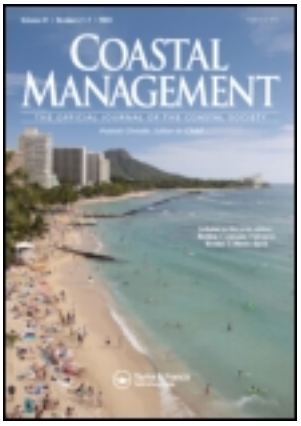

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Flood Protection in Venice under Conditions of Sea-Level Rise: An Analysis of Institutional and Technical Measures

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Flood Protection in Venice under Conditions of Sea-Level Rise: An Analysis of Institutional and Technical Measures

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It is widely acknowledged that in times of climate change loss of coastal resources and risk for human life can be minimized by implementing adaptation strategies. Such strategies need to encompass a balanced mix of non-structural (institutional) and structural (technical) measures based on sound scientific knowledge. This article discusses measures carried out to protect the city of Venice, Italy from flooding (locally known as "high water"), and reflects on their ability to anticipate a possible acceleration of sea-level rise as induced by climate change. It is based on scientific literature, legislative and policy documents of key institutions, reports and documents of organizations working on Venice issues, newspaper articles, and interviews. Our analysis shows that the synergic action of the hydraulic defense infrastructure under construction is in principle adequate to withstand a broad range of sea-level rise scenarios for the next 100 years. However, when the goal is to use these investments effectively major changes in the existing institutional arrangements will be required in the years to come. The Venice findings point out the difficulties and yet the importance of identifying and implementing both non-structural and structural measures to adapt to climate change.

Keywords coastal management, climate change, institutions, storm surge barriers, water governance

Introduction

Adaptation has been acknowledged worldwide as a strategy to cope with the unavoidable impacts of climate variability and change (IPCC 2001, 2007a,b; EC 2009a). Coastal system studies have increasingly focused on the development of adaptation strategies and measures to deal with sea-level rise (SLR) (IPCC 1990, 2007a; EC 2009b).

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Traditional coastal defense strategies (i.e., building defense infrastructure), can no longer be assumed as the only possible response in coastal areas increasingly at risk due to SLR (Kundzewicz 2002; Few, Brown, and Tompkins 2007). Scientists and practitioners alike conclude that a balanced mix of *non-structural* and *structural* measures based on sound scientific knowledge is crucial to maintain ecological, economic, and social coastal functions[1] in the face of changing climatic conditions (Smith and Lenhart 1996; Smit et al. 1999; Wheaton and Maciver 1999; Kundzewicz 2002; Kabat et al. 2005; Smit and Wandel 2006). Non-structural measures include legal, institutional, and organizational measures such as legislation, policy, regulations, management and planning instruments, organizations, and informational systems for coastal ecosystems and resources management (Smith and Lenhart 1996; Smit et al. 1999; Kundzewicz 2002). Structural measures include *hard* (e.g., sea walls, dikes, dams, storm surge barriers, diversions) and *soft* (e.g., beach nourishment, salt-marsh protection and reconstruction) technological and engineering infrastructures often designed for long-term functioning.

Planning and implementing multiple options requires complex decision-making and novel approaches to coastal resource management (Few, Brown, and Tompkins 2007). Major legal, institutional, financial, and organizational barriers need to be addressed (IPCC 2007a; EC 2009a). Because adaptation responses strongly depend on specific local geographical, climatic, and socioeconomic characteristics of coastal regions (IPCC 2007a), sound scientific, technical and resource management knowledge needs to be tailor-made at local level.

Venice and its lagoon are a well-known example of a complex and vulnerable artificially conserved natural system (Bevilacqua 1998; Ramieri 2000; Ravera 2000; Musu 2001; Rinaldo 2009). Similar to many other coastal regions, SLR in the Venice lagoon is expected to increase erosion; the frequency, intensity and height of tidal floods (locally called *acqua alta*, meaning high water); and loss of habitat and biodiversity. In the 1970s, safeguarding Venice and its lagoon became a national priority in response to an extreme high water event occurred in 1966. To protect Venice and its lagoon from such high water events and other natural and human-induced hazards, the Italian government established a legal framework known as the Special Law for Venice. This framework consists of a number of national laws and ministerial decrees, which set objectives, responsibilities, regulations, actions and measures, and allocates funds for safeguarding Venice and its lagoon. National, regional and local authorities are in charge of framework's implementation (Bevilacqua 1998; Amorosino 1996, 2002).

The main goal of the Special Law is to protect Venice and the other lagoon settlements from high water by implementing different integrated measures. Today we know that SLR is likely to accelerate and that consequently the frequency of high water events is likely to increase faster than anticipated when the plans were made (see section on SLR and high water below for detailed information). Against this background the following key question is raised: *Will measures that are being carried out within the Special Law regime to protect Venice from high water be adequate in the face of the expected accelerated SLR induced by climate change?*

The question is addressed by answering the following three sub-questions:

- What are the SLR projections and the expected frequency of high water events in Venice by 2100?
- What measures have been taken to protect Venice from high water?
- Will these measures still be adequate in the face of expected accelerated SLR?

We could not find in the literature a satisfactory description, analysis, and discussion of the integrated action of the different high water protection measures that are being implemented in Venice, being most discussion focused mostly on the main infrastructure, that is, a system of mobile barriers to separate the lagoon from the sea during high water events (see sections below). With this study we want to fill this gap.

The next section describes our methodology and data. The article then reviews SLR and high water projections for Venice, and illustrates the measures to protect Venice from high water. The two sets of information are subsequently combined. The last two sections of this article finally discuss our findings and limitations and provide the conclusions.

Methodology and Data Used for This Study

Information presented in the following sections was obtained from scientific literature, archive analysis, and interviews. The collected documents included pieces of law and regulation; policy, plan and program documents; assessment and thematic reports; newspaper articles; and notes and transcriptions of interviews.

SLR and high water trends and projections for Venice and the north Adriatic were derived from scientific literature and studies conducted by local agencies (i.e., the Venice Water Authority, the Venice Municipality-Tidal Forecasting and Early Warning Center, the Consortium for Coordination of Research Activities Concerning the Venice Lagoon System (Co.Ri.La.), the National Research Council-Venice Office, and Centro Internazionale Città d'Acqua). This information was used to answer the first research question.

To answer the second research question, first the climate adaptation literature was reviewed in search of a framework for interpreting the measures in terms of adaptation. Then data were analyzed according to this framework (i.e., structural vs. non-structural measures). The body of the Special Law for Venice led to identify key organizations, responsibilities, and relevant policies and plans documents. From these documents the non-structural measures and structural measures were identified and described.

To answer the third research question, the first two sets of information were combined. To relate non-structural measures and SLR, the information gained through policy documents, reports, newspaper articles, and interviews was used; to relate structural measures and SLR, the technical characteristics of infrastructure were compared with the SLR scenarios.

Press information collected over the past six years allowed gaining understanding about the different perspectives on the protection of Venice from high water and their evolution in time. Thematic and assessment reports of local organizations and documents published by environmental groups and other nongovernmental organizations (NGOs) (i.e., Italia Nostra, Assemblea Permanente NoMOSE, WWF, Associazione Ambiente Venezia, Venice in Peril Fund) provided information on relevant environmental and economic issues regarding the structural measures.

Finally, policymakers, scientists, and practitioners of local private and public organizations knowledgeable about the safeguarding of the Venice lagoon were interviewed between March and June 2010. The interviews involved 16 out of 17 experts contacted. The interviewees were selected on the basis of our experience in the field, so as to represent as many perspectives as possible on the safeguarding of Venice. Notes and transcriptions of the interviews were used in our analysis. The interviewees requested to remain anonymous, therefore a list of names is not provided and interviewees are only referred to by their position in a manner that does not allow individual identification. The person who did not

accept to be interviewed is member of an environmental NGO. The person told us to refer to the NGO's website as the source of information and opinion of the group. Questions revolved around climate change scenarios, impacts and adaptation, and present and future governance of the Venice lagoon.

