VENICE: THE NEED FOR INNOVATION

Over the past one hundred years, the warming of Earth’s oceans paired with the melting of polar ice caps has caused global sea levels to significantly rise. According to the National Oceanic and Atmospheric Administration, in just the last twenty-five years, global sea levels have risen nearly sixty-seven millimeters, and are expected to continue to rise at a rate of more than 3.2 millimeters per year. The presence of higher sea levels creates danger for coastal regions, as storm surges become more powerful and flooding becomes more frequent [1].

Additionally, according to control system developer ABB, when Venice is flooded, its economy grinds to a halt, as businesses are forced to shut down and tourism (a major facet of Venice’s economy; the city expects nearly eighty thousand visitors per day) drastically lessen [4]. Venice’s flooding dilemma is highlighted by the catastrophe of 1966, which as described by U.K. newspaper Independent, abnormally high tides, engorged rivers, and strong winds submerged the city in nearly two meters of water [5]. From then on, Venice knew it needed to find a solution for its flooding problems. However, with Venice’s unique lagoon ecosystem, a solution was needed that would protect the city from floods without disturbing its fragile environment. Normal flood prevention techniques would not be appropriate; innovation was needed. In the early 2000s, Venice revealed its flood-fighting innovation, the MOSE Mobile Floodgate system. Consisting of seventy-eight rising and lowering barriers placed in the three major water inlets around Venice, MOSE has been designed from the ground up for Venice to fight surges of high tides.

An example of a coastal region being put in harm’s way by rising sea levels is Venice, Italy. While Venice has historically been prone to flooding, in the past century, the flooding has become much more frequent and intense. Per Technology in Society, rising sea levels coupled with the fact that the city of Venice is literally sinking (its overall elevation has dropped considerably due to environmental and human factors) has resulted in huge damages to the city’s historic architecture, economy, and surrounding lagoon ecosystem due to flooding [2]. The Italian Ministry of Infrastructure and Transport, Public Works Department of the Triveneto Area describes the damage caused by erosion from floodwaters to buildings, masonry, and coasts as “incalculable” [3].

FLOOD PREVENTION AND MOSE MOBILE FLOODGATES

William Earls, wke4@pitt.edu, Mena Lora 3:00, Weiyi Chen, wec67@pitt.edu, Sanchez 5:00

Abstract - Venice, Italy, an exemplar of both European and world culture, has historically been impacted by flooding. However, in recent years, the flooding, caused by abnormally high tides and rising sea levels, has become more frequent and more intense, resulting in what the Hangar Design Group describes as “incalculable” damage to both the city and its surrounding lagoon environment. To protect Venice’s treasured history and culture, engineers designed and constructed MOSE, a mobile floodgate system. Consisting of a series of seventy-eight rising and lowering gates, MOSE has the ability to seal the three major water inlets around Venice, preventing high tides from the Adriatic Sea overtaking the Venetian Lagoon. With sea levels continuously rising, flooding will likely continue to be a problem for Venice and other coastal regions as a result of high tides. However, the innovation provided by MOSE and other mobile gate systems provide examples of how those regions can protect themselves from the growing danger of flooding while utilizing innovative technology suitable for the needs of their environment. Using a combination of scientific data, information provided by developers, and other sources, we intend to research MOSE and similar floodgate technologies and describe the impact the innovation could have on not just protecting and sustaining Venice and its historic value, but improving flood control and ecosystem preservation throughout the world.

Key Words – Flood prevention, Flooding in the Venetian lagoon, High tides, Impact of rising sea levels, MOSE mobile floodgates, Venice.

RISING SEA LEVELS AND ITS EFFECT ON VENICE: THE NEED FOR INNOVATION

Venice, known also as the “floating city,” was built on 118 small islands that are linked with bridges and canals [6]. The city is no stranger to innovation in engineering. Its thirteenth century engineering projects and world-famous water-filled canals highlight the city’s ever-present sense of ingenuity [2]. Many of the buildings are not built directly on the islands; instead, they are built on elevated wooden beads....
Platforms that are supported by wooden stakes on the seabed. This elevation development helped Venice to stay safe from raising water levels during periods of high tides. But in recent years, abnormally high tides caused by rising sea levels have caused severe damage to the city, as the higher flooding levels have rendered Venice’s elevation less effective, as they are simply not high enough. However, given Venice’s unique landscape and infrastructure, ordinary flood prevention techniques are simply not suitable for Venice. This has forced Venice’s local government and Italy’s national government to take measures and come up with a solution for the flooding problem [7].

