2426

Date	Median Time of Counter Reading*	Average Current Speed* (cm/s)	Tide Cycle	All Recorded Current Speeds* (cm/s)			
9/11/2012	7:00	5.618666667	High Tide	6.944	4.672	6.186667	4.672
9/11/2012	10:05	-16.876	Outgoing	-16.876	-16.876	-16.876	
9/11/2012	13:48	-20.58133333	Low Tide	-23.228	-20.052	-18.464	

Appendix E: Water Level Data

San Marco Water Level

ISMAR Segment: 2239

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	7:02	40		40	40	40		
14/11/12	16:57	-28		-28	-28	-28		
14/11/12	20:11	3.333333		2	4	4		

ISMAR Segment: 2240, 2241

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	9:55	83		83	83	83		
14/11/12	13:09	49.66666667		49	50	50		
14/11/12	16:55	-18.33333333		-20	-17	-18		
14/11/12	20:09	3.666666667		4	4	3		

ISMAR Segment: 2246

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	7:13	38.66667		39	37	40		
14/11/12	10:05	86.33333		87	86	86		
14/11/12	13:20	41.66667		42	42	41		
14/11/12	17:06	-34.3333		-33	-35	-35		
14/11/12	20:20	5.333333		5	5	6		

ISMAR Segment: 2263

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	7:09	40.5		43	40	40	39	
14/11/12	10:01	81.66667		84	80	81		
14/11/12	13:18	42		43	42	41		
14/11/12	17:02	-38		-38	-38	-38		
14/11/12	20:16	9.333333		10	9	9		

ISMAR Segment: 2267

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	7:19	43.66667		45	43	43		
14/11/12	7:21	43.66667		42	45	44		
14/11/12	10:11	84.33333		86	84	83		
14/11/12	10:14	88		87	87	90		
14/11/12	13:25	40.75		41	41	41	40	
14/11/12	13:27	42.66667		42	43	43		
14/11/12	17:12	-40		-39	-41	-41	-39	-40
14/11/12	20:25	6		6	6	6		

ISMAR Segment: 2288

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	7:40	46.33333		46	47	46		
14/11/12	10:32	85.66667		86	85	86		
14/11/12	13:37	36		36	36	36		
14/11/12	17:27	-32		-34	-31	-31		
14/11/12	20:37	16		16	16	16		

ISMAR Segment: 2290

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	7:28	52		54	51	53	50	
14/11/12	10:24	90		89	89	92		
14/11/12	13:34	40.33333		41	40	40		
14/11/12	17:23	37		36	38	37		
14/11/12	20:33	21		21	21	21		

ISMAR Segments: 2375, 2376

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	6:45	31.33333333		30	30	34		
14/11/12	9:44	90		89	92	89		
14/11/12	12:54	50		50	50	50		
14/11/12	16:49	-28		-28	-28	-28		
14/11/12	19:45	-8.333333333		-8	-8	-9		

ISMAR Segment: 2458

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	6:39	30.33333333		30	30	31		
14/11/12	9:38	78		78	78	78		
14/11/12	12:50	53.66666667		53	54	54		
14/11/12	16:35	-22		-22	-22	-22		
14/11/12	19:41	-7		-7	-7	-7		

ISMAR Segment: 2460

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
14/11/12	6:55	37		37	37	37		
14/11/12	9:50	83		83	83	83		
14/11/12	13:04	36.33333		36	37	36		
14/11/12	16:49	-32		-32	-32	-32		
14/11/12	19:55	-2		-3	-2	-1		

Cannaregio Water Level

ISMAR Segment: 2024

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:35	83.66666667		84	83	84		
9/11/2012	10:38	47		49	47	45		
9/11/2012	14:11	2.333333333		2	3	2		
9/11/2012	17:01	15		15	15	15		
9/11/2012	20:02	38.66667		38	38	40		

ISMAR Segment: 2025

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:44	100		100	100	99	101	
9/11/2012	14:17	9.333333333		9	10	9		
9/11/2012	17:08	38.33333333		38	37	40		
9/11/2012	20:06	44.66666667		46	44	44		

ISMAR Segment: 2027

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	6:53	78			78	78	78	
9/11/2012	10:06	55.6666667			56	56	55	
9/11/2012	13:47	6.33333333			6	6	7	
9/11/2012	16:43	23.3333333			22	25	23	
9/11/2012	19:46	36.3333333			36	37	36	

ISMAR Segment: 2028

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:29	83		83	83	83		
9/11/2012	10:41	47.66666667		49	47	47		
9/11/2012	20:14	38		36	41	37		

ISMAR Segment: 2034

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:50	82.66666667		81	84	83		
9/11/2012	10:46	44.66666667		47	44	43		
9/11/2012	14:21	1.333333333		0	1	3		
9/11/2012	17:15	17.66666667		18	18	17		
9/11/2012	20:10	40.33333333		41	40	40		

ISMAR Segment: 2036

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:56	85.66666667		87	88	82		
9/11/2012	10:51	49.5		45.5	49.5	53	5	
9/11/2012	14:30	10.5		11.5	9.5	10.5		
9/11/2012	17:22	37.75		39.5	37.5	37.5	36.5	

ISMAR Segment: 2039_1

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	8:01	83.1		84.5	81.5	81.5	84.5	83.5
9/11/2012	10:55	41.16666667		39.5	41.5	42.5		
9/11/2012	14:37	2.166666667		0.5	2.5	3.5		
9/11/2012	17:27	10		11.5	9.5	9.5	9.5	
9/11/2012	20:16	42.16666667		41.5	40.5	44.5		

ISMAR Segment: 2039_2

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	8:04	80.25		82	81	79	79	
9/11/2012	14:41	4.333333333		4	4	5		
9/11/2012	17:32	22.33333333		21	23	23		
9/11/2012	20:20	39.66666667		41	40	38		