The analysis was facilitated by the fact that the first and the second authors of this article have firsthand experience in the functioning of the Venice system as they have worked in the role of researcher (first author) and expert member (second author) of the Ufficio di Piano for the past 6 years. This is a technical committee advising the national government on priorities to safeguarding Venice and its lagoon from a physical, environmental, and socioeconomic perspective. The two authors were involved in the preparation of the 67 Ufficio di Piano meetings from October 2004 to December 2010 and attended all of them; these include those (about one third) to which experts (policymakers, practitioners, and scientists) were invited to report on specific issues regarding the safeguarding of Venice (including the high water issue). The two authors were also involved in the drafting of the Ufficio di Piano advisory documents and thematic reports. Most of this information (minutes, notes, presentations) is confidential and could not be directly used for quotation in this study. Nonetheless, we did use the Ufficio di Piano advisory documents and thematic reports that are publicly available.[2]

Sea-Level Rise and its Impacts in Terms of High Water in the Venice Lagoon

The city of Venice has experienced variations of lagoon water level for centuries. The phenomenon consists of a temporary (tidal and surge driven) rise in sea level that floods part of Venice and the other lagoon urban areas for a few hours. This may occur several times a year, particularly in the winter months. *Acqua alta* (high water) is defined as a tide exceeding +80 cm with respect to the conventional zero. The conventional zero is the average sea level measured at Punta della Salute station in Venice in 1897 (mean sea level—m.s.l.). A water level of +80 cm m.s.l. starts flooding the lower parts of the city. Exceptional high water is a tide exceeding +110 cm m.s.l. This tidal peak floods 14% of the city of Venice. Extreme high water is a tide exceeding +140 cm m.s.l. This tidal peak causes about 50% of the city of Venice to be flooded (Venice Municipality—Tidal Forecasting and Early Warning Center 2010). Depending on the magnitude of the event, high water may lead to temporary interruption of economic and social activities and citizen mobility, and may damage shop assets and warehouses. In the long term, frequent high water events impair monuments, urban buildings, and infrastructure (e.g., canal banks, building foundations, historical and artistic heritage, and lagoon embankments).

Local land subsidence and global eustatic processes significantly affect the mean water level in the Venice lagoon. According to several studies conducted in the past decades (Gatto and Carbognin 1981; Carbognin et al. 1995, 2004, 2010; Tosi et al. 2002; Brambati et al. 2003), the historical center of Venice has sunk about 23–25 cm relative to the mean sea level over the past one hundred years. Twelve cm was lost due to land subsidence, both natural (3 cm) and human-induced (9 cm due to groundwater extraction); 11–13 cm was lost as a consequence of global eustatic processes. Since groundwater exploitation has been regulated by law in the 1970s, land subsidence in the city of Venice and most of its surrounding areas has decreased to natural rate. Detailed investigation conducted with SAR-based techniques shows that present subsidence is less than 1–2 mm/yr (Tosi et al. 2010). Specifically, the historical center of Venice presents sinking rates that are generally lower than 1 mm/yr with an average of 0.5 mm/yr (Tosi et al. 2002; Carbognin et al. 2004, 2010; Teatini et al. 2010). In the north and south lagoon and in the littorals however,

the rate of subsidence is about 2–4 mm/yr mostly due to the subsoil characteristics, peat oxidation, and minor groundwater exploitation in these areas (Tosi et al. 2009). Investigation on archeological markers and tidal notches conducted by Antonioli and colleagues (2007) indicates a long-term subsidence rate of 0.75 mm/yr in the northern Adriatic region. Vellinga and colleagues (2010) considered this value as representative of the average long-term trend and used it in their estimations of relative SLR for the Adriatic (see following paragraphs).

The contribution of eustatic processes to the mean sea level in the Venice lagoon is highly uncertain. Scientists agree on the existence of fluctuation and the absence of an unambiguous trend (Canestrelli et al. 2001; Pirazzoli and Tomasin 2002; Camuffo and Sturaro 2004; Carbognin et al 2004; Zanchettin, Traverso, and Tomasino 2006; Ferla et al. 2007). According to Pirazzoli and Tomasin (2002) and Zanchettin, Traverso, and Tomasino (2006), fluctuation is correlated with internal Mediterranean dynamics and possibly solar activity, but the mechanisms are not fully clear, let alone well predicted. Figure 1 shows the mean sea level recorded in Venice since 1872 and the trend-line over different time scales. Although a trend of rising mean sea level seems to emerge from the centenary records, on shorter time scales positive as well as negative variations are revealed (Camuffo and Sturaro 2004; Carbognin et al. 2004; Ferla et al. 2007). On average the eustatic rise excluding the contribution of land subsidence was 1.2 mm/yr since 1890 (Carbognin et al. 2010). However, Carbognin and colleagues (2010) argue that to establish a real trend of mean water level in the Venice lagoon, long-term data sets are needed in order to overcome periodical multi-decadal oscillations.

A number of studies (Mag.Acque-CVN 1997; Co.Ri.La. 1999; Plag 2008; Carbognin et al. 2010; Vellinga et al. 2010) estimated future SLR for the Adriatic. They all consider global warming as a contribution to SLR and a continuing long term rate of local land subsidence, sub-surface compaction and tectonics. Scenarios range from 0.31 m (Co.Ri.La. 1999) up to 1.35 m (Plag 2008) in 2100, reflecting major uncertainties particularly on the rate of melting of ice sheets (Table 1). The most recent SLR scenarios for Venice have been developed by a group of international experts (Vellinga et al. 2010) and are illustrated in Figure 2. The range Vellinga and colleagues consider plausible is between –16 and +84 cm SLR by 2100, which does not fully exclude the theoretical possibility of mean sea level falling as a result of increased evaporation of the Mediterranean Sea water. It does neither exclude a rapidly accelerating rate of SLR in the second half of the 21st century due to accelerated ice sheet melting. The authors consider the range between 20 cm and 80 cm by 2100 as a realistic scenario for engineering purposes.

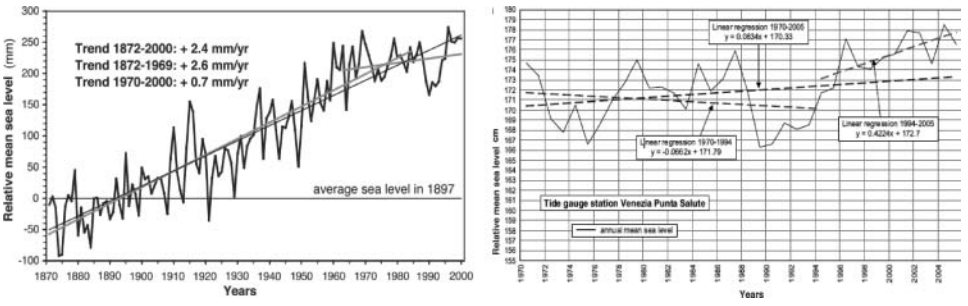


Figure 1. Variation of the mean sea level in the Venice lagoon for the period 1872–2009 (left side) and focus for the period 1970–2005 (right side). Source: Camuffo and Sturaro 2004, pg. 218 (left) and Ferla et al. 2007, pg. 95 (right). Reprinted with permission.