Traditional flood prevention techniques include construction of dams, levees, floodwalls, and channel improvements. Dams are usually enormous concrete/steel walls built across water channels to obstruct water flow. Water accumulates on one side of the dam and can be released gradually at a controlled rate. If only considering their ability to block high tides from reaching Venice, building traditional dams across the lagoon’s inlet could be feasible to some degree. However, a major problem of dams is that by impeding the water flow, they also block the way of animals and organisms that live in the water, which can disrupt the natural balance of the area and even lead to destruction of the lagoon’s ecosystem (see section ADVANTAGES, DISADVANTAGES, AND THE SUSTAINABILITY OF MOSE below for more detail) [8].

Coastal armoring is another technique that consists of constructing concrete seawalls and earthen levees to protect the land from strong waves and flooding. Compared to dams, coastal armoring is relatively low-cost but it is also more vulnerable to erosis, as the structures are made up of earthen materials instead of tougher materials like steel. In Venice’s situation, they would need to build levees and seawalls all around the city, which is not realistic given the size of the city and the cost of maintaining such a great number of levees. Plus, much of Venice is built over the sea, so blocking out all the water will cause the wet wooden supports that the city is built upon to rot, which would cause even more serious damage to the city and its foundation [8].

As stated earlier, the city of Venice and its lagoon surroundings are extremely fragile environments. According to Dimitri Deheyn and Lisa Shaffer of Technology in Society, Venice’s biggest dilemma is in finding a way to block high tides from overtaking the city while still allowing a lagoon ecosystem to properly function [2]. Therefore, simply damming up the inlets surrounding the area or using traditional floodgates would not be appropriate, as they would prevent the lagoon from healthily exchanging water from the Adriatic Sea. Additionally, constructing levees would be very inefficient and would provide an eyesore for citizens of Venice. In an interview with Discover, Giovanni Cecconi, an engineer on the MOSE project, stated “People said, ‘I don’t want to see it.’ It is the landscape of Venice” [9]. The people of Venice are very proud of their city’s rich history and distinct aesthetic. They did not want a project that would be visually obtrusive and sully Venice’s renowned appearance. Therefore, large permanent above-ground structures like dams or levees would not be well-received by the people of Venice.

Given the unlikely level of success traditional flood prevention methods would provide, combined with Venice’s fragile environment and its citizen’s desire for a non-obtrusive structure, Venice concluded that there was no existing solution to their dilemma. Therefore, Venice needed a new way to solve their flooding problem and the MOSE mobile floodgate system was determined to be a plausible solution.

**MOSE MOBILE FLOODGATES: TECHNOLOGY AND DEVELOPMENT**

MOSE, the Electromechanical Experimental Module (“Modulo Sperimentale Elettromeccanico” in Italian) is Venice’s attempt at a solution to its flooding problems. As mentioned earlier, MOSE is a series of seventy-eight twenty meter long barriers distributed among the three major water inlets surrounding Venice that rise and lower as needed [9].

As described by Water Technology, each gate is comprised of a hollow metal box that is laid within a steel and concrete channel at the floor of the inlet, with one end attached to the channel with a hinge [10]. When positioned on the seafloor, the hollow gates fill with water. This causes the overall density of the gate to be greater than that off the seawater, causing it to sink and remain stationed on the seafloor. When MOSE is activated and the gates are needed to rise (often referred to as the “alarm” phase), they utilize hydraulics and are pumped with compressed air, which dispels the water. The result is the hollow metal box having a lesser density than the surrounding seawater, causing the end not attached by the hinge to rise to the surface. This idea is illustrated by the following two diagrams from the official MOSE website:

![MOSE floodgate in its lowered position](image)
To clarify the system’s procedure, the schematic provides a logic flowchart of the process. Tidal forecast is carried out continuously every hour by acquiring data of tide, wind, rain, and river discharge to predict the maximum water level. When the predicted water level exceeds the highest tidal point in recorded in a the past ten years, it is regarded as a “critical event” and the gates will start to close immediately. Otherwise, the system will keep running until it predicts a water level that surpasses the safeguarding threshold (65cm to 100cm, depending on different inlets) and will subsequently enter into alert mode in which gates are raised. As for the procedure that opens the gates, the gates would open when the forecasted water level is decreasing, the water level measured in the sea is lower than the water level in the lagoon, or the forecasted water level does not exceed the safety water level in the next 4 hours [11].