ISMAR Segment: 2047

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)			
9/11/2012	8:11	83.66666667		85	82	84	
9/11/2012	10:56	42.33333333		42	43	42	
9/11/2012	14:48	1.333333333		0	3	1	
9/11/2012	17:56	17		17	17	17	
9/11/2012	20:24	40.66666667		39	41	42	

ISMAR Segment: 2054

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	8:28	77.66666667		77	77	79		
9/11/2012	11:14	37.5		37	37	38	38	
9/11/2012	15:03	0.25		1	0	0	0	
9/11/2012	17:36	27		23	29	29		
9/11/2012	20:34	40.33333333		41	41	39		

ISMAR Segments: 2402, 2403

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)			
9/11/2012	8:18	78.66666667		76	80	80	
9/11/2012	11:02	36.33333333		37	35	37	
9/11/2012	14:54	4.666666667		1	5	8	
9/11/2012	17:54	29		29	29	28	30

ISMAR Segment: 2416

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:16	80.6666667		81	81	80		
9/11/2012	10:28	48.6666667		50	49	47		
9/11/2012	14:02	5		6	4	5		
9/11/2012	16:52	12.6666667		13	12	13		
9/11/2012	19:55	38.3333333		39	38	38		

ISMAR Segment: 2419

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
9/11/2012	7:05	79.33333333		78	79	81		
9/11/2012	10:14	55.33333333		55	55	56		
9/11/2012	13:54	7.25		8	7	6	8	
9/11/2012	16:33	17		15	18	18		
9/11/2012	19:30	32.33333333		32	32	33		

San Polo and San Croce Water Level

ISMAR Segment: 2203

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:04	43.33333		43	45	42		
27/11/12	9:12	80		81	79	81	83	76
27/11/12	12:48	41.66667		42	44	39		
27/11/12	16:18	4		4	1	7		
27/11/12	19:30	51		51	51	51		

ISMAR Segment: 2204

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:00	42.66667		42	42	44		
27/11/12	9:08	77.6		77	77	79	77	78
27/11/12	12:45	43		43	43	43		
27/11/12	16:15	3.333333		4	3	3		
27/11/12	19:27	49		49	49	49		

ISMAR Segment: 2299

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	5:42	42.33333		43	41	43		
27/11/12	9:00	79.33333		82	80	76		
27/11/12	12:32	44.5		44	44	47	43	
27/11/12	16:05	6		6	6			
27/11/12	19:17	49.33333		50	50	48		

ISMAR Segment: 2316

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	5:36	57.66667		57	58	58		
27/11/12	8:52	79		79	79	79		
27/11/12	12:28	47.33333		48	47	47		
27/11/12	16:00	8.666667		10	9	7		
27/11/12	19:14	51		51	51	51		

ISMAR Segment: 2321

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:24	54		54	54	54		
27/11/12	9:31	81		81	81	81		
27/11/12	13:06	38.33333		38	38	39		
27/11/12	16:33	4.666667		4	5	5		
27/11/12	19:46	56.66667		56	57	57		

ISMAR Segment: 2347

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:20	49.66667		49	50	50		
27/11/12	9:28	79.33333		79	80	79		
27/11/12	13:03	33.33333		34	33	33		
27/11/12	16:30	3.333333		4	3	3		
27/11/12	19:43	54.66667		55	55	54		

ISMAR Segment: 2349

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	5:56	42.66667		43	42	43		
27/11/12	9:04	76.66667		77	77	76		
27/11/12	12:38	46.66667		48	48	44		
27/11/12	16:10	5.333333		2	5	9		
27/11/12	19:23	45.66667		45	46	46		

ISMAR Segment: 2351

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:18	50.66667		52	52	48		
27/11/12	9:25	80		80	79	81		
27/11/12	13:01	37.33333		37	38	37		
27/11/12	16:29	4		4	4	4		
27/11/12	19:41	52.66667		53	53	52		

ISMAR Segment: 2360

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:29	53.66667		53	54	54		
27/11/12	13:08	35.33333		35	35	36		
27/11/12	16:35	5.333333		5	5	6		
27/11/12	19:47	55.25		56	56	55	54	

ISMAR Segment: 2362

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:34	54		54	54	54		
27/11/12	9:37	81		81	81	81		
27/11/12	13:11	33.33333		33	33	34		
27/11/12	16:37	4		4	4	4		
27/11/12	19:50	51.33333		51	52	51		

ISMAR Segment: 2377

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:14	49		49	48	50		
27/11/12	9:21	81.66667		82	82	81		
27/11/12	12:57	40.6		41	41	42	41	38
27/11/12	16:26	4.666667		5	4	5		
27/11/12	19:38	50.66667		50	50	52		

ISMAR Segment: 2387

Date	Median Time of Water Level Reading	Average Water Level (cm)		All Recorded Water Levels (cm)				
27/11/12	6:10	47.25		48	48	46	47	
27/11/12	9:18	82.5		83	83	82	82	
27/11/12	12:54	41.66667		42	42	41		
27/11/12	16:24	2.666667		4	3	1		
27/11/12	19:36	52.66667		52	53	53		

Appendix F: 1999 vs. 2012 Comparison Data

Incoming Tide:

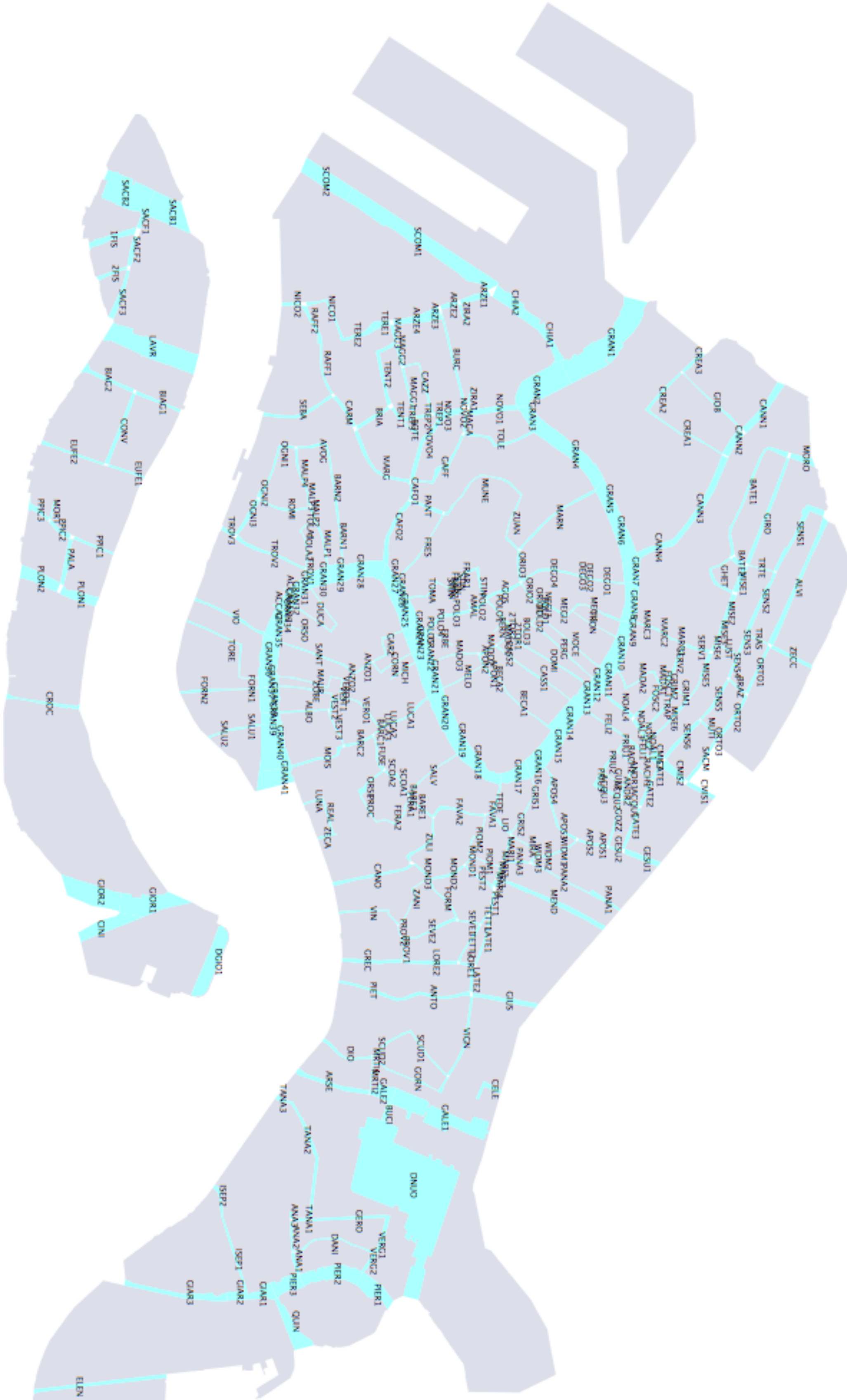
ISMAR Segment	WPI Segment	2012 Incoming Velocity (cm/s)	1999 Incoming Velocity (cm/s)	Incoming Difference
2460	ANZO1	-20.052	-20.33	0.28
2240	GARZ	-13.27366667	-11.69	-1.583666667
2375/2376	LUCA1	18.86098333	10.46	8.400983333
2267	MAUR	-14.26933333	-16.59	2.32
2290	MOIS	-27.46266667	-25	-2.462666667

Outgoing Tide:

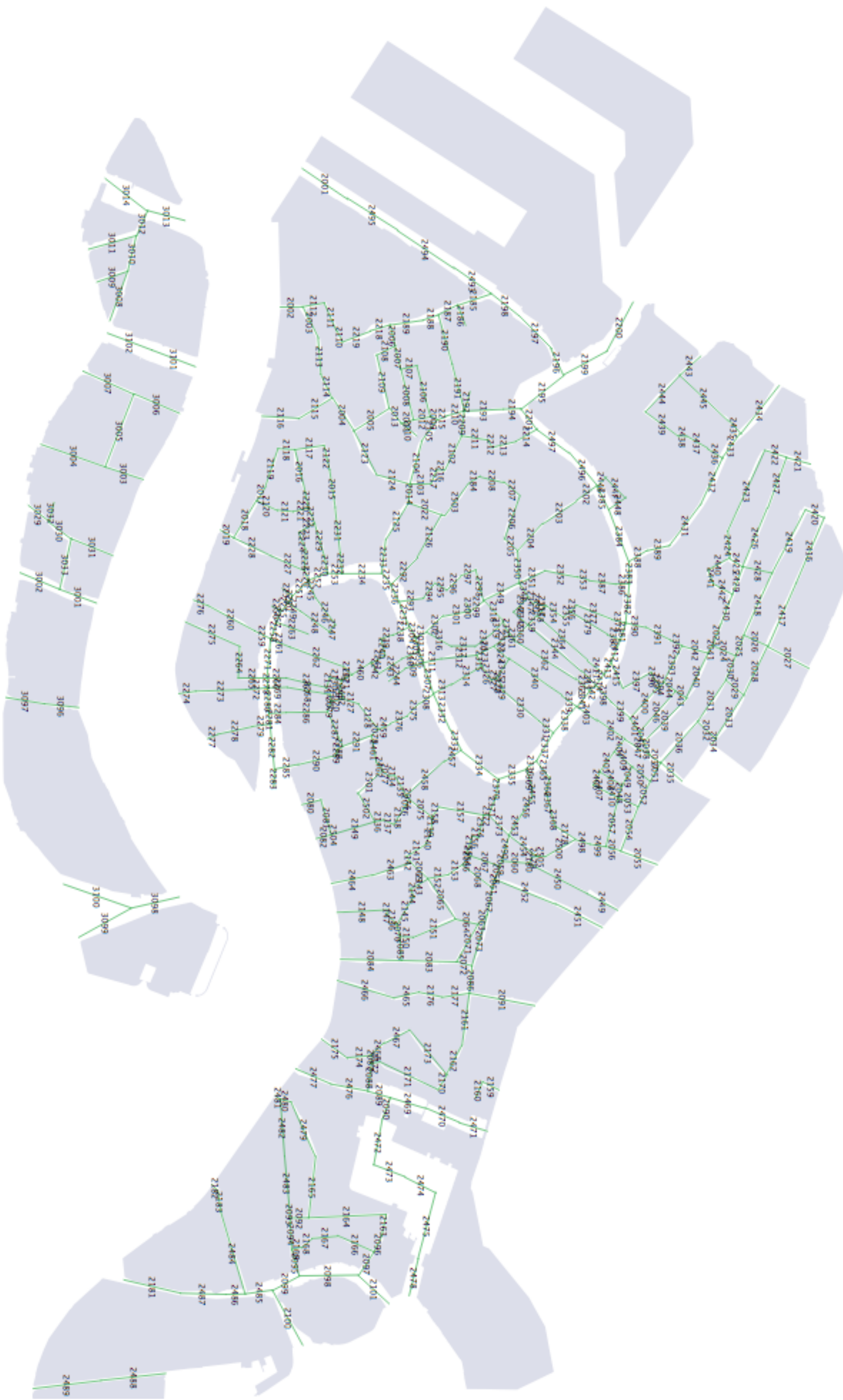
ISMAR Segment	WPI Segment	2012 Outgoing Velocity (cm/s)	1999 Outgoing Velocity (cm/s)	Outgoing Difference
2416	ALVI	-32.756	-26.30	-6.46
2460	ANZO1	25.34533333	30.50	-5.15
2291	BARC2	40.4975	37.96	2.5375
2047	FELI1	17.93466667	23.3	-5.365333333
2402/2403	FELI2	-46.51866667	-29.25	-17.27
2240	GARZ	15.288	19.87	-4.582
2426	GIRO	16.876	8.30	8.58
2375/2376	LUCA1	-21.90466667	-13.41	-8.494666667
2267	MAUR	15.55266667	21.74	-6.187333333
2290	MOIS	27.72733333	33.33	-5.602666667
2419	SENS1	21.64	16.90	4.74
2036	SENS6	25.87466667	13.2	12.67466667

Appendix G: Segment Identification

Appendix G1: Map of WPI Segments



Appendix G2: Map of ISMAR Segments



Appendix G3: WPI and ISMAR Segment Database

ISMAR Segment	WPI Segment	Canal Name
2001	SCOM2	Canal de la Scomenzera
2002	NICO2	Rio de S. Nicolò dei Mendicoli
2003	RAFF2	Rio de l'Anzolo Rafael
2004	CARM	Rio dei Carmini
2005	BRIA	Rio Briati
2006	MAGG3	Rio de S. Maria Maggior
2007	MAGG2	Rio de S. Maria Maggior
2008	MAGG1	Rio de S. Maria Maggior
2009	TREP1	Rio dei Tre Ponti
2010	BOTE	Rio de le Bote
2011	TREP3	Rio dei Tre Ponti
2012	TREP2	Rio dei Tre Ponti
2013	TENT1	Rio del Tentor
2014	CAFO1	Rio de Ca' Foscari
2015	BARN2	Rio de S. Barnaba
2016	MALP4	Rio del Malpaga
2017	OGNI2	Rio dei Ognisanti
2018	OGNI3	Rio dei Ognisanti
2019	TROV3	Rio de S. Trovaso
2020	VEST1	Rio de la Veste
2021	ANZO2	Rio de S. Anzolo
2022	PANT	Rio de S. Pantalon
2023	MISE3	Rio de la Misericordia
2024	LUST	Rio dei Lustraferi
2025	SENS3	Rio de la Sensa
2026	TRAS	Rio dei Trasti
2027	ZECC	Rio dei Zecchini
2028	ORTO1	Rio de la Madona de l'Orto
2029	BRAZ	Rio Brazzo
2030	SENS4	Rio de la Sensa
2031	SENS5	Rio de la Sensa
2032	MUTI	Rio dei Muti
2033	ORTO2	Rio de la Madona de l'Orto
2034	ORTO3	Rio de la Madona de l'Orto
2035	CMIS2	Canal de la Misericordia
2036	SENS6	Rio de la Sensa
2037	CMIS3	Canal de la Misericordia
2038	NOAL1	Rio de Noal
2039	MISE6	Rio de la Misericordia
2040	MISE5	Rio de la Misericordia
2041	MISE4	Rio de la Misericordia
2042	SERV1	Rio dei Servi
2043	GRIM1	Rio Grimani
2044	GRIM2	Rio Grimani
2045	NOAL2	Rio de Noal

2046	TRAP	Rio del Trapolin
2047	FELI1	Rio de S. Felice
2048	ANDR2	Rio de S. Andrea
2049	ANDR1	Rio de S. Andrea
2050	RACH1	Rio de la Racheta
2051	CATE1	Rio de S. Caterina
2052	CATE2	Rio de S. Caterina
2053	ACQU1	Rio de l'Acqua Dolce
2054	CATE3	Rio de S. Caterina
2055	GESU1	Rio dei Gesuiti
2056	GESU2	Rio dei Gesuiti
2057	GOZZ	Rio del Gozzi
2058	MARI3	Rio de S. Marina
2059	MARI2	Rio de S. Marina
2060	PANA3	Rio de la Panada
2061	MARI4	Rio de S. Marina
2062	PEST1	Rio del Pestrin
2063	TETT1	Rio de la Tetta
2064	SEVE1	Rio de S. Severo
2065	FORM	Rio de S.M. Formosa
2066	MOND1	Rio del Mondo Novo
2067	PIOM1	Rio del Piombo
2068	PEST2	Rio del Pestrin
2069	MOND3	Rio del Mondo Novo
2070	PROV2	Rio de S. Provolo o de l'Osmarin
2071	TETT2	Rio de la Tetta
2072	LORE1	Rio de S. Lorenzo