Table 1
Sea-level rise projections for the Venice region by 2100

Source	Low scenario (m)	High scenario (m)
Mag.Acque 1997	+0.04	+0.53
Co.Ri.La. 1999	+0.16	+0.31
Plag 2008	+0.45	+1.35
Carbognin et al. 2010	+0.17	+0.53
Vellinga et al. 2010	-0.16	+0.84

Because of the described processes (i.e., land subsidence and eustatism), the frequency of high water events has considerably increased in Venice over the past one hundred years. Exceptional high water events increased from an average of 1 event every 2 years in the period 1872–1955 to an average of 4 events per year in the period 1955–2010 (Figure 3). Even extreme high water events seem to have become more frequent: between 2008 and 2010 three of the highest events ever recorded occurred. Accelerated SLR as a consequence of climate change is likely to exacerbate the increasing trend of high water in the decades to come, even though other scenarios cannot be excluded. According to the estimates of Mag.Acque-CVN (1997, Figure 4-left), a mean sea level 30 cm higher than the present time would imply extreme high water to flood the city of Venice 3 times a year on average. A more recent estimate of Scotti (2010) foresees an average of 90 exceptional high water events per year in case of +60 cm SLR by 2100. Carbognin et al. (2010) suggest a much higher number of exceptional events already with +50 cm SLR (i.e., 250 per year) (Figure 4-right). However, all these estimates are only indicative because important parameters influencing high water, such as barometric pressure, direction and intensity of winds, intensity of precipitation in the catchment basin, and marine circulation are affected by great uncertainty at regional and sub-regional scales (Ramieri 2000). For

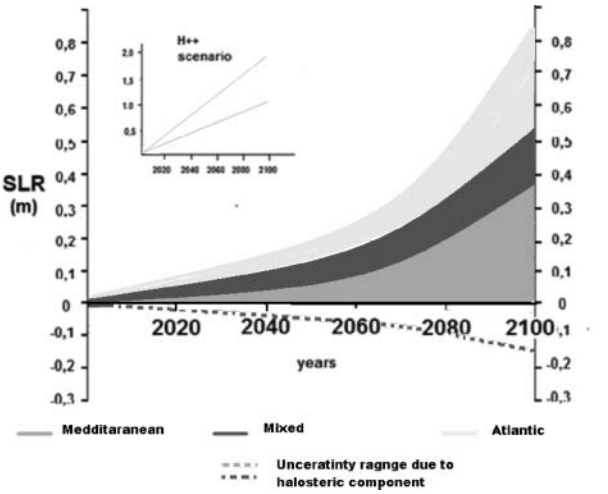


Figure 2. Sea-level rise scenarios for the Venice region at the end of the 21st century. Source: Vellinga et al. 2010, pg. 51.

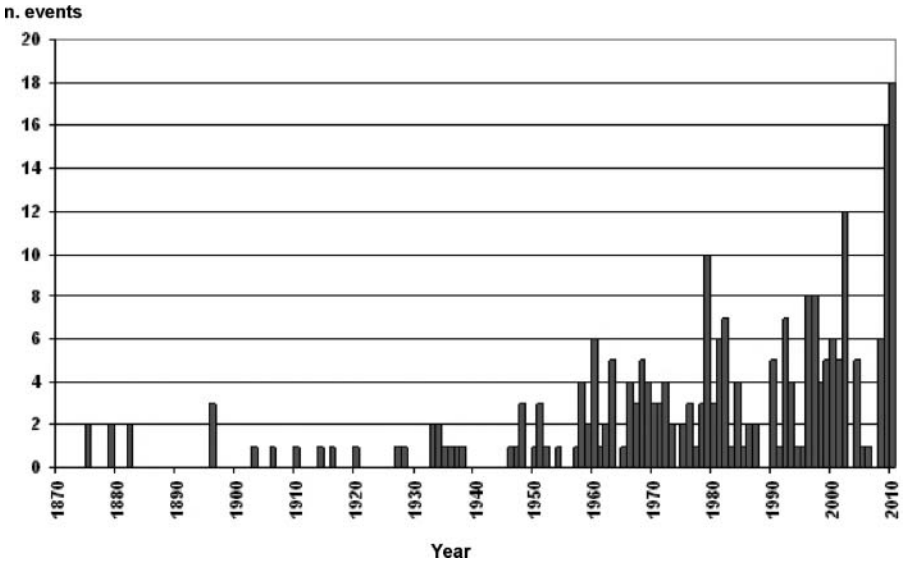


Figure 3. Annual frequency of exceptional high water events (with level equal or above +110 cm m.s.l.) in Venice between 1872 and 2010. Source: Venice Municipality—Tidal Forecasting and Early Warning Center 2011.

example, Pirazzoli and Tomasin (1999) found a decline in the frequency and strength of the Bora wind, an intensification of the Scirocco wind, and an increase of atmospheric pressure, which may be in part connected to inter-decadal climate variability but also to a climatic shift due to global warming. In terms of frequency, height, and intensity of high water, a reduction of the Bora wind and an increase of atmospheric pressure act positively (i.e., reduce high water), whereas an intensification of the Scirocco acts negatively (i.e., increases high water).

Tidal peaks (cm)	Mean annual frequency for current m.s.l	Mean annual frequency for m.s.l. +10 cm	Mean annual frequency for m.s.l. +20 cm	Mean annual frequency for m.s.l. +30 cm
+80	39	94	204	356
+100	7	16	39	94
+120	1	3	7	16
+140	1/6 y	½ y	1	3

* All estimates refer to the year 2100

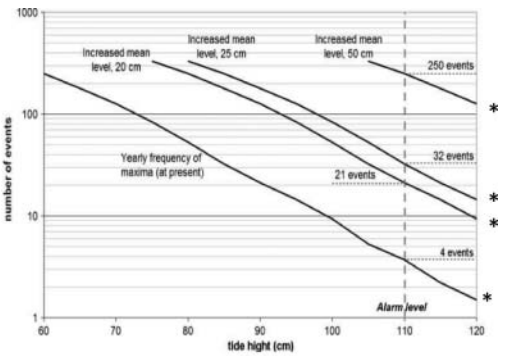


Figure 4. Expected frequency of high water peaks in Venice according to four different SLR scenarios. *All estimates refer to the year 2100. Source: Mag.Acque-CVN (1997, pg. 80) (left) and Carbognin et al. 2010, pg. 1045 (right). Reprinted with permission.

Measures to Protect Venice from High Water

The following sections illustrate the measures that are being taken to protect Venice from high water according to the non-structural/structural measures framework.

Non-Structural Measures: The Special Law for Venice Regime

Extreme weather events are often catalysts for change. Indeed, the Italian government started taking actions to protect Venice and its lagoon from high water and environmental degradation immediately after the 1966 flood, which had caused enormous damages to historical buildings, economic activities, and to the lagoon environment (Obici 1967; Amorosino 1996, 2002; Bevilacqua 1998; Rinaldo 2009).

A Special Law for Venice regime has been established since 1973. The Law n. 171 of April 16, 1973, the Law n. 798 of November 29, 1984, and the Law n. 139 of February 5, 1992 are the main laws that set objectives, responsibilities, instruments, measures, and economic resources for carrying out safeguarding activities. In the late 1990s, in addition to the laws, the Italian government set water quality objectives and regulated the total maximum load of a number of pollutants specifically for the Venice lagoon and the water bodies of its catchment basin.

The main objectives of the Special Law were protection of urban centers from high water; protection of coastal strips from erosion and sea storms; re-establishment of the hydro-geo-morphological equilibrium of the lagoon; safeguarding of the environment (both natural and man-made); abatement of pollution both in the catchment basin and the lagoon basin; and promotion of socioeconomic development of the Venice region (Italian Law n. 171 of April 16, 1973; Italian Law n. 798 of November 29, 1984).

To achieve the Special Law objectives, national, regional, and local governmental authorities have developed plans, implemented programs, and carried out works in the lagoon basin, the catchment basin, and the coastal strip. The institutional setting established by the Special Law is depicted in Figure 5 and Table 2. Each responsible authority acts independently through its own program of measures and within its administrative boundary. To increase efficiency, administrations implement joint actions through specific inter-institutional legal agreements (e.g., Inter-institutional agreement among Venice Water Authority, Veneto Region and Venice Municipality of August 1993 on local defenses in the city of Venice).

