Protecting Venice from tidal floods in times of climate change

The author has five years working experience as member of the technical secretariat of the Ufficio di Piano (UdP) Committee appointed for advising the national government on priorities about works to safeguard Venice and its lagoon in 2004. The UdP is a mixed committee of national and international scientists and national, regional and local policy-makers. The author is currently doing a PhD on the subject "institutions for managing flood and environment in the Venice lagoon in times of climate change".

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Introduction
Safeguarding Venice is a national priority since 1973 when the so called "special legislation for Venice" regime was established with the aim to protect urban centers from tidal floods and sea storms, prevent erosion, restore typical lagoon habitats and abate pollution. National, regional and local administrations are in charge of implementing programs, plans and projects to achieve the "special legislation" goals (Amorosino 2002; Bevilacqua 1998). The national government regularly allocates funds and takes the most important political decisions regarding measures to implement.

Similarly to many other coastal regions, sea level rise induced by global warming is one of the major threat that Venice will have to face in the years to come. Sea level rise is expected to exacerbate existing problems, i.e. tidal floods, erosion and loss of habitat and biodiversity. The expected major impact is the increase of frequency, distribution and elevation of tidal floods, which will negatively affect urban and lagoon systems. Impacts include damage to buildings and infrastructures (i.e. drainage systems, canal banks, building foundations, historical and artistic heritage, and lagoon embankments), temporary interruption of economic activities and citizen mobility, and damage to shop assets and warehouses. Greater water depth in the lagoon basin will also affect ecosystems functioning and water salinity (Bourdeau et al. 1998; Cecconi 1997; Mag.Acque 1997; Ramieri 2000; Ravera 2000). Positive effects, such as pollutants dilution, are also expected due to a greater volume of water inside the lagoon (Cecconi 1997).

The chosen solution to protect Venice from tidal floods and sea level rise consists of an integrated system of different measures that has been debated for more than 20 years and whose effectiveness and impacts are still controversial. In the following sections I will illustrate these measures and present some reflections on their ability to protect Venice from sea level rise.

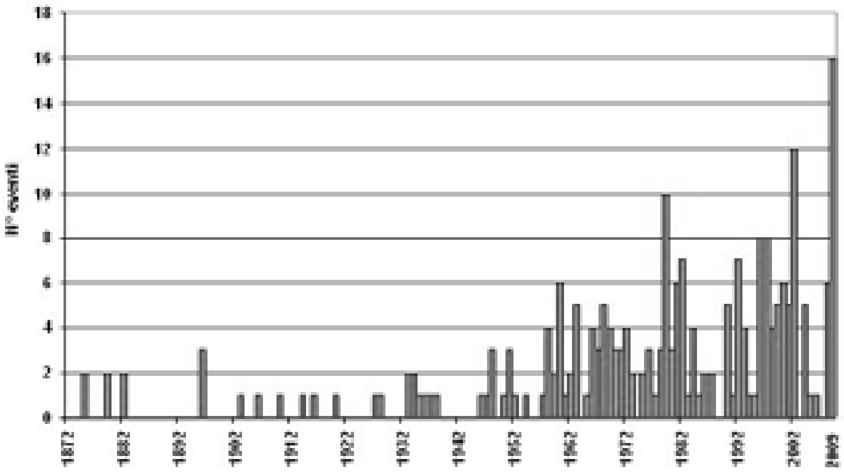

Figure 1. Annual frequency of high water events in Venice with level equal or above +110 cm m.s.l. between 1872 and 2009 [source: Venice Municipality Centre for Tidal Forecast, 2010]

[1] *High water is defined as a tide exceeding +80 cm 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. that floods more than 10% of Venice. Extreme high water is a tide exceeding +140 cm m.s.l., which causes 90% of the city to be flooded.*

Tidal floods and sea-level rise in the Venice lagoon

The city of Venice has experienced high variations of lagoon water level for centuries. The tidal flood phenomenon is locally known as *high water* [1], and consists of a temporary (tidal and surges driven) rise in the sea level that floods part of Venice and the other lagoon urban areas for a few hours. It may occur several times a year, particularly in fall and spring.

Frequency of tidal floods has significantly increased since 1950s *(fig. 1)* due to human-induced and natural land subsidence and global eustatic processes. Relative sea level rose 25 cm in the past one hundred years with an average eustatic rise of 1.2 mm/yr since 1890 (Carbognin et a. 2009). As consequence, exceptional high waters -above +110 cm, flooding more than 10% of the city of Venice- increased from 1-2 times per year to 16 times in 2009. In 2008 the fourth highest water level ever recorded (+156 cm m.s.l.) flooded more than 90%, causing damages for several million Euros. In December 2009 five exceptional high waters and two extreme high waters -above +140 cm, flooding more than 90% of the city- occurred in a timeframe of less than two weeks.