2073	LATE1	Rio de S. Giovanni Laterano
2074	BARE2	Rio dei Bareteri
2075	BARE1	Rio dei Bareteri
2076	FERA1	Rio dei Ferali
2077	SCOA2	Rio dei Scoacamini
2079	VEST2	Rio de la Veste
2080	LUNA	Rio de la Luna o dei Giardinetti
2081	REAL	Rio de la Luna o dei Giardinetti
2082	ZECA	Rio de la Luna o dei Giardinetti
2083	LORE2	Rio de S. Lorenzo
2084	GREC	Rio dei Greci
2085	PROV1	Rio de S. Provolo o de l'Osmarin
2086	LATE2	Rio de S. Giovanni Laterano
2087	BARC1	Rio dei Barcaroli
2087	MRTI1	Rio de San Martin
2088	MRTI2	Rio de San Martin
2089	GALE2	Canal de le Galeazze
2090	BUCI	Canale Bucintoro
2091	GIUS	Rio de S. Giustina
2092	TANA1	Rio de la Tana
2093	ANA3	Rio de S. Ana
2094	ANA2	Rio de S. Ana
2095	ANA1	Rio de S. Ana
2096	VERG1	Rio de le Vergini
2097	VERG2	Rio de le Vergini

2098	PIER2	Canal de S. Piero
2099	PIER3	Canal de S. Piero
2100	QUIN	Rio de Quintavale
2101	PIER1	Canal de S. Piero
2102	GAFF	Rio del Gaffaro e del Malcanton
2103	GAFF	Rio del Gaffaro e del Malcanton
2104	NOVO4	Rio Novo
2105	NOVO4	Rio Novo
2106	CAZZ	Rio de la Cazziola e de Ca' Rizzi
2107	CAZZ	Rio de la Cazziola e de Ca' Rizzi
2108	TENT2	Rio del Tentor
2109	TENT2	Rio del Tentor
2110	TERE2	Rio de le Terese
2111	NICO1	Rio de S. Nicolò dei Mendicoli
2112	NICO1	Rio de S. Nicolò dei Mendicoli
2113	RAFF1	Rio de l'Anzolo Rafael
2114	RAFF1	Rio de l'Anzolo Rafael
2115	SEBA	Rio de S. Sebastian e S. Basegio
2116	SEBA	Rio de S. Sebastian e S. Basegio
2117	AVOG	Rio de l'Avogaria
2118	OGNI1	Rio dei Ognisanti
2119	OGNI1	Rio dei Ognisanti
2120	ROMI	Rio de le Romite
2121	ROMI	Rio de le Romite
2122	AVOG	Rio de l'Avogaria
2123	MARG	Rio de S. Margherita
2124	MARG	Rio de S. Margherita
2125	CAFO2	Rio de Ca' Foscari
2126	FRES	Rio de la Frescada
2127	VERO1	Rio Menuo o de la Verona
2128	VERO1	Rio Menuo o de la Verona
2129	VERO2	Rio Menuo o de la Verona
2130	MAUR	Rio de S. Maurizio e rio Malatin
2131	MAUR	Rio de S. Maurizio e rio Malatin
2132	SANT	Rio del Santissimo
2133	ZOBE	Rio de S.M. Zobenigo
2134	SCOA1	Rio dei Scoacamini
2135	SCOA1	Rio dei Scoacamini
2136	FERA2	Rio dei Ferali
2137	FERA2	Rio dei Ferali
2138	FERA2	Rio dei Ferali
2139	ZULI	Rio de S. Zulian
2140	ZULI	Rio de S. Zulian
2141	ZULI	Rio de S. Zulian
2142	ZULI	Rio de S. Zulian
2143	ZANI	Rio de S. Zaninovo o del Remedio
2144	ZANI	Rio de S. Zaninovo o del Remedio
2145	ZANI	Rio de S. Zaninovo o del Remedio

2146	VIN	Rio del Vin
2147	VIN	Rio del Vin
2148	VIN	Rio del Vin
2149	Rii tera	Rii tera a volto
2150	SEVE2	Rio de S. Severo
2151	SEVE2	Rio de S. Severo
2152	MOND2	Rio del Mondo Novo
2153	MOND2	Rio del Mondo Novo
2154	PIOM2	Rio del Piombo
2155	PIOM2	Rio del Piombo
2156	PIOM2	Rio del Piombo
2157	FAVA2	Rio de la Fava
2158	FAVA2	Rio de la Fava
2159	CELE	Rielo drio la Celestia o de l'Arsenal
2160	CELE	Rielo drio la Celestia o de l'Arsenal
2161	VIGN	Rio de S. Francesco de la Vigna
2162	VIGN	Rio de S. Francesco de la Vigna
2163	GERO	Rio de S. Gerolamo
2164	GERO	Rio de S. Gerolamo
2165	TANA2	Rio de la Tana
2166	DANI	Rielo de S. Daniel
2167	DANI	Rielo de S. Daniel
2168	DANI	Rielo de S. Daniel
2169	DANI	Rielo de S. Daniel
2170	GORN	Rio de le Gorne