At the national level, an Inter-ministerial Coordinating Committee (called *Comitatone*) guarantees coordination and control of all safeguarding activities. The committee is chaired by the president of the Council of Ministers (prime minister) and is made up of national government ministers and representatives of the regional and local authorities. It mainly allocates funds and takes the most important political decisions regarding the safeguarding measures. In 2004, the Italian government decided to support the Comitatone with a technical advisory Committee, called *Ufficio di Piano*. This is a permanent body made up of national and international experts and national, regional, and local policymakers in charge of advising on priorities for safeguarding Venice and its lagoon.

At the local level the responsible authorities are the Venice Water Authority, the Veneto Region, the Venice Municipality, and the Chioggia Municipality. The Venice Water Authority, which is the local representation of the Ministry of Infrastructure, is responsible for water management and hydraulic safety within the lagoon basin since 1907. It is also in charge of overseeing the planning and execution of major safeguarding works. To guarantee

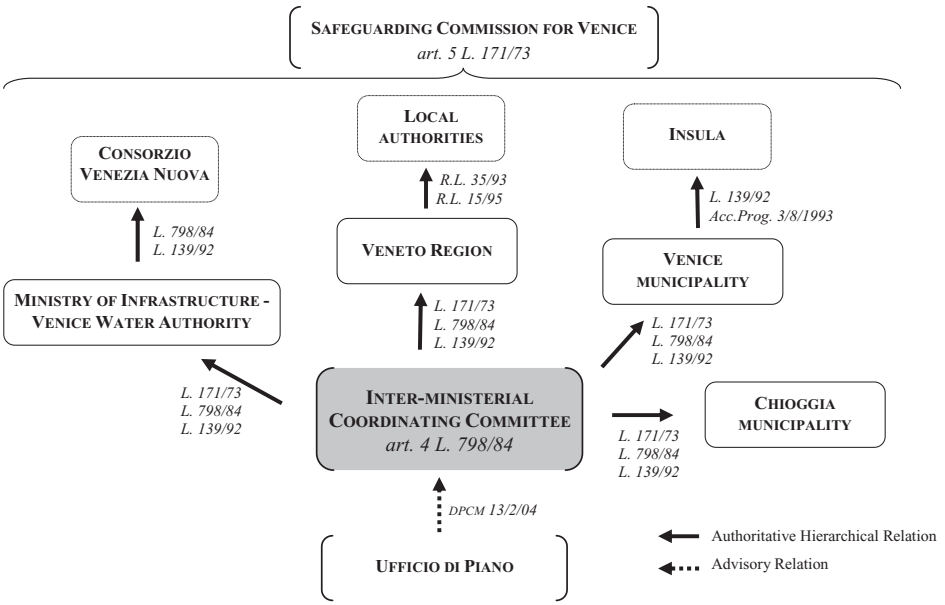


Figure 5. Institutional setting established by the Special Law for Venice and other related regulations. Legend: L. = Law; R.L. = Regional Law; DPCM = Decree of the President of the Council of Ministers; Acc.Prog. = Inter-institutional Agreement. Source: Munaretto and Huitema 2012.

rapid and unitary execution of these works, an executive agency named Consorzio Venezia Nuova (CVN) has been established as a concessionaire of the Ministry of Infrastructure. The CVN is a private corporation made up of Italian construction and engineering companies pursuing public goals. It executes works according to a General Plan of Interventions, which includes measures to protect the lagoon urban centers from high water and sea storms, and to improve environmental and ecosystem quality. The plan also comprises scientific studies and systematical monitoring of the lagoon environment including tidal forecasts. The Veneto Region is in charge of abating water pollution in the catchment basin of the lagoon. This is an area of 2.000 km^2 counting 4 provinces, 108 municipalities (including the Venice and Chioggia Municipality), and more than 1 million inhabitants. The region allocates the Special Law funds to local authorities (e.g., municipalities, water bodies, land reclamation consortia) through a plan named Piano Direttore 2000. The plan includes measures to monitor and reduce pollutants and nutrient load into river tributaries and to reduce runoff from the catchment basin into the lagoon. Finally, the Venice and Chioggia municipalities oversee and, when appropriate, intervene in the maintenance of historical, cultural and architectural heritage and support the socioeconomic development of their territory. They act according to their own program of safeguarding measures. To carry out the works the Venice Municipality set up a mixed private-public company called Insula, which executes works such as renovating public infrastructure, dredging canals within the city, restoring bridges and buildings' foundations, raising city streets and pavements, and renovating underground utilities (e.g., water and gas pipes, electric wires). A specific office of the Venice Municipality funded with the Special Law resources is the Tidal Forecasting and Early Warning Center that elaborates tidal forecast and alert the population in case of

Table 2

Programs, plans, and projects implemented through the Special Law for Venice and other relevant policy instruments for the safeguarding of Venice

Safeguarding objectives	Responsible authority	Instruments to implement the objectives	Measures
Protection from extreme high waters	Venice Water Authority—Consorzio Venezia Nuova	General Plan of Intervention—Protection from extreme high waters	Mobile barriers system at the lagoon inlets
Protection from the most frequent high waters	Venice Water Authority—Consorzio Venezia Nuova Venice Municipality— Insula	General Plan of Intervention— Local defenses Program of Measures to Protect the *Insulae* of Venice	Raising and structural consolidation of quayside, embankments and public paved areas Protection of ground floor property and rear-lying private and public areas (e.g. courtyards and gardens) from flooding Reorganization and adaptation of the network of underground infrastructure and the drainage system to avoid flow-back through drains
Defense of costal strips from sea storm and erosion	Venice Water Authority—Consorzio Venezia Nuova	General Plan of Intervention—Coastal protection	Dune belt reconstruction Beaches reconstruction Reinforcement of jetties, breakwaters and ancient sea wall
Prevention of environmental degradation and erosion and nature conservation	Venice Water Authority—Consorzio Venezia Nuova	General Intervention Plan—Morphological Restoration Plan	Salt marshes, mudflats and shallows reconstruction and protection Protection of islands from erosion Canal re-calibration Eelgrass planting
Pollution abatement in the lagoon	Venice Water Authority—Consorzio Venezia Nuova	General Intervention Plan— Pollution abatement	Securing industrial canals banks (which is part of the Porto Marghera Master Plan, see below) Securing of former dumps in the lagoon Polluted sediment removal

Pollution abatement in the drainage basin	Veneto Region	Piano Direttore 2000	Construction of sewerage system Adjustment of sewage treatment plant Construction of aqueducts River naturalization Recreation of transitional wetlands and phyto-purification areas Adjustment of drainage network Grant to farmers for green agriculture
Environmental monitoring and tidal forecast	Venice Water Authority and Consorzio Venezia Nuova Veneto Region Venice Municipality	Surveillance and Anti-pollution Service Informative Service Regional Environmental Monitoring Network Tidal Forecasting and Early Warning Center	Water, sediment, flora, fauna, tide monitoring stations in the lagoon Research and studies (including modeling) on environmental components Tidal forecasting Water monitoring stations in the rivers of the drainage basin and in the Adriatic sea Research and studies on environmental components Tidal forecasting Early warning system
Historical and non-historical buildings restoration and maintenance; urban infrastructure renovation; socio-economic revitalization of the lagoon urban centers	Venice Water Authority Venice Municipality Chioggia Municipality	Three-year Plan of Measures Program of Measures for Safeguarding the City of Venice Program of Measures for Safeguarding the City of Chioggia	Restoration of historical buildings owned by the State Restoration of historical buildings owned by the municipality Restoration of public buildings used for social services Grant for private buildings restoration and buying Renovation of bridges, building foundations, city canal shores, drainage shafts and utilities, dredging of the city canals (integrated with public walkway raising; carried out by Insula for the Venice municipality) Buying and urbanization of areas for the settlement of productive activities