MOSE is operated by an ABB-designed control system, which controls the hydraulic systems within the gates, allowing them to fill accordingly with air or water [4]. While much of MOSE’s operation is relegated to this control system, its activation is still initiated by human input. The control system is housed at a command center known as the Arsenal. Here, research and observations of tidal patterns, weather, and sea levels are studied and archived. Workers use this data to forecast tides and water levels, and ultimately choose when to activate an alarm phase [3]. According to Ecological Economics, there is no set water level at which the barriers are raised, but a height of one hundred centimeters is typically used as a starting point. During an alarm phase, when high tides are expected, engineers activate MOSE, and the gates fully rise in thirty minutes. Once risen, the control system regulates the barriers and aims to keep them at their optimal angle of forty-five degrees by increasing or decreasing the amount of water in each gate to act as a ballast. As each barrier is a separate body, the control system regulates each one and ensures that there is minimal space between them, thus allowing only a relatively small amount of water to pass through the gaps. The optimal angle at which the barriers stand is forty-five degrees, but this angle can fluctuate based on the real-time maintenance of the control system [12]. When the alarm phase is complete, and the tide levels are deemed safe, the barriers are re-filled with water, increasing their overall density and causing them to sink, and return to their flat position on the seafloor. This process requires only fifteen minutes [4].

MOSE’s series of floodgates are located within three water inlets surrounding the Venetian lagoon: Lido, which hosts forty-one gates; Malamocco, which hosts nineteen gates; and Chioggia, which hosts eighteen gates [3]. The locations of the inlets are shown in the following map, provided by Environmental Earth Science:
The inlets serve as entryways to the lagoon from the Adriatic Sea, and MOSE provides a way to put up a temporary barrier between the shallows of the lagoon and the deeper sea. Being a lagoon, it is critical that the delicate balance between the shallows and deeper seas is maintained [2].

After being presented to and approved by the Italian Higher Council of Public Works, MOSE began its construction in 2003, and is currently in its final phases of construction [10]. According to Citylab, the project is expected to be complete and fully operational by June 2018 [14]. In addition to constructing MOSE, Venice has launched supplementary initiatives for protecting the Venetian Lagoon. These projects include periodic maintenance and cleaning of the embankments in which the barriers reside to keep MOSE at peak performance, improving pavement throughout the city to direct floodwaters away from the city, and building up quaysides (banks surrounding rivers and channels) and coasts to restore them and provide the lagoon with additional protection from seawater [9].

Small floodgates, referred to as “Baby MOSE,” have also been installed in certain canals of Venice that are more susceptible to flooding. These smaller floodgates serve as extra protection if water make it past MOSE’s initial defense. These smaller gates are capable of blocking tides up to one hundred and thirty centimeters. While not as ambitious or effective as the main MOSE barriers, they provide auxiliary defenses should flooding overcome MOSE and enter the city [3]. An example of a “Baby MOSE” gate is shown below:

Venice hopes that the construction of MOSE as well as its additional projects will provide the area with the support it is in desperate need of, and will help preserve the city and its ecosystem.

ADVANTAGES, DISADVANTAGES, AND THE SUSTAINABILITY OF MOSE

When evaluating MOSE, it is key to remain as objective as possible and consider the technology’s strengths as well as its weaknesses. As MOSE is currently not 100% operational, it has largely been untested by the high tides it aims to block. However, simulations performed by Georg Umgiesser and Bruno Matticchio of Ocean Dynamics provide insight into what can be expected of MOSE’s ability. The simulation includes data and analyses of the barriers’ ability to keep tides at or below safe levels, the amount of seawater able to leak through the gates during times of strong winds, and the barriers’ interference with Venice port activity.