2171	GORN	Rio de le Gorne
2172	GORN	Rio de le Gorne
2173	SCUD1	Rio dei Scudi e de la S. Ternita
2174	DIO	Rio de la Ca' di Dio
2175	DIO	Rio de la Ca' di Dio
2176	ANTO	Rio de S. Antonin
2177	ANTO	Rio de S. Antonin
2178	APOS3	Rio dei Ss. Apostoli
2179	WIDM3	Rio Widman
2180	WIDM3	Rio Widman
2181	GIAR3	Rio dei Giardini
2182	ISEP2	Rio de S. Isepo
2183	ISEP2	Rio de S. Isepo
2184	MUNE	Rio de le Muneghete
2185	ARZE1	Rio de l'Arzere e de S. Marta
2186	ZIRA2	Rio de Sant'Andrea de la Zirada
2187	ARZE2	Rio de l'Arzere e de S. Marta
2188	ARZE3	Rio de l'Arzere e de S. Marta
2189	ARZE4	Rio de l'Arzere e de S. Marta
2190	BURC	Rio de le Burchiele
2191	BURC	Rio de le Burchiele
2192	ZIRA1	Rio de Sant'Andrea de la Zirada
2193	NOVO1	Rio Novo
2194	NOVO1	Rio Novo

2195	GRAN2	Canal Grande
2196	CHIA1	Canal de S. Chiara
2197	CHIA1	Canal de S. Chiara
2198	CHIA2	Canal de S. Chiara
2199	GRAN1	Canal Grande
2200	GRAN1	Canal Grande
2201	GRAN3	Canal Grande
2202	MARN	Rio Marin
2203	MARN	Rio Marin
2204	MARN	Rio Marin
2205	ZUAN	Rio de S. Zuane Evangelista
2206	ZUAN	Rio de S. Zuane Evangelista
2207	MUNE	Rio de le Muneghete
2208	MUNE	Rio de le Muneghete
2209	MAGA	Rio del Magazen
2210	NOVO2	Rio Novo
2211	TOLE	Rio dei Tolentini e de la Crose
2212	TOLE	Rio dei Tolentini e de la Crose
2213	TOLE	Rio dei Tolentini e de la Crose
2214	TOLE	Rio dei Tolentini e de la Crose
2215	NOVO3	Rio Novo
2216	GAFF	Rio del Gaffaro e del Malcanton
2217	GAFF	Rio del Gaffaro e del Malcanton
2218	TERE1	Rio de le Terese

2219	TERE2	Rio de le Terese
2220	MALP3	Rio del Malpaga
2221	ROMI	Rio de le Romite
2222	MALP2	Rio del Malpaga
2223	TOLA1	Rio de la Toletta
2224	TOLA2	Rio de la Toletta
2225	TOLA2	Rio de la Toletta
2226	TROV1	Rio de S. Trovaso
2227	TROV2	Rio de S. Trovaso
2228	TROV2	Rio de S. Trovaso
2229	MALP1	Rio del Malpaga
2231	BARN1	Rio de S. Barnaba
2232	BARN1	Rio de S. Barnaba
2233	CAFO2	Rio de Ca' Foscari
2234	GRAN28	Canal Grande
2235	GRAN27	Canal Grande
2236	GRAN26	Canal Grande
2237	GRAN25	Canal Grande
2238	GARZ	Rio de Ca' Garzoni
2239	GARZ	Rio de Ca' Garzoni
2240	GARZ	Rio de Ca' Garzoni
2241	GARZ	Rio de Ca' Garzoni
2242	CORN	Rio de Ca' Corner
2243	CORN	Rio de Ca' Corner
2244	MICH	Rio de Ca' Michiel
2245	DUCA	Rio del Duca o de S. Vidal
2246	DUCA	Rio del Duca o de S.

		Vidal
2247	DUCA	Rio del Duca o de S. Vidal
2248	DUCA	Rio del Duca o de S. Vidal
2249	DUCA	Rio del Duca o de S. Vidal
2250	GRAN32	Canal Grande
2251	GRAN31	Canal Grande
2252	GRAN30	Canal Grande
2253	GRAN29	Canal Grande
2255	GRAN33	Canal Grande
2257	GRAN34	Canal Grande
2258	GRAN35	Canal Grande
2259	VIO	Rio de S. Vio
2260	VIO	Rio de S. Vio
2261	SANT	Rio del Santissimo
2262	SANT	Rio del Santissimo
2263	ORSO	Rio de l'Orso
2264	TORE	Rio de le Toresele
2265	TORE	Rio de le Toresele
2266	MAUR	Rio de S. Maurizio e rio Malatin
2266	PIET	Rio de la Pietà
2267	MAUR	Rio de S. Maurizio e rio Malatin
2268	ZOBE	Rio de S.M. Zobenigo
2269	ZOBE	Rio de S.M. Zobenigo
2270	GRAN37	Canal Grande
2271	GRAN36	Canal Grande

2272	FORN1	Rio de la Fornasa
2273	FORN2	Rio de la Fornasa
2274	FORN2	Rio de la Fornasa
2275	TORE	Rio de le Toresele
2277	SALU2	Rio de la Salute
2278	SALU1 and SALU2	Rio de la Salute
2279	SALU1	Rio de la Salute
2279	VIO	Rio de S. Vio
2280	GRAN38	Canal Grande
2281	GRAN39	Canal Grande
2282	GRAN40	Canal Grande
2283	GRAN41	Canal Grande
2284	ALBO	Rio de l'Alboro o de le Ostreghe
2285	MOIS	Rio de S. Moisè
2286	ALBO	Rio de l'Alboro o de le Ostreghe
2287	VEST3	Rio de la Veste
2288	MOIS	Rio de S. Moisè
2289	MOIS	Rio de S. Moisè
2290	MOIS	Rio de S. Moisè
2291	BARC2	Rio dei Barcaroli
2292	FRES	Rio de la Frescada
2293	TOMA	Rio de S. Tomà
2294	TOMA	Rio de S. Tomà
2295	TOMA	Rio de S. Tomà
2296	FRAR1 and	Rio dei Frari