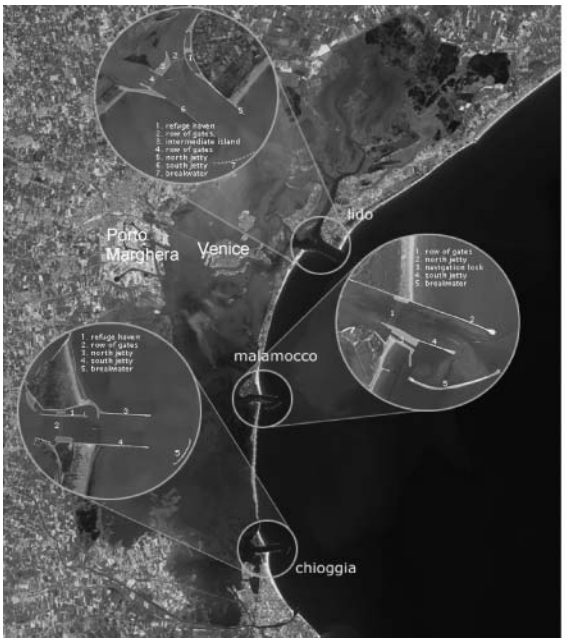
(Continued on next page)

Table 2

Programs, plans, and projects implemented through the Special Law for Venice and other relevant policy instruments for the safeguarding of Venice *(Continued)*

Other instruments for addressing emergencies (not included in the Special Law but directly affecting the safeguarding of the lagoon)			
Objectives	Responsible authority	Instruments to implement the objectives	Measures
Cleaning up of the Porto Marghera industrial area	Environmental Ministry, Veneto Region, Venice Municipality, Venice Province, other local authorities	Master Plan for the Remediation of Porto Marghera Industrial Area Conference of Services Protocols of Implementation	The industrial area of Porto Marghera is in the national list of the most polluted sites. Its remediation is not directly included in the Special Laws for Venice. Remediation is mostly funded with resources obtained from polluting industries
Dredging of the large port navigation channels and disposal of the polluted sediment	Extraordinary Commissioner for the Environmental and Socio-Economic Emergency Related to the Large Port Navigation Channels in the Venice Lagoon	Program of Measures	Ad hoc interventions, mainly consisting of infrastructure to solve acute situations
Removal of structural barriers that caused a major flooding of Mestre in 2007 after an intense rainfall event	Extraordinary Commissioner for the Emergency related to the Exceptional Meteorological Events of 26 September 2007 that have stricken part of the Veneto Region	Program of Measures	

Source: our elaboration based on the Special Law for Venice; policy, program and plan documents of the organizations cited in the second column of the table.



Some numbers of the MOSE system in Venice

4 the number of mobile barriers being constructed at the lagoon inlets (**2** at the Lido inlet, **1** at Malamocco and **1** at Chioggia)

78 the total number floating gates, hinged to the inlet bed

18.5 m x 20 m x 3.6 m length, width and thickness of the smallest gate (Lido – Treporti row)

29.6 m x 20 m x 4.5 m length, width and thickness of the largest gate (Malamocco row)

1 lock for large shipping at the Malamocco inlet (**370 m x 48 m x -14 m** length, width and depth) enabling port activities to continue when the gates are in operation

3 small locks (**2** at Chioggia and **1** at Lido-Treporti) to allow the transit of fishing boats and other smaller vessels when the gates are in operation

2 breakwaters (**1** at Chioggia about 522 m long and a peak height of 2.5 m and **1** at Malamocco about 1300 m long and a peak height of from 3 to 4 m above m.s.l.)

4-5 hours the average duration of each closure

30 minutes the time required to manoeuvre the gates in position (raised)

4.9 billion euro the total cost of the project

Figure 6. Project design of the mobile barrier system to protect Venice from flooding (MOSE). Source: CVN 2010.

expected high water through cell phone messages and a system of sirens and information panels in the city.

In addition to these agencies, there is a local technical committee, called Safeguarding Commission for Venice instituted by the 1973 Special Law. Made up of a majority of technical experts, the committee makes its binding advice to project developers and approving authorities on all building works and territorial transformation planned by private and public bodies within the Venice lagoon. The committee was meant to cease its activity after the plans for the implementation of the safeguarding measures had been approved. To date, although the plans have been adopted, the committee still operates.

There are also other authorities implementing measures for the safeguarding of Venice outside the Special Law framework (see Table 2). Particularly, the Ministry of the Environment is responsible for the remediation of the industrial area of Porto Marghera, located along the inner lagoon coast. The area was formally characterized as a contaminated site of national interest in 1998 (see Figure 6 for location). A number of works for the remediation of the site are carried out by the CVN through several inter-institutional agreements between the Venice Water Authority, the Veneto Region, the Venice Province and the Venice Municipality.

Since 1984, the government has allocated about 10.2 billion Euros to achieve the safeguarding objectives, of which 8.8 billion Euros have been spent until 2009 (Ufficio di Piano 2010). According to the latest funding requirement expressed by the Venice Water Authority, the Veneto Region and the Venice and Chioggia municipality, about 6.1 billion Euros are still required to enable the completion of the safeguarding activities as intended at the time the Special Law was passed (Ufficio di Piano 2010). The distribution of national funds to the local authorities is shown in Figure 7. The allocation of funds depends on the

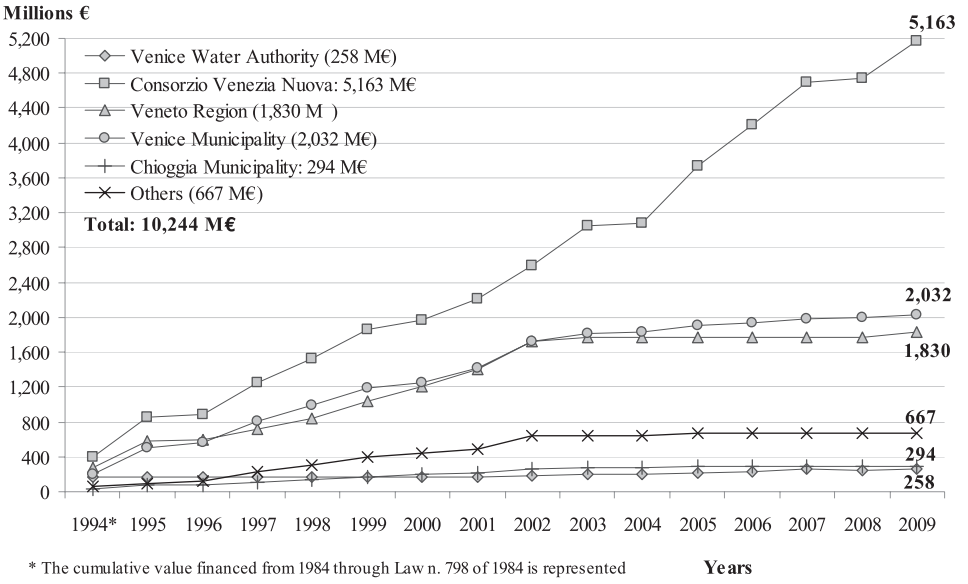


Figure 7. Cumulative spending of national funds per agency allocated through the Special Law for Venice in the period 1984–2009. Source: Ufficio di Piano 2010.

type of activities that each agency carries out. The share of funds directly channeled to the CVN to execute the works has substantially increased since 2003 when the company started the construction of storm surges barriers at the lagoon inlets. At present the construction of the barriers is absorbing much of the resources, while other works (such as the construction of local defenses, see next section) are under-financed.

Structural Measures to Protect Venice from High Water

Within the framework of the Special Law, the solution that the government chose to protect the Venice lagoon urban areas from high water consists of an integrated system of measures being constructed at the lagoon inlets and in the lagoon urban centers. The total investment for these specific measures is about 5.9 billion Euros. The amount granted so far is 3.6 billion Euros, representing 35% of the 10.2 billion allocated by the Italian government for the whole safeguarding intervention until 2009. The responsible authorities (Venice Water Authority through the CVN and Venice Municipality through Insula) have so far spent 3.3 billion on studies, projects and infrastructure for high water protection (Ufficio di Piano 2010).