The simulation, which took place over the span of three years, shows that MOSE, had it been in place, would have adequately protected Venice from flooding. The simulation shows that over the course of the three years and under the assumption that tide forecasts are accurate, the tides would have overcome the barriers only twenty-one times, with most of those occurrences resulting in only a few centimeters of flooding for a short period of time. However, the simulation also notes that if a eustatic (global) increase of thirty centimeters in sea level occurs, MOSE would not nearly be as effective, and the city would have experienced high water five times. The simulation also details the leakage of seawater through the barriers, which occurs during period of strong winds. The following graph from Ocean Dynamics illustrates...
the correlation between wind speed (m/s), the independent variable, and water level rise (mm/hr), the dependent variable:

\[
\text{Leakage of water through mobile barriers}
\]

**FIGURE 6** [11]

Wind speed (m/s) and correlation to water leakage

As can be seen by the graph, there is an almost exponential relationship between wind speed and leakage. This is due to the wind’s ability to redistribute water amongst the lagoon and create depth gradients, which can result in water leaking through the barriers and into the lagoon during times of high tides. The simulation also notes that when the barriers are in their upright position during an alarm phase, ships are unable to pass through the inlets and are therefore unable to reach Venice’s harbors. *Ocean Dynamics* provides a chart showing the average daily distribution of ships entering the Venetian Lagoon:

\[
\text{Distribution of ships during the day}
\]

**FIGURE 7** [11]

Frequency and distribution of ships in Venetian Harbor during an average day

The authors describe how if the gates were closed during a particularly busy time interval, such as hour five or hour ten, the Venetian shipping industry would suffer as ships would not be able to reach Venice, and the city would be unable to import or export [11].

The simulation offers valuable insight concerning the advantages and disadvantages of MOSE. On the positive side, MOSE shows that it can be successful at protecting Venice from high tides. Additionally, the barriers are only visible when raised, which fulfills citizens’ desire for a structure that would not distract from the city’s beauty. However, on the negative side, evidence, as described by the simulation, shows that if sea levels continue to rise, MOSE may eventually become ineffective, as the gates, even when fully raised, would not be high enough to combat the higher tides associated with higher sea levels. Tests performed in 2013 confirmed MOSE’s effectiveness at rising and blocking tides, but the buildup of debris in the gates’ channels resulted in the barriers being unable to lower until a dive team cleared the mechanisms [14]. The barriers’ tendency to prevent ships from entering the lagoon while raised creates another issue. While the gates are raised, only small ships can enter the lagoon, while large ships such as barges or cruise liners are forced to remain outside until the gates are lowered. According to *Engineering and Technology*, a major driving force behind MOSE is its supposed ability to strengthen Venice’s economy by preventing flooding that inundates the city’s economy [15]. But, if shipping becomes restricted by MOSE’s presence, will it result in much of an economic benefit? Another downside of MOSE is the significant amount of controversy surrounding its development. Despite beginning construction in 2003, MOSE is just now entering its final phases of development. Additionally, its initial budget of €1.5 billion has more than tripled to an actual cost of €5.5 billion. Also, in 2014, it was determined that at least €20 million had been siphoned from the project’s budget by the mayor of Venice in the form of kickbacks. The amount of difficulty and setback faced by MOSE has led many to believe that the project may have been overambitious, and that MOSE’s design flaws will stunt its ability to properly fulfill its purpose [14]. Critics have suggested that the funds used to construct MOSE would have had greater impact preventing flooding if used on a series of smaller projects, such as building up and strengthening canal walls to protect the lower portion of the city.

Another critical component of the MOSE project is its effect on the sustainability of the Venetian Lagoon. As stated earlier, the lagoon is an extremely fragile environment, and even small changes to the ecosystem can wreak havoc. The impact of flooding combined with human activity has greatly eroded the earth in the lagoon. For example, the flooding itself has washed away a great amount of soil and sand from the area. Additionally, earlier attempts at preventing floods included taking sand and soil from the lagoon to build levees and jetties. While this procedure had some capability of protecting certain areas by blocking surges of floodwater, it ultimately took a greater toll on the environment as the lagoon’s natural balance between soil and water was disrupted. Large amounts of underground water have also been pumped from the earth for
industrial purposes, further impacting the soil-water balance. In total, the combination of human activity and flooding in the Venetian lagoon area has resulted in an overall elevation drop of twenty-five centimeters. The erosion and elevation drop have compounded the impact of flooding by making it easier for high floodwater to enter the area. This is particularly impactful to small coastal villages who rely on natural barriers like coasts and beaches for protection from floods.