	FRAR2	
2297	FRAR1	Rio dei Frari
2298	STIN	Rio de S. Stin
2299	POLO2	Rio de S. Polo
2300	AMAL	Rio Amalteo
2301	POLO3	Rio de S. Polo
2302	POLO4	Rio de S. Polo
2303	POLO5	Rio de S. Polo
2304	GRAN24	Canal Grande
2305	GRAN23	Canal Grande
2306	GRAN22	Canal Grande
2307	GRAN21	Canal Grande
2308	LUCA1	Rio de S. Luca
2309	MICH	Rio de Ca' Michiel
2310	CORN	Rio de Ca' Corner
2311	MADO3	Rio della Madonnetta
2312	MADO3	Rio della Madonnetta
2313	MELO	Rio dei Meloni
2314	MELO	Rio dei Meloni
2315	APON2	Rio de S. Aponal
2316	ERBE	Rielo de le Erbe
2317	Rii tera	Rii tera a volto
2318	POLO1	Rio de S. Polo
2319	BERN	Rielo S. Antonio-de Ca' Bernardo
2320	Rii tera	Rii tera a volto
2321	2TOR2	Rio de le Do Torre
2322	MADO1	Rio della Madonnetta
2323	MADO2	Rio della Madonnetta
2324	CASS2	Rio de S. Cassan
2325	Rii tera	Rii tera a volto
2326	APON1	Rio de S. Aponal
2327	BECA2	Rio de le Becarie
2328	BECA1	Rio de le Becarie
2329	BECA1	Rio de le Becarie
2330	BECA1	Rio de le Becarie
2331	BECA1	Rio de le Becarie
2332	GRAN20	Canal Grande
2333	GRAN19	Canal Grande
2334	GRAN18	Canal Grande
2335	GRAN17	Canal Grande
2336	GRAN16	Canal Grande
2337	GRAN15	Canal Grande
2338	GRAN14	Canal Grande
2339	CASS1	Rio de S. Cassan
2340	CASS1	Rio de S. Cassan
2341	GRAN13	Canal Grande
2342	GRAN12	Canal Grande
2343	PERG	Rio de la Pergola o de Ca' Pesaro
2344	PERG	Rio de la Pergola o de Ca' Pesaro
2345	Rii tera	Rii tera a volto
2346	Rii tera	Rii tera a volto
2347	ORIO1	Rio de S. Giacomo dell'Orio

2348	ORIO2	Rio de S. Giacomo dell'Orio
2349	AGOS	Rio de S. Agostin
2350	ORIO3	Rio de S. Giacomo dell'Orio
2351	DEGO4	Rio de S. Zan Degolà
2352	DEGO4	Rio de S. Zan Degolà
2353	DEGO2	Rio de S. Zan Degolà
2353	DEGO3	Rio de S. Zan Degolà
2354	MEGI2	Rio del Megio
2355	MEGI2	Rio del Megio
2356	MEGI1	Rio del Megio
2357	MEGI3	Rio del Megio
2358	BOLD1	Rio de S. Boldo
2359	BOLD2	Rio de S. Boldo
2360	BOLD3	Rio de S. Boldo
2361	2TOR1	Rio de le Do Torre
2362	DOMI	Rio de S. Maria Mater Domini
2363	DOMI	Rio de S. Maria Mater Domini
2364	MOCE	Rio Mocenigo o de la Rioda o de S. Stae
2365	APOS4	Rio dei Ss. Apostoli
2366	APOS4	Rio dei Ss. Apostoli
2367	APOS4	Rio dei Ss. Apostoli
2368	APOS3	Rio dei Ss. Apostoli
2369	GRIS1	Rio de S.Giovanni Grisostomo
2370	TEDE	Rio del Fontego dei Tedeschi

2371	TEDE	Rio del Fontego dei Tedeschi
2372	FAVA1	Rio de la Fava
2373	LIO	Rio de S. Lio
2374	PIOM2	Rio del Piombo
2375	LUCA1	Rio de S. Luca
2376	LUCA1	Rio de S. Luca
2377	MEGI1	Rio del Megio
2378	MEGI1	Rio del Megio
2379	TRON	Rio de Ca' Tron
2380	TRON	Rio de Ca' Tron
2381	GRAN9	Canal Grande
2382	GRAN8	Canal Grande
2383	GRAN7	Canal Grande
2384	GRAN6	Canal Grande
2385	GRAN5	Canal Grande
2387	DEGO1	Rio de S. Zan Degolà
2388	CANN4	Canal de Cannaregio
2389	CANN4	Canal de Cannaregio
2390	MARC3	Rio de S. Marcuola
2391	MARC2	Rio de S. Marcuola
2392	MARC1	Rio de S. Marcuola
2393	SERV2	Rio dei Servi
2394	FOSC1	Rio de S. Fosca
2395	MADA1	Rio de la Madalena
2396	MADA2	Rio de la Madalena
2397	MADA2	Rio de la Madalena
2398	NOAL4	Rio de Noal

2399	NOAL4	Rio de Noal
2400	FOSC2	Rio de S. Fosca
2401	NOAL3	Rio de Noal
2402	FELI2	Rio de S. Felice
2403	FELI2	Rio de S. Felice
2404	PRIU1	Rio Priuli
2405	PRIU2	Rio Priuli
2406	PRIU3	Rio Priuli
2407	ACQU3	Rio de l'Acqua Dolce
2408	GUER	Rio de la Guerra
2409	RACH2	Rio de la Racheta
2410	ACQU2	Rio de l'Acqua Dolce
2411	MOCE	Rio Mocenigo o de la Rioda o de S. Stae
2412	GRAN10	Canal Grande
2413	GRAN10	Canal Grande
2414	GRAN11	Canal Grande
2415	MADA2	Rio de la Madalena
2416	ALVI	Rio de S. Alvise
2417	ALVI	Rio de S. Alvise
2418	SENS2	Rio de la Sensa
2419	SENS1	Rio de la Sensa
2420	SENS1	Rio de la Sensa
2421	MORO	Rio de Ca'Moro
2422	BATE1	Rio del Batelo
2423	BATE1	Rio del Batelo
2424	BATE1	Rio del Batelo
2425	BATE2	Rio del Batelo