Projections of sea level rise for the Venice region are affected by great uncertainty. Scenarios span from 0.31 m (Co.Ri.La. 1999) to 1.35 m (Plag, 2009) by 2100 *(table 1)*. The highest scenario is less likely to happen as it considers an acceleration of the melting of the Antarctic ice sheet, which is one of the most uncertain factors.

Expected tidal floods according to different sea level rise scenarios have also been estimated. According to some estimates (Mag.Acque 1997, *table 2*) extreme high waters will occur 3 times per year in case of +30 cm sea level rise by 2100. Looking at the number of extreme high water events occurred in 2008 and 2009 these scenario seem to be not so far in the future. More recently, Carbognin et al. (2009) have estimated the number of exceptional high waters by 2100 to occur 250 times per year in case of +50 cm sea level rise. However, these estimates are only indicative as projections at regional and sub-regional scale of changes in parameters that influence tidal floods, such as barometric pressure, direction and intensity of winds, intensity of precipitation in the drainage basin, and marine circulation are affected by great uncertainty (Pirazzoli and Tomasin 2002; Ramieri 2000).

Measures to protect Venice from tidal floods

To protect Venice's lagoon built areas from tidal floods, an integrated system of different measures at the lagoon inlets and within urban centers is under construction. The total investment is about 5.5 billion Euros, of which 3.2 billion Euros have already been spent (Ufficio di Piano, 2009). National and local authorities are in charge of carrying out the works.

Mobile barriers

To protect urban centers from extreme tidal floods, the national government is constructing a system of mobile barriers at the three lagoon inlets called MOSE, Modulo Sperimentale Elettromeccanico, or elecromechanical module. These will regulate tidal floods by temporarily separating the lagoon from the sea for the duration of the tidal event *(fig. 2)*. 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 +110 cm above safeguarding level is forecasted, the barriers are closed through the introduction of compressed air into the gates that removes water and forces them to float (Mag.Acque 1997; Gentilomo and Cecconi 1997; Mag. Acque 2010). Navigation during closure will be assured by one lock for large ships and three small locks for the transit of fishing boats and other small

Source	Sea-level rise projection in 2100 for the Venice area	
	Low scenario (m)	*High scenario (m)*
Mag.Acque 1997	0.04	0.53
Co.Ri.La. 1999	0.16	0.31
Carbognin 2009	0.17	0.53
Plag 2009	0.45	1.35

Table 1. Sealevel rise projection in 2100 for the Venice region

Tidal peaks (cm)	Mean anual frequency for current m.s.nl.	Mean annual frequency for m.s.l. +10cm	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	1/2 y	1	3

Table 2. Annual frequency of different tidal peaks according to four different sea-level rise scenarios[source: Mag.Acque, 1997 p. 80]

[2] *For further details about the mobile barriers project see the proponent web site www.salve.it*

vessels. About 60% of the work has been completed (2010) and the system will be operating in 2014[2].

Additional measures

To protect urban centers from the most frequent tidal floods, two additional set of measure are being implemented: complementary measures at the lagoon inlets and local defenses in the built areas inside the lagoon. Complementary measures will reduce tidal levels in Venice by an average of 3-4 cm (Mag. Acque, 2010). This result is obtained by raising and protecting part of the lagoon bed in the inlet channels and constructing sea side breakwaters to abate the prevalent winds.

In addition, the national government and the Venice municipality are implementing a wide program of so called local defenses in the lagoon urban areas since the beginning of the 1990s. Local defense strategy consists of raising the lagoon quaysides, embankments and public paved areas as much as possible up to +110 cm above safeguarding level or more. However, it is not possible to raise uniformly the entire inhabited areas because of the architectonical structure of the historical urban centers. Therefore, small urban areas will still be flooded by tidal floods of a height below the safeguarding level. Among these, there is the historical San Marco square in Venice which can only be partially protected up to +100 cm. If the government will guarantee sufficient and continuous funding, the local defenses in the city of Venice will be completed by 2030 (Venice municipality, 1999).

Coping with sea-level rise

At present, the mobile barrier system in Venice is considered one of the engineering solutions in the field of climate change adaptation. The barriers are designed to withstand +60 cm above present mean sea level and a tide level of +3 meters (Mag. Acque, 2010). However, in situation of prolonged tidal floods, a hydrologic and hydrodynamic model study suggests that the barriers can effectively protect Venice up to a future sea level of +50 cm[3] (Rinaldo et al 2008). This level of protection included in the project design is adequate given the current sea level rise scenarios and the life span of the infrastructure (50 to 100 years). In case of higher eustatic scenario the mobile barriers would not be sufficient to protect Venice because vast low laying territories surrounding the lagoon would be inundated from land and from sea. In this situation a different strategy to protect the whole coastal region would be required. Eventually, drastic options including a full closure of the lagoon are unavoidable in case of a sea level rise of more than +60 cm, and should be considered[4].