Another problem facing the lagoon is pollution. Navigation channels were built into the area to allow watercraft to traverse the area. Watercraft often leak substances such as oil into the channels, and when the water level in those channels rises, the pollutants often get dragged into the lagoon. Pollutants in the lagoon have deteriorated the quality of the water and the habitats of many species, and are destroying marshes within the lagoon.

Venice considers its natural features to be its first line of defense against flooding. However, with erosion and pollution having a greater impact on the environment than ever, these natural features are at risk of being destroyed. Venice hopes that MOSE can aid in the sustainability of its lagoon. Primarily, MOSE’s ability to keep large surges of floodwater out of the interior of the lagoon should reduce the effect of erosion. Additionally, Italy is sponsoring numerous projects to restore the lagoon environment to its natural state. These include reconstituting marshes, transplanting grass, and instituting conservation zones to reduce pollution. MOSE and its related projects will play a very important role in the sustainability of the Venetian Lagoon [3].

Another important area in which MOSE provides sustainability is in Venice’s economy. As the historic and world-renowned city attracts more than eighty thousand visitors per day, Venice’s economy is extremely dependent on tourism. Flooding of major areas like the city square often grind foot traffic, and in effect, the city’s economy, to a halt [4]. If tourists are not able to traverse the city, they will not be able to stimulate Venice’s economy, which puts the economy of the entire region at risk as it is so dependent on these tourists. One of Venice’s other important industries, shipping, is also affected by the flooding. In similar fashion to its effect on tourism, if flooding inundates the city, its harbor and port activity will severely slow down. However, the development of MOSE provides a very simple solution to these problems: stop the flooding, and tourism and shipping will be able to continue as normal. Therefore, if MOSE proves to be effective at stopping high tides from infiltrating the city, Venice can return to normalcy and restore its position as a global tourism hotspot, helping to sustain a healthy economy.

Sustaining Venice’s culture and livelihood is another key aspect of MOSE. Since 1980, Venice’s population has dropped from 120,000 to just 60,000. Additionally, Venice has an extremely aged population. It’s average citizen age is 50 years old, the highest of any Italian city [14]. Flooding has been a major cause of Venice’s decreasing population, as the inconveniences and hazards it creates has caused many people to move to the Italian mainland. Additionally, many jobs that are unrelated to tourism have also moved to the mainland, providing additional incentive for people to move away from Venice. In order to preserve its iconic culture, the city had to find a way to establish healthier population levels, or it would disappear over time due to a lack of residents and a gradually decreasing population. In response to these issues, the MOSE project provides multiple ways to solve this dilemma. Essentially, if flooding can be reduced, the city will become much more appealing to potential residents. In addition to MOSE’s construction, Venice has also constructed elevated walkways that allow for foot travel around the city even if floodwaters infiltrate the city [4]. These efforts aim to make the city a more appealing place to live and visit, which will strengthen Venice’s role as not just a tourist attraction, but also as a city where people would be willing to live in permanently.

Preventing floods also allows for the preservation of Venetian culture, as the city can operate as normal and will not be subjected to the mercy of the high tides. MOSE ultimately aims to return Venice’s culture to normalcy and has the potential to help restore Venice to its former glory and sustain its world-renowned sense of culture.

MOBILE FLOODGATES: IMPACT AND INNOVATION

As MOSE has yet to be truly tested, the jury is still out on its effectiveness at protecting Venice. However, multiple aspects of MOSE are innovative and will likely play a strong role in the advancement of flood prevention technology. MOSE’s extremely quick operation speed, being able to raise itself in only thirty minutes and lower itself in fifteen, are extremely valuable abilities to have when dealing with phenomena as volatile as tides. Additionally, MOSE is relatively small when compared to other floodgate technologies, and its lessened obtrusiveness will be a valuable development for similar technologies. With sea levels rising at alarming rates throughout the entire Earth, flooding will continue to be a problem coastal regions will have to face, and MOSE provides an important example of the innovation that flood prevention is in great need of.