Storm Surge Barriers at the Lagoon Inlets. At the three lagoon inlets the CVN is constructing a system of storm surge mobile barriers known as MOSE (Modulo Sperimentale Elettromeccanico or Experimental Elecromechanical Module, see Figures 6 and 8). The system aims to protect the city of Venice and the other lagoon settlements from extreme and exceptional high water events by temporarily separating the lagoon from the sea for the duration of the flood event. The system consists of 78 independent floating gates with hinges fixed in the bottom of the inlet channel. In normal tide conditions the gates lie full of water, flat in their housings buried into the inlet channel bottom. Every time a tide of

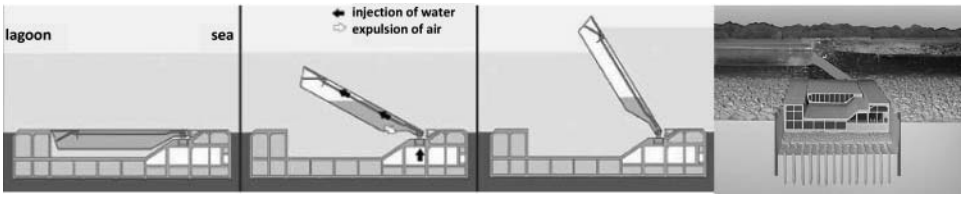


Figure 8. Functioning of the floating gates (first three figures from left) and cross-section of the gates and of the housing buried in the inlet bottom (on right). Source: CVN 2010.

+110 cm above m.s.l. (so called *safeguarding level*) is forecasted, the barriers are raised through the introduction of air into the gates that removes the water and forces the gates to float (Fice and Scotti 1990; Mag. Acque-CVN 1992; Gentilomo and Cecconi 1997; CVN 2010; Scotti 2010; see Figure 8). Navigation passage in and out of the lagoon during closure time is possible through locks: one lock for large ships and three small locks for the transit of fishing boats and other small vessels such as yacht and other recreation boats. On average the barriers remain closed for about 4–5 hours including the duration of the event and the gates opening and closure times (Mag. Acque-CVN 1997). However, depending on the meteorological conditions determining the tidal event (particularly the intensity and duration of winds and low atmospheric pressure) the gates may be closed much longer, typically 11 hours plus operational time (Rinaldo et al. 2008).

The barriers can protect the lagoon from a tidal level up to 3 m above m.s.l. and can withstand SLR up to 60 cm above current mean sea level (CVN 2010; interview: policymaker, June 2010). Pirazzoli (1991) however, argues that the barriers would suffice only up to +30 cm SLR and that for higher levels part of Venice would be flooded even when the barriers are in operation. In two other studies Pirazzoli and Umgiesser (2003, 2006) show that in case of +50 cm SLR and situations of long-lasting closures due to adverse meteorological conditions, the water level in the lagoon may rise about +18 cm due to possible fluxes of fresh water into the lagoon from precipitation, river runoff, and seepage of sea water between the gates. On the same line of reasoning, a more recent study of Rinaldo et al. (2008), considering the same parameters of Pirazzoli and Umgiesser, suggested that in case of prolonged closures the mobile barriers can effectively protect Venice up to +50 cm rise of sea level without significantly altering the water level in the lagoon. In this study Rinaldo and colleagues have also demonstrated that the assumptions in the Pirazzoli and Umgiesser studies are too conservative.

Figure 6 shows the project and provides some relevant numbers. More than 60% of the works has been completed in 2010 and, assuming funding will be timely ensured, the system will be operating in 2014 (CVN 2010). Once in operation, the maintenance costs of the barriers will be about 12 million Euros per year on average, that is, about 0.25% of the investment, which is estimated at 4.9 billion Euros for the completion of the barriers.

Additional Measures to Protect Venice from High Water. To abate the level of the most frequent high water events (below the safeguarding level requiring closing the gates), two additional sets of measures are being implemented: complementary measures at the lagoon inlets and local defenses in the built areas inside the lagoon. The Venice Water Authority through the CVN is responsible for constructing the complementary measures and the local defenses in the lagoon settlements and in some areas of Venice. The Venice Municipality

through the company Insula carries out local defense works within the city of Venice and some islands within its municipal domain.

Complementary measures comprise raising and protecting specific sections of the lagoon bed in the inlet channels by constructing sea side breakwaters to the south of the inlets so as to reduce wave height and enable navigation. They also aim to increase resistance to the inflow of water thus reducing tidal levels in the lagoon by an average of 3–4 cm (Umgiesser 2004; CVN 2010). Works have been completed except for the breakwater at Lido inlet (construction was approved in 2010). Preliminary results show that the tidal level in the lagoon is being reduced by about 2 cm (eng. Giovanni Cecconi, Consorzio Venezia Nuova, personal communication, May 2008).

The local defense strategy consists of raising lagoon quaysides, embankments, and public paved areas in the city of Venice and other lagoon urban settlements as much as possible up to +110 cm above m.s.l. or more. The ultimate goal is to create a basic level such that the gates have to be closed only when the predicted tidal storm surge level is more than 110 cm above m.s.l. Works started in the beginning of the 1990s. The intervention is integrated with the restoration of buildings foundation, bridges, and underground utilities. So far, about 43% of the planned works for raising public walkways has been completed and nearly 77% of the planned lagoon embankments have been restored (Ufficio di Piano 2010). It is not possible, however, to raise uniformly the entire lagoon urban areas up to the safeguarding level because of the architectonical structure of the historical centers. Assuming sufficient and regular funding will be available, the local defenses in the city of Venice will be completed by 2030.

An Assessment of the Ability of the Measures to Protect Venice from High Water in the Face of Future Sea-Level Rise

The following two sub-sections combine the information previously given in order to answer the question whether the measures being implemented to protect Venice from high water will suffice in the face of future SLR. As in the previous sections, we will use the non-structural versus structural measures distinction.

Non-Structural Measures and Sea-Level Rise

The governance system established by the Special Law in the Venice lagoon is rather complex. Overlap of responsibility and limited coordination of knowledge and management instruments are major sources of inefficiency (Dente et al. 2001; Musu 2001; Fletcher and Da Mosto 2004; OECD 2010). Programs for solving problems are often not fully implemented because of lack of transparency in governability, accountability, and legitimacy of the different parties (Musu 2001). In particular, the debate concerning whether or not to build the mobile barriers has polarized the scientific, political and social community for two decades (Da Mosto et al. 2005). This disagreement has generated a situation of political friction which has led to less than optimal institutional cooperation in the past decades. Nowadays this history of political friction does not make it easy to accomplish the reform of the Special Law which is increasingly advocated by the local scientific and political communities. A number of attempts to reform the law have already failed. Even the last attempt coordinated by the minister of Public Administration and Innovation in 2010 has not encountered the favor of all involved parties and may not succeed.

Another important aspect is that the financing system of the Special Law does not assure a full continuity and sufficient availability of funds to complete the safeguarding works. As

a consequence of this financial discontinuity some programs are being implemented without a long term guarantee for completion and coordination, with some activities more ahead than others. Most notably, in the year 2014 the mobile barriers are planned to be operational while the local defenses in Venice will not be completed before 2030. This implies that large areas of Venice will still be flooded by high water events below the safeguarding level at least until 2030, or it implies that the closing regime will be adjusted accepting more frequent closure of the barriers until local protection up to 1.10 m is completed.

Finally, for the proper management of the mobile barriers tidal forecasts have to be accurate, reliable, and made timely available to the barrier manager (Collegio di Esperti di Livello Internazionale 1998). Next to meteo-marine data for making the tide forecast other data such as river discharge will be required to control the water level in the lagoon with the barriers in operation. At present, two agencies develop tidal forecasts (the CVN and the Venice Municipality) and the Venice Region is responsible for the monitoring of the rivers in the catchment basin. According to the Ufficio di Piano (2007), these agencies are not always prepared to share data and information. One single data production and storage system does not exist. Monitoring activities are only partially coordinated and procedures are not fully standardized yet. Agencies often conduct monitoring programs for relatively short periods and different purposes and scientific research is not always timely addressing emerging problems such as climate change. Consequently, data are often not fully comparable, some are duplicated, other are missing (Ufficio di Piano 2007; 2010).