A major concern is related to the impacts caused by an increasing number of inlet closures due to sea level rise in the coming decades. In the long term, frequent and prolonged closures are likely to negatively affect hydrodynamic, ecosystems, water quality and port activities. However, the integrated action of mobile barriers, complementary measures and local defenses buys time as it reduces the number of closures, thus extending the lifetime of the barriers. In addition, not all tidal floods will require the lagoon to be completely separated from the sea. Depending on the characteristics and scale of the tidal event, there may be simultaneous closure of all three inlets, closure of one inlet at a time, or partial closure of each inlet. This flexibility helps maintaining water exchange, and functioning of the port activities. Moreover, it is possible to take advantage of this flexibility to achieve environmental goals such as improvement of water quality and habitat conservation besides the main objective of physical protection of the lagoon urban centers from tidal floods. This may be achieved by using partial closures to force water circulation into the lagoon - improving vivification - or by closing the barriers during strong wind events - to prevent sediment loss to the sea. These options are worth exploring in the coming years as they will influence the management strategy of the barriers.

Challenges for the governance of the lagoon

The existing "special legislation" regime has led to overlap of responsibilities, lack of inter-institutional cooperation, and poor coordination of knowledge and management instruments. This caused inefficiency and conflicts, with programs that almost never are fully implemented (Musu, 2001) because of lack of transparency in governability, accountability and legitimacy of the different parties (Vellinga and Lasage, 2005). Furthermore, the financing system does not assure continuity of funds to complete the works, causing administration's programs to be implemented without continuity and coordination with some activities that are more ahead than others. A major issue in this context is the need of reliable tidal forecast for the proper management of the mobile barriers. To avoid false alarms, and therefore minimize the number of inlets closures, tidal forecasts have to be accurate. At present, data to forecast tidal flood are collected by different administrations and there are two agencies providing tidal projections. This led to inefficient use of financial and human resources.

The existing safeguarding governance system undermines the effective management of the mobile barriers and of the lagoon as a whole. To overcome current inefficiencies major institutional reforms are required within a new special legislation regime grounded on the emerging management needs and a climate change perspective. In this context, timely and adequate tidal forecast for the management of the

[3] *The study takes into account possible fluxes of fresh water into the lagoon from precipitation, river run-off and seepage of sea water between the barriers during long-lasting closure of the inlets due to adverse meteorological conditions (Rinaldo et al. 2008)*

[4] *With reference to long-term solutions, it is worth mentioning that some discussion is taking place around the hypothesis of deep injection of brackish water under the city of Venice to raise up wide part of the city at one time (Comerlati et al. 2004; Castelletto et al. 2008; Carbognin 2009). This idea needs to be carefully investigated, as the Venice lagoon underground could not be sufficiently stable.*

barriers and sound scientific knowledge to support decision-making may be ensured by the integration of existing monitoring networks and tidal forecast agencies.

From a construction phase to a governance phase: some final reflections

The "special legislation" regime was established more than 30 years ago with the objective of protecting Venice from tidal floods and environmental degradation by means of new hydraulic infrastructures. The integrated system of mobile barriers, complementary measures and local defenses being built at the inlets and in the urban centers is in principle adequate to protect Venice for at least the next 50 to 100 years, given various sea level rise scenarios. This gives at least 50 more years to adjust the defense strategy and plan new solutions according to new scientific knowledge. However, all infrastructures have to be completed as it is the synergic action of all of them that ensures effective protection. Therefore, works that are behind schedule have to be speeded up by removing administrative and procedural barriers and ensuring sufficient and time scheduled funds. In the next few years, it is also crucial to integrate the environmental monitoring networks and the tidal forecast systems for the proper management of the mobile barriers.

The construction phase of the defense infrastructures is under way. Designing the mobile barriers closure regime and a novel safeguarding governance system for the whole lagoon is the issue to address in the coming years. All interested parties, i.e. policy makers, scientists, private sectors and civil society should be involved in the process leading to the revision of the "special legislation" regime. On the one hand, the "book of the rules and of the exceptions to the rules" (Dente, 2010 personal communication) for the management of the barrier closures should be designed according to a ladder of safeguarding goals (e.g. protection from high waters vs environmental goals vs economic interests) which have to be agreed upon by all interested parties as it involves trade-offs. On the other hand, a new safeguarding governance system of the whole Venice lagoon should define administrations' responsibility, planning and management instruments, and mechanisms for fund supply and allocation. Finally, to timely adjust the safeguarding strategy according to new scientific knowledge a mechanism to revise the rules will also have to be developed. This is crucial given the uncertainty related to SLR projections in order to take no regrets decisions about measures to safeguard Venice in the long term.

Venice can be saved despite climate

Some numbers of the mobile barriers system (MOSE) in Venice:

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

18.5m X 20m x 3.6m length, width and thickness of the smallest gate (lido – Tredporti row)

29.6m x 20m x4.5m length, width and thickness of the largest gate (Malamocco row)

1 lock for large shipping at the Malamocco inlet (***370m x 48m x -14m*** 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 522m long and a peak height of 2.5m and 1 at Malamocco about 1300m long and a peak height of from 3 to 4m)

4-5 hours the average duration of each closure

30 minutes the required to manoeuvre the gates

4,678 milion euro the total costs of the project

Figure 2. Project design of the mobile barrier system to protect Venice from tidal floods (MOSE) [source: Mag. Acque, 2010]

change. Decades of studies generated technical and scientific knowledge to face current environmental risks. However, if not properly managed, the whole investment may fail to achieve the goal. This is a risk that Venetians can not take as Venice may not have another chance to survive.

Literature*

Bevilacqua P. (1998) Venezia e le acque, Donzelli Editore.

Bourdeau P., J. M.Martin, C. C. Mei, I. Musu & P.Vellinga (1998) Report on the mobile gates project for the tidal flow regulation at the Venice lagoon inlets, Venice.

Carbognin L., P. Teatini, A. Tomasin & L.Tosi (2009) Global change and relative sea level rise at Venice: what impact in term of flooding. Climate Dynamics. doi: 10.1007/s00382-009-0617-5.

Gentilomo M. & G. Cecconi (1997) Flood protection system designed for Venice. Hydropower Dams. Vol. 2.

Magistrato alle Acque di Venezia-Consorzio Venezia Nuova (1997) Interventi alle bocche lagunari per la regolazione dei flussi di marea - Studio di impatto ambientale del progetto di massima, technical report, Venice.

Magistrato alle Acque di Venezia – Consorzio Venezia Nuova (2010) www.salve.it

Musu I. edited by (2001) Sustainable Venice: Suggestions for the future. Dordrecht Ed. Kluwer Academic Publishers.

Ramieri E. (2000) An overview of the vulnerability of Venice to the impacts of climate change and sea level rise, FEEM - Fondazione Eni Enrico Mattei. Available at: http://www.feem.it/Feem/Pub/Publications/WPapers/WP2000-022.htm?WP_Year=2000&WP_Page=1

Rinaldo A, L. Nicotina, E. Alessi Celegon, F. Beraldin, G. Botter, L. Carniello, G. Cecconi, A. Defina, T. Settin, A. Uccelli, L. D'Alpaos & M. Marani (2008) Sea level rise, hydrologic runoff, and the flooding of Venice. Water Resources Research. Vol. 44, No. 12.

Ufficio di Piano – DPCM 13 febbraio 2004 (2009) Legislazione speciale per Venezia. Attività di salvaguardia. Quadro finanziario e delle realizzazioni fisiche. Aggiornamento al 31.12.2008. Venezia. Available at: http://magisacque.it/uff_piano/uff_piano_salvaguardia.htm

Vellinga P. & R. Lasage (2005) Venice, an issue of sustainability. Scientific paper no. 68 in Flooding and environmental challenges for Venice and its lagoon: state of knowledge edited by Fletcher C.A. and Spencer T.. Cambridge University Press.

Venice Municipality-Insula (1999) Piano Programma degli interventi integrati per il risanamento igienico ed edilizio di Venezia e le sue isole, Venezia.

** The list includes only part of the references quoted in the text. For a complete list and additional references, contact the author at stefania.munaretto@unive.it*

Samenvatting

Dankzij zeespiegelstijging zullen overstromingen, erosie en verlies van habitat in de lagune van Venetië toenemen. Behoudsmaatregelen worden uitgevoerd binnen een "speciaal wetgevend regime" sinds 1973. De oplossing om Venetië te beschermen tegen overstromingen en getijdenenergie stijging van de zeespiegel bestaat uit een geïntegreerd systeem van mobiele stormvloedkeringen en aanvullende maatregelen in de lagunekust en lokale afweer in de stedelijke centra. Deze infrastructuur is toereikend voor ten minste de komende 50 tot 100 jaar gegeven de zeespiegelstijging in verschillende scenario's. Op dit moment is het ontwerpen van een "mobiel barrières afsluiting regime" en een vrijwaring van het governance-systeem voor de hele lagune een nieuw probleem om bij de kop te pakken.