2426	GIRO	Rio de S. Girolamo
2427	GIRO	Rio de S. Girolamo
2428	TRTE	Rio de le Torete
2429	MISE1	Rio de la Misericordia
2430	MISE2	Rio de la Misericordia
2431	CANN3	Canal de Cannaregio
2432	CANN3	Canal de Cannaregio
2433	CANN2	Canal de Cannaregio
2434	CANN1	Canal de Cannaregio
2435	GIOB	Rio de S. Giobbe
2436	CREA1	Rio de la Crea
2437	CREA1	Rio de la Crea
2438	CREA1	Rio de la Crea
2439	CREA1	Rio de la Crea
2440	GHET	Rio del Ghetto Novo
2441	GHET	Rio del Ghetto Novo
2442	GHET	Rio del Ghetto Novo
2443	CREA3	Rio de la Crea
2444	CREA2	Rio de la Crea
2445	GIOB	Rio de S. Giobbe
2446	Rii tera	Rii tera a volto
2447	Rii tera	Rii tera a volto
2448	Rii tera	Rii tera a volto
2449	PANA1	Rio de la Panada
2450	PANA2	Rio de la Panada
2451	MEND	Rio dei Mendicanti o de S. Zanipolo
2452	MEND	Rio dei Mendicanti o de

		S. Zanipolo
2453	GRIS2	Rio de S.Giovanni Grisostomo
2454	MIRA	Rio dei Miracoli
2455	GRIS1	Rio de S.Giovanni Grisostomo
2456	GRIS1	Rio de S.Giovanni Grisostomo
2457	SALV	Rio de S. Salvador
2458	SALV	Rio de S. Salvador
2459	LUCA2 and LUCA3	Rio de S. Luca
2460	ANZO1	Rio de S. Anzolo
2461	FUSE	Rio dei Fuseri
2462	FUSE	Rio dei Fuseri
2463	CANO	Rio de la Canonica o de Palazzo
2464	CANO	Rio de la Canonica o de Palazzo
2465	ANTO	Rio de S. Antonin
2467	SCUD1	Rio dei Scudi e de la S. Ternita
2468	SCUD2	Rio dei Scudi e de la S. Ternita
2469	GALE1	Canal de le Galeazze
2470	GALE1	Canal de le Galeazze
2471	GALE1	Canal de le Galeazze
2472	DNUO	Darsena Nova e Novissima
2473	DNUO	Darsena Nova e Novissima
2474	DNUO	Darsena Nova e Novissima
2475	DNUO	Darsena Nova e Novissima
2476	ARSE	Rio de l'Arsenal
2477	ARSE	Rio de l'Arsenal
2478	DNUO	Darsena Nova e Novissima
2479	TANA2	Rio de la Tana
2480	TANA2	Rio de la Tana
2481	TANA3	Rio de la Tana
2482	Rii tera	Rii tera a volto
2483	Rii tera	Rii tera a volto
2484	ISEP1	Rio de S. Isepo
2485	GIAR1	Rio dei Giardini
2486	GIAR2	Rio dei Giardini
2487	GIAR3	Rio dei Giardini
2488	ELEN	Rio de S. Elena
2489	ELEN	Rio de S. Elena
2490	MARI1	Rio de S. Marina
2491	ORIO1	Rio de S. Giacomo dell'Orio
2492	VERO2	Rio Menuo o de la Verona
2493	SCOM1	Canal de la Scomenzera
2494	SCOM1	Canal de la Scomenzera
2495	SCOM1	Canal de la Scomenzera
2496	GRAN4	Canal Grande
2497	GRAN4	Canal Grande
2498	APOS2	Rio dei Ss. Apostoli

2499	APOS1	Rio dei Ss. Apostoli
2500	WIDM1	Rio Widman
2501	ORSE	Rio e Bacino Orseolo
2502	PROC	Rio de le Procuratie
2503	MUNE	Rio de le Muneghete
2504	ZECA	Rio de la Luna o dei Giardinetti
2505	WIDM2	Rio Widman
3001	PLON1	Rio del Ponte Longo
3002	PLON2	Rio del Ponte Longo
3003	EUFE1	Rio de S. Eufemia
3004	EUFE2	Rio de S. Eufemia
3005	CONV	Rio de le Convertite
3006	BIAG1	Rio de San Biagio
3007	BIAG2	Rio de San Biagio
3008	SACF3	Sacca Fisola
3009	2FIS	Ramo secondo de Sacca Fisola
3010	SACF2	Sacca Fisola

3011	1FIS	Ramo primo de Sacca Fisola
3012	SACF1	Sacca Fisola
3013	SACB1	Sacca San Biagio
3014	SACB2	Sacca San Biagio
3029	PPIC3	Rio del Ponte Piccolo
3030	PPIC2	Rio del Ponte Piccolo
3031	PPIC1	Rio del Ponte Piccolo
3032	MORT	Rio Morto
3033	PALA	Rio de la Palada
3096	CROC	Rio de la Croce
3097	CROC	Rio de la Croce
3098	GIOR1	Canale de San Giorgio Maggior
3099	CINI	Canale Cini
3100	GIOR2	Canale de San Giorgio Maggior
3101	LAVR	Rio dei Lavraneri
3102	LAVR	Rio dei Lavraneri