The above suggests that the existing government system set up by the Special Law is not sufficiently geared toward efficient and effective management of the mobile barriers and of the Venice lagoon. Building the barrier in itself is not a guarantee that it will work efficiently and effectively. A well-coordinated institutional system would definitely provide a better starting position.

Structural Measures and Sea-Level Rise

The preliminary project of the mobile barriers was reviewed by a committee of international experts between 1996 and 1998. The committee took SLR induced by climate change into account (Collegio di Esperti di Livello Internazionale 1998). In particular, on the basis of the 1995 IPCC scenarios and other scientific studies (e.g., Blondeaux et al. 1982, 1986; Camuffo 1993; Cecconi et al. 1998; Marzocchi and Mulargia 1996; Rusconi 1993 in Collegio di Esperti di Livello Internazionale 1998), the international committee came to the conclusion that the barriers offered adequate protection from SLR according to the climate knowledge existing at that time (Collegio di Esperti di Livello Internazionale 1998).

Given present time SLR scenarios for the Adriatic Sea, the conclusion of the international committee still holds. The mobile barriers in fact ensure full protection up to +50 cm SLR, which most likely will not occur before 2080 (see Figure 2). In the long term, when the mean sea level will rise by 60 cm or more, completely new options for the future of the Venice lagoon will have to be considered as the barriers would close about 50% or more of the time, remaining open only during low tide for a few hours. In this situation, the flushing of the lagoon would be greatly reduced, polluting substances would not be removed anymore, and the lagoon would gradually become a more fresh water body.

Present time SLR projections do not exclude extreme scenarios between 1 and 2 m in 2100 (Vellinga et al. 2010). However, an acceleration of ice sheets melting and consequent SLR will take time and such extreme scenarios are not likely to take effect before 2050 (Vellinga et al. 2010). Considered that in economic evaluation practice (cost–benefit analysis) of long lasting investments the first 40 years of the investment are by far the most

important, the MOSE investment is still worth doing as it will ensure protection from high water for at least 40 years thus giving time to plan further adaptation options.

As sea level rises and the closure of the barriers become more frequent the ecological system of the lagoon is likely to be affected although the impact is difficult to quantify (Collegio di Esperti di Livello Internazionale 1998; Ministero dell'Ambiente 1998; Pirazzoli and Umgiesser 2003; Italia Nostra 2009; interviews: public officers, scientist, practitioners, April 2010). According to environmentalists and skeptics (Italia Nostra 2009; interviews: public officers, scientist, April 2010), the lagoon water quality will gradually worsen as consequence of more frequent and subsequent closures. A number of reasons speak in favor of minor negative ecological effects of separating the lagoon from the sea, however. First, high water events mainly occur in winter when biological activity is relatively low (Mag. Acque-CVN 1997; Collegio di Esperti di Livello Internazionale 1998). Second, the rate of water flow through the lagoon inlets is such that leaving the barriers open for a few hours should rinse out most of the pollutants that accumulate inside (Gacic et al. 2002). Third, by increasing water depth in the lagoon and water exchange at the inlets, SLR will increase the dilution of pollutants and their expulsion at sea (Cecconi 1997; Ramieri 2000). Fourth, the lagoon water quality has improved in the last ten years, even though water quality objectives have not been fully achieved yet (Ufficio di Piano 2008, 2010). Finally, because not all high water events require the lagoon to be completely separated from the sea and the barriers are made up of independent gates, partial closures of the barriers are also possible (e.g., closure of one inlet at a time or partial closure of each inlet). This option would ensure maintaining water exchange and therefore minimize ecological damages in the long term. Partial closures may also be used to force water circulation into peripheral areas so as to wash them out, thus improving water quality (Rosatti, Bonaventura, and Poli 2002). This use of the barriers may alter the lagoon hydrodynamic and the network of tidal canals, however (interview: local agency officer, April 2010).

With reference to the possibility to use partial closures, Figure 9 shows two management strategies of the barriers according to different SLR scenarios. As sea level rises, either partial closures of the barriers can be introduced or the level of the local defenses can be raised. Raising the local defenses is an extremely costly and not everywhere applicable solution that can be deferred by using partial closures (Figure 9-right). Partial closures may be very effective as they can reduce the water level in the lagoon during a high water event by 10–20 cm or even more (Scotti 2010). This approach gives time to test innovative solutions and find the resources to carry out the works if needed. One option recently advanced is uplifting the city of Venice through seawater water injection in deep aquifer

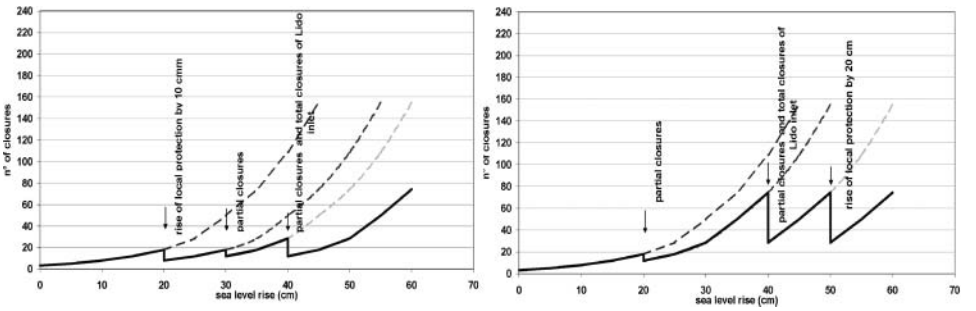


Figure 9. Different management strategies for the mobile barriers in Venice according to various SLR scenarios. Source: Scotti 2010.

underlying the lagoon (Comerlati et al. 2004; Castelletto et al. 2008; Gambolati et al. 2009; Ferronato et al. 2008). According to Comerlati et al. (2004) this solution might raise the city of Venice by 25–30 cm in 10 years. However, the level of risk of major damage to city structure and buildings due to uneven land uplifting is matter of scientific debate (see for example, Gambolati 2009; Schrefler et al. 2009).

In addition to the mobile barriers, the combined action of local defenses and complementary measures minimize the urban surface that is flooded by high water events below the safeguarding level (Mag.Acque-CVN 1992; 1997). At present time, a tidal peak of +110 cm above m.s.l. floods about 14% of the city of Venice on average 4 times per year (see Figure 4-right). With local defenses in place only the small districts that cannot be raised up to +110 cm will still be flooded. These include some valuable areas such as San Marco square in Venice, however. The complementary measures will further help reducing the flooded urban surface by abating tidal levels of about 2–3 cm. The small number of centimeters suggests that this effect is not very important. However, this effect should be compared with the cost of heightening the local defenses by a similar level.

Against this background, we conclude that the integrated system of mobile barriers, complementary measures and local defenses under construction is in principle adequate to protect Venice lagoon urban centers for at least the next 70 years, and probably beyond, given various SLR scenarios, increased frequency of high water events and the expected number of closures of the barriers.

Discussion

Below, the findings of this article following the non-structural versus structural measures structure are discussed.

Looking at the non-structural measures, a first observation is that in order to improve management efficiency and effectiveness in the Venice lagoon the existing institutional system needs major reorganization. This reorganization needs to go in the direction of simplification, transparency, and coordination of sectors, activities (including tidal forecasting), and levels of government over a commonly defined territory including the lagoon, the catchment basin, and the near-shore sea. Transparency would imply clear definition of responsibilities, horizontal and vertical relation of planning instruments with other spatial and sectoral plans, mechanisms for funding supply and allocation, and assessment and evaluation procedures. For example, the definition of mechanisms to revise rules and procedures could facilitate timely adjustment of the safeguarding strategy according to new climate knowledge. Integrating the existing tidal forecast centers would improve accuracy and reliability of forecasts as well as efficiency. By rationalizing monitoring systems and financial resources a single agency could for example have resources to invest in new technology and scientific research such as studying the effects of climate change on frequency, height, and intensity of high water.