While unique in its own design and functionality, MOSE shares some aspects of its technology with other floodgates technologies around the world.

The Thames Barrier, located in Woolwich, England, United Kingdom, consists of ten massive steel floodgates and spans the River Thames. According to the United Kingdom’s Environment Agency, each gate is nearly five stories high and weighs about thirty-three hundred tons. In similar fashion to MOSE, the Thames Barrier’s chief objective is to protect a city from the dangers of high waters, which in its own case is London. Controllers utilize data such as tide levels and weather forecasts to decide when to raise the gates. When not in use, the Thames Barrier’s gates lay flat and parallel to the riverbed. When activated they are rotated upwards with a wheel-and-axle-like system and stand at about perpendicular to the
William Earls
Weiyi Chen

riverbed [16] The process is illustrated below, with a diagram from BBC:

![Thames Barrier Diagram](image)

**FIGURE 8 [17]**

Depiction of Thames Barrier activation process

Another example of floodgate activation technology similar to MOSE is the Maeslant Barrier, also known as Maeslantkering, in Rotterdam, Netherlands. Similar to the aforementioned Venice flood of 1966, the Netherlands also experienced a monstrous flood which, in 1953, killed over eighteen hundred people, according to maritime news source gCaptain [18]. So, like Venice, Rotterdam constructed a floodgate of its own, shown below:

![Maeslantkering](image)

**FIGURE 9 [18]**

Maeslantkering: Rotterdam, Netherlands

One of the largest moving structures in the world, Maeslantkering consists of twin 240 meter barriers. The barriers usually sit on top of the shores of the Rotterdam port, and when activated, are pulled by small train-like vehicles, and rotate on shoulder-like ball-and-hinge joint into position across the waterway. One unique aspect of Maeslantkering is its operating procedure. Unlike MOSE and the Thames Barrier, which are activated by human input, Maeslantkering is controlled solely by computers. When water levels become three meters higher than Amsterdam ordinance zero, its reference point, the gates begin their closing procedure. An interesting innovation Maeslantkering provides is its approach to maintenance. As mentioned earlier, while MOSE was undergoing early tests, debris often built up underneath the gates, preventing them from being closed without intervention of diving teams to clear it away. Maeslantkering’s gates, however, do not make contact with the riverbed, but “hover” just above it. This creates a strong pressure gradient as water current is forced through a much smaller area. The increased pressure results in very strong tides beneath the gates, which are capable of removing silt and other debris from the bottom [18].

The development of mobile floodgates like those previously described is crucial in today’s world. MOSE, the Thames Barrier, and Maeslantkering show how innovation can be used to overcome problems. In their case, mankind needed a way to fight back against the advances of nature, and utilized pure ingenuity to show mastery over terrain. MOSE, being the newest of these barriers, provides its own important innovations that will pay dividends to the prevention of flooding.

**CONCLUSION: OVERALL ANALYSIS OF MOSE**

When faced with a dangerous and increasingly-worsening flooding problem, Venice, Italy looked to the innovation of engineers for an answer. Inspired by other similar floodgate technology like the Thames Barrier and Maeslantkering, Italy’s MOSE Mobile Floodgate System has the potential to be a great innovator for flood prevention technology.

While the degree of its success at protecting Venice is still being tested, and drawing absolute conclusions now would be premature, it will without a doubt act as a pioneer for floodgate technology. MOSE’s extremely fast operating speed and lack of obtrusiveness to its surroundings are groundbreaking developments. Whereas the Thames Barrier and Maeslantkering are truly massive structures, MOSE provides an example of a smaller-scale alternative that will likely appeal to smaller coastal regions in need of protection from floods. MOSE does raise questions about its long-term effectiveness, given the rate at which sea levels are rising and may continue to rise, and its efficiency in regards to construction costs and time, but its innovative components make it a well-known example of innovation.

With sea levels continuously rising and flooding in coastal regions becoming increasingly common, MOSE provides an example of innovation that will prove to be invaluable in the further development of flood prevention around the world.

**SOURCES**


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