Consultation and direct involvement of all stakeholders (i.e., policymakers, scientists, private sectors, and civil society) could assure the necessary consensus, for such a major reform to take place.

This reform would also benefit from a comprehensive policy evaluation of the current Special Law (evaluations have occasionally occurred only from an environmental and economic perspective). The closest example to a policy evaluation is the study of Dente et al. (2001), which suggests that the centralistic government system set by the Special Law has substantially failed because the Comitatone has failed its main goal of taking coordinating functions.

A second observation relates to where financial resources to complete infrastructural works and pay the maintenance should come from. This is still matter of debate. Maintenance costs of the barriers are high. International examples such as the flood barrier in London and that in Rotterdam suggest that the State takes responsibility to pay for the maintenance. Regarding other safeguarding works such as local defenses, urban infrastructure and historical buildings, it is probably part of the duties of the local municipality to ensure the maintenance, as it is in other cultural heritage cities in Italy. A balance needs to be found, however, as Venice is a city of international importance, where deterioration of historical buildings and infrastructure is accelerated by the fact that they lay on the water.

As for the structural measures, we believe it would be practical to consider the long term future while undertaking present priorities. SLR beyond +50–60 cm would require developing a large-scale strategy for the whole coastal region. Eventually, drastic options for the lagoon, including a full closure, could become unavoidable. Discussion about far future options may regard technical aspects such as using parts of the infrastructure (the hard structures that have shaped the inlets, such as the jetties, the breakwaters, the foundation structures, the navigation locks, the havens, and so on) as the basis for additional works. Starting this discussion now that the barriers are still under construction would have the advantage of allowing making some adjustments if needed in this phase. Any change in the present construction, however, would be very expensive and therefore only possible if critical risks or major opportunities are identified.

We finally suggest that adopting an adaptive approach (Holling 1978; Walters 1986; Schreiber et al. 2004) in the management of the barriers (i.e., learning by doing) would facilitate prompt adjustment of the defense strategy so as to prevent irreversible ecosystems damages to occur. This implies establishing a monitoring system of the effects of the closures on ecosystems and water quality. Particularly, extra closures to force water circulation in the lagoon require carful experimental design and close monitoring of the environmental effects.

Discussion on the Methodology and Study Limitations

The results of the present study are based on a number of data collection strategies and information sources. Reflecting on the fact that two of the authors participated in meetings of the Ufficio di Piano, it is important to report both advantages and disadvantages. Although the involvement may have introduced a bias towards either favoring or disfavoring the outcome, this was outweighed by the advantages. One of the advantages was that participating to the Ufficio di Piano activities gave the unique opportunity to gain a thorough understanding of the Venice formal and informal system. It also facilitated access to different interviewees. The knowledge gained working with the Ufficio di Piano was supplemented with documental information and interviews. The policy documents allowed for a look into the (planned) future, while the legal documents helped identification of legal responsibilities. The interviewees were chosen such that different perspectives on the safeguarding of Venice were represented and indeed different opinions were expressed. The use of peer-reviewed scientific articles helped distinguishing between local preconception and scientific knowledge, particularly about climate change and the mobile barriers. Newspaper articles were also included, because these ensured that the researchers would not miss issues relevant to the general public and the public's perception of Venice governance and management issues. In addition, because the Ufficio di Piano is a technical advisory committee with a majority of independent members from Italy and Europe that gained information from all different

public and private organizations in charge of safeguarding Venice lagoon, our perspective goes beyond the policy dominated views of the administrations and the government.

Our research has focused on SLR and its impacts in terms of high water in Venice. The Special Law, however, funds a number of different measures. In addition, the Venice lagoon can be affected by global warming consequences other than SLR. For example, increase of water temperature and changes in precipitation patterns are likely to affect hydrological conditions and biogeochemical processes, water quality and salinity and therefore ecosystem functioning and biodiversity. A comprehensive assessment of the ability of all safeguarding measures to withstand different climate change impacts was beyond the scope of our analysis. Indeed, we think such an assessment is required as baseline for adjusting the defense strategy in the long term.

Summary and Conclusions

This article described the measures carried out to protect Venice from high water under the so-called Special Law regime and reflected on their ability to anticipate SLR induced by climate change. First, it was made plausible that a +50 cm SLR scenario expected not before 2080 in the Venice region would have a significant impact in terms of increased frequency of high water in Venice. The uncertainty related to this finding was also highlighted. Second, it was shown that in Venice different infrastructural works (structural measures) are being carried out to protect the lagoon urban centers from high water within the so-called Special Law regime (non-structural measures). Third, it was pointed out that the ability of these measures to protect Venice from accelerated SLR will depend on timely completion of all infrastructure for which a regular flow of financial resources is needed as well as on an effective management strategy and the implementation of a novel governance regime for the lagoon watershed.

Venice is illustrative of the type of problems that many coastal cities are facing at present (see, e.g., the Dutch Wadden Sea in Munaretto and Klostermann 2011). Climate change and in particular SLR poses a major challenge to long-term coastal management (Nicholls and Klein 2005). Although there is not a single, correct approach for coastal management and allocation of coastal resources, exchange of experience and practice via for instance coastal cities networks stimulates dissemination of knowledge, awareness, and the development of tailored solutions (EC 1999b). The knowledge base and the advanced technology developed for the protection of Venice can be of interest to other coastal cities. Scientists, practitioners, and coastal managers in Venice are actively participating to international coastal networks to share knowledge and experience.

The Venice case also suggests at least two main points of importance considering climate change is a global challenge. First, high level of technical and scientific knowledge and infrastructure alone does not necessarily lead to the expected level of safety of the coast. Adaptation requires coastal protection infrastructure (structural measures) as well as governance arrangements (non-structural measures) ensuring effective integrated management of the coastal area, nearshore waters, and watershed. Degradation of coastal and marine environment is still not fully under control in Venice as it is not in most European coastal areas because the development of integrated approaches to coastal management does not receive adequate attention (Suman, Guerzoni, and Molinaroli 2005; EUCC 1999; EC 1999a, 1999b).

Second, governance of adaptation represents a new concern for policymakers, requiring a change in attitude towards more long-term policymaking. Strengthening local long-term planning mechanisms could support decisions regarding coastal defense infrastructure with

long life span. Improvements can also be obtained with greater cross-scale and cross-sector integration and coordination of knowledge, planning, and management systems. Finally, because adaptation is financially demanding in coastal areas, mechanisms to make financial resources available are also needed. This may imply reformulating priorities and ensuring longer-term availability of resources for existing sectoral plans and programs integrating climate change considerations rather than making new programs.

Concluding, the above suggests that decades of studies funded by the Special Law regime generated technical and scientific knowledge and allowed building infrastructure that could make Venice one of the foremost regions adapting to climate change, provided that resources for timely completion of all infrastructure and subsequent maintenance are ensured and that the Special Law is revised in the direction of political and financial rebalancing of power and competences of local, regional, and national authorities.

Notes

1. Important coastal functions include regulation of hydrological flows, formation and retention of soil and silt, storm protection and flood control, retention and processing of nutrients and organic matter, providing habitat for biodiversity, providing food, opportunities for recreational activities and non-commercial uses, waste assimilation, pollution control and detoxification, opportunities for transportation, and space for housing (Costanza et al. 1997).

2. All Ufficio di Piano advisory documents and thematic reports are publicly available at http://www.magisacque.it/uff_piano/uff_piano.htm. Minutes, notes, and presentations can be viewed with the first and second author, previous acquisition of permission from the Ufficio di Piano through its chairman, the president of the Venice Water Authority